Integrated Monitoring Report: Water Years 2014-2019

(October 2013-September 2019)

   

Submitted to the San Francisco Bay and
Central Valley Regional Water Quality Control Boards
in Compliance with NPDES Permit Provision C.8.h.v

NPDES Permit Nos. CAS612008 and CAS083313

March 18, 2020

A Program of Contra Costa County, its Incorporated Cities and Towns,
and the Contra Costa Flood Control & Water Conservation District

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Contra Costa Clean Water Program

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(October 2013-September 2019)

March 18, 2020

Prepared for

Contra Costa Clean Water Program
255 Glacier Drive
Martinez, California 94553

Contra Costa Clean Water Program Participants

- Cities of Antioch, Brentwood, Clayton, Concord, Danville (Town), El Cerrito, Hercules, Lafayette, Martinez, Moraga (Town), Oakley, Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon, and Walnut Creek
- Unincorporated Contra Costa County
- Contra Costa County Flood Control & Water Conservation District

Prepared by

ADH Environmental
3065 Porter Street, Suite 101
Soquel, California 95073

In association with

Wood Environment & Infrastructure Solutions, Inc.
180 Grand Avenue, Suite 1100
Oakland, California 94612

and

Armand Ruby Consulting
2441 Rifle Range Drive
Royal Oaks, California 95076

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Acronyms and Abbreviations

ASCI	algal species composition index
BASMAA	Bay Area Stormwater Management Agencies Association
BSM	biofiltration soil media
CASQA	California Stormwater Quality Association
CCCWP	Contra Costa Clean Water Program
Bay	San Francisco Bay / San Francisco Estuary
BMP	best management practice
CC-IBI	Contra Costa Index of Biological Integrity
CEDEN	California Environmental Data Exchange Network
COLD	cold-water fisheries habitat beneficial use
CSCI	California Stream Condition Index
CVRWQCB	Central Valley Regional Water Quality Control Board
Delta	Sacramento-San Joaquin River Delta
District	Contra Costa County Flood Control & Water Conservation District
DO	dissolved oxygen
DOC	dissolved organic carbon
EBMUD	East Bay Municipal Utility District
HDS	hydrodynamic separator
IBI	index of biological integrity
IMR	integrated monitoring report
IMS	Information Management System
MMI	multi-metric index
MRP	Municipal Regional Stormwater Permit
MS4	municipal separate storm sewer system
NPDES	National Pollutant Discharge Elimination System
O&M	operations and maintenance
OFEE	oil filled electrical equipment
PHab	physical habitat
PCB	polychlorinated biphenyl
PG&E	Pacific Gas and Electric Company
PMU	priority margin unit
POC	pollutants of concern
P/S Studies	Pilot and Special Studies
QAPP	quality assurance project plan
RAA	Reasonable Assurance Analysis
RMC	Regional Monitoring Coalition
RMP	Regional Monitoring Program for Water Quality in San Francisco Bay
RWQCB	Regional Water Quality Control Board
S&T Program	Status & Trends Monitoring Program
SAP	sampling and analysis plan
SSC	suspended sediment concentration
SCVURPPP	Santa Clara Valley Urban Runoff Pollution Prevention Program
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SMCWPPP	San Mateo Countywide Water Pollution Prevention Program
SOP	standard operating procedure
SPoT	Stream Pollution Trends

SSID	stressor/source identification
STLS	Small Tributaries Loading Strategy
SWAMP	California Surface Water Ambient Monitoring Program
TMDL	total maximum daily load
TOC	total organic carbon
TSS	total suspended solids
WARM	warm-water fisheries habitat beneficial use
Water Board	Regional Water Quality Control Board
WILD	wildlife habitat beneficial use
WLA	waste load allocation
WWTP	wastewater treatment plant
WY	water year

Table i. Summary of Water Year 2019 Creek Status Monitoring Stations

Site ID	Creek Name	Land Use	Latitude	Longitude	Bioassessment PHab Chlorine Nutrients	Water Toxicity and Sediment Toxicity and Chemistry (Dry Weather)	Temperature	Continuous Water Quality	Pathogen Indicator Bacteria
204R02180	Alamo Creek	Region 2, Urban	37.77915	-121.90058	X				
204R02587	Moraga Creek	Region 2, Urban	37.84235	-122.14516	X				
206R01792	Refugio Creek	Region 2, Urban	37.99608	-122.24448	X				
206R02048	Rodeo Creek	Region 2, Urban	38.03034	-122.26516	X				
206R02455	Wildcat Creek	Region 2, Urban	37.93845	-122.29939	X				
206R02560	Refugio Creek	Region 2, Urban	38.00760	-122.26665	X				
207R01280	Franklin Creek	Region 2, Non-Urban	38.00274	-122.16804	X				
207R01655	East Branch Grayson Creek	Region 2, Urban	37.93774	-122.06370	X				
544R02037	Marsh Creek	Region 5, Urban	37.90691	-121.71558	X				
544R02505	Marsh Creek	Region 5, Urban	37.99168	-121.69589	X				
206R00551	San Pablo Creek	Region 2, Urban	37.96205	-122.33608			X		
206R00960	Rodeo Creek	Region 2, Urban	38.00737	-122.22129			X	X	
206R01319	San Pablo Creek	Region 2, Urban	37.96744	-122.36554			X		
207R02615	Walnut Creek	Region 2, Urban	37.98070	-122.05162			X		
544R04613	Marsh Creek	Region 5, Urban	37.99152	-121.69608					X
203BAX045	Baxter Creek	Region 2, Urban	37.93096	-122.32397					X
206PLN010	Pinole Creek	Region 2, Urban	38.00706	-122.29008					X
206SPA230	San Pablo Creek	Region 2, Urban	37.88118	-122.18817			X	X	
207ALH010	Alhambra Creek	Region 2, Urban	38.01676	-122.13592					X
543EAN010	Lake Alhambra	Region 5, Urban	38.01076	-121.79633					X
544MSH045	Marsh Creek	Region 5, Urban	37.93731	-121.70803		X			

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Preface

Contra Costa County lies within both the Region 2 and Region 5 jurisdictions of the California State Water Resources Control Board (Figure i). The countywide stormwater program is subject to both the Region 2 municipal regional stormwater National Pollutant Discharge Elimination System Municipal Regional Stormwater Permit (MRP)[1] and the equivalent Region 5 permit[2].

This Integrated Monitoring Report complies with MRP Provision C.8.h.v for reporting of all data in water years 2014-2019 (October 1, 2013-September 30, 2019). Data were collected pursuant to Provision C.8 of the MRP. Data presented in this report were produced under the direction of the Regional Monitoring Coalition and the Contra Costa County Clean Water Program (CCCWP) using regional/probabilistic and local/targeted monitoring designs as described herein.

In early 2010, several members of the Bay Area Stormwater Management Agencies Association (BASMAA) joined to form the Regional Monitoring Coalition (RMC) to coordinate and oversee water quality monitoring required by the MRP. The RMC includes the following stormwater program participants:

- Alameda Countywide Clean Water Program
- Contra Costa Clean Water Program
- San Mateo Countywide Water Pollution Prevention Program
- Santa Clara Valley Urban Runoff Pollution Prevention Program
- Fairfield-Suisun Urban Runoff Management Program
- City of Vallejo and Vallejo Sanitation and Flood Control District

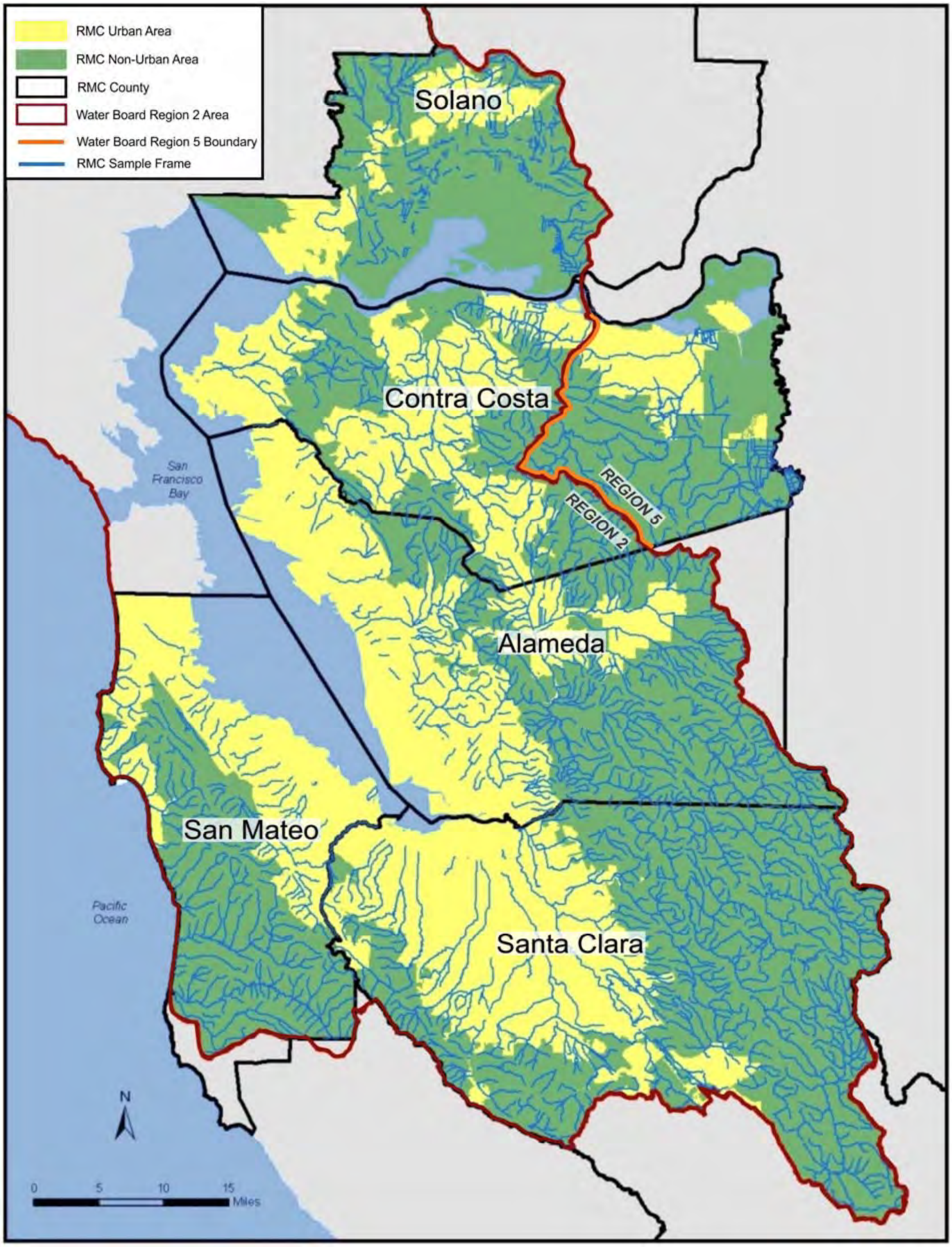
In accordance with the BASMAA RMC multi-year work plan (Work Plan; BASMAA, 2011) and the creek status and long-term trends monitoring plan (BASMAA, 2012), monitoring data were collected in accordance with the BASMAA RMC quality assurance project plan (BASMAA, 2016a) and the BASMAA RMC standard operating procedures (BASMAA, 2016b). Where applicable, monitoring data were derived using methods comparable with methods specified by the California Surface Water Ambient Monitoring Program (SWAMP) Quality Assurance Program Plan[3]. Data presented in this report were also submitted electronically to the San Francisco Estuary Institute or Moss Landing Marine Laboratories for transmittal to the Regional Water Quality Control Board on behalf of the CCCWP Permittees and pursuant to the MRP Provision C.8.h.ii requirements for electronic data reporting.

[1] The San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) issued the MRP to 76 cities, counties and flood control districts (i.e., the Permittees) in the Bay Area on Oct. 14, 2009 (SFBRWQCB, 2009). On Nov. 19, 2015, SFBRWQCB issued Order No. R2-2015-0049. This amendment supersedes and rescinds Order Nos. R2-2009-0074 and R2-2011-0083, and became effective Jan. 1, 2016 (SFBRWQCB, 2015). The BASMAA programs supporting MRP regional projects include all MRP Permittees, as well as the cities of Antioch, Brentwood and Oakley, which are not named as Permittees under the MRP but have voluntarily elected to participate in MRP-related regional activities.

[2] The Central Valley Regional Water Quality Control Board (CVRWQCB) issued the East Contra Costa County Municipal NPDES Permit (Order No. R5-2010-0102) on Sep. 23, 2010 (CVRWQCB, 2010).

[3] The current SWAMP Quality Assurance Program Plan is available at: https://www.waterboards.ca.gov/water_issues/programs/swamp/qapp/swamp_QAPrP_2017_Final.pdf

Figure i. BASMAA Regional Monitoring Coalition Area, County Boundaries and Major Creeks



Executive Summary

The Contra Costa Clean Water Program (CCCWP) gathers and reports monitoring data to help its program members comply with the Municipal Regional Stormwater National Pollutant Discharge Elimination System Permit (MRP). Understanding the monitoring data through statistical and graphical analysis helps tell the story of:

- How urban settings and activities affect the quality of Contra Costa County's creeks and coastal waters
- What reasonable and foreseeable measures can help improve water quality where it is impaired
- What measures are needed to protect existing high value water resources

This Integrated Monitoring Report (IMR) integrates, analyzes, and summarizes data resulting from six years (2014-2019) and about six million dollars spent monitoring water quality and creek health in Contra Costa County. CCCWP monitors water quality in compliance with the MRP on behalf of unincorporated Contra Costa County, the Contra Costa Flood Control and Water Conservation District (District), and the 19 cities and towns who are Permittees enrolled in the MRP. The IMR summarizes and integrates the results of monitoring data gathered directly by CCCWP monitoring contractors, as well as through regional collaborations with the Bay Area Stormwater Management Agencies Association (BASMAA) and the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP).

Data gathered during water years 2014-2019 fulfill the reporting requirements of Provision C.8.h.iii and C.8.h.v of the MRP. The submittal of this IMR follows the second permit cycle of the MRP (MRP 2.0, 2015-2020). Lessons learned from MRP 1.0 monitoring (2012-2013) as reported in the previous IMR (2014) are also referred to in this 2019 IMR.

The approximately 49-page main body of this IMR is organized by permit provision. The appendices to the main body contain detailed monitoring reports and work plans totaling approximately 1,000 pages. This eight-page executive summary organizes the content so that readers can follow the logic from permit requirement, to monitoring findings, to recommendations, and understand the value added by publicly funded monitoring resources.

Compliance Options (MRP Provision C.8.a; IMR Sections 1.1 and 1.2)

In early 2010, CCCWP joined with several other members of BASMAA to participate in a regional collaborative effort to coordinate water quality monitoring required by the MRP. BASMAA is a 501(c)(3) nonprofit organization comprised of the municipal stormwater programs in the San Francisco Bay Area. The resulting regional monitoring collaborative is called the BASMAA Regional Monitoring Coalition (RMC). The benefit of the RMC to the CCCWP Permittees is to assure that the final results meet Water Board expectations for data content and quality, and to provide consistent and comparable data for the region.

Monitoring Protocols and Data Quality (MRP Provision C.8.b; IMR Section 1.3)

The RMC has developed standard operating procedures (SOPs), quality assurance project plans (QAPPs), and a draft sampling and analysis plan (SAP) to guide monitoring efforts.

San Francisco Estuary Receiving Water Monitoring (MRP Provision C.8.c)

CCCWP contributes to the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). The RMP's Status & Trends Monitoring Program and the Pilot and Special Studies efforts provide useful tools for the CCCWP. The RMP is a long-term, discharger-funded monitoring program that is directed by a steering committee represented by regulatory agencies and the regulated community.

Creek Status Monitoring (MRP Provision C.8.d; IMR Section 3.1 and 3.3; Appendices 1 and 2)

Creek status monitoring entails two components:

- Regional/probabilistic sampling to characterize creek health using bioassessment, water quality, and physical habitat assessments (regional creek status)
- Local/targeted monitoring of creek health using continuous monitoring of temperature, dissolved oxygen, pH, and conductivity, plus grab sampling for pathogen indicators (local creek status)

Regional creek status monitoring began during MRP 1.0 with development of a random stratified sampling design through the RMC. The design provided a sample draw that was randomized to the extent possible, with some site rejection and re-drawing a random sample necessitated by site access and safety constraints or other non-qualifying conditions (e.g., non-wadable stream depths or tidally influenced). The end result is a regional data set representing urban creek health that can be statistically analyzed to understand how physical and water quality factors affect creek health.

The evidence shows that aquatic life beneficial uses are not fully supported due to a variety of physical habitat, climatic (rainfall), and watershed/land use factors. The numeric analysis and narrative discussion of bioassessment data indicates that the beneficial uses of wildlife habitat (WILD), warm water fisheries habitat (WARM), and cold-water fisheries habitat (COLD) are attained to varying degrees in Contra Costa County streams.

Local creek status monitoring provides more detail on specific water quality factors (e.g., dissolved oxygen, temperature) that affect creek health. Analysis of achieving water quality objectives, with a focus on dissolved oxygen and temperature, indicates that San Pablo and Wildcat Creeks show the most promise for attaining beneficial use of COLD; however, attainment of COLD water quality objectives for those two creeks is also not 100 percent. Those and other creeks monitored show partial or full attainment of WARM, with the consistent pattern that failure to attain dissolved oxygen >5 mg/L is most common in summer and is typically driven by day-night photosynthesis/metabolism cycles of in-stream algae and/or macrophytes.

Grab sampling for pathogen indicators showed exceedances can occur downstream of locations impacted by human activity, such as off-leash dog parks, duck feeding areas and encampments. These findings are part of a broader discussion at the MRP 3.0 Steering Committee level and among other California Public Agencies (e.g., Caltrans) about how California's housing crisis and the resulting high numbers of people who lack permanent housing can affect water quality in some instances.

Pesticides and Toxicity Monitoring (MRP Provision C.8.g) (IMR Section 3.2; Appendix 1)

Numeric water quality objectives for diazinon and chlorpyrifos are consistently attained in the creeks monitored by CCCWP in water years 2012-2019. This monitoring was performed in Marsh Creek in compliance with CVRWQCB's Total Maximum Daily Load (TMDL) requirements. The outcome of no detections is attributed to a phaseout of consumer use of these pesticides.

Narrative water quality objectives for "no toxic substances in toxic amounts" are not consistently attained. Toxicity in sediments was observed in seven of the 12 assessments of the sediment quality triad performed in Contra Costa County (Appendix 1, Table 5.11). Chemical analysis shows pyrethroid pesticides are present in sufficient concentrations to account for observed toxicity. CCCWP's pesticide and toxicity monitoring in compliance with MRP Provision C.8.g, and follow-up with stressor source identification studies conducted during MRP 1.0, established links between observed toxicity and pesticides. As evidenced by lessons learned from diazinon and chlorpyrifos, this type of evidence can be used by regulatory agencies to establish meaningful control programs that make a difference. Data from CCCWP, other Bay Area stormwater programs, and statewide efforts can help build a record to support future regulatory controls of pesticides that have emerged to replace diazinon and chlorpyrifos.

Stressor/Source Identification Projects (MRP Provision C.8.e; IMR Section 4; Appendix 3)

MRP 2.0 requires stressor/source identification (SSID) projects to be considered when one or more monitoring result triggers a candidate for a follow-up project. SSID projects are intended to be oriented toward taking action(s) to alleviate stressors and reduce sources of pollutants. Provision C.8.e allows CCCWP, as a participant in a regional collaboration, to perform one SSID project within Contra Costa County addressing creek water quality issues and participate in one regional project to fulfill this permit requirement. The local project identified root causes and potential strategies to ameliorate fish mortality in Marsh Creek. The regional project addresses the question of how to implement a programmatic control measure approach for PCBs in equipment related to electric power transmission.

The Marsh Creek SSID study addressed 10 documented fish kills over the past 14 years in Marsh Creek. The study identified low dissolved oxygen as a root cause of recurrent fish kills. The low dissolved oxygen results from a confluence of conditions that occur within the unique configuration of Marsh Creek:

- low flow channel geometry
- daily photosynthetic cycles
- prolonged periods of diminished flows followed by a light to moderate first flush storm event

Two years of continuous monitoring supported by the Contra Costa County Flood Control & Water Conservation District (the District) revealed the factors that could lead to potentially lethal low dissolved oxygen conditions. After the first year, the data indicated that intermittent dry weather flows (e.g., from irrigation) were associated with improved nighttime dissolved oxygen sags. Based on this observation, the City of Brentwood Wastewater Treatment Plan (WWTP) agreed to perform a flow augmentation pilot project.

The pilot nighttime flow augmentation project demonstrably abated a severe dissolved oxygen sag during a critical condition reached after the first flush storm event of the 2019-2020 season. The monitoring yielded a conclusive answer to a vexing water quality issue that was observed up to 10 times since 2005. The pilot flow augmentation project suggests a small amount of flow at night can avoid or ameliorate critical dissolved oxygen conditions. The SSID study has reached a conclusion, in that CCCWP has answered the monitoring question.

The project now pivots to Permittee-led actions. The District has agreed to fund additional continuous monitoring on Marsh Creek. The City of Brentwood has indicated willingness to extend the flow augmentation pilot, subject to water supply constraints resulting from local demand for recycled water. The purpose of the WWTPs augmentation pilot is to learn how flow helps avoid critically low dissolved oxygen, and to evaluate continuous monitoring as an early warning system to trigger flow enhancements as needed. If this is a viable strategy, there are other potential flow augmentation sources (e.g. Marsh Creek itself, groundwater, or irrigation return water). The use of the Brentwood WWTP's recycled water for the pilot program is helpful to perform a controlled study but does not commit or assume that valuable recycled water is available for the future. The Contra Costa Watershed Forum provides an established venue for discussing local watershed management strategies among community members and public agencies, such as the findings of this local SSID study.

The regional SSID project for MRP 2.0 addresses oil-filled electrical equipment (OFEE) as a potential source of PCBs to urban stormwater. The goal of the project is to understand the current inventory of PCBs in OFEE belonging to power companies, the potential for accidents and spills to release PCBs to city streets and ultimately storm drains, and current practices for cleaning up and documenting spills. The project scope assumes some improvement in the thoroughness, consistency, and documentation of spill response is possible. The result of the project would be a framework for power companies to describe their enhanced spill response BMPs, and for stormwater programs to credit implementation of the enhanced BMPs as a PCB load reduction.

The original scope of the project was for San Francisco Bay Regional Water Quality Control Board staff to lead information gathering from Pacific Gas and Electric Company (PG&E), while the BASMAA project consultants would gather information from local municipal power companies. Key deliverables from the BASMAA regional project would inform the approach to gathering and interpreting data PG&E and municipal power companies, and the approach to using the information gathered from all parties to develop the framework. Unfortunately, a delay was encountered related to obtaining information from PG&E in the time and manner needed to complete the project. The project is being re-scoped to address the original goals by developing the crediting framework for this programmatic PCB control measure based on readily available information from municipal power companies.

Pollutants of Concern Monitoring (MRP Provision C.8.f; IMR Section 5.0; Appendices 4, 5 and 6)

Pollutants of concern (POC) load monitoring is intended to assess inputs of POCs to the Bay from local tributaries and urban runoff, assess progress toward achieving waste load allocations (WLAs) for TMDLs, and help resolve uncertainties associated with loading estimates for these pollutants. The MRP directs Permittees to address five priority information management needs: Source Identification, Contributions to Bay Impairment, Management Action Effectiveness, Loads and Status, and Trends.

Source identification studies primarily address PCBs, although useful land-use data on mercury has also been developed. Since 2014, CCCWP and Permittee staff have conducted source area assessments to delineate high interest parcels and areas for consideration of property referrals and focused implementation planning for PCBs and mercury load reductions. The source property referral process is anticipated to be an important tool for achieving PCB load reductions.

CCCWP supports source identification assessments of contaminants of emerging concern through an RMP special study (Appendix 8A). CCCWP also supports an RMP study of PCB Contributions to Bay Impairment along the Bay margins through a Fate and Transport Study of PCBs (Appendix 8B). The RMP Pollutants of Concern Reconnaissance Monitoring Progress Report (Appendix 6) addresses loads and status, as well as trends, of POC loads. These special studies are examples of CCCWP monitoring obligations that are met through funding the RMP, which in turn funds special studies such as this directly from the RMP and also leveraged from Supplemental Environmental Project[4] funding.

MRP Permittees agreed to collectively conduct POC monitoring for management action effectiveness via a BASMAA regional project to evaluate the effectiveness of selected stormwater treatment controls. BASMAA agreed to focus this monitoring effort on two treatment options with the potential to reduce PCBs and mercury discharges: enhanced bioretention filters (Appendix 4A) and hydrodynamic trash separators (Appendix 4B). The PCBs in Infrastructure Caulk Project report (BASMAA, 2018) was submitted in the CCCWP fiscal year 2017-2018 annual report as Attachment 12.3. Early work in this project addressed source identification, while latter work was focused on verifying management action effectiveness.

CCCWP began implementation of a methylmercury control study in 2012 to fulfill requirements of the Central Valley Permit (C.11.l). A methylmercury control study work plan was prepared to 1) evaluate the effectiveness of existing best management practices (BMPs) for the control of methylmercury; 2) evaluate additional or enhanced BMPs, as needed, to reduce mercury and methylmercury discharges to the Sacramento-San Joaquin River Delta (Delta); and 3) determine the feasibility of meeting methylmercury WLAs. A final report was submitted in October 2018 which incorporates monitoring efforts conducted since spring 2015.

In 2015, the Contra Costa County Department of Public Works completed construction of a hard-piped stormwater diversion valve capable of diverting stormwater from the wet well of the North Richmond Stormwater Pump Station into the sanitary sewage conveyance system serving the West County Wastewater District. That diversion project was a legacy requirement of MRP 1.0 which completed during MRP 2.0 due to planning, permitting, design, and construction delays. Results from monitoring the management action effectiveness of this stormwater diversion project in the summer and fall of 2015 are in Appendix 4C.

POC Lessons Learned – Water Years 2014-2019

PCBs

Source property investigation is progressing and continues to be an important pathway to make progress toward target load reductions. Eight potential source properties have been either referred to the Water Board (three sites) or identified as self-abated (five sites). For sites that have been referred, the Water Board is granting half credit for the countywide required load reduction estimate using accounting methods established through the Reasonable Assurance Analysis (RAA) (BASMAA, 2020). For sites that have been self-abated, the Water Board grants full credit.

Over the past five years monitoring PCBs in urban settings, it has become increasingly apparent to CCCWP that “low hanging fruit” in the form of obvious source properties is hard to find. In effect, achieving the TMDL WLAs for PCBs assigned to Contra Costa County may require control measures at facilities that are beyond the reach of the Contra Costa Permittee’s regulatory jurisdiction. CCCWP anticipates a substantial amount of POC investigation effort in MRP 3.0 will be dedicated to carefully documenting where potential source properties may be directly impacting the MS4, and where there are potential source properties outside the reach of direct investigation and regulation by municipal permittees.

[4] The California State Water Resources Control Board defines Supplemental Environmental Projects as environmentally beneficial projects that a discharger voluntarily agrees to undertake.

Partial credit is conditioned on Permittees performing enhanced operations and maintenance (O&M) around the referral sites to intervene with the transport of PCB-contaminated sediments from source properties to the MS4. Enhanced O&M measures include more frequent street sweeping, installation of stormwater treatment devices (such as green infrastructure), full trash capture screens, and hydrodynamic separators. Future monitoring efforts will support enhanced O&M.

Mercury and Methylmercury

CCCWP's monitoring and participation in regional collaborations establishes background mercury and methylmercury concentrations in soils. There was no evidence for elevated mercury or methylmercury in sediments reaching Lower Marsh Creek from Upper Marsh Creek. This is a helpful source identification finding because the historic Mount Diablo Mercury Mine is located in Upper Marsh Creek. Monitoring data gathered to-date tend to support the concept that Marsh Creek Reservoir does not transmit sediments with elevated mercury concentrations to the lower watershed.

In response to concerns raised by CCCWP over the technological and economic feasibility of achieving required targets for methylmercury concentrations in stormwater discharges, technical peer reviewers inquired through their review of CCCWP's report whether achieving methylmercury mass reductions is feasible by reducing the volume of stormwater discharged. This will lead to an RAA study to model how much stormwater infiltration may be achieved after implementing all reasonable and foreseeable green infrastructure capital projects in the jurisdiction of Permittees subject to the CVRWQCB's Delta Methylmercury TMDL (the Cities of Brentwood, Antioch, and Oakley).

Nutrients and Copper

CCCWP monitors nutrients to help characterize the nutrient concentrations of urban stormwater, addressing a data gap identified in the San Francisco Bay Nutrient Management Strategy[5]. The snapshot of nutrient concentrations provided by CCCWP monitoring generally supports the assumptions made in the Regional Watershed Spreadsheet Model[6] used to estimate stormwater nutrients loads.

For source assessment and trends analysis, evaluating whether human-caused enrichment of copper in sediments is one way to discern human sources from natural background. Copper concentrations in sediments and, in particular, storm-borne sediments from urban settings, are especially relevant to understanding the effect of brake pad wear on urban stormwater quality. Copper was formerly present in high performance brakes and is released from abrasion during braking. Recognizing this, municipal stormwater programs banded together and successfully lobbied the brake pad manufacturing industry to negotiate a long-term reformulation of brake pad materials, leading to eventual product substitution. This would presumably lead to less release of copper into urban settings from brake pads. Product reformulation and substitution is a long-term process, as is the aging and replacement of the U.S. vehicle fleet. The gradual decline of copper in urban sediments is likely on the timescale of decades rather than years.

A snapshot comparing copper concentrations in storm-borne sediments from an urbanized area to storm-borne sediments from open/agricultural land in one watershed (Marsh Creek) showed that the copper concentrations in suspended sediments present in urban stormwater was about ten-fold greater than the

[5] The San Francisco Bay Nutrient Management Strategy is an RMP initiative for developing the science needed for informed decisions about managing nutrient loads and maintaining beneficial uses within the Bay. https://www.sfei.org/rmp/nutrients

[6] The Regional Watershed Spreadsheet Model was developed by the San Francisco Estuary Institute and RMP partners to estimate average annual regional and sub-regional scale pollutant loads for the San Francisco Bay Area. https://www.sfei.org/projects/regional-watershed-spreadsheet-model

average crustal abundance of copper, and much higher compared to agricultural/open space sediments of Sand Creek.

This monitoring data provided a glimpse of how, for understandable reasons, two different land uses have different particle ratios of copper. A more helpful story would be data from a variety of locations, and a monitoring design that addresses the anticipated timescale of changes in the copper particle ratios as a result of phasing out copper in brake pads. The current paradigm of minimum numbers of annual copper samples does not aid or incentivize monitoring efforts addressing these types of more thoughtful studies of human copper sources and the effects of copper control measures.

Recommendations for Creek Status Monitoring in MRP 3.0

Based on the lessons learned summarized above, CCCWP recommends replacing the probabilistic sampling design for bioassessment with a targeted approach in MRP 3.0. Baseline conditions have been reasonably well characterized at this point. Future deployment of CCCWP monitoring resources should address data gaps in areas that have heretofore been difficult to access, identifying high-value stream habitat resources that merit protection and/or enhancement and (where possible) characterizing before and after conditions where restoration or other watershed management actions are expected to improve creek health.

Recommendations for the SSID Monitoring Program in MRP 3.0

The SSID program has been successful at the local study level in Marsh Creek. At the regional level, progress on the PCB Source Identification from Electrical Equipment Study is impeded by factors outside of BASMAA member agencies' control. The main recommendation for change to the SSID program is that SSID study completion be accepted when programs have submitted conclusive final reports, rather than requiring approval by the executive officer of the Water Board. Review of the SSID study matrix (Appendix 3A) reveals that very few of the projects have been approved as complete. Studies must have finite endpoints so that resources can be applied to the other problems identified. Rather than making executive officer approval the default, Permittees and Programs should be granted the trust, based on prior successes in MRP 1.0 and MRP 2.0, to carry out projects to completion and to document the outcomes when declaring them complete. Water Board staff may always request more effort through participation in the BASMAA Monitoring and Pollutants of Concern Committee.

Recommendations for POC Monitoring in MRP 3.0

CCCWP intends to focus POC monitoring efforts for PCBs on source property investigations and effectiveness evaluations. Effectiveness evaluations will address the efficacy and outcomes of enhanced O&M near source properties referred to the Water Board. CCCWP recommends minimum sampling effort be prescribed for the permit term, rather than annually. This request also applies to copper monitoring – the level of effort is best prescribed for the permit term, not annually.

Additional nutrient monitoring does not seem helpful to CCCWP's priorities at this point, as there are no obvious management actions or data gaps that relate to nutrient monitoring. If some additional attention to nutrients in stormwater is warranted, a better approach may be to include language requiring Permittees to "conduct or cause to be conducted" a study of nutrients from stormwater, targeting needs identified through the San Francisco Bay Nutrient Management Strategy.

Monitoring Costs

Table ii summarizes the typical annual monitoring costs that CCCWP has incurred over the course of MRP 2.0. Overall, direct monitoring costs in the form of payments to consultants, contractors, and regional collaboratives, such as BASMAA and the Regional Monitoring Program cost nearly $1 million per year, out of an overall annual program budget of $3.5 million. Monitoring is the second largest single cost category, after staff salaries.

Staff salaries represent an indirect monitoring cost as well. Oversight of the monitoring program requires the attention of a full time technical professional staff person, as well as extensive involvement by the program manager and oversight by Permittees who fund the program. The recommendations in this report are intended to contain existing direct monitoring costs, make the optimum use out of funds expended, and make the most efficient use of staff resources necessary to support the monitoring program.

Table ii. Summary of Typical Annual CCCWP Monitoring Costs under MRP 2.0

MRP Section	Task	Cost
C.8.d, C.8.g	Creek Status and Pesticides Monitoring	$260,000
C.8.h	Urban Creek Monitoring Reports	80,000
C.8.e	SSID Project	90,000
C.8.f	POC Monitoring and Reporting	75,000
C.10.b	Trash	140,000
C.16.5	MeHg Monitoring (Per CVRWQCB)	5,000
C.8.a	Regional Monitoring Program (RMP)	170,000
Various	BASMAA Regional Projects	50,000
Various	Consultant Technical Support	100,000
	Total	*$970,000*

Costs in this table do not include CCCWP staff/augmented staff time.

1 Introduction

This Integrated Monitoring Report was prepared by the Contra Costa Clean Water Program (CCCWP) on behalf of its 21 member agencies (19 cities/towns, County of Contra Costa, and Contra Costa County Flood Control and Water Conservation District). The report fulfills monitoring and reporting requirements of the Municipal Regional Stormwater Permit (MRP) issued by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) (Order No. R2-2015-0049; SFBRWQCB, 2015)). MRP Provision C.8.h.iii specifies the procedures and schedule for interpreting and reporting monitoring data collected during water year 2019 (October 1, 2018-September 30, 2019). Further, MRP Provision C.8.h.v requires submittal of an integrated monitoring report (IMR) by the fifth year of the permit term on March 31, 2020. The IMR is to describe findings and lessons learned based on monitoring results since the previous IMR submittal (SFBRWQCB, 2014).

All monitoring data presented in this report were submitted electronically to the water boards by CCCWP and may be obtained via the San Francisco Bay Area Regional Data Center (www.sfei.org/sfeidata.htm). Data collected from receiving waters may be obtained via the California Environmental Data Exchange Network (CEDEN) (http://www.ceden.org).

This report is organized by the sub-provisions of MRP Provision C.8, as follows:

Table 1. Report Content

Section	Content
1.1	Compliance Options (MRP Provision C.8.a)
1.2	Monitoring Protocols and Data Quality (MRP Provision C.8.b)
2.0	San Francisco Estuary Receiving Water Monitoring (MRP Provision C.8.c)
3.0	Creek Status Monitoring (MRP Provision C.8.d) and Pesticides and Toxicity Monitoring (MRP Provision C.8.g) (Appendices 1 and 2)
4.0	Stressor/Source Identification Projects (MRP Provision C.8.e) (Appendix 3A)
4.1	Marsh Creek Stressor and Source Identification Study: Year 2 Report (MRP Provision C.8.e) (Appendix 3C)
5.0	Pollutants of Concern Monitoring (MRP Provision C.8.f) (Appendices 4A, 4B, 4C, 5 and 6)
6.0	Recommendations for future monitoring approaches

Figure 1 maps the locations of CCCWP monitoring stations associated with Provision C.8 compliance for water years 2014-2019, including creek status, pesticides and toxicity, pollutants of concern (POC), and the Marsh Creek stressor/source identification (SSID) study. Table 2 documents the coordinates and parameters monitored by water year.

Figure 1. Creek Status, Pollutants of Concern, Pesticides and Toxicity, and Stressor/Source Identification Monitoring Stations – WY 2014-2019

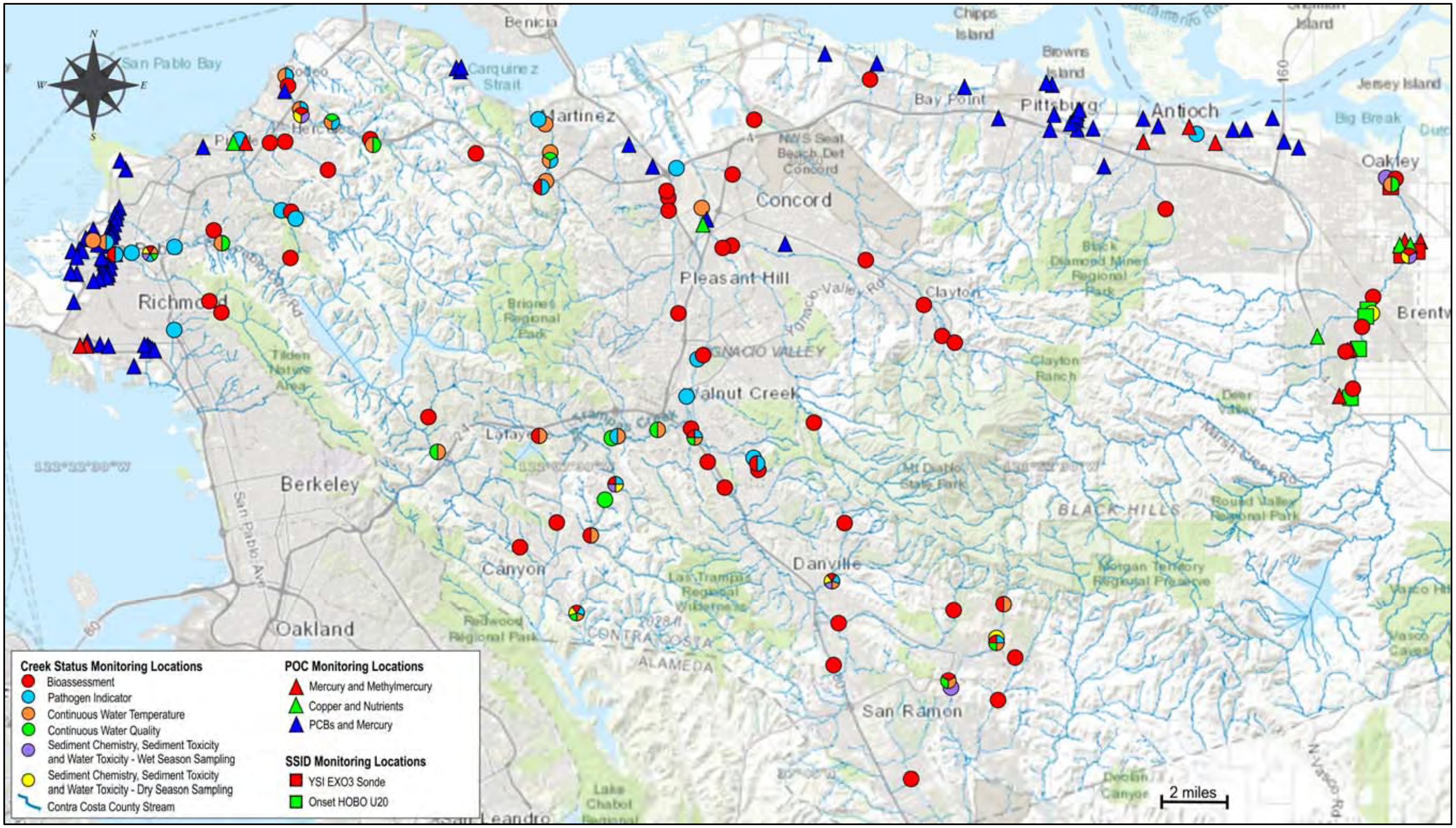


Table 2. Creek Status Monitoring Stations – WY 2014-2019

Site ID	Creek Name	Land Use	Latitude	Longitude	Bioassess-ment PHab Chlorine Nutrients	Water Toxicity and Chemistry (Wet Weather)	Water Toxicity and Sediment Toxicity and Chemistry (Dry Weather)	Water Temperature	Continuous Water Quality	Pathogen Indicator Bacteria
WY 2014										
206RDO003	Rodeo	Region 2, Urban	38.01995	-122.25917				X		X
206RDO025	Rodeo	Region 2, Urban	38.01593	-122.24249				X	X	X
206R00407	Wildcat	Region 2, Urban	37.94274	-122.30593	X					
206R00551	San Pablo	Region 2, Urban	37.96207	-122.33625	X	X	X	X	X	X
206R00599	Appian	Region 2, Urban	37.97156	-122.30328	X					
206R00919	Castro	Region 2, Urban	37.96030	-122.26370	X					
206R01024	Rodeo	Region 2, Urban	38.03433	-122.26616				X		X
207R00379	Green Valley (West Branch)	Region 2, Urban	37.85224	-121.97756	X					
207R00619	Donner	Region 2, Urban	37.92852	-121.92762	X					
207R00651	Sans Crainte	Region 2, Urban	37.87545	-122.02232	X					
207R00823	Galindo	Region 2, Urban	37.96493	-122.03602	X					
207R00843	Grizzly	Region 2, Urban	37.86806	-122.09589	X	X	X			X
207R00880	Tributary of Suisun Bay	Region 2, Urban	38.03292	-121.96469	X					
WY 2015										
204R00388	West Branch of Alamo	Region 2, Urban	37.80352	-121.89936	X			X	X	X
207R00891	Green Valley	Region 2, Urban	37.82838	-121.98444	X	X	X	X		X
206R00960	Rodeo	Region 2, Urban	38.00768	-122.22185	X					
206R01024	Rodeo	Region 2, Urban	38.01993	-122.25920	X	X	X			
544R01049	Dry	Region 5, Urban	37.92213	-121.71938	X					
543R01103	West Antioch	Region 2, Urban	37.98026	-121.81226	X					
204R01156	Tributary of Alamo	Region 2, Urban	37.79739	-121.88988	X					
207R01163	San Ramon	Region 2, Urban	37.88713	-122.05534	X			X	X	X
207R01227	San Ramon	Region 2, Urban	37.87703	-122.04847	X					
207R01271	Walnut	Region 2, Urban	37.918973	-122.05388						X
544R01305	Marsh	Region 5, Urban	37.94454	-121.70527	X					
206R01319	San Pablo	Region 2, Urban	37.96689	-122.35916				X		X

Table 2. Creek Status Monitoring Stations – WY 2014-2019

Site ID	Creek Name	Land Use	Latitude	Longitude	Bioassess-ment PHab Chlorine Nutrients	Water Toxicity and Chemistry (Wet Weather)	Water Toxicity and Sediment Toxicity and Chemistry (Dry Weather)	Water Temperature	Continuous Water Quality	Pathogen Indicator Bacteria
WY 2016										
207R00779	Las Trampas Creek	Region 2, Urban	37.84714	-122.10892	X					
207R01271	Walnut Creek	Region 2, Urban	37.92031	-122.05124	X					
207R01291	Grayson Creek	Region 2, Urban	37.98503	-122.06891	X					
207R01307	Lafayette Creek	Region 2, Urban	37.88772	-122.13563	X			X		
204R01412	West Branch Alamo Creek	Region 2, Urban	37.787959	-121.92410	X			X	X	
204R00388	West Branch Alamo Creek2	Region 2, Urban	37.80526	-121.89915						
204R01604	West Branch Alamo Creek	Region 2, Urban	37.81911	-121.89583	X			X		
207R01447	Franklin Creek	Region 2, Urban	37.99012	-122.13346	X					X
206R01495	Pinole Creek	Region 2, Urban	37.97844	-122.26257						X
204R01519	Rimer Creek	Region 2, Urban	37.81545	-122.11620	X		X	X	X	X
206R01536	Ohlone Creek	Region 2, Urban	38.00738	-122.27424	X					
207R01611	San Ramon Creek	Region 2, Urban	37.89076	-122.05710	X					
206SPA020	San Pablo Creek	Region 2, Urban	37.96283	-122.34562						X
206SPA030	San Pablo Creek	Region 2, Urban	37.96293	-122.34497						X
WY 2017										
204R01412	West Branch Alamo Creek	Region 2, Urban	37.99069	-122.13252			X			X
207R01447	Franklin Creek	Region 2, Urban	37.99012	-122.13346				X		
207R01547	Grayson Creek	Region 2, Urban	37.98729	-122.06967	X					
207R01591	Tributary of Walnut Creek	Region 2, Urban	37.99442	-122.03566	X					
207R01595	Mt. Diablo Creek	Region 2, Urban	37.95949	-121.96674	X					
207R01643	Mt. Diablo Creek	Region 2, Urban	37.92581	-121.92104	X					
207R01675	Sans Crainte Creek	Region 2, Urban	37.87660	-122.02369	X					X
207R01812	Sycamore Creek	Region 2, Urban	37.81161	-121.98097	X					
204R01819	Tributary of Laguna	Region 2, Urban	37.85246	-122.12644	X					
207R01847	Pine Creek	Region 2, Urban	37.96457	-122.04116	X					
207R01860	Sycamore Creek	Region 2, Urban	37.81677	-121.92161	X					

Table 2. Creek Status Monitoring Stations – WY 2014-2019

Site ID	Creek Name	Land Use	Latitude	Longitude	Bioassess-ment PHab Chlorine Nutrients	Water Toxicity and Chemistry (Wet Weather)	Water Toxicity and Sediment Toxicity and Chemistry (Dry Weather)	Water Temperature	Continuous Water Quality	Pathogen Indicator Bacteria
207R01931	San Ramon Creek	Region 2, Urban	37.86655	-122.03974	X					
207R02635	Las Trampas Creek	Region 2, Urban	37.89031	-122.07461				X	X	
207R02891	Las Trampas Creek	Region 2, Urban	37.88673	-122.09715				X		X
207R03403	Walnut Creek	Region 2, Urban	37.90381	-122.05921						X
207R04544	Alhambra Creek	Region 2, Urban	38.00026	-122.12993				X	X	X
WY 2018										
204R02068	South San Ramon Creek	Region 2, Urban	37.74792	-121.94346	X					
206R01495	Pinole Creek	Region 2, Urban	37.97919	-122.26354	X			X		
206R02203	Lauterwausser Creek	Region 2, Urban	37.89550	-122.19260	X					
206R02343	Wildcat Creek	Region 2, Urban	37.96171	-122.35447	X					X
207R01600	Mt. Diablo Creek	Region 2, Urban	38.01669	-122.02438	X					
207R01899	Mitchell Creek	Region 2, Urban	37.94118	-121.93701	X					
207R02315	Grayson Creek	Region 2, Urban	37.97958	-122.06860	X					
207R04027	Pine Creek	Region 2, Non-Urban	37.89318	-121.99378	X					
544R01737	Marsh Creek	Region 5, Urban	37.96267	-121.68748	X	X	X			
544R01993	Marsh Creek	Region 5, Urban	37.93229	-121.71109	X					
204R01412	West Branch Alamo Creek	Region 2, Urban	37.78499	-121.92294						
544R04613	Marsh Creek	Region 5, Urban	37.99031	-121.69585						
207ALH015	Alhambra Creek	Region 2, Urban	38.01490	-122.13257				X		
207ALH110	Alhambra Creek	Region 2, Urban	38.00346	-122.12968				X		
206SPA125	San Pablo Creek	Region 2, Urban	37.96621	-122.29918				X	X	
207WAL025	Grayson Creek	Region 2, Urban	37.99699	-122.06491						X
207WAL411	Las Trampas Creek	Region 2, Urban	37.86159	-122.10146					X[1]	
206R00727	Pinole Creek	Region 2, Urban	37.97961	-122.26835						X
207R01675	Sans Crainte Creek	Region 2, Urban	37.87644	-122.02348						X
207R02891	Las Trampas Creek	Region 2, Urban	37.88692	-122.09717					X[2]	
206R03927	San Pablo Creek	Region 2, Urban	37.96480	-122.32364						X

Table 2. Creek Status Monitoring Stations – WY 2014-2019

Site ID	Creek Name	Land Use	Latitude	Longitude	Bioassess-ment PHab Chlorine Nutrients	Water Toxicity and Chemistry (Wet Weather)	Water Toxicity and Sediment Toxicity and Chemistry (Dry Weather)	Water Temperature	Continuous Water Quality	Pathogen Indicator Bacteria
WY 2019										
204R02180	Alamo Creek	Region 2, Urban	37.77915	-121.90058	X					
204R02587	Moraga Creek	Region 2, Urban	37.84235	-122.14516	X					
206R01792	Refugio Creek	Region 2, Urban	37.99608	-122.24448	X					
206R02048	Rodeo Creek	Region 2, Urban	38.03034	-122.26516	X					
206R02455	Wildcat Creek	Region 2, Urban	37.93845	-122.29939	X					
206R02560	Refugio Creek	Region 2, Urban	38.00760	-122.26665	X					
207R01280	Franklin Creek	Region 2, Non-Urban	38.00274	-122.16804	X					
207R01655	East Branch Grayson Creek	Region 2, Urban	37.93774	-122.06370	X					
544R02037	Marsh Creek	Region 5, Urban	37.90691	-121.71558	X					
544R02505	Marsh Creek	Region 5, Urban	37.99168	-121.69589	X					
206R00551	San Pablo Creek	Region 2, Urban	37.96205	-122.33608				X		
206R00960	Rodeo Creek	Region 2, Urban	38.00737	-122.22129				X	X	
206R01319	San Pablo Creek	Region 2, Urban	37.96744	-122.36554				X		
207R02615	Walnut Creek	Region 2, Urban	37.98070	-122.05162				X		
544R04613	Marsh Creek	Region 5, Urban	37.99152	-121.69608						X
203BAX045	Baxter Creek	Region 2, Urban	37.93096	-122.32397						X
206PLN010	Pinole Creek	Region 2, Urban	38.00706	-122.29008						X
206SPA230	San Pablo Creek	Region 2, Urban	37.88118	-122.18817				X	X	
207ALH010	Alhambra Creek	Region 2, Urban	38.01676	-122.13592						X
543EAN010	East Antioch Creek	Region 5, Urban	38.01076	-121.79633						X
544MSH045	Marsh Creek	Region 5, Urban	37.93731	-121.70803			X			

1 Location of 2018 spring deployment in Las Trampas Creek

2 Location of 2018 summer deployment in Las Trampas Creek

1.1 Regional Monitoring Coalition (RMC) Overview

In early 2010, CCCWP joined with several other members of the Bay Area Stormwater Management Agencies Association (BASMAA) to participate in a regional collaborative effort to coordinate water quality monitoring required by the MRP. BASMAA is a 501(c)(3) nonprofit organization comprised of the municipal stormwater programs in the San Francisco Bay Area. The resulting regional monitoring collaborative is called the BASMAA Regional Monitoring Coalition (RMC). Details of the respective RMC stormwater program participants and their co-permittees are presented in Table 3.

Table 3. Regional Monitoring Coalition Participants

Stormwater Programs	RMC Participants
Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)	Cities of Campbell, Cupertino, Los Altos, Milpitas, Monte Sereno, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, Sunnyvale, Los Altos Hills, and Los Gatos; Santa Clara Valley Water District; and Santa Clara County
Alameda Countywide Clean Water Program	Cities of Alameda, Albany, Berkeley, Dublin, Emeryville, Fremont, Hayward, Livermore, Newark, Oakland, Piedmont, Pleasanton, San Leandro, and Union City; Alameda County; Alameda County Flood Control and Water Conservation District; and Zone 7 Water Agency
Contra Costa Clean Water Program (CCCWP)	Cities/Towns of Antioch, Brentwood, Clayton, Concord, El Cerrito, Hercules, Lafayette, Martinez, Oakley, Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon, Walnut Creek, Danville, and Moraga; Contra Costa County; and Contra Costa County Flood Control and Water Conservation District
San Mateo Countywide Water Pollution Prevention Program (SMCWPPP)	Cities and towns of Belmont, Brisbane, Burlingame, Daly City, East Palo Alto, Foster City, Half Moon Bay, Menlo Park, Millbrae, Pacifica, Redwood City, San Bruno, San Carlos, San Mateo, South San Francisco, Atherton, Colma, Hillsborough, Portola Valley, and Woodside; San Mateo County Flood Control District; and San Mateo County
Fairfield-Suisun Urban Runoff Management Program	Cities of Fairfield and Suisun City
Vallejo Permittees	City of Vallejo and Vallejo Sanitation and Flood Control District

In June 2010, the Permittees notified the Water Board in writing of their agreement to participate in the RMC to collaboratively address creek status and related monitoring requirements in MRP Provision C.8. The RMC's goals are to:

- Assist Permittees in complying with the requirements of MRP Provision C.8 (Water Quality Monitoring)
- Develop and implement regionally consistent creek monitoring approaches and designs in the Bay Area through the improved coordination among RMC participants and other agencies, such as the Regional Water Quality Control Board (RWQCB), that share common goals
- Stabilize the costs of creek monitoring by reducing duplication of effort (e.g., development of quality assurance project plans)

In February 2011, the RMC developed a multi-year work plan (RMC Work Plan; BASMAA, 2011) to provide a framework for implementing regional monitoring and assessment activities required under MRP Provision C.8. The RMC Work Plan summarized RMC-related projects planned for implementation between fiscal years 2009-2010 and 2014-2015. Projects were collectively developed by RMC representatives to the BASMAA Monitoring and Pollutants of Concern Committee and were conceptually agreed to by the BASMAA board of directors.

Based on the requirements described in Provision C.8 of the original (2009) MRP, a total of 27 regional projects were identified in the RMC Work Plan. Regionally implemented activities to provide standardization and coordination for the RMC Work Plan were conducted under the auspices of BASMAA. Scopes, budgets, and contracting implementation mechanisms for BASMAA regional projects follow BASMAA's operational policies and procedures, approved by the BASMAA board of directors. MRP Permittees, through their stormwater program representatives on the board of directors and its subcommittees, collaboratively authorize and participate in BASMAA regional projects or tasks. Regional project costs are shared by either all BASMAA members or among those Phase I municipal stormwater programs subject to the MRP. CCCWP and other RMC participants coordinate their monitoring activities through meetings and communications of the RMC work groups and the BASMAA Monitoring and Pollutants of Concern Committee .

1.2 Compliance Options (C.8.a)

Provision C.8.a. (Compliance Options) of the MRP allows the Permittees to comply with all monitoring requirements by contributing to their county-wide stormwater program through regional collaboration or by using data collected by a third-party. The primary vehicle for regional collaboration on creek status monitoring is the RMC, which coordinates member programs on monitoring needs, including:

- Shared standard operating procedures
- Shared quality assurance project plans (QAPPs)
- Site selection and number of sites per program
- Timing of sample events
- Data QA/QC procedures
- Database management

The main benefit of the RMC to the CCCWP Permittees is assurance that the final results meet Water Board expectations for data content and quality. The MRP defines the type, amount and frequency of monitoring; however, many details of execution require operator judgements (e.g., how to screen bioassessment sites or what are acceptable data quality objectives). Discussion at the RMC provides a single point of communication and common documentation to align the details across programs and allow the Water Board to comment on approach. The RMC is likely cost-neutral, in that the staff time and consultant support necessary to collaborate is offset by the cost efficiencies achieved by sharing methods and documents.

CCCWP works with third-party water quality monitoring partners to benefit local, regional and statewide monitoring efforts. Provision C.8.a.iii allows Permittees to work with third-party organizations such as the SFBRWQCB, CVRWQCB, California State Water Resources Control Board, or California Department of Pesticide Regulation, to fulfill monitoring requirements if data meets the water quality objectives described in Provision C.8.b. Monitoring locations in Contra Costa County are sampled as part of the state's Surface Water Ambient Monitoring Program (SWAMP) and assessed for pesticide pollution and toxicity through the Stream Pollution Trends (SPoT) Program (Phillips, B.M., et al., 2016). SPoT monitors status and trends in sediment toxicity and sediment contaminant concentrations in selected large rivers throughout California and relates contaminant concentrations and toxicity test results to watershed land uses.

CCCWP staff and other designated representatives participate with the Small Tributaries Loading Strategy (STLS) program (BASMAA, 2013) of the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) to conduct pollutants of concern monitoring at Contra Costa sites, as further described in Section 5.

MRP Permittees agreed to collectively conduct POC monitoring for management action effectiveness and for Provision C.12.e compliance monitoring through BASMAA regional projects. The overall goals of monitoring were to evaluate the effectiveness of selected stormwater treatment controls to provide information needed to support RAA development and to investigate polychlorinated biphenyl (PCB)-containing caulks and sealants within storm drain and roadway infrastructure which added to the fulfillment of MRP Provisions C.12.e. and C.8.f requirements. This work is further described in Section 5.

In addition, CCCWP supports efforts by local creek groups to monitor the San Pablo, Wildcat, Walnut, Grayson, and Marsh Creek watersheds.

1.3 Monitoring Protocols and Data Quality (C.8.b)

Provision C.8.b of the MRP and the Central Valley Permit requires water quality data collected by the Permittees to comply with and be of a quality consistent with the State of California's SWAMP standards, set forth in the SWAMP quality assurance project plan (QAPP) and SOPs. RMC protocols and procedures were developed to assist Permittees with meeting SWAMP data quality standards and developing data management systems which allow for easy access to water quality monitoring data by Permittees.

1.3.1 Standard Operating and Data Quality Assurance Procedures

For creek status monitoring, the RMC adapted existing SOPs and the QAPP developed by SWAMP to document the field procedures necessary to produce SWAMP-comparable[7], high quality data among RMC participants. The QAPP and SOPs of the RMC creek status monitoring program were updated to accommodate MRP 2.0 requirements in March 2016 (Version 3; BASMAA, 2016a and 2016b). The RMC creek status monitoring program QAPP was updated in January 2020 to be consistent with SWAMP protocols revised in 2017 to 2019.

For POC monitoring, a draft sampling analysis plan (SAP; CCCWP, 2016a) and QAPP (CCCWP, 2016b) were developed in 2016 to guide the monitoring efforts for each POC task. CCCWP's monitoring contractor implemented contracts with various laboratories for the analyses of all water and sediment samples.

BASMAA members conducted quality assurance reviews of the data collected for RMC programs consistent with the data quality objectives and protocols defined in the RMC QAPP and SOPs.

1.3.2 Information Management System Development/Adaptation

Permittees are required to report annually on water quality data collected in compliance with the MRP and Central Valley Permit. To facilitate data management and transmittal, the RMC participants developed an Information Management System (IMS) to provide SWAMP-compatible storage and import/export of data for all RMC programs, with data formatted in a manner suitable for uploading to CEDEN.

BASMAA subsequently supplemented the IMS to accommodate management of POC data collected by the RMC programs. The expanded IMS provides standardized data storage formats which allow RMC

[7] Further details on SWAMP comparability are available at https://www.waterboards.ca.gov/water_issues/programs/quality_assurance/comparability.html

participants to share data among themselves and to submit data electronically to the SFBRWQCB and CVRWQCB.

2 San Francisco Estuary Receiving Water Monitoring (C.8.c)

CCCWP contributes to the RMP, specifically the Status & Trends Monitoring Program (S&T Program) and the Pilot and Special Studies (P/S Studies). These efforts provide useful tools for CCCWP. Brief descriptions of the S&T Program and P/S Studies are provided below.

As described in MRP Provision C.8.c, Permittees are required to conduct or cause to be conducted receiving water monitoring in the Bay. Permittees comply with this provision by making financial contributions through the CCCWP to the San Francisco Bay RMP. Additionally, Permittees actively participate in RMP committees and work groups through Permittee and/or stormwater program representatives.

The Sacramento-San Joaquin River Delta (Delta) Regional Monitoring Program serves a similar function in fulfilling receiving water monitoring requirements for dischargers located within the jurisdiction of the Central Valley Regional Water Quality Control Board (CVRWQCB). Some CCCWP Permittees (the cities of Brentwood, Antioch, and Oakley, and portions of unincorporated Contra Costa County and the Contra Costa County Flood Control District) are located within the CVRWQCB's jurisdiction; however, by agreement with the SFRWQCB and the CVRWQCB, those Permittees also meet receiving water monitoring requirements through funding the San Francisco Bay RMP. This is consistent with the historic approach of managing the entire countywide program as a single, integrated program.

The RMP is a long-term, discharger-funded monitoring program directed by a steering committee and represented by regulatory agencies and the regulated community. In addition to regulators and the regulated community, the RMP Technical Committee includes participation by a local a non-governmental organization that specializes in water quality in the Bay. The goal of the RMP is to assess water quality in San Francisco Bay. The regulated community includes Permittees, publicly owned treatment works, dredgers, and industrial dischargers.

The RMP is intended to answer the following core management questions:

1. Are chemical concentrations in the estuary potentially at levels of concern and are associated impacts likely?
2. What are the concentrations and masses of contaminants in the estuary and its segments?
3. What are the sources, pathways, loadings, and processes leading to contaminant-related impacts in the estuary?
4. Have the concentrations, masses, and associated impacts of contaminants in the estuary increased or decreased?
5. What are the projected concentrations, masses, and associated impacts of contaminants in the estuary?

The RMP budget is generally broken into two major program elements: Status & Trends Monitoring and Pilot/Special Studies. The RMP publishes reports and study results on its website at www.sfei.org/rmp.

2.1 RMP Status & Trends Monitoring Program

The Status & Trends Monitoring Program (S&T Program) is the long-term contaminant monitoring component of the RMP. The S&T Program was initiated as a pilot study in 1989 and was redesigned in 2007 based on a more rigorous statistical design aimed at enabling the detection of trends. The S&T Program is comprised of the following program elements:

- Long-term water, sediment and bivalve monitoring
- Episodic toxicity monitoring
- Sport fishing monitoring
- USGS hydrographic and sediment transport studies
- Factors controlling suspended sediment in San Francisco Bay
- USGS monthly water quality data
- Triennial bird egg monitoring (cormorant and tern)

Additional information on the S&T Program and associated monitoring data are available for download via the RMP website at www.sfei.org/content/status-trends-monitoring.

2.2 RMP Pilot and Special Studies

The RMP conducts pilot and special studies on an annual basis through committees, workgroups and strategy teams. Studies usually are designed to investigate and develop new monitoring measures related to anthropogenic contamination or contaminant effects on biota in the estuary. Special studies address specific scientific issues that RMP committees and standing workgroups identify as priority for further study. These studies are developed through an open selection process at the workgroup level and are selected for further funding through RMP committees. Results and summaries of the most pertinent pilot and special studies can be found on the RMP web site (www.sfei.org/rmp).

2.3 Participation in Committees, Workgroups and Strategy Teams

CCCWP and/or other BASMAA representatives participate in the following RMP committees and workgroups:

- Steering Committee
- Technical Review Committee
- Sources, Pathways and Loadings Workgroup
- Emergent Contaminant Workgroup
- Nutrient Technical Workgroup
- Strategy teams (e.g., Small Tributaries, PCBs)

Committee and workgroup representation are provided by CCCWP, other stormwater program staff, and/or individuals designated by RMC participants. Representation includes participation in meetings, review of technical reports and work products, co-authoring or review of articles included in the RMP's annual publication *Pulse of the Estuary*, and general program direction to RMP staff. Representatives of the RMP also provide timely summaries and updates to and receive input from BASMAA stormwater program representatives (on behalf of the Permittees) during workgroup meetings to ensure the Permittees' interests are represented.

3 Creek Status Monitoring (C.8.d and C.8.g)

This section presents an integrated summary of creek status monitoring conducted by CCCWP in compliance with Provision C.8 of the MRP. After the overview of the monitoring management questions, strategy, and regional collaboration presented below, Section 3.1 describes the approach to regional/probabilistic creek status monitoring. Section 3.3 presents the approach to pesticide and toxicity monitoring. Section 3.2 describes the approach to targeted local creek status monitoring. Lessons learned about creek status monitoring are summarized in Section 3.4, and recommendations for monitoring during MRP 3.0 are presented in Section 3.5.

Creek status monitoring parameters, methods, occurrences, duration, and minimum number of sampling sites for each stormwater program are described in Provision C.8.d of the MRP. Creek status monitoring coordination through the RMC began in October 2011 and continues annually. Status and trends monitoring was conducted in non-tidally influenced, flowing water bodies (i.e., creeks, streams and rivers).

The RMC's strategy for creek status monitoring is described in the Creek Status and Long-Term Trends Monitoring Plan (BASMAA, 2011). The monitoring methods follow the protocols described in the updated BASMAA RMC QAPP (Version 3; BASMAA, 2016a) and SOPs for creek status and pesticides and toxicity monitoring (Version 3; BASMAA, 2016b). The purpose of these SOPs is to provide RMC participants with a common basis for application of consistent monitoring protocols across jurisdictional boundaries. These protocols form part of the RMC's quality assurance program to ensure validity of the resulting data and comparability with SWAMP protocols.

The creek status monitoring parameters required by MRP Provisions C.8.d and C.8.g are divided into two types: those conducted under a regional/probabilistic design, and those conducted under a local/targeted design. This distinction is shown in Table 4 for the required creek status monitoring parameters. The combination of these monitoring designs allows each individual RMC-participating program to assess the status of beneficial uses in local creeks within its program (jurisdictional) area, while also contributing data to answer management questions at the regional scale (e.g., differences between aquatic life conditions in urban and non-urban creeks).

The RMC monitoring strategy for complying with MRP 2.0 requirements includes continuing a regional ambient/probabilistic monitoring component, and a component based on local/targeted monitoring, as in the previous permit term. The analysis of results from the two creek status monitoring components conducted in water year 2019 is presented in Appendix 1 and Appendix 2, respectively.

Creek status monitoring data for each water year are submitted annually by the CCCWP to the SFBRWQCB and CVRWQCB by March 31 of the following year.

Table 4. Creek Status Monitoring Elements (per MRP Provisions C.8.d. and C.8.g.) Monitored as Either Regional/Probabilistic or Local/Targeted Parameters

Biological Response and Stressor Indicators	Monitoring Design	
	Regional (Probabilistic)	Local (Targeted)
Bioassessment, physical habitat assessment, CSCI	X	X[1]
Nutrients (and other water chemistry associated with bioassessment)	X	X[1]
Chlorine	X	X[2]
Stream Surveys (CRAM)		X[3,4]
Water toxicity (wet and dry weather)	NA	NA
Water chemistry (pesticides, wet weather)	NA	NA
Sediment toxicity (dry weather)	NA	NA
Sediment chemistry (dry weather)	NA	NA
Continuous water quality (sonde data: temperature, dissolved oxygen, pH, specific conductance)		X
Continuous water temperature (data loggers)		X
Pathogen indicators (bacteria)		X

1 Provision C.8.d.i.(6) allows for up to 20 percent of sample locations to be selected under a targeted monitoring design. This design change was made under MRP Order No. R2-2015-0049 (SFBRWQCB, 2015).

2 Provision C.8.d.ii.(2) provides options for probabilistic or targeted site selection. In water years 2014-2019, chlorine was measured at probabilistic sites.

3 Under MRP Order No. R2-2009-0074 (SFBRWQCB, 2009), stream surveys (stream walking and mapping) were required and sampled under a probabilistic monitoring design. The sampling method specified is the United Stream Assessment or equivalent. In water years 2014-2015, the California Rapid Assessment Method was selected.

4 The stream survey requirement was removed under MRP Order No. R2-2015-0049 (SFBRWQCB, 2015); therefore, data presented in this report were collected pursuant to MRP Order No. R2-2009-0074 (SFBRWQCB, 2009) and is applicable to water years 2014 and 2015 only.

CRAM California Rapid Assessment Method

CSCI California Stream Condition Index

NA Monitoring parameter not specific to either monitoring design

3.1 Regional/Probabilistic Creek Status Monitoring

The Regional/Probabilistic Creek Status Monitoring Report, WY 2019 (Appendix 1) documents the methods and results of monitoring performed by CCCWP during water year 2019 under the regional/probabilistic monitoring design developed by the RMC. During each water year, 10 sites are monitored by CCCWP for bioassessment, physical habitat, and related water chemistry parameters. To date, 80 sites have been sampled since the inception of the program in water year 2012.

RMC probabilistic monitoring sites are drawn from a sample frame consisting of a creek network geographic information system data set within the RMC boundary[8] (BASMAA, 2011), including stream segments from all perennial and non-perennial creeks and rivers running through urban and non-urban areas within the portions of the five RMC participating counties within the SFBRWQCB boundary, and the eastern portion of Contra Costa County which drains to the CVRWQCB region. A map of the BASMAA RMC area, equivalent to the area covered by the regional/probabilistic design "sample frame", is shown in Figure i. The sites selected from the regional/probabilistic design master sample draw and monitored in water year 2019 are shown graphically in Figure 1.

The probabilistic design required several years to produce sufficient data to develop a statistically robust characterization of regional creek conditions. BASMAA conducted a regional project to analyze

[8] Based on discussion during RMC meetings, with SFBRWQCB staff present, the sample frame was extended to include the portion of Eastern Contra Costa County that ultimately drains to San Francisco Bay to address parallel provisions in CCCWP's Central Valley Region Permit for Eastern Contra Costa County.

bioassessment monitoring data collected by the RMC Programs during the five-year period from 2012-2016 (Appendix 7). That analysis can be used to help inform recommendations for potential changes to the monitoring program. The project has also developed a fact sheet presenting the report findings in a format accessible to a broad audience.

Per MRP 2.0 Provisions C.8.d. and C.8.g., the creek status monitoring results are subject to potential follow-up actions, if they meet certain specified threshold triggers. If monitoring results meet the requirements for follow-up actions, the results are compiled on a list for consideration as potential SSID projects, per MRP Provision C.8.e. The results are compared to other regulatory standards, including the Basin Plan (SFBRWQCB, 2017) water quality objectives where available and applicable.

3.2 Pesticides and Toxicity Monitoring (C.8.g)

Pesticides and toxicity monitoring are separated into their own sub-provision in MRP 2.0 (C.8.g). The pesticides/toxicity monitoring requirements are further separated into:

- C.8.g.i. Toxicity in Water Column – Dry Weather
- C.8.g.ii. Toxicity, Pesticides and Other Pollutants in Sediment – Dry Weather
- C.8.g.iii. Wet Weather Pesticides and Toxicity Monitoring

The RMC QAPP and SOPs were updated in water year 2016 to implement the new requirements of MRP Provision C.8.g (BASMAA, 2016a and 2016b). The full reporting of the pesticides and toxicity monitoring is included in Appendix 1, along with the remainder of the regional/probabilistic creek status monitoring.

Additionally, in early 2016, as a project under the statewide Strategy to Optimize Resource Management of Storm Water (Storm Water Strategy AKA "STORMS"), the California State Water Resources Control Board began developing "Urban Pesticide Amendments" to the statewide water quality control plans for the control of pesticide discharges from municipal separate storm sewer systems (MS4s). The STORMS Urban Pesticides Amendments project involves the active participation of the California Department of Pesticide Regulation and the California Stormwater Quality Association (CASQA), working collaboratively with the Water Boards, and includes three components: 1) MS4 permit requirements, 2) regulatory coordination, and 3) a monitoring program. These three components are expected to provide an appropriate regulatory and scientific framework from which to address the underlying issues of pesticides pollution and associated toxicity in urban receiving waters. The RMC programs help support these efforts by contributing funding through BASMAA to support CASQA's participation in developing amendments and designing a statewide pesticides and toxicity monitoring program.

3.2.1 Toxicity in Water Column – Dry Weather (C.8.g.i)

Water samples are collected annually from one monitoring site during dry weather, in accordance with the dry weather sample index period that initiates on July 1 and continues through September 30. Toxicity testing is run for several different aquatic species, as required by MRP 2.0. Sampling is conducted at a site selected from the probabilistic design for bioassessment monitoring, or at a site targeted to address management questions. Results of dry weather water toxicity testing are presented in Appendix 1.

3.2.2 Toxicity, Pesticides and Other Pollutants in Sediment – Dry Weather (C.8.g.ii)

Once per year during the dry season (July 1 through September 30), sediment samples are collected and tested for toxicity to several different aquatic species, as required by MRP 2.0. Sampling is conducted at a site selected from the probabilistic design for bioassessment monitoring, or at a site targeted to address management questions.

Concurrent with the sediment toxicity sampling described above, sediment chemistry samples are collected for analysis of a select list of pesticides, polycyclic aromatic hydrocarbons, trace elements, total organic carbon (TOC) and grain size. All sediment analytical chemistry (pesticides and other pollutants), grain size analysis and toxicity test results are presented in Appendix 1.

Stressor evaluation results for sites with data collected for sediment chemistry, sediment toxicity, and bioassessment parameters by CCCWP over the first seven years of the RMC regional/probabilistic monitoring effort (water years 2012-2019) are summarized in Appendix 1.

3.2.3 Wet Weather Pesticides and Toxicity Monitoring – Wet Weather (C.8.g.iii)

Once per permit cycle during the wet season (October 1 through April 30), water column samples are collected and tested for toxicity to several different aquatic species, as required by MRP 2.0. Sampling is conducted at two sites from the probabilistic design for bioassessment monitoring, or at sites targeted to address management questions.

Concurrent with the water column toxicity sampling described above, water chemistry samples are collected for analysis of a select list of pesticides. Although not required by MRP 2.0, CCCWP includes sampling and analysis of dissolved organic carbon (DOC), TOC and suspended sediment concentration (SSC). All analytical chemistry (pesticides, DOC, TOC and SSC) and toxicity test results are presented in Appendix 1.

3.3 Local/Targeted Creek Status Monitoring

The Integrated Local/Targeted Creek Status Monitoring Report, WY 2014-2019 (Appendix 2) documents the results of targeted monitoring performed by CCCWP during water year 2019. Within Contra Costa County, targeted monitoring is conducted annually at:

- Four continuous water temperature monitoring locations
- Two general water quality monitoring locations
- Five pathogen indicator bacteria monitoring locations

Site locations are identified using a targeted monitoring design based on the directed principle to address the following management questions:

1. What is the range of general water quality measurements at targeted sites of interest?
2. Do general water quality measurements indicate potential impacts to aquatic life?
3. What are the pathogen indicator concentrations at creek sites where contact recreational water may occur?

Targeted monitoring data are evaluated against MRP threshold triggers, to assess the potential need for follow-up. The results of water year 2019 monitoring are summarized in Appendix 2.

3.4 Lessons Learned from Creek Status Monitoring – 2012-2019

Lessons learned from creek status monitoring are informed by monitoring over two permit cycles (MRP 1.0 and MRP 2.0) covering the period 2012-2019. The plethora of numeric indices and thresholds can be overwhelming to managers and the general public absent some context and interpretation. To aid in understanding monitoring outcomes, it helps to re-state the original motivation for using bioassessment to quantify creek health. As noted in the MRP 2.0 Fact Sheet entry supporting Provision C.8:

> *"…the required receiving water monitoring integrates the physical, biological and chemical effects to the water body of all MS4 discharges from multiple outfalls over multiple storms (i.e., time and space), yielding more useful data than outfall monitoring to determine compliance with the permit."*

Receiving water monitoring by the methods prescribed in Provision C.8 yields more useful data than outfall monitoring to determine compliance with the permit. Compliance with the permit, in turn, is assessed by evaluating the results of creek status monitoring to address two management questions:

- Are water quality objectives, both numeric and narrative, being met in local receiving waters, including creeks, rivers and tributaries?
- Are conditions in local receiving waters supportive of or likely supportive of beneficial uses?

Lessons learned for probabilistic, targeted, and pesticides/toxicity monitoring are summarized in each subsection below, with reference back to those two core management questions and some reflection as to whether the approaches used are generally useful to answering the questions. The reflection on lessons learned sets the stage for monitoring recommendations to guide MRP 3.0.

3.4.1 Lessons Learned from Regional/Probabilistic Monitoring

Are water quality objectives, both numeric and narrative, being met in local receiving waters, including creeks, rivers and tributaries?

The very few numeric water quality objectives applicable to regional/probabilistic monitoring are generally attained, except for ammonia. The only water quality parameters monitored concurrent with site bioassessments with applicable water quality objectives are ammonia, chloride and nitrate+nitrite. Looking back on the water quality monitoring results from bioassessment sites in Contra Costa County for water years 2012-2019, chloride and nitrate+nitrite generally met water quality objectives at all times and locations sampled. The same was true for ammonia, except in water year 2018 when ammonia exceedances began to occur. Four of 10 sites sampled exceeded the 25 µg/L ammonia water quality objective in water year 2019 and two of 10 exceeded the objective in water year 2019. Ammonia concentrations above the 25 µg/L water quality objective ranged from 29 to 169 µg/L.

The narrative water quality objective for toxicity is directly relevant to bioassessment, pesticide, and toxicity monitoring:

> *All waters shall be maintained free of toxic substances in concentrations that are lethal to or that produce other detrimental responses in aquatic organisms. Detrimental responses include, but are not limited to, decreased growth rate and decreased reproductive success of resident or indicator species. There shall be no acute toxicity in ambient waters. Acute toxicity is defined as a median of less than 90 percent survival, or less than*

> *70 percent survival, 10 percent of the time, of test organisms in a 96-hour static or continuous flow test.*
>
> *There shall be no chronic toxicity in ambient waters. Chronic toxicity is a detrimental biological effect on growth rate, reproduction, fertilization success, larval development, population abundance, community composition, or any other relevant measure of the health of an organism, population, or community.*
>
> *Attainment of this objective will be determined by analyses of indicator organisms, species diversity, population density, growth anomalies, or toxicity tests (including those described in Chapter 4), or other methods selected by the Water Board. The Water Board will also consider other relevant information and numeric criteria and guidelines for toxic substances developed by other agencies as appropriate.*
>
> *The health and life history characteristics of aquatic organisms in waters affected by controllable water quality factors shall not differ significantly from those for the same waters in areas unaffected by controllable water quality factors.*

The first two paragraphs of the narrative directly address toxicity test results as well as pesticide concentration monitoring. Toxicity is detected in sediments of Contra Costa County creeks, and when it is detected the evidence consistently points to concentrations of pesticides that are high enough to cause a toxic response. The last two paragraphs of the narrative objective address benthic invertebrate and algal communities as they are affected by controllable water quality factors.

The meaning of bioassessment scores helps interpret whether or not the narrative is attained. Benthic indices of biological integrity (IBI) reflect the composition of the biological communities of invertebrates living in creek beds. Low scores indicate poor creek health – the communities are dominated by organisms such as blood worms and crayfish which have a high tolerance for pollutants and physical stressors, such as high temperature and low dissolved oxygen (DO). High scores indicate relatively greater species richness and abundance and/or the presence of more sensitive species (e.g., water boatmen). A statewide IBI system, known as the California Stream Condition Index (CSCI), references in-stream conditions to expected conditions based on climate and geography. The Contra Costa IBI (CC-IBI) provides the same value of contextualized interpretation of IBI data, but specific to Contra Costa County.

In addition to benthic IBIs, IBIs have been developed for algal communities. Similar to benthic IBI scores, high scores indicating good creek health results from high algal species richness and presence of algal species that are more pollutant-sensitive, whereas lower scores generally reflect a much lower rich species composition and higher abundance of pollutant-tolerant species. Like benthic IBI metrics, multi-metric index (MMI) algal species composition indices (ASCIs) have been developed for quantitative assessments of stream health. This report deals with a diatoms-only MMI-ASCI and a hybrid MMI-ASCI, following SWAMP guidance.

Finally, physical habitat measurements (e.g., how much cobble is present and how embedded in sediments are cobbles, water velocities) are also used to develop stream condition indices. In this report, a “mini-PHab score” and an index of physical integrity score are used to quantify physical habitat condition.

In this monitoring program, much of the effort performing analyses and developing graphics, tables, and narratives supporting the evaluation of creek health focuses on the question of where creek health is better or worse, and do the various indices tell a consistent story about creek health.

At present, the comparison thresholds in the MRP are not by themselves numeric water quality objectives. The California State Water Resources Control Board is developing water quality objectives for biological endpoints that may be applied in the future to compare against numeric measures of creek health. Until statewide objectives are adopted, CCCWP uses the CSCI, ASCI and related metrics as indicators of creek status with respect to the elements of the narrative objective addressing “species diversity, population density” and the “health and life history characteristics of aquatic organisms.” Analysis of physical habitat measures, physical and chemical water quality parameters, and watershed and land use factors helps us quantify which of those factors influence metrics of biological community health. To the extent that any of these water quality factors are controllable, this information can guide restoration planning.

In comparison to the various indices discussed above, CCCWP’s bioassessment data shows that biological conditions in urban creeks in Contra Costa County are generally impacted. Physical habitat plays a significant role in this degradation of creek health. Water quality and antecedent rainfall also contribute to in-stream conditions.

The various indices as measures of creek health tend to agree, especially when the indices point to good creek health. Where the indices at times differ, it is usually a matter of degree (i.e., how bad is the bad and how good is the good). The CSCI tends to assign poor conditions everywhere. In contrast, the CC-IBI offers more of a gradient in stream conditions, which helps prioritize impacted areas for follow-up.

Are conditions in local receiving waters supportive of or likely supportive of beneficial uses?

The numeric water quality objectives for ammonia, chloride, and nitrate+nitrite cited above pertain to municipal potable water supply. Except for the limited subset of ammonia exceedances, this beneficial use is generally attained. The potential impact on groundwater quality of the limited elevated ammonia concentrations detected is unknown. The creeks in question with elevated ammonia are not known to be intentionally used by a municipal water supplier for groundwater recharge.

The evidence from creek status monitoring shows that aquatic life beneficial uses are not fully supported due to a variety of physical habitat, climatic (rainfall), and watershed/land use factors.

The numeric analysis and narrative discussion of bioassessment data indicates that the beneficial uses of wildlife habitat (WILD), warm water fisheries habitat (WARM), and cold-water fisheries habitat (COLD) are attained to varying degrees in Contra Costa County streams. This finding is consistent with more detailed analysis of temperature and dissolved oxygen through local/targeted monitoring programs.

Is the regional/probabilistic monitoring approach generally useful to addressing those two questions?

The data developed through the regional/probabilistic creek status monitoring approach has provided a robust baseline characterization of creek health in Contra Costa County and context with Bay Area and California streams. Work done so far has been useful; however, the value of adding more probabilistic data in the near term is questionable. Rather than continuing the program of probabilistic sampling, CCCWP would prefer to focus resources on monitoring to detect change and where change occurs. This means identifying known or potential future creek restorations, green infrastructure projects, or other watershed management actions that may be expected to improve creek health. Before and after monitoring will help test management hypotheses about the expected magnitude and timing of stream condition in response to management actions.

The RMC approach to draw a random sample of candidate bioassessment sites, and then revise the random draw based on owner permissions and safe access, may have skewed the representativeness of the bioassessment data. Specifically, streams that are accessed only by permission of the East Bay Municipal Utility District (EBMUD) have not been well sampled in Contra Costa County because the permissions process presents schedule challenges. Owing to the surrounding land use, these streams may have better creek health compared to the population of sites monitored to date. CCCWP seeks to iterate the RMC site selection protocols during MRP 3.0 so that future bioassessment monitoring efforts can more directly target known data gaps, as well as areas where potential future changes may lead to potential future improvements in bioassessment scores.

3.4.2 Lessons Learned from Pesticides/Toxicity Monitoring

Are water quality objectives, both numeric and narrative, being met in local receiving waters, including creeks, rivers, and tributaries?

Numeric water quality objectives for diazinon and chlorpyrifos are consistently attained in the creeks monitored by CCCWP in water years 2012-2019. This monitoring was performed in Marsh Creek in compliance with CVRWQCB's TMDL requirements. The outcome of no detections is attributed to a phaseout of consumer use of these pesticides.

Narrative water quality objectives for "no toxic substances in toxic amounts" are not consistently attained. Toxicity in sediments was observed in seven of the 12 assessments of the sediment quality triad performed in Contra Costa County (Appendix 1, Table 5.11). Chemical analysis shows that pyrethroid pesticides are present in sufficient concentrations to account for observed toxicity.

Are conditions in local receiving waters supportive of or likely supportive of beneficial uses?

The evidence from pesticide and toxicity monitoring shows that aquatic life beneficial uses are not fully supported due to pesticide impacts. Conditions can improve in response to control measures, as evidenced by lessons learned from diazinon and chlorpyrifos.

Is the Pesticide/Toxicity Monitoring approach generally useful to addressing those two questions?

The pesticide and toxicity monitoring approach has established links between observed toxicity and pesticides. As evidenced by lessons learned from diazinon and chlorpyrifos, this type of evidence can be used by regulatory agencies to establish meaningful control programs that make a difference. Data from CCCWP, other Bay Area stormwater programs, and statewide efforts can help build a record to support future regulatory controls of pesticides that have emerged to replace diazinon and chlorpyrifos.

3.4.3 Lessons Learned from Local/Targeted Monitoring

Are water quality objectives, both numeric and narrative, being met in local receiving waters, including creeks, rivers, and tributaries?

Local/targeted monitoring using continuous monitoring addresses water temperature, conductivity, pH, turbidity and dissolved oxygen. These parameters have water quality objectives that generally relate to WARM and COLD beneficial uses. Objectives for conductivity are generally attained in most Contra Costa creeks monitored, except for Rodeo Creek. The Rodeo Creek location consistently exceeds the conductivity objective, pointing to the possible influence of groundwater at the location monitored. The pH of water generally stays within bounds established by the Basin Plan (6.5 < pH > 8.5) at frequencies specified in the MRP; exceptions occur at San Ramon and San Pablo Creeks, where the pH exceeded 8.5 30 percent and 21 percent of the time, respectively. The daytime peak of pH values, coincident with daily dissolved oxygen peaks at the locations monitored, point to photosynthetic cycling as a root cause of pH exceedances.

Attainment of dissolved oxygen and temperature thresholds was less widespread throughout the county than conductivity and pH attainment. Of the creeks monitored during MRP 2.0, San Pablo Creek had the most consistent attainment of the dissolved oxygen water quality objective relevant to COLD (> 7 mg/L), although during the summer monitoring period this threshold was never attained at location 206SPA125. Temperatures in San Pablo Creek also generally attained MRP thresholds at most locations and times. Referring back to the IMR from MRP 1.0, Wildcat Creek also showed the most favorable temperature conditions of all creeks monitored in Contra Costa County over the past two permit cycles. Thus, the most consistent attainment of temperature and water quality objectives pertinent to COLD in monitored creeks are Wildcat and San Pablo Creeks. This observation is aligned with the land uses and the relatively cooler climate in west county watersheds, as compared to central and eastern county watersheds.

Attainment of the water quality objective for WARM (DO > 5 mg/L) is also variable for the 16 different sonde deployments conducted 2012-2019 (Table 5). The objective is generally attained during the spring deployments. During the summer, at least half of the sonde deployments indicated dissolved oxygen lower than 5 mg/L during isolated incidents. Five of the 16 had more prolonged incidents, including Marsh Creek.

Marsh Creek was selected for a stressor/source identification study in 2017 that was concluded in 2019. The study identified low dissolved oxygen as a root cause of recurrent fish kills. The study is complete and, having identified flow augmentation as a potential corrective action, Permittees are now evaluating the effectiveness of this potential remedy and the implications for longer term strategies to maintain and enhance water quality in Marsh Creek.

Grab sampling for pathogen indicators showed that exceedances occur downstream of locations where people live outdoors, or in recreational vehicles and other temporary accommodation that lack centralized sanitary sewage services. Not all exceedances were attributed to anthropogenic sources, as the presence of waterfowl on stream banks and in the stream channel were also suspected to contribute to elevated levels of fecal indicator bacteria.

Table 5. Summary of Attainment of DO > 5 mg/L in Contra Costa County Creeks

Creek/Location	Year Monitored	DO > 5 mg/L in Spring?	DO > 5 mg/L in summer?
Rodeo Creek @ Franklin Canyon Golf Course	2019	Yes	Unknown[1]
San Pablo Creek @ Santa Maria Way	2019	Yes	Yes
Las Trampas Creek @ Lafayette Community Park	2018	Yes	Generally, yes; one incident DO < 5 mg/L
San Pablo Creek @ Earth Island Institute	2018	Generally, yes; one incident of DO < 5 mg/L	Generally, no; only during mid-day peaks does DO attain > 5 mg/L
Las Trampas Creek @ Camino Posada Court	2017	Yes	Yes
Alhambra Creek @ F Street	2017	Yes	Generally, no; only during mid-day peaks does DO attain > 5 mg/L; one low DO event lasted 48 hours
West Branch of Alamo Creek @ Red Willow Road	2016	Yes	Generally, no; only during mid-day peaks does DO attain > 5 mg/L; one low DO event lasted 48 hours
Rimer Creek @ Camino Pablo	2016	Yes	Yes
West Branch of Alamo Creek	2015	Generally, yes; with two brief incidents of DO < 5 mg/L	Initially, yes; but DO dropped below 5 mg/L for last 5 days of monitoring
San Ramon Creek	2015	Yes	Yes, with one very brief incident of DO < 5 mg/L
Rodeo Creek @ Muir Land Trust	2014	No	No
San Pablo Creek @ Rock Harbor Church	2014	Yes	Yes
Pinole Creek at Pinole Library	2013	Yes	Generally, yes; four brief incidents DO < 5 mg/L
San Pablo Creek (Camino Encinas @ Moraga Way)	2013	Yes	Yes
Walnut Creek (Arroyo Way @ Civic Drive)	2012	Yes	Yes
Marsh Creek @ Fish Ladder	2012 - Present	SSID study completed that identified low DO as cause of recurrent fish kills. Permittees are evaluating and implementing corrective measures.	

1 Monitoring equipment failed during the summer deployment.

2 Stressor/source identification

Are conditions in local receiving waters supportive of or likely supportive of beneficial uses?

The analysis of water quality objectives – with a focus on dissolved oxygen and temperature – indicates that San Pablo and Wildcat Creeks show the most promise for attaining beneficial use of COLD; however, attainment of COLD water quality objectives for those two creeks is also not 100 percent. Those and other creeks monitored show partial or full attainment of WARM, with the consistent pattern that failure to attain dissolved oxygen > 5 mg/L is most common in summer and is typically driven by day-night photosynthesis/metabolism cycles of in-stream algae and/or macrophytes.

The beneficial use of Water Contact Recreation (REC-1), as assessed by the risks of full immersion (i.e., swimming) are not attained, especially downstream of known human sources of pathogen indicators. The appropriateness of full contact immersion as a risk indicator in streams that are wadable (at most) has not been evaluated.

Is the local/targeted monitoring approach generally useful to address those two questions?

Continuous monitoring is a cost-effective, solutions-oriented approach to characterizing stream health. As described in Section 4 and Appendix 3C, the approach supported direct understanding of the root causes of low dissolved oxygen and resulting fish kills in Marsh Creek. The insights gained from continuous monitoring also led to flow augmentation as a pilot intervention project. The summary of attainment of COLD and WARM provided above is a useful road map to guide future deployment of monitoring resources in MRP 3.0 and subsequent permit cycles.

Monitoring for pathogen indicators was helpful to verify where human activity, such as off-leash dog parks, duck feeding areas or encampments, could negatively impact the designated beneficial use. Future monitoring for pathogens indicators should focus on effectiveness. The monitoring management question should be, as municipalities define and implement maximum extent practicable measures to manage water quality impacts that result from human activity, how is water quality improved?

3.5 Recommendations for Creek Status Monitoring in MRP 3.0

Based on the lessons learned summarized above, CCCWP makes the following recommendations for the creek status monitoring program established in Provision C.8 of the MRP:

- Replace the probabilistic sampling design for bioassessment in MRP 3.0 with a targeted sampling design. The review of data gathered to date shows that baseline conditions have been reasonably well characterized at this point. Future deployment of CCCWP monitoring resources should address the following priorities:
  - Filling data gaps in areas that have heretofore been difficult to access (i.e., EBMUD-owned lands). In addition to identifying problem areas, CCCWP also seeks to identify high-value stream habitat resources that merit protection and/or enhancement.
  - Characterizing before and after conditions where restoration or other watershed management actions are expected to improve creek health.
- Where Water Board has the discretion, consider prescribing minimum numbers of samples for the permit term, rather than annually. The total number of samples required for the permit terms establishes a floor of sampling effort. CCCWP requests some flexibility to plan monitoring efforts so that they are optimized to gain maximum value for the effort and cost applied.
  - Often, the best approach is a monitoring effort concentrated over one to three years, rather than spreading the effort equally over five years.
  - Overly prescribing the monitoring frequency at the annual interval can diminish the quality of the monitoring design and resulting outcomes, or cause CCCWP to seek exceptions.
  - This was a lesson learned during MRP 1.0. The requirement to sample a minimum number of storms per year forced monitoring contractors to sample any available storm event to meet the minimum number, regardless of storm size. This skewed the monitoring toward more frequent, less intense storms. Recognizing that under those conditions, Marsh Creek monitoring was not capturing important flow events from the upper watershed, where the historic Mount Diablo Mercury mine is located, CCCWP sought and obtained an exception to eliminate the minimum number in favor of conserving resources to sample Marsh Creek

when flows from large, later season events convey water from the upper watershed past Marsh Creek Reservoir. This approach has provided important evidence that mercury-impacted sediments do not appear to be transported into lower Marsh Creek during large storm events.

– Seeking exceptions takes time and effort. If MRP 3.0 monitoring requirements constrain the monitoring design to less than optimum, CCCWP and the Water Board may need to accept that the outcomes and insights gained from the monitoring effort may be diminished compared to a monitoring design that allows flexibility for timing and focusing resources.

4 Stressor/Source Identification Projects (C.8.e)

MRP 2.0 requires SSID projects to be considered when one or more monitoring results trigger a candidate for a follow-up project. SSID projects are intended to be oriented toward taking action(s) to alleviate stressors and reduce sources of pollutants.

A list of monitoring results exceeding thresholds is maintained by the RMC participants from which the SSID projects can be selected based on criteria in MRP Provision C.8.e.ii. MRP Provision C.8.e.ii.(1) requires Permittees who conduct SSID projects through a regional collaborative (such as the BASMAA RMC) to collectively initiate a minimum of eight new SSID projects (with at least one for toxicity) during the permit term. Most of those projects are conducted by individual programs addressing local needs. RMC programs have agreed that the distribution of the eight required SSID projects will be as follows:

- 2 each: Santa Clara and Alameda counties
- 1 each: San Mateo and Contra Costa counties
- 1 jointly: Fairfield/Suisun and Vallejo
- 1 regionally: All BASMAA participants

The process for identifying and selecting MRP 2.0 SSID projects through the RMC includes the following elements:

- Review monitoring results annually (C.8.d, C.8.f and C.8.g) and update the regional trigger exceedance matrix, which includes evaluation of TMDL thresholds (including pyrethroid toxicity units) to accommodate MRP 2.0 Provision C.9. requirements.

- Jointly consider the threshold trigger results and select follow-up SSID projects from the matrix based on criteria, such as magnitude of threshold exceedance, parameter (for a variety of parameters), likelihood stormwater management action(s) could address the exceedance, and similar priorities.

- Plan and implement eight SSID projects during the permit term, with the one required project for CCCWP beginning by the third year of the permit term.

A summary of all BASMAA RMC SSID projects proposed or currently being conducted for MRP 2.0 is also included in Appendix 3A.

The SSID project being conducted by BASMAA as a regional project is focused on electrical utilities as a potential source of PCBs in urban stormwater runoff. The work plan and status update for that SSID project is included in Appendix 3B.

4.1 Marsh Creek SSID Study

As detailed above, in accordance with MRP 2.0 Provision C.8.e, SSID projects are required to be considered when any monitoring result(s) trigger a candidate for a follow-up project.

Dating back to 2005, there have been 10 documented fish kills over the past 14 years in Marsh Creek, including the most recent event of Sep. 17, 2019 that effectively concluded the SSID study. These events are often associated with intermittent dry season flows or storm events with varying antecedent dry periods. With agreement from SFBRWQCB and CVRWQCB staff, CCCWP investigated the potential causes of fish kills observed in lower Marsh Creek as its MRP 2.0 SSID study. Details of the Marsh Creek SSID study are presented in Appendix 3C.

The Marsh Creek SSID study identified low dissolved oxygen as a root cause of recurrent fish kills. The low dissolved oxygen results from a confluence of conditions that occur within the unique configuration of Marsh Creek:

- At low flows, Marsh Creek is a series of interconnected pools between check dams which were installed to reduce velocities that cause channel scour.
- Dissolved oxygen cycles naturally due to photosynthesis/metabolism cycles of in-stream algae and plants, peaking by day and reaching a minimum at night.
- During the summer dry season, minimum dissolved oxygen levels reached at night depend on flow. Higher flows lead to higher nighttime minimum dissolved oxygen levels. This is due to a combination of well-aerated water reaching the stream from the WWTP, and increased velocities across the riffles formed by check-dams, which re-aerates water.
- During summer and early fall irrigation seasons, nighttime WWTP flows reaching Marsh Creek can approach zero due to irrigation demand for recycled water.
- First flush storm events which wash biological organisms and organic matter into the creek create biochemical oxygen demand that can lower the dissolved oxygen in the creek to the point that lethal levels occur.

After the first year of the study, a flow augmentation pilot project was implemented by the WWTP. Each day for two months, beginning on Sep. 15, 2019, the WWTP would store 250,000 gallons of water by day and release it over a 6-hour period at night, thus avoiding zero flow conditions concurrent with the nighttime dissolved oxygen minimum resulting from algal/plant metabolism. Coincidentally, the first storm of the season occurred on Sep. 16, 2019, one day after the flow augmentation began. The normal daily rise in dissolved oxygen was observed to reverse, and the following day a relatively small fish kill (~100 fish) occurred, but the fish mortality was observed to occur exclusively upstream of the WWTP on Sep. 17, 2019 and later. Continuous monitoring data documented that intervention with the flow augmentation pilot helped avoid creating lethally low dissolved oxygen conditions along the two-mile reach of Marsh Creek downstream of the WWTP. If not for the pilot flow augmentation, the fish kill event of Sep. 17, 2019 would likely have resulted in many more fish dying, as has occurred in the past.

The SSID study has reached a conclusion in that CCCWP has answered the monitoring question. The project now pivots to Permittee-led actions. The Contra Costa Flood Control and Water Conservation District has agreed to fund additional continuous monitoring on Marsh Creek. The City of Brentwood has indicated willingness to extend the flow augmentation pilot study, subject to water supply constraints resulting from local demand. The study also establishes a foundation for planning alternatives for the future management of Marsh Creek upstream of the WWTP.

4.2 Regional Source Identification Study of PCBs from Electrical Utility Equipment

In late 2018, BASMAA contractors developed a work plan for a regional SSID project addressing releases and spills of PCBs from electrical utility equipment. The regional SSID project (Electrical Utilities as a Potential PCBs Source to Stormwater in the San Francisco Bay Area) was triggered by fish tissue monitoring in the Bay that led to the Bay being designated as impaired on the Clean Water Act Section 303(d) list and the adoption of a TMDL for PCBs in 2008. Subsequent PCBs monitoring by the BASMAA RMC partners and the RMP suggests that diffuse sources of PCBs are present throughout the region. One potential source of PCBs to stormwater is releases and spills from electrical utility equipment.

PCBs were historically used in several types of electrical utility equipment, some of which still contain PCBs. Although much of the PCB-containing equipment has been removed from service, some remains in use, and releases and spills from the equipment may be occurring at levels approaching the TMDL WLA. However, the information currently available is not adequate to fully quantify the scope and magnitude of electrical utility applications as a source of PCBs to stormwater. The information gap is partially due to state and federal regulatory levels for reporting and clean-up of PCBs spills that are higher than the PCB levels needed to comply with the PCBs TMDL requirements. Furthermore, stormwater programs have neither the authority to compel electrical utilities to provide information about spills, equipment replacement programs, and clean-up protocols, nor the authority to require additional controls. Therefore, BASMAA identified a need to develop and implement a regional SSID work plan to further understand the magnitude and extent of this potential PCBs source, and identify controls (if necessary) that could be put into place to reduce the water quality impacts of this source.

The work plan was submitted with each countywide stormwater program's water year 2018 urban creeks monitoring report (CCCWP, 2018a). It presents a framework for working with the Water Board, which does have jurisdictional authority over electrical utility companies. The overall goal for the regional SSID project is to investigate electrical utility equipment as a source of PCBs to urban stormwater runoff and identify appropriate actions and control measures to reduce this source. Building on the information presented by the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP, 2018), this project is designed to achieve the following three objectives:

- Gather information from Bay Area utility companies to improve estimates of current PCBs loadings to MS4s from electrical utility equipment, and document current actions conducted by utility companies to reduce or prevent release of PCBs from their equipment.
- Identify opportunities to improve spill response, cleanup protocols, or other programs designed to reduce or prevent releases of PCBs from electrical utility equipment to MS4s.
- Develop an appropriate mechanism for municipalities to ensure adequate clean-up, reporting and control measure implementation to reduce urban stormwater loadings of PCBs from electrical utility equipment.

A possible outcome of this SSID project is a recommendation that Bay Area municipalities submit a referral to designate electrical utility equipment and properties as a "Categorical Source", which is a type of source property described in more detail in Interim Accounting Methodology for TMDL Loads Reduced (BASMAA, 2017). A Categorical Source designation would facilitate development of a regional approach to abate this source under the regulatory authority of the Water Board. The Categorical Source designation was developed specifically to address potential sources of PCBs that are widespread and distributed across multiple jurisdictions, such as electrical utility applications. MRP Permittees, as a group, can refer an entire source category to the Water Board. Although local agencies may still identify and refer individual electrical utility properties to the Water Board for abatement, addressing these facilities and equipment as a Categorical Source may prove to be a more effective and efficient way to reduce PCBs loads from this source category. The information gained during this project will also provide data that municipalities can use to develop a methodology to account for PCBs load reductions that can be achieved through implementation of a regional control measure program for electrical utilities. Pacific Gas and Electric Company (PG&E), a non-municipally owned electrical utility company, is by far the largest electrical utility company in the Bay Area, and likely the largest single user of PCBs in the Bay Area. As such, PG&E is likely the largest current source of PCBs released to MS4s from electrical utility equipment.

4.2.1 Overview of the Regional SSID Work Plan

The detailed work plan for the SSID study appears in Appendix 3B.

4.2.2 Current Status of the Regional SSID Project

Implementation of the regional SSID work plan began in water year 2019. As part of Subtask 1.1, the project team, with the assistance and input of the BASMAA project management team, developed a letter addressed to the Water Board. The letter requested the Water Board use its regulatory authority to compel PG&E (the only non-municipally owned electrical utility in the Bay Area) to provide the information required to complete the desktop analysis described under Task 1. The letter identified the specific data BASMAA would like to receive from PG&E in order to better understand the extent and magnitude of PCBs released from OFEE; identify the most appropriate actions to prevent or reduce releases from this source; and develop and implement effective reporting and control measures. BASMAA submitted the letter to the Water Board in August 2019. Water Board staff have indicated they will actively seek opportunities to communicate with non-municipally owned utilities (i.e., PG&E) to request the information BASMAA identified in its letter. However, ongoing bankruptcy proceedings may prolong the receipt of information from PG&E which, in turn, will likely prolong the project completion.

In the meantime, BASMAA began implementing a parallel approach in early water year 2020 that focuses on a partnership with municipally-owned electrical utilities in the MRP area. Although these municipally-owned electrical utilities represent a tiny fraction of the electrical utility equipment and properties in the MRP area, BASMAA member agencies have a better opportunity to work with these utilities and gather the type of information needed to conduct the desktop analysis, albeit at a smaller scale. In November and December 2019, BASMAA held a series of meetings with representatives from municipally-owned electrical utilities and associated municipal staff in the MRP area to discuss the project and information needs. Based on input provided during these meetings, BASMAA developed an information request for municipally owned electrical utilities similar to the request sent to the Water Board for PG&E data.

BASMAA intends to continue this project during water year 2020. The new request for information will be submitted to each of the municipally owned electrical utilities in the MRP area in the near future. The BASMAA project team will proceed with the desktop analysis upon receipt of data from these utility partners. It is anticipated that the final project report will be submitted to the Water Board with the Program's water year 2020 urban creeks monitoring report by Mar. 31, 2021.

4.3 Recommendations for the SSID Monitoring Program in MRP 3.0

The SSID program has been successful at the local study level in Marsh Creek. At the regional level, progress on the PCB Source Identification from Electrical Equipment Study is impeded by factors outside of the BASMAA member agencies' control. The recommended change to the SSID program is that SSID study completion be accepted when programs have submitted conclusive final reports, rather than requiring approval by the executive officer of the Water Board. Review of the SSID Study Matrix (Appendix 3A) reveals that very few of the projects have been approved as complete. Studies must have finite endpoints so that resources can be applied to other problems identified. Rather than making executive officer approval the default, Permittees and Programs should be granted the trust, based on prior successes in MRP 1.0 and MRP 2.0, to carry out projects to completion and to appropriately document the outcomes when declaring them complete. If needed, Water Board staff can request more effort through participation in the BASMAA Monitoring and Pollutants of Concern Committee.

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5 Pollutants of Concern Monitoring (C.8.f)

POC load monitoring is intended to assess inputs of POCs to the Bay from local tributaries and urban runoff, assess progress toward achieving WLAs for TMDLs, and help resolve uncertainties associated with loading estimates for these pollutants. Section 5.1 begins with a summary of activities conducted to further those objectives during MRP 2.0. Specific deliverables, either previously reported or included as appendices, are called out with activity descriptions. Section 5.2 concludes with a summary of lessons learned that lead to recommendations for POC monitoring during MRP 3.0 which are summarized in Section 5.3.

POC monitoring addresses five priority information management needs:

1. **Source Identification** – identifying which sources or watershed source areas provide the greatest opportunities for reductions of POCs in urban stormwater runoff.
2. **Contributions to Bay Impairment** – identifying which watershed source areas contribute most to the impairment of San Francisco Bay beneficial uses (due to source intensity and sensitivity of discharge location).
3. **Management Action Effectiveness** – providing support for planning future management actions or evaluating the effectiveness or impacts of existing management actions.
4. **Loads and Status** – providing information on POC loads, concentrations, and presence in local tributaries or urban stormwater discharges.
5. **Trends** – evaluating trends in POC loading to the Bay and POC concentrations in urban stormwater discharges or local tributaries over time.

Connections to priority management information needs are described for monitoring activities in the discussion below.

5.1 POC Monitoring Activities – WY 2014-2019

POC monitoring methods are continuously reviewed and updated as necessary. An updated QAPP (CCCWP, 2016b) and SAP (CCCWP, 2016a) were developed in water year 2016 to implement the POC, toxicity, and pesticide monitoring requirements in MRP 2.0 Provisions C.8.f and C.8.g.

5.1.1 Source Identification

Since 2014, CCCWP and Permittee staff have conducted source area assessments to delineate high interest parcels and areas for consideration of property referrals and focused implementation planning for PCBs and mercury load reductions. Street dirt drop inlet sediments and stormwater runoff were sampled to locate high interest areas for PCBs source property referral and abatement. These monitoring activities address source identification. Additionally, stormwater monitoring was conducted in targeted locations for copper, nutrients, mercury and methylmercury. A summary report of these data is presented in Pollutants of Concern Integrated Monitoring Report: Water Years 2014-2019 (Appendix 5).

MRP Provision C.8.f. (Pollutants of Concern Monitoring) Table 8.2 calls for conducting or causing to conduct a study that addresses relevant management information needs for emerging contaminants, at least alternative flame retardants. BASMAA representatives are currently working with the RMP to develop a workplan for a special study to account for relevant contaminants of emerging concern in stormwater and would address at least perfluorooctanesulfonate (known as PFOS), per- and polyfluoroalkyl substances (known as PFAS), and alternative flame retardants being used to replace polybrominated diphenyl ethers (known as PBDEs). Details of this process are described in Appendix 8A.

5.1.2 Contribution to Bay Impairment

MRP Provision C.12.g requires Permittees to conduct or cause to be conducted a “Fate and Transport Study of PCBs.” The purpose of the study is to determine whether some areas along the Bay margins are disproportionately influenced by PCBs from urban runoff, potentially making the corresponding upland watersheds a higher priority for PCB control measures. CCCWP causes a Fate and Transport Study of PCBs to be conducted through financial support of the RMP, and through participation in RMP work groups. Study proponents claim that “advancing knowledge of drainages where urban runoff PCBs are particularly important in food web accumulation” could allow the SFBRWQCB to explore revising the PCBs TMDL to prioritize actions affecting sensitive margin areas.

The RMP Fate and Transport Study of PCBs (Appendix 8B) has identified four “priority margin units” (PMUs):

- Richmond Harbor (Contra Costa)
- Steinberger Slough (San Mateo)
- San Leandro Bay (Alameda)
- Emeryville Crescent (Alameda)

Conceptual models have been developed for three of the four PMUs, but not for the Richmond Harbor. According to the summary of this study (Appendix 8B), the Richmond Harbor conceptual model was not developed “due to budget limitations and because other RMP efforts were deemed a higher priority.” The next step, where conceptual models have been developed, would be monitoring to verify conceptual models. It is unclear how this PCBs Fate and Transport study will guide or affect implementation of PCB control measures in Contra Costa County in the foreseeable future.

5.1.3 Trends, Loads and Status

MRP 2.0 places an increased focus on finding watersheds, source areas, and source properties that are potentially more polluted and upstream from sensitive Bay margin areas (high leverage sites). To support this focus, a stormwater reconnaissance monitoring program was developed and implemented beginning in water year 2015 by the RMP through the STLS workgroup. From water years 2015-2019, 16 stormwater sampling locations within Contra Costa County were monitored for PCBs and mercury by the RMP. These monitoring results are summarized in the RMP Pollutants of Concern Reconnaissance Monitoring Progress Report, Water Years 2015-2019 (Appendix 6). The content of that report addresses loads and status as well as trends of POC loads. Additional loads and status data regarding nutrients and copper were produced by CCCWP during water years 2014-2019 and are summarized below under “Lessons Learned.”

5.1.4 Management Action Effectiveness

MRP Permittees agreed to collectively conduct POC monitoring for management action effectiveness via a BASMAA regional project. The overall goal of monitoring was to evaluate the effectiveness of selected stormwater treatment controls to provide information needed to support RAA development. BASMAA agreed to focus this monitoring effort on two treatment options with the potential to reduce PCBs and mercury discharges: hydrodynamic separator (HDS) units and enhanced bioretention filters. HDS monitoring focused on collecting sediment removed from HDS unit sumps during maintenance to evaluate the PCBs and mercury load reduction effectiveness. Enhanced bioretention filter monitoring focused on testing various biochar in soil media mixes to identify those which improve PCBs and mercury load removal. The final project reports associated with these studies are attached in Appendices 4A and 4B.

MRP Provision C.12.e. requires Permittees to collect samples of caulk and other sealants used in storm drain or roadway infrastructure in public rights-of-way and to investigate whether PCBs are present in such material and in what concentrations. This work was conducted as a BASMAA regional project and contributed to partial fulfillment of the POC monitoring required by Provision C.8.f of the MRP to address PCBs source identification. The PCBs in Infrastructure Caulk Project report (BASMAA, 2018) was submitted in the CCCWP fiscal year 2017-2018 annual report as Attachment 12.3. Early work in this project addressed source identification, while latter work was focused on verifying management action effectiveness.

CCCWP credited a due portion of the BASMAA regional project monitoring work in fulfillment of POC requirements under MRP Provision C.8.f, as summarized in Pollutants of Concern Monitoring Report, Water Year 2018 Sampling and Analysis (CCCWP, 2018b).

CCCWP began implementation of a methylmercury control study in 2012 to fulfill requirements of the Central Valley Permit (C.11.l). A methylmercury control study work plan (AMEC, 2013) was prepared to 1) evaluate the effectiveness of existing best management practices (BMPs) for the control of methylmercury; 2) evaluate additional or enhanced BMPs, as needed, to reduce mercury and methylmercury discharges to the Delta; and 3) determine the feasibility of meeting methylmercury WLAs. A final report was submitted in October 2018 which incorporates monitoring efforts conducted since spring 2015 (CCCWP, 2018c). CCCWP has continued to collect at least eight methylmercury samples per year, per Provision C.16.5.g.(1) of the MRP addressing East County methylmercury monitoring requirements.

In 2015, the Contra Costa County Department of Public Works completed construction of a hard-piped stormwater diversion valve capable of diverting stormwater from the wet well of the North Richmond Stormwater Pump Station into the sanitary sewage conveyance system serving the West County Wastewater District. That diversion project was a legacy requirement of MRP 1.0 which completed during MRP 2.0 due to planning, permitting, design, and construction delays. Results from monitoring the management action effectiveness of this stormwater diversion project in the summer and fall of 2015 are in Appendix 4C.

5.2 POC Lessons Learned – WY 2014-2019

This section summarizes lessons learned from monitoring PCBs, mercury and methylmercury, nutrients, and copper from 2014 to 2019. Monitoring priorities in future permit cycles are discussed as they flow from the lessons learned.

5.2.1 PCBs

Source property investigation is progressing and continues to be an important pathway to make progress toward target load reductions. Eight potential source properties have been either referred to the Water Board (three sites) or identified as self-abated (five sites). For sites that have been referred, Water Board is granting half credit for the countywide required load reduction estimate using accounting methods established through the Reasonable Assurance Analysis (BASMAA, 2020). For sites that have been self-abated, the Water Board grants full credit.

Partial credit for referral sites is conditioned on Permittees performing enhanced operations and maintenance (O&M) around the site to intervene with the transport of PCB-contaminated sediments from source properties to the MS4. Enhanced O&M include more frequent street sweeping, installation of stormwater treatment devices (such as green infrastructure), full trash capture screens, and hydrodynamic separators. Future monitoring efforts will support enhanced O&M in two ways: 1) monitoring resources will be used to help define the migration pathways for contaminated sediments to leave the site and enter the MS4; and 2) monitoring will be used to evaluate the effectiveness of enhanced O&M.

Over the past five of years monitoring PCBs in urban settings, it has become increasingly apparent to CCCWP that “low hanging fruit” in the form of obvious source properties is hard to find. The latest RMP reconnaissance report (Appendix 6) notes that only 15 percent of old industrial acreage within Contra Costa County has been monitored for PCBs to date. This reflects a significant challenge faced by CCCWP in monitoring watershed management areas for PCBs. Old industrial land areas in Contra Costa County do not generally drain to a single outlet to the Bay. Rather, the old industrialized shoreline of Contra Costa County contains numerous facilities regulated under the Industrial General Permit, many of which discharge directly to the Bay rather than to the local MS4.

In effect, achieving the TMDL WLAs for PCBs assigned to Contra Costa County may require control measures at facilities that are beyond the reach of the Contra Costa Permittees’ regulatory jurisdiction. CCCWP anticipates that a substantial amount of POC investigation effort in MRP 3.0 will be dedicated to carefully documenting where potential source properties may be directly impacting the MS4, and where there are potential source properties that are outside the reach of direct investigation and regulation by municipal Permittees.

The stormwater diversion to sanitary treatment pilot project from MRP 1.0 yielded disappointingly small loads. Construction of the project was delayed, and so monitoring did not occur until 2015 and is therefore reported in Appendix 4C as part of this IMR submittal. The low mercury and PCB loads diverted to sanitary treatment resulted from three factors:

- The capacity of the receiving sanitary sewer conveyance system constrains diversion flow rates to 250 gpm, for a stormwater pump station that is rated for 135,000 gpm
- The total suspended solids (TSS) concentrations of the diverted stormwater were not very high in the pilot watershed – 34 mg/L and 52 mg/L for dry and wet weather diversions, respectively
- The PCB/TSS ratios (11-134 ng/g) and Mercury/TSS ratios (270-690 ng/g) were more typical of Bay Area background concentrations than of the elevated concentrations often found in old industrial areas

Based on these lessons learned, cost-benefit analysis, and the outcomes of the diversion pilot, CCCWP does not recommend further monitoring of this type of control measure in future permit cycles.

CCCWP supported two BASMAA regional studies of the effectiveness of stormwater treatment. *Evaluation of Mercury and PCBs Removal Effectiveness of Full Trash Capture Hydrodynamic Separator Units* (Appendix 4B) established unit removal efficiencies used in the source control load reduction accounting. Demonstrating that full trash capture provides some PCB and mercury removal also justifies using trash capture as an enhanced O&M tool around PCB referral sites.

Pollutant Removal from Stormwater with Biochar Amended Bioretention Soil Media (BSM) (Appendix 4A) investigated whether the addition of biochar to bioretention soil media would improve removal effectiveness for mercury and PCBs. Biochar is a form of activated carbon that is known to adsorb and retain organic pollutants. The improvement of PCB removal effectiveness by adding biochar was marginal at best. Influent PCBs in the study ranged from approximately 10,000 to 20,000 pg/L. Effluent PCBs for the control and the biochar-amended soils ranged from approximately 400 to 4,700 pg/L. The minimum and range appeared to move down, but the improvement was not statistically significant because the effluent data were highly variable. No statistically significant differences between biochar brands was demonstrable.

For mercury, the control biofiltration soil media (BSM), with no biochar added, slightly <u>increased</u> mercury concentrations from 4 to 10 ng/L in the influent and from to 7 to 15 ng/L in the effluent. In contrast, the effluent from biochar-amended BSM ranged from 2 to 15 ng/L. Repeated runs showed highly variable performance for each type of biochar tested.

The fact that the control media <u>increased</u> mercury concentrations points to an issue previously noted in pilot studies of bioretention for treating mercury (e.g., Caltrans, 2013). Mercury is ubiquitous, present in soils, sediments, and water at some detectable concentration. Leaching of soil particles from BSM can <u>increase</u> mercury concentrations in water, as occurred in this study. Any potential ameliorating benefit of adding biochar was barely discernable – statistical analysis revealed no difference between the different types of biochar tested.

The lesson learned from the biochar amendment study is that municipal resources for effectiveness monitoring should focus on established technologies. Applied research to develop new technology is best carried out by product manufacturers and vendors. CCCWP Permittees seek to implement controls for pollutants of concern, including PCBs, using established technologies to the maximum extent practicable. Innovative technologies should be tested and optimized by product manufacturers and independently verified, rather than developed and proven by the municipal stormwater agencies who would be the ultimate buyers of such technologies.

In summary, for future permit cycles, key questions to resolve through monitoring include:

- Clearly defining investigation endpoints – how much evidence is needed to determine a watershed as “fully investigated” and halt further exploration for potential source properties?
- Clearly defining the process for closing a case (i.e., what information is needed to call the investigation and abatement of a particular site complete)?
- Where are the remaining potential source properties that discharge to the MS4, and where are there potential source properties that are beyond the direct jurisdiction of municipal Permittees.
  - What are specific activities that qualify as “enhanced O&M?”
  - How much good do they do?
  - What are the costs and consequences of those activities?

5.2.2 Mercury and Methylmercury[9]

CCCWP monitors mercury and methylmercury to fulfill not only the SFBRWQCB TMDL requirements adopted in Provisions C.8 and C.11 of the MRP, but also to fulfill the CVRWQCB TMDL requirements for methylmercury monitoring adopted in Provision C.16.5.g of the MRP. In October 2018, CCCWP submitted a methylmercury control study report (CCCWP, 2018c) to the CVRWQCB. Key findings from the study include:

- Mercury and methylmercury are both associated with suspended sediment in urban stormwater.
- Particle ratios help differentiate contaminated sediments from background sediments
  - **Total Mercury**: Typical Bay Area background mercury concentrations in suspended sediments are approximately 0.3 mg/kg. In contrast, suspended sediments in an old industrial area of Richmond have approximately 1 mg/kg mercury. Concentrations exceeding 1 mg/kg are also more typical of watersheds draining old mercury mines.
  - **Methylmercury:** Typical Bay Area background methylmercury concentrations in suspended sediments range from 3 to 15 µg/kg, or about 1 to 5 percent of the total mercury concentration. This is consistent with national studies of methylmercury, which showed that in typical watersheds 1 to 5 percent of the total mercury is present as methylmercury, whereas watersheds with substantial wetland areas that efficiently convert mercury to methylmercury have more than 10 percent of the total mercury present as methylmercury. Thus, the study did not reveal evidence of persistent biogeochemical conditions that increase methylmercury in urban stormwater discharges.
- There was no evidence for elevated mercury or methylmercury in sediments reaching Lower Marsh Creek from Upper Marsh Creek[10]. This finding is important because the historic Mount Diablo Mercury Mine is located in Upper Marsh Creek. A key monitoring question has been whether elevated mercury or methylmercury in suspended sediments is observed in Lower Marsh Creek when upper watershed flows overtop Marsh Creek Reservoir and reach Lower Marsh Creek.
- Monitoring in Lower Marsh Creek detected some preliminary evidence for episodic occurrence of suspended sediments having elevated methylmercury concentrations (i.e., 6 ng/g, compared to background concentrations of 1 to 3 ng/g). This occurred during the rise of the hydrograph in a late season (April 2013) storm. This could indicate the influence of microbial activity either upland or in-stream as a result of ponds that form between erosion control check dams constructed along the creek bottom.
- Background concentrations of methylmercury can easily lead to mercury concentrations in stormwater exceeding the 0.06 ng/L “implementation goal” cited in the Delta Methylmercury TMDL. Achieving 0.06 ng/L methylmercury as an annual average `in surface waters or stormwater discharges is not deemed technically or economically feasible.

[9] Methylmercury is mercury bonded to a carbon atom. It is a form of mercury that poses greater risks of accumulation in aquatic food webs to levels considered harmful to human and wildlife consumers of fish.

[10] Upper Marsh Creek and Lower Marsh Creek are divided by the Marsh Creek Reservoir, which only sporadically flows into Lower Marsh Creek during high rainfall years after extended periods of rain.

In response to concerns raised by CCCWP over the technological and economic feasibility of achieving 0.06 ng/L methylmercury in stormwater discharges, technical peer reviewers inquired through their review of CCCWP's report whether achieving load reductions is feasible by reducing the volume of stormwater discharged. This will lead to a reasonable assurance analysis study to model how much stormwater infiltration may be achieved after implementing all reasonable and foreseeable green infrastructure capital projects in the jurisdiction of the Permittees subject to the Delta Methylmercury TMDL (the Cities of Brentwood, Antioch and Oakley).

5.2.3 Nutrients

CCCWP monitors nutrients to help characterize the nutrient concentrations of urban stormwater, addressing a data gap identified in the San Francisco Bay Nutrient Management Strategy. A summary of external nutrient loads to San Francisco Bay (Novick and Senn, 2014) found that, based on initial order-of-magnitude estimates, stormwater does not contribute substantially to loads at the sub embayment scale in South and Central Bay, but may contribute non-trivial loads to San Pablo and Suisun Bays during certain times of the year. As these are the receiving waters of much of Contra Costa County, CCCWP is interested in tracking further developments of the San Francisco Bay Nutrient Management Strategy. CCCWP collected and analyzed 18 samples for nutrients from a variety of locations, as documented in Appendix 5, and is on track to complete the requisite minimum 20 nutrient samples by the end of the permit term.

The SFEI External Nutrient Loads to San Francisco Bay report (Novick and Senn, 2014) also stated that urban stormwater loads were estimated based on modifications of the Regional Watershed Spreadsheet Model (RWSM) developed by the RMP's Small Tributaries Loading Strategy Workgroup. Table 6 compares RWSM assumptions about nutrient concentrations in urban and agricultural stormwater to measurements from CCCWP. Monitoring data generally support RWSM assumptions about nutrients in urban stormwater. The CCCWP samples for agricultural runoff are generally lower than RWSM assumptions but should not be considered representative – they were only two samples collected after a single storm event from the Sand Creek drainage.

Table 6. Comparison of Nutrient Concentrations Measured by CCCWP with Regional Watershed Spreadsheet Model Assumptions

Land Use	Ammonia		Nitrate		Dissolved Phosphorus	
	RWSM Assumption	CCCWP Measured	RWSM Assumption	CCCWP Measured	RWSM Assumption	CCCWP Measured
Open	0.1	NA	0.3	NA	0.1	NA
Urban[1]	0.2-0.4	0.09-0.19	0.4-0.7	<0.02-0.73	0.4-0.5	<0.01-0.03
Agricultural[2]	1.3	0.04-0.06	8.9	0.6	0.6	0.06-0.07

1 Five samples collected in Lower Marsh Creek in water years 2017-2019
2 Two samples collected in Sand Creek, tributary to Mash Creek, on Sep. 17, 2019
NA Parameter not analyzed
RWSM Regional Watershed Spreadsheet Model

The snapshot of nutrient concentrations by land use presented in Table 6 suggests the assumptions made in the RWSM are generally supported. The need for additional information, and what kind of additional information about urban stormwater would be helpful, is unclear.

5.2.4 Copper

CCCWP has collected 18 of the 20 required copper samples and is on track to complete the rest by the end of the permit term. None of the 18 samples collected from 2014 to 2019 exceeded water quality objectives for dissolved copper in surface waters (Appendix 5, Table 9).

Discerning background copper from human-caused sources is challenging because copper is a naturally occurring trace element, present at about 60 mg/kg in the continental crust of the earth (Lide, 2004). Much of the variation of the total copper concentration in stormwater results from variation in suspended sediments concentration. For source assessment and trends analysis, evaluating human-caused enrichment of copper in sediments is one way to discern human sources from natural background.

Copper concentrations in sediments and, in particular, storm-borne sediments from urban settings are especially relevant to understanding the effect of brake pad wear on urban stormwater quality. Copper was formerly present in high performance brakes and is released from abrasion during braking. Recognizing this, municipal stormwater programs banded together and successfully lobbied the brake pad manufacturing industry to negotiate a long-term reformulation of brake pad materials, leading to eventual product substitution and less release of copper into urban settings from brake pads. Product reformulation and substitution is a long-term process, as is the aging and replacement of the U.S. vehicle fleet. The gradual decline of copper in urban sediments is likely on the timescale of decades rather than years.

Table 7 provides a snapshot comparing copper concentrations in storm-borne sediments from the urbanized area of Lower Marsh Creek to storm-borne sediments from the open/agricultural land areas of Sand Creek, a tributary to Marsh Creek. The last column shows that the copper concentrations in suspended sediments present in urban stormwater was about ten-fold greater than the average crustal abundance of copper, and much higher compared to agricultural/open space sediments of Sand Creek.

Table 7. Summary of Copper, Suspended Sediment Concentration, and Ratios in the Marsh Creek Watershed During the Storm Event of Sep. 17, 2019

Station Code	Sample Date	Collection Time	Dissolved Copper (µg/L)	Total Copper (µg/L)	Suspended Sediment Concentration (mg/L)	Total Cu/SSC Ratio[1] (mg/kg)	Average +/- Standard Deviation Total Cu/SSC Ratios[1] (mg/kg)
LMC-544MSH025	09/17/19	6:15	4	5.3	9.4	564	643 +/- 422 (Urban)
		10:00	3.7	4.4	3.5	1257	
LMC-544R01737	09/17/19	6:35	1.5	2.8	9.1	308	
		10:15	2.1	3.9	8.8	443	
SND	09/17/19	7:35	1.3	3.2	40	80	126 +/- 65 (Open/Agricultural)
		10:40	1.3	1.9	11	173	

1 Copper to suspended sediment concentration ratio

This is a glimpse of how two different land uses have different particle ratios of copper, for understandable reasons. A more helpful story would be data from a variety of locations, and a monitoring design that addresses the anticipated timescale of changes in the copper particle ratios as a result of phasing out copper in brake pads. The current paradigm of minimum numbers of annual copper samples does not aid or incentivize monitoring efforts addressing these types of more thoughtful studies of human copper sources and the effects of copper control measures.

5.3 Recommendations for POC Monitoring in MRP 3.0

CCCWP intends to focus POC monitoring efforts for PCBs on source property investigations and effectiveness evaluations. Effectiveness evaluations will address the efficacy and outcomes of enhanced O&M near source properties that have been referred to the Water Board. Consistent with recommendations for creek status monitoring, CCCWP also recommends that minimum sampling effort be prescribed for the permit term, rather than annually. This request also applies to copper monitoring – the level of effort is best prescribed for the permit term, not annually.

Additional nutrient monitoring does not seem helpful to CCCWP's priorities at this point, as there are no obvious management actions or data gaps related to nutrient monitoring. If some additional attention to nutrients in stormwater is warranted, a better approach may be to include language requiring Permittees to "conduct or cause to be conducted" a study of nutrients from stormwater, targeting needs identified through the San Francisco Bay Nutrient Management Strategy.

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6 Monitoring Costs

Table 8 summarizes the typical annual monitoring costs CCCWP has incurred over the course of MRP 2.0. Overall, direct monitoring costs in the form of payments to consultants, contractors, and regional collaboratives, such as BASMAA and the Regional Monitoring Program, cost nearly $1 million per year, out of an overall annual program budget of $3.5 million. Monitoring is the second largest single cost category, after staff salaries.

Staff salaries represent an indirect monitoring cost as well. Oversight of the monitoring program requires the attention of a full time technical professional staff person, as well as extensive involvement by the program manager and oversight by Permittees who fund the program. The recommendations in this report are intended to contain existing direct monitoring costs, make the optimum use of funds expended, and make the most efficient use of staff resources necessary to support the monitoring program.

Table 8. Summary of Typical Annual Monitoring Costs Under MRP 2.0

MRP Section	Task	Cost
C.8.d, C.8.g	Creek Status and Pesticides Monitoring	$260,000
C.8.h	Urban Creek Monitoring Reports	80,000
C.8.e	SSID Project	90,000
C.8.f	POC Monitoring and Reporting	75,000
C.10.b	Trash	140,000
C.16.5	MeHg Monitoring (Per CVRWQCB)	5,000
C.8.a	Regional Monitoring Program (RMP)	170,000
Various	BASMAA Regional Projects	50,000
Various	Consultant Technical Support	100,000
	Total	*$970,000*

Costs in this table do not include CCCWP staff/augmented staff time.

In addition to funding receiving water monitoring in San Francisco Bay, the RMP funds pilot and special studies (see Section 5). A summary of BASMAA regional projects, including project cost estimates and estimates of CCCWP's cost share, is presented in Table 9.

Table 9. Summary of BASMAA Regional Projects, Including Project Cost Estimates and CCCWP Share

Fiscal Year	Project Name	BASMAA Committee	Total Cost	CCCWP Share
15-16	Pesticides Toxicity - Regulatory Modernization	Board of Directors	32,000	5,882
15-16	Biotreatment Soil Mix Review	Development Committee	10,000	1,838
15-16	Creek Status Monitoring Coordination (RMC 3c)	Monitoring/POCs Committee	14,000	5,220
15-16	Updates to QA/QC Module for the RMC SWAMP-format Creek Status Database (RMC 3g)	Monitoring/POCs Committee	5,000	1,001
15-16	POC Monitoring Information Management and QC (RMC 6a)	Monitoring/POCs Committee	10,000	2,002
15-16	Interim accounting methodology and reporting tools (C.12.b) (Geosyntec WW2121/EOA BA08)	Monitoring/POCs Committee	40,000	8,006
15-16	Building materials management framework guidance (C.12.f) (EOA BA09)	Monitoring/POCs Committee	25,000	5,004
15-16	CW4CB Project Management and Related Tasks	Monitoring/POCs Committee	72,298	14,471
15-16	IPM Partnership Program XVII (OWOW)	Public Information/Participation Committee	40,000	5,515
15-16	Alternative Trash Assessment Methodology On-Land Clean-up Pilot Study Design and SAP	Trash Committee	19,998	6,856
16-17	EPA Grant Application	Board of Directors	32,500	6,506
16-17	Pesticides Toxicity - Regulatory Modernization (C.9.f)	Board of Directors	32,000	5,887
16-17	Alternative GI Facility Sizing Analysis (C.3.j.i.(2)(g))	Development Committee	30,000	6,006
16-17	Creek Status Monitoring Coordination (RMC 3c)	Monitoring/POCs Committee	14,000	5,225
16-17	Infrastructure caulk study Sampling and Analysis Plan (C.12.e)	Monitoring/POCs Committee	0	0
16-17	CW4CB Project Management and Related Tasks	Monitoring/POCs Committee	53,194	10,649
16-17	POC Monitoring for Source Identification and Management Action Effectiveness (C.8.f and C.12.e)	Monitoring/POCs Committee	65,000	13,012
16-17	On-Call Services for Maintenance of RMC Monitoring Database (C.8.b/h)	Monitoring/POCs Committee	10,000	2,002
16-17	RAA Approach Support (C.11/12.c; C.11/12.d)	Monitoring/POCs Committee	80,000	16,015
16-17	PCBs Materials Management during Building Demolition - Outreach, Protocol, Tools, and Training (C.12.f)	Monitoring/POCs Committee	100,000	20,019
16-17	Trash Amendments Planning (13267 Order)	Phase II Committee	161,266	0
16-17	IPM Partnership Program XVIII (OWOW) (C.9.e.ii.(1) /E.7.a)	Public Information/Participation Committee	40,000	5,519
16-17	Receiving Water Trash Monitoring Program Plan	Trash Committee	149,887	34,177
16-17	Receiving Water Trash Monitoring Program Plan II	Trash Committee	29,500	5,905
17-18	Pesticides Toxicity - Regulatory Modernization (C.9.f)	Board of Directors	32,000	5,921
17-18	Creek Status Monitoring Coordination (RMC 3c)	Monitoring/POCs Committee	14,000	5,236
17-18	POC Monitoring for Source Identification and Management Action Effectiveness (C.8.f/C.12.e)	Monitoring/POCs Committee	280,000	68,538
17-18	On-Call Services for Maintenance of RMC Monitoring Database (C.8.b/h)	Monitoring/POCs Committee	10,000	2,013
17-18	Regional Monitoring Coalition (RMC) 5-year Bioassessment Report (C.8.h)	Monitoring/POCs Committee	50,000	10,063
17-18	Managing PCBs-Containing Materials and Wastes during Building Demolition - Phase I: Developing an Implementation Framework, Guidance Materials, and Tools for Permittees (C.12.f)	Monitoring/POCs Committee	229,001	46.087
17-18	E.12 Manual Update	Phase II Committee	15,000	0
17-18	IPM Partnership Program XIX (OWOW) (C.9.e.ii.(1) /E.7.a)	Public Information/Participation Committee	50,000	9,252

Table 9. Summary of BASMAA Regional Projects, Including Project Cost Estimates and CCCWP Share

Fiscal Year	Project Name	BASMAA Committee	Total Cost	CCCWP Share
18-19	Pesticides Toxicity - Regulatory Modernization (C.9.f)	Board of Directors	32,000	5,925
18-19	Planning Conference (GI Plans, SRPs, RAA, Funding Roadmap)	Board of Directors	30,000	5,556
18-19	On-Call Services for Maintenance of RMC Monitoring Database (C.8.b/h)	Monitoring/POCs Committee	10,000	2,012
18-19	Creek Status Monitoring-Related Coordination (RMC 3c) (C.8.d/e/g)	Monitoring/POCs Committee	14,000	5,234
18-19	Regional SSID Project Work Plan (C.8.e)	Monitoring/POCs Committee	20,000	4,025
18-19	RMC Database QA/QC Tool - POC Data (C.8.f)	Monitoring/POCs Committee	3,000	604
18-19	POC Monitoring for Source Identification and Management Action Effectiveness (C.8.f/C.12.e)	Monitoring/POCs Committee	40,000	8,050
18-19	Redesign of Bioassessment Monitoring Program (C.8.h)	Monitoring/POCs Committee	50,000	10,062
18-19	Refined Source Control Load Reduction Accounting for RAA (C.11.d/C.12.d)	Monitoring/POCs Committee	100,000	20,125
18-19	Managing PCBs-Containing Materials and Wastes during Building Demolition - Phase I: Developing an Implementation Framework, Guidance Materials, and Tools for Permittees (C.12.f)	Monitoring/POCs Committee	42,258	8,504
18-19	Trash Control Plan (13267 Order)	Phase II Committee	20,000	0
18-19	IPM Partnership Program XX (OWOW) (C.9.e.ii.(1)/E.7.a)	Public Information/Participation Committee	40,000	7,408
18-19	Preliminary and Final Reports on Trash Receiving Water Monitoring Program Plan and Related Tasks (C.10.b.v)	Trash Committee	60,000	12,075
		Total	*2,206,902*	*423,408*

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Contra Costa Clean Water Program

Regional/Probabilistic Creek Status Monitoring Report: Water Year 2019

(October 2018-September 2019)

March 18, 2020

Submitted to

Contra Costa Clean Water Program
255 Glacier Drive
Martinez, California 94553

Submitted by

Armand Ruby Consulting
2441 Rifle Range Drive
Royal Oaks, CA 95076

and

ADH Environmental
3065 Porter Street, Suite 101
Soquel, California 95073

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Soquel, California 95073

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List of Acronyms and Abbreviations

ACCWP	Alameda Countywide Clean Water Program
AFDM	ash-free dry mass
A-IBI	algal index of biological integrity
ASCI	Algae Stream Condition Index
Basin Plan	common term for the Regional Water Quality Control plan
BASMAA	Bay Area Stormwater Management Agencies Association
B-IBI	benthic index of biological integrity
BMI	benthic macroinvertebrate
CCCWP	Contra Costa Clean Water Program
CCMAP	Contra Costa Monitoring and Assessment Program
Central Valley Permit	East Contra Costa County Municipal NPDES Permit
cm	centimeter
CSCI	California Stream Condition Index
CVRWQCB	Central Valley Regional Water Quality Control Board
FSURMP	Fairfield-Suisun Urban Runoff Management Program
GIS	geographic information system
GRTS	Generalized Random Tessellated Stratified
IBI	Index of Biological Integrity
IMR	Integrated Monitoring Report
IPI	Index of Physical Habitat Integrity
LC_{50}	lethal concentration to 50 percent of test organisms
m	meters
MCL	maximum contaminant level
MDL	method detection limit
MMI	multi-metric index
MRP	Municipal Regional Permit
MUN	municipal and domestic water supply
ND	not detected
NPDES	National Pollutant Discharge Elimination System
NT	non-target
PAH	polycyclic aromatic hydrocarbon
PEC	probable effect concentration
PHab	physical habitat assessment
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
PSA	perennial streams assessment
RL	reporting limit
RMC	Regional Monitoring Coalition
RPD	relative percent difference
SCVURPPP	Santa Clara Valley Urban Runoff Pollution Prevention Program
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SMC	Southern California Stormwater Monitoring Coalition
SMCWPPP	San Mateo Countywide Water Pollution Prevention Program
SOP	standard operating procedure
SSID	stress/source identification
SWAMP	Surface Water Ambient Monitoring Program
TEC	threshold effect concentration

TNS	target not sampled (or sampleable)
TOC	total organic carbon
TS	target sampled
TU	toxic unit
U	unknown
UCMR	Urban Creeks Monitoring Report
USEPA	U.S. Environmental Protection Agency
WY	water year

Acknowledgements

This report was prepared by Armand Ruby Consulting, in association with ADH Environmental, under contract to and supervision of the Contra Costa Clean Water Program (CCCWP). The report format and organization are in part derived from the original region-wide Regional Monitoring Coalition (RMC) monitoring report for water year 2012 (Regional Urban Creeks Status Monitoring Report, Appendix A to the Water Year 2012 Urban Creeks Monitoring Report), prepared jointly by EOA, Inc. and Armand Ruby Consulting as a regional project for the RMC participants.

In addition to the RMC participants, San Francisco Bay Regional Water Quality Control Board staff members Kevin Lunde and Jan O'Hara participated in the RMC work group meetings, which contributed to the design and implementation of the RMC Monitoring Plan. These staff members also provided input on the outline of the initial regional urban creek status monitoring report and threshold trigger analyses conducted herein.

CCCWP staff, specifically Khalil Abusaba, provided project supervision and review of draft documents. Christian Kocher served as project manager for ADH Environmental, lead consultant to CCCWP. The staff of ADH Environmental also contributed to both the content and production of this report, with respect to data compilation and extraction, organization of metadata, and graphics production. Marco Sigala of Coastal Conservation and Research in Moss Landing provided algae data analysis and interpretation, and assistance with preparation of watershed GIS information and other metrics used in computation of CSCI scores and IPI scores.

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Preface

The Regional Monitoring Coalition of the Bay Area Stormwater Management Agencies Association developed a probabilistic design for regional characterization of selected creek status monitoring parameters. The Regional Monitoring Coalition is comprised of the following program participants:

- Alameda Countywide Clean Water Program
- Contra Costa Clean Water Program
- San Mateo Countywide Water Pollution Prevention Program
- Santa Clara Valley Urban Runoff Pollution Prevention Program
- Fairfield-Suisun Urban Runoff Management Program
- City of Vallejo and Vallejo Sanitation and Flood Control District

This report fulfills reporting requirements for the portion of the regional/probabilistic creek status monitoring data generated within Contra Costa County during water year 2019 (Oct. 1, 2018-Sep. 30, 2019) through the Regional Monitoring Coalition's probabilistic design for certain parameters monitored per Municipal Regional Stormwater Permit provisions C.8.d and C.8.g. This report is an appendix to the Contra Costa Clean Water Program's Integrated Monitoring Report for water years 2014-2019 and complements similar reports submitted by each of the other participating Regional Monitoring Coalition programs on behalf of their respective permittees.

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Executive Summary

This report documents the results of monitoring performed by Contra Costa Clean Water Program (CCCWP) during water year 2019 (Oct. 1, 2018-Sep. 30, 2019), for parameters originally covered under the regional/probabilistic monitoring design developed by the Regional Monitoring Coalition (RMC). As a component of CCCWP's Integrated Monitoring Report (IMR) for water years 2014-2019, this report also includes a comprehensive analysis of the monitoring results produced by CCCWP's creek status monitoring since the previous IMR in March 2014 (CCCWP, 2014). For the prior IMR, the multi-year analysis of regional/probabilistic parameters covered water years 2012 and 2013 (ARC, 2014).

Other creek status monitoring parameters were addressed using a targeted design, with regional coordination and common methodologies. Together with the creek status monitoring data reported in the local/targeted creek status monitoring report for water years 2014-2019 (CCCWP, 2020), this submittal fulfills reporting requirements for creek status monitoring specified in provisions C.8.d and C.8.g of the Municipal Regional Permit (MRP) for urban stormwater issued by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB; Order No. R2-2015-0049), as amended by Order No. R2-2019-0004, incorporating the eastern portion of Contra Costa County within the requirements of the MRP.

The probabilistic design requires several years to produce sufficient data to develop a statistically robust characterization of regional creek conditions. The Bay Area Stormwater Management Agencies Association (BASMAA) conducted a regional project involving analysis of bioassessment monitoring data collected during a five-year period (water years 2012-2016) by the RMC programs (BASMAA, 2019). That analysis can be used to provide recommendations for potential changes to the monitoring program. The project also will develop a fact sheet that presents the report findings in a format accessible to a broad audience.

Summary of Water Year 2019 Creek Status Monitoring: Regional/Probabilistic Parameters

During water year 2019, 10 sites were monitored by CCCWP under the RMC regional/probabilistic design for bioassessment, physical habitat, and water chemistry parameters. One site also was monitored for water and sediment toxicity and sediment chemistry.

The bioassessment and related data are used to develop a preliminary condition assessment for the monitored sites. The water and sediment chemistry and toxicity data are used in conjunction with physical habitat data to evaluate potential stressors which may affect aquatic habitat quality and beneficial uses. Various metrics and indices are also computed to aid in the condition assessment and stressor analysis.

Biological Conditions

California Stream Condition Index (CSCI) scores were calculated from the CCCWP bioassessment data beginning in WY 2016. The CSCI uses location-specific geographic information system (GIS) data to compare the observed benthic macroinvertebrate (BMI) taxonomic data to expected BMI assemblage characteristics from reference sites with similar geographical characteristics. The calculated CSCI scores for 2019 samples are again below the MRP 2.0 threshold of 0.795 for nine of the 10 sites monitored, indicating degraded benthic biological communities at those nine sites. Additional work will need to be done with the CSCI scores in relation to this threshold to make a clearer assessment of relative biological conditions for these urban streams.

For the 2019 analysis, the benthic invertebrate community indices (CSCI, Contra Costa B-IBI, SoCal B-IBI) correlated well with each other; the CSCI and Contra Costa B-IBI scores both correlated fairly well with the H20 Algal IBI; and the Contra Costa B-IBI correlated fairly well with the D18 A-IBI. Overall, the biological metrics correlated fairly well for the water year 2019 data.

The two algal community indices (D18 and H20) were well correlated with each other, and the H20 algae index correlated fairly well with the B-IBI indices, including CSCI. The D18 algae index correlated fairly well with the Contra Costa B-IBI but did not correlate as well with the CSCI. The water year 2019 results were more mixed than the water year 2018 analysis, in which neither algal index correlated well with the other factors.

ASCI scores are calculated for CCCWP bioassessment sites for the first time in water year 2019; the results indicate a range of site conditions.

The Marsh Creek sediment sample was determined to be highly toxic to *Chironomus dilutus* in both the original (Jul. 23, 2019) dry weather sample, and in the follow-up retest (sample collected Sept. 18, 2019). The dry weather water sample was not toxic to any of the four test species. As in prior years, the principal stressors affecting water and sediment quality – specifically causing toxicity – appear to be pesticides.

Based on an analysis of the regional/probabilistic data collected by CCCWP during water year 2019, the stressor analysis is summarized as follows:

Physical Habitat (PHab) Conditions

Index of Physical Habitat Integrity (IPI) scores were again calculated from the physical habitat (PHab) data compiled during the spring 2019 bioassessment monitoring. Three sites ranked as "Likely intact" (Wildcat Creek, Marsh Creek (544R02505), and Moraga Creek), while only one (Rodeo Creek) ranked as "Very likely altered".

The IPI scores correspond fairly well with the 2019 mini-PHab scores, as the creek sites with the higher IPI scores generally correspond with the sites with the highest mini-PHab scores, and the creek sites with lower IPI scores generally are also the sites with the lowest mini-PHab scores. A notable exception is the Marsh Creek (544R02505) site, which has the second highest IPI score and one of the lowest mini-PHab scores.

The four biological metrics tested (CSCI, Contra Costa B-IBI, D18 A-IBI, H20 A-IBI) correlated well with each other and with the mini-PHab index, and the two PHab indices correlated well with each other. The CC B-IBI also correlated well with the SoCal B-IBI. These results support the idea that there may be an observable connection between stream physical habitat condition and benthic biological community health.

Water Quality

Of 12 water quality parameters required in association with bioassessment monitoring, applicable water quality standards were only identified for ammonia, chloride, and nitrate+nitrite (for sites with MUN beneficial use only). Two of the results generated at the 10 sites monitored for un-ionized ammonia during water year 2019 exceeded the applicable water quality standard; all water year 2019 chloride and nitrate+nitrite results met the applicable standards.

Water Toxicity

The dry weather water sample was not toxic to any of the four test species.

Sediment Toxicity

The Marsh Creek sediment sample was determined to be highly toxic to *Chironomus dilutus* in both the original (Jul. 23, 2019) dry weather sample, and in the follow-up retest (sample collected Sept. 18, 2019). Pyrethroid pesticide concentrations were determined to be more than sufficient to have caused the observed sediment toxicity.

Sediment Chemistry

Several of the common urban pyrethroid pesticides were detected at the water year 2019 sediment monitoring site. The calculated toxic unit (TU) equivalent of 1.84 is sufficient to have caused the observed toxicity to *Chironomus dilutus* in the sediment toxicity testing for this sample. The TU equivalent calculated for bifenthrin (1.33) alone is sufficient to have caused the observed sediment toxicity.

Sediment Triad Analyses

Bioassessment, sediment toxicity, and sediment chemistry results from water year 2019 were evaluated as the three lines of evidence used in the triad approach for assessing overall stream condition and added to the compiled results for water years 2012-2019. Good correlation is observed throughout that period in the triad analysis between pyrethroid concentrations with TU ≥1 and sediment toxicity.

Chemical stressors, particularly pesticides, may be contributing to the degraded biological conditions indicated by the low B-IBI scores in many of the monitored streams. The principal stressors identified in the chemical analyses from the 2019 monitoring are pesticides, specifically bifenthrin, and other pyrethroid pesticides in sediments.

Summary of Multi-Year Analysis, Regional/Probabilistic Parameters

Biological conditions in Contra Costa County urban creeks are generally impacted, as indicated by analysis of bioassessment results from 76 monitoring sites over the course of eight years (2012-2019). Physical habitat factors play a significant role in degradation of in-stream biota, with water quality factors and antecedent rainfall also contributing to in-stream conditions.

Factors that have a positive influence on in-stream biological conditions for benthic macroinvertebrates and algae include higher percentages of fast water within the reach, higher percentages of coarse gravel, and higher diversity of natural substrate types.

Factors that tend to negatively impact in-stream biota include higher percentages of fines or substrate smaller than sand, higher percentages of slow water in the reach, and elevated chloride or conductivity.

Algae assemblages tend to benefit from higher antecedent rainfall in the 60-90-day range and are negatively impacted by elevated temperatures.

Throughout the study period, sediment toxicity and occasional water toxicity are chronic occurrences, with toxicity typically attributable to the presence of pyrethroid and sometimes other pesticides, including recently fipronil and imidacloprid.

Bioassessment, sediment toxicity, and sediment chemistry results from water years 2012-2019 were evaluated as the three lines of evidence used in the triad approach for assessing overall stream condition. Good correlation is observed throughout that period between pyrethroid concentrations with TU ≥1 and sediment toxicity.

Chemical stressors, particularly pesticides, may be contributing to the degraded biological conditions indicated by the low biological condition scores in many of the monitored streams. The principal stressors identified in the chemical analyses from the water year 2012-2019 monitoring are pesticides, specifically bifenthrin, and other pyrethroid pesticides in sediments.

The assessments provided in the comprehensive analysis may be used to guide creek restoration efforts.

1 Introduction

This report documents the results of monitoring performed by Contra Costa Clean Water Program (CCCWP) during water year 2019 (Oct. 1, 2018-Sep. 30, 2019), for parameters originally covered under the regional/probabilistic monitoring design developed by the Regional Monitoring Coalition (RMC). Other creek status monitoring parameters were addressed using a targeted design, with regional coordination and common methodologies. Together with the creek status monitoring data reported in the local/targeted creek status monitoring report for water year 2019 (CCCWP, 2020), this submittal fulfills reporting requirements for creek status monitoring specified in provisions C.8.d and C.8.g of the Municipal Regional Permit (MRP) for urban stormwater issued by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB; Order No. R2-2015-0049), as amended by Order No. R2-2019-0004, incorporating the eastern portion of Contra Costa County within the requirements of the MRP.

As a component of CCCWP's Integrated Monitoring Report (IMR) for water years 2014-2019, this report also includes a comprehensive analysis of the monitoring results produced by CCCWP's creek status monitoring for regional/probabilistic parameters. The multi-year analysis nominally covers water years 2014-2019, as required by MRP Provision C.8.h.v. (the current IMR is required to cover the years since the previous IMR, which covered water years 2012 and 2013). However, because metrics were available for a wide range of physical, chemical and biological metrics for water years 2012-2016 in the BASMAA Five-Year Bioassessment Report (BASMAA, 2019), CCCWP has included data and metrics from water years 2012-2019 for parts of the current analysis.

1.1 Regulatory Context

Contra Costa County lies within the jurisdictions of both the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB; Region 2) and the Central Valley Regional Water Quality Control Board (CVRWQCB; Region 5). Municipal stormwater discharges in Contra Costa County previously were regulated by the requirements of two National Pollutant Discharge Elimination System (NPDES) stormwater permits: the MRP in Region 2 (Order No. R2-2015-0049[1]), and the East Contra Costa County Municipal NPDES Permit (Central Valley Permit) in Region 5 (Order No. R5-2010-0102[2]).

Prior to the reissuance of the MRP in 2015, the requirements of the two permits were effectively identical. With the reissued MRP, there were some differences between the MRP and the Central Valley Permit, although in most respects the creek status monitoring and reporting requirements remained similar. For this report, the creek status monitoring and reporting requirements specified in the reissued MRP are considered the prevailing requirements. Sites in the Central Valley Region have been monitored as part of the creek status monitoring required by both permits. Per agreement between the Central Valley and San Francisco Regional Water Quality Control Boards on Feb. 13, 2019, the SFBRWQCB adopted Order

[1] The San Francisco Bay Regional Water Quality Control Board adopted the reissued Municipal Regional Stormwater NPDES Permit (Order No. R2-2015-0049) to 76 cities, counties and flood control districts (i.e., permittees) in the Bay Area on Nov. 19, 2015 (SFBRWQCB, 2015), effective Jan. 1, 2016. The BASMAA programs supporting MRP regional projects include all MRP permittees, plus the eastern Contra Costa County cities of Antioch, Brentwood, and Oakley, which have voluntarily elected to participate in the RMC. The RMC regional monitoring design was expanded to include the eastern portion of Contra Costa County which is within the Central Valley Region (Region 5) to assist CCCWP in fulfilling parallel provisions in the Central Valley Permit.

[2] The Central Valley Regional Water Quality Control Board issued the East Contra Costa County Municipal NPDES Permit (Order No. R5-2010-0102) on Sep. 23, 2010 (CVRWQCB, 2010). This Order was superseded by Order No. R2-2019-0004, incorporating the eastern portion of Contra Costa County within the requirements of the MRP, Order No. R2-2015-0049, on Feb. 13, 2019.

No. R2-2019-0004, to include the eastern portion of Contra Costa County under the jurisdiction of the MRP, rendering the Central Valley Permit obsolete for the purposes of this report.

CCCWP conducted extensive bioassessment monitoring prior to the adoption of the original MRP (SFBRWQCB, 2009). Summaries of those findings can be found in Preliminary Assessment of Aquatic Life Use Condition in Contra Costa Creeks, Summary of Benthic Macroinvertebrate Bioassessment Results (2001-2006) (CCCWP, 2007), and Contra Costa Monitoring and Assessment Program, Summary of Benthic Macroinvertebrate Bioassessment Results (2011) (Ruby, 2012).

1.2 Regional Monitoring Coalition

The regional/probabilistic design was developed and implemented by the Regional Monitoring Coalition of BASMAA. This monitoring design allows each RMC participating program to assess stream ecosystem conditions within its program area (e.g., county boundary), while contributing data to answer regional management questions about water quality and beneficial use conditions in the creeks of the San Francisco Bay Area.

The RMC was formed in early 2010 as a collaboration among several BASMAA members representing MRP permittees (Table 1.1), to implement the creek status monitoring requirements of the MRP through a regionally coordinated effort.

Table 1.1 Regional Monitoring Coalition (RMC) Participants

Stormwater Programs	RMC Participants
Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)	Cities of Campbell, Cupertino, Los Altos, Milpitas, Monte Sereno, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, Sunnyvale, Los Altos Hills, and Los Gatos; Santa Clara Valley Water District; and Santa Clara County
Alameda Countywide Clean Water Program (ACCWP)	Cities of Alameda, Albany, Berkeley, Dublin, Emeryville, Fremont, Hayward, Livermore, Newark, Oakland, Piedmont, Pleasanton, San Leandro, and Union City; Alameda County; Alameda County Flood Control and Water Conservation District; and Zone 7 Water Agency
Contra Costa Clean Water Program (CCCWP)	Cities/Towns of Antioch, Brentwood, Clayton, Concord, El Cerrito, Hercules, Lafayette, Martinez, Oakley, Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon, Walnut Creek, Danville, and Moraga; Contra Costa County; and Contra Costa County Flood Control and Water Conservation District
San Mateo Countywide Water Pollution Prevention Program (SMCWPPP)	Cities and towns of Belmont, Brisbane, Burlingame, Daly City, East Palo Alto, Foster City, Half Moon Bay, Menlo Park, Millbrae, Pacifica, Redwood City, San Bruno, San Carlos, San Mateo, South San Francisco, Atherton, Colma, Hillsborough, Portola Valley, and Woodside; San Mateo County Flood Control District; and San Mateo County
Fairfield-Suisun Urban Runoff Management Program (FSURMP)	Cities of Fairfield and Suisun City
Vallejo Permittees	City of Vallejo and Vallejo Sanitation and Flood Control District

The goals of the RMC are to:

- Assist RMC permittees in complying with requirements in MRP provision C.8 (water quality monitoring)
- Develop and implement regionally consistent creek monitoring approaches and designs in the San Francisco Bay Area through improved coordination among RMC participants and other agencies sharing common goals (e.g., regional water quality control boards, Regions 2 and 5, and SWAMP)

- Stabilize the costs of creek monitoring by reducing duplication of effort and streamlining monitoring and reporting

The RMC Work Group is a subgroup of the BASMAA Monitoring and Pollutants of Concern Committee, which meets and communicates regularly to coordinate planning and implementation of monitoring-related activities. The RMC Work Group meetings are coordinated by an RMC coordinator and funded by the RMC's participating county stormwater programs. This work group includes staff from the SFBRWQCB at two levels: those generally engaged with the MRP, as well as those working regionally with the State of California's Surface Water Ambient Monitoring Program (SWAMP). Through the RMC Work Group, the BASMAA RMC developed a quality assurance project plan (QAPP; BASMAA, 2016a), standard operating procedures (SOPs; BASMAA, 2016b), data management tools, and reporting templates and guidelines. Costs for these activities are shared among RMC members.

The RMC divided the creek status monitoring requirements required by MRP provisions C.8.d and C.8.g into those parameters which could reasonably be included within a regional/probabilistic design and those which, for logistical and jurisdictional reasons, should be implemented locally using a targeted (non-probabilistic) design. The assignments of the various activities have adapted over time; the monitoring elements currently included in each category are specified in Table 1.2. Creek status monitoring data collected by CCCWP at local/targeted sites (and not included in the regional/probabilistic design) are reported separately in Appendix 2 of the IMR (CCCWP, 2020).

Table 1.2 Creek Status Monitoring Elements per MRP Provisions C.8.d. and C.8.g., Monitored as Either Regional/Probabilistic or Local/Targeted Parameters

Biological Response and Stressor Indicators	Monitoring Implementation	
	Regional (Probabilistic)	Local (Targeted)
Bioassessment, physical habitat assessment, CSCI	X	X[1]
Nutrients (and other water chemistry associated with bioassessment)	X	X[1]
Chlorine	X	X[2]
Stream Surveys (CRAM)		X[3,4]
Water toxicity (wet and dry weather)	NA	NA
Water chemistry (pesticides, wet weather)	NA	NA
Sediment toxicity (dry weather)	NA	NA
Sediment chemistry (dry weather)	NA	NA
Continuous water quality (sonde data: temperature, dissolved oxygen, pH, specific conductance)		X
Continuous water temperature (data loggers)		X
Pathogen indicators (bacteria)		X

1 Provision C.8.d.i.(6) allows for up to 20 percent of sample locations to be selected under a targeted monitoring design. This design change was made under MRP Order No. R2-2015-0049.

2 Provision C.8.d.ii.(2) provides options for probabilistic or targeted site selection. In water years 2014-2019, chlorine was measured at probabilistic sites.

3 Under MRP Order No. R2-2009-0074, stream surveys (stream walking and mapping) were required and sampled under a probabilistic monitoring design. The sampling method specified is the United Stream Assessment or equivalent. In water years 2014-2015, the California Rapid Assessment Method was selected.

4 The stream survey requirement was removed under MRP Order No. R2-2015-0049; therefore, data presented in this report were collected pursuant to MRP Order No. R2-2009-0074 and is applicable to water years 2014 and 2015 only.

CSCI California Stream Condition Index

CRAM California Rapid Assessment Method

NA Monitoring parameter not specific to either monitoring design

1.3 Report Organization

The remainder of this report addresses study area and monitoring design (Section 2), data collection and analysis methods (Section 3), results and data interpretation (Section 4), the comprehensive multi-year analysis (Section 5), and conclusions and next steps (Section 6). Additional information on other aspects of permit-required monitoring is found elsewhere in the IMR and its appendices (CCCWP, 2020).

2 Study Area and Monitoring Design

2.1 Regional Monitoring Coalition Area

For the purposes of the regional/probabilistic monitoring design, the study area is equal to the RMC area, encompassing the political boundaries of the five RMC participating counties, including the eastern portion of Contra Costa County which drains to the Central Valley region. A map of the BASMAA RMC area, equivalent to the area covered by the regional/probabilistic design sample frame, is shown in Figure 2.1.

2.2 Regional Monitoring Design

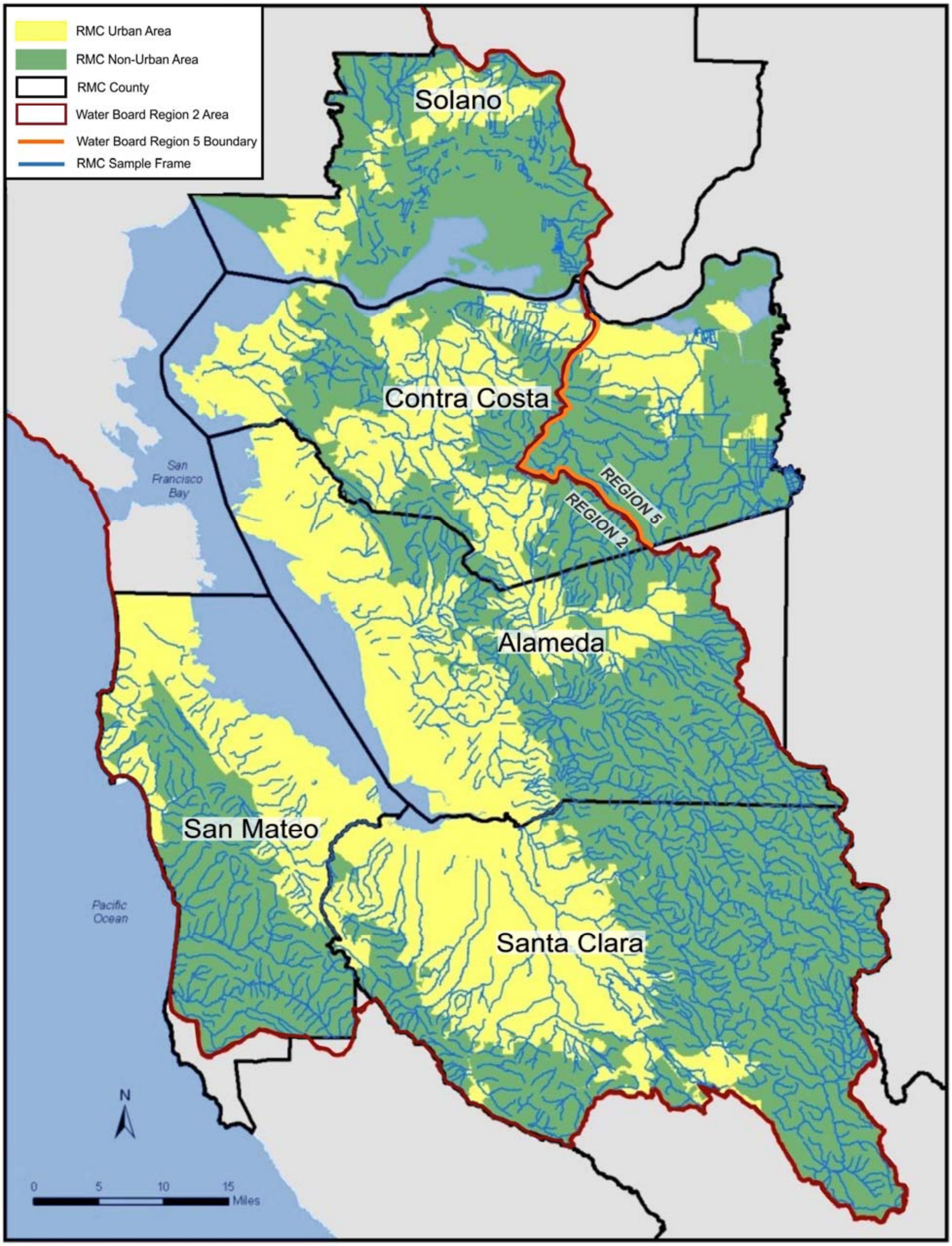
In 2011, the RMC developed a regional/probabilistic monitoring design to identify ambient conditions of creeks in the five main counties subject to the requirements of the MRP. The regional design was developed using the Generalized Random Tessellation Stratified (GRTS) approach developed by the U.S. Environmental Protection Agency (USEPA) and Oregon State University (Stevens and Olson, 2004). The GRTS approach has been implemented in California by several agencies, including the statewide Perennial Streams Assessment (PSA) conducted by SWAMP (Ode et al., 2011) and the Southern California Stormwater Monitoring Coalition's (SMC's) regional monitoring (Southern California Stormwater Monitoring Coalition, 2007). The RMC area is considered to define the sample frame and represent the sample universe from which the regional "sample draw" (the randomized list of potential monitoring sites) is produced.

2.2.1 Management Questions

The RMC regional monitoring probabilistic design was developed to address the following management questions:

- What is the condition of aquatic life in creeks in the RMC area? Are water quality objectives met and are beneficial uses supported?
- What is the condition of aquatic life in the urbanized portion of the RMC area? Are water quality objectives met and are beneficial uses supported?
- What is the condition of aquatic life in RMC participant counties? Are water quality objectives met and are beneficial uses supported?
- To what extent does the condition of aquatic life in urban and non-urban creeks differ in the RMC area?
- To what extent does the condition of aquatic life in urban and non-urban creeks differ in each of the RMC participating counties?
- What are major stressors to aquatic life in the RMC area?
- What are major stressors to aquatic life in the urbanized portion of the RMC area?
- What are the long-term trends in water quality in creeks over time?

Figure 2.1 Map of BASMAA RMC Area, County Boundaries and Major Creeks



The regional design includes bioassessment monitoring to address the first set of questions regarding aquatic life condition. Assemblages of freshwater organisms are commonly used to assess the biological integrity of water bodies because they provide direct measures of ecological condition (Karr and Chu, 1999).

Benthic macroinvertebrates (BMIs) are an essential link in the aquatic food web, providing food for fish and consuming algae and aquatic vegetation (Karr and Chu, 1999). The presence and distribution of BMIs can vary across geographic locations based on elevation, creek gradient, and substrate (Barbour et al., 1999). These organisms are sensitive to disturbances in water and sediment chemistry, as well as to physical habitat, both in the stream channel and along the riparian zone. Due to their relatively long life cycles (approximately one year) and limited migration, BMIs are particularly susceptible to site-specific stressors (Barbour et al., 1999).

Algae also are increasingly used as indicators of water quality, as they form the autotrophic base of aquatic food webs and exhibit relatively short life cycles which respond quickly to chemical and physical changes. Diatoms are found to be particularly useful for interpreting some causes of environmental degradation (Hill et al., 2000); therefore, both BMI and algae taxonomic data are used in the aquatic life assessments.

Additional water quality parameters, including water and sediment toxicity testing and chemical analysis, along with physical habitat characteristics, are then used to assess potential stressors to aquatic life.

2.2.2 Site Selection

Status and trends monitoring was conducted in non-tidally influenced, flowing water bodies (i.e., creeks, streams and rivers). The water bodies monitored were drawn from a master list which included all perennial and non-perennial creeks and rivers running through urban and non-urban areas within the RMC area. Sample sites were selected and attributed using the GRTS approach from a sample frame consisting of a creek network geographic information system (GIS) data set within the RMC boundary (BASMAA, 2011), within five management units corresponding to the five participating RMC counties. The National Hydrography Dataset Plus (1:100,000) was selected as the creek network data layer to provide consistency with both the statewide PSA and the SMC, and the opportunity for future data coordination with these programs.

The RMC sample frame was stratified by county and land use (i.e., urban and non-urban) to allow for comparisons within those strata. Urban areas were delineated by combining urban area boundaries and city boundaries defined by the U.S. Census Bureau of 2000. Non-urban areas were defined as the remainder of the areas within the sample universe (RMC area).

Based on discussion during RMC meetings with SFBRWQCB staff present, RMC participants weight their sampling to ensure at least 80 percent of monitored sites are in urban areas and not more than 20 percent are in non-urban areas. RMC participants coordinated with SWAMP and Regional Water Quality Control Board staff by identifying additional non-urban sites from their respective counties for SWAMP monitoring. For Contra Costa County, SWAMP monitoring included non-urban bioassessment sites chosen from the probabilistic sample draw in the Region 2 (San Francisco Bay) area of Contra Costa County, with the regional focus varying annually.

2.3 Monitoring Design Implementation

The number of probabilistic sites monitored annually in water years 2012-2019 by CCCWP are shown by land use category in Table 2.1. This tally includes non-urban sites monitored by SWAMP personnel.

Table 2.1 Number of Urban and Non-Urban Bioassessment Sites Sampled by CCCWP and SWAMP in Contra Costa County During Water Years 2012-2019

Monitoring Year	Contra Costa County Land Use	
	Urban Sites	Non-Urban Sites [1]
WY 2012	8	2/2
WY 2013	10	0/3
WY 2014	10	0/1
WY 2015	10	0/1
WY 2016	10	0/0
WY 2017	10	0/0
WY 2018	9	1/0
WY 2019	9	1/0
Total	76	9

1 Non-urban sites are shown as sampled by CCCWP/SWAMP for each year. The total represents combined non-urban sites.

3 Monitoring Methods

3.1 Site Evaluation

Sites identified in the regional sample draw were evaluated by each RMC participant in numerical order using the process defined in the RMC SOPs (BASMAA, 2016b). Each site was evaluated to determine if it met the following RMC sampling location criteria:

1. The location (latitude/longitude) provided for a site is located on or is within 300 meters (m) of a non-impounded receiving water body
2. The site is not tidally influenced
3. The site is wadable during the sampling index period
4. The site has sufficient flow during the sampling index period to support SOPs for biological and nutrient sampling
5. The site is physically accessible and can be entered safely at the time of sampling
6. The site may be physically accessed and sampled within a single day
7. Landowner(s) grants permission to access the site[3]

In the first step, these criteria were evaluated to the extent possible using desktop analysis.

For sites which successfully passed the initial desktop analysis, site evaluations were completed during the second step via field reconnaissance visits. Based on the outcome of the site evaluations, sites were classified into one of four categories:

Target Sampleable (TS): sites meeting all seven criteria were classified as target sampleable (TS)

Target Non-Sampleable (TNS): sites meeting criteria 1 through 4, but not meeting at least one of criteria 5 through 7, were classified as target non-sampleable (TNS)

Non-Target (NT): sites not meeting at least one of criteria 1 through 4 were classified as non-target status and were not sampled

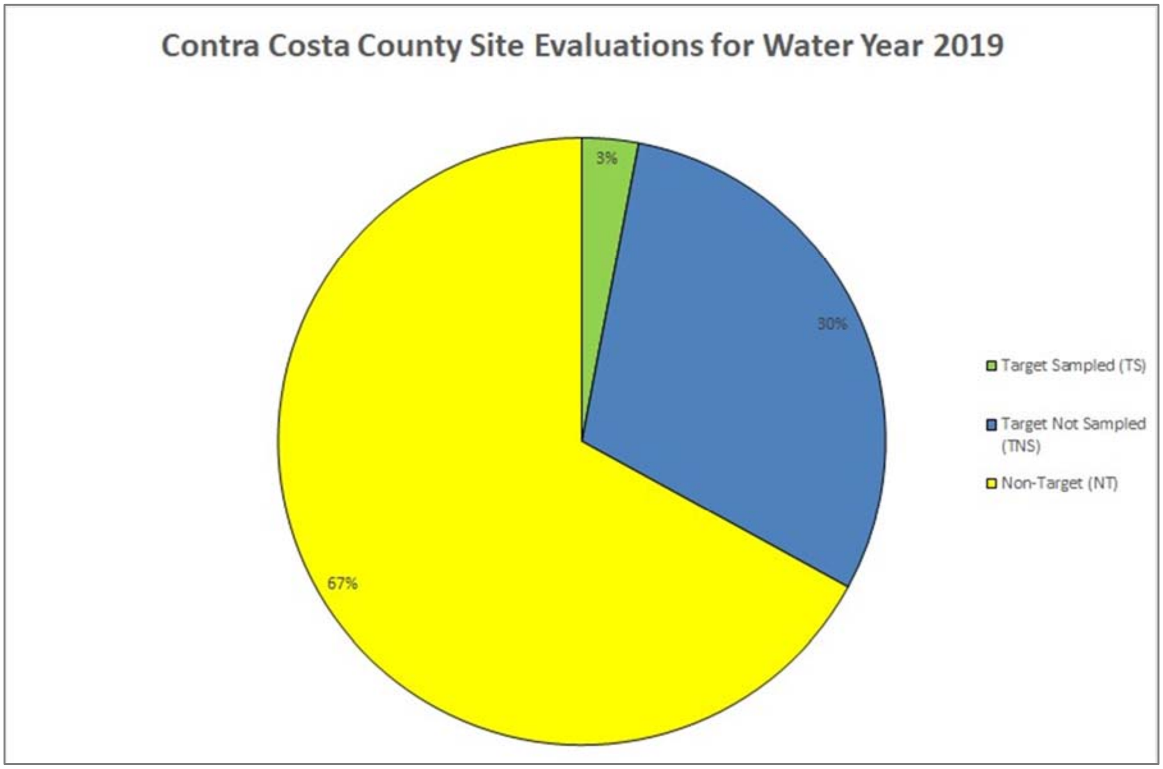
Unknown (U): sites were classified with unknown status and not sampled when it could be reasonably inferred, either via desktop analysis or a field visit, the site was a valid receiving water body and information for any of the seven criteria was unconfirmed

The outcomes of these site evaluations for CCCWP sites for water year 2019 are illustrated in Figure 3.1. A relatively small fraction of sites evaluated each year are classified as target sampleable sites. The target sampleable category is a minority of sites evaluated for 2019, in part because the 2019 site evaluations included a large number of non-urban desktop recons (accounting for a larger proportion of

[3] If landowners did not respond to at least two attempts to contact them, either by written letter, e-mail or phone call, permission to access the respective site was effectively considered to be denied.

non-target sites), and also because the remaining available 2017-2018 target site evaluations were prioritized for the probabilistic design, per RMC protocols.

Figure 3.1 Results of CCCWP Site Evaluations for Water Year 2019



During the site evaluation field visits, flow status was recorded as one of five categories:

Wet Flowing: continuously wet or nearly so; flowing water

Wet Trickle: continuously wet or nearly so; very low flow; trickle less than 0.1 L/second

Majority Wet: discontinuously wet; greater than 25 percent by length of stream bed covered with water; isolated pools

Minority Wet: discontinuously wet; less than 25 percent of stream bed by length covered with water; isolated pools

No Water: no surface water present

Observations of flow status during pre-wet-weather, fall site reconnaissance events and during post-wet-weather, spring sampling were combined to classify sites as perennial or nonperennial as follows:

Perennial: fall flow status is either Wet Flowing or Wet Trickle, and spring flow is sufficient to sample

Non-Perennial: fall flow status is Majority Wet, Minority Wet, or No Water, and spring flow is sufficient to sample

The probabilistic sites selected for monitoring in water year 2019, following site evaluation, are shown graphically in Figure 3.2 as the bioassessment sites, and are listed with additional site information in Table 3.1. As shown in Table 3.1, one additional site (Marsh Creek, site 544MSH045) was the site selected for dry weather water toxicity, sediment toxicity and sediment chemistry testing. Wet weather (stormwater) chemistry and toxicity testing was not conducted in water year 2019, as the relevant MRP requirements had previously been met.

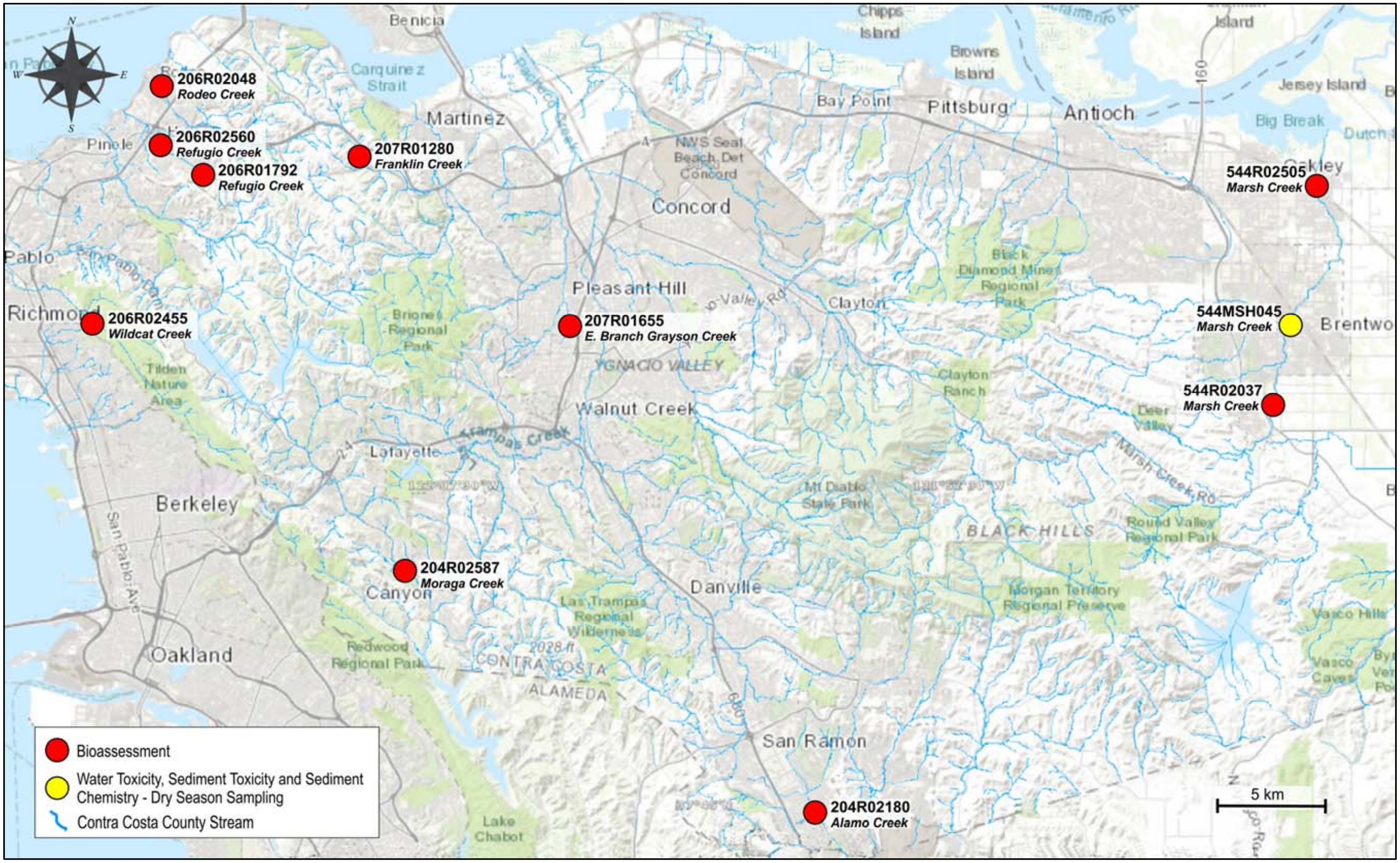
Table 3.1 Site Locations, Monitoring Parameters and Dates Sampled at CCCWP Sites from the RMC Probabilistic Monitoring Design in Water Year 2019

Site ID	Creek Name	Land Use	Latitude	Longitude	Bioassessment, PHab, Chlorine, Nutrients	Stormwater Toxicity and Chemistry[1] (Wet Weather)	Water Toxicity and Sediment Toxicity and Chemistry (Dry Weather)
204R02180	Alamo Creek	Urban	37.77915	-121.90058	06/12/19		
204R02587	Moraga Creek	Urban	37.84235	-122.14516	06/11/19		
206R01792	Refugio Creek	Urban	37.99608	-122.24448	05/08/19		
206R02048	Rodeo Creek	Urban	38.03034	-122.26516	06/13/19		
206R02455	Wildcat Creek	Urban	37.93845	-122.29939	05/07/19		
206R02560	Refugio Creek	Urban	38.0076	-122.26665	05/08/19		
207R01280	Franklin Creek	Non-urban	38.00274	-122.16804	05/09/19		
207R01655	E Branch Grayson Creek	Urban	37.93774	-122.06370	05/06/19		
544R02037	Marsh Creek	Urban	37.90691	-121.71558	05/06/19		
544R02505	Marsh Creek	Urban	37.99168	-121.69589	06/12/19		
544MSH045	Marsh Creek	Urban	37.93731	-121.70803			07/23/19
544MSH045	Marsh Creek	Urban	37.93731	-121.70803			09/18/19[2]

1 Wet weather monitoring was not conducted in water year 2019.

2 Sample collected for toxicity re-test following finding of significant toxicity in the 7/23/2019 Marsh Creek sample.

Figure 3.2 Contra Costa County Creek Status Sites Monitored in Water Year 2019



Note: Bioassessment sites are those selected from the RMC Probabilistic Monitoring Design

3.2 Field Sampling and Data Collection Methods

Field data and samples were collected in accordance with existing SWAMP-comparable methods and procedures, as described in the RMC QAPP (BASMAA, 2016a) and the associated SOPs (BASMAA, 2016b). The SOPs were developed using a standard format describing health and safety cautions and considerations, relevant training, site selection, and sampling methods/procedures. Sampling methods/ procedures include pre-fieldwork mobilization activities to prepare equipment, sample collection, and demobilization activities to preserve and transport samples, as well as to avoid transporting invasive species between creeks. The SOPs relevant to the monitoring discussed in this report are listed in Table 3.2.

Procedures for sample container size and type, preservative type, and associated holding times for each regional/probabilistic analyte are described in RMC SOP FS-9 (BASMAA, 2016b). Procedures for completion of field data sheets are provided in RMC SOP FS-10, and procedures for sample bottle labeling are described in RMC SOP FS-11 (BASMAA, 2016b).

Table 3.2 RMC Standard Operating Procedures Pertaining to Regional Creek Status Monitoring

SOP	Procedure
FS-1	BMI and algae bioassessments and physical habitat assessments
FS-2	Water quality sampling for chemical analysis, pathogen indicators, and toxicity testing
FS-3	Field measurements, manual
FS-6	Collection of bedded sediment samples
FS-7	Field equipment cleaning procedures
FS-8	Field equipment decontamination procedures
FS-9	Sample container, handling, and chain-of-custody procedures
FS-10	Completion and processing of field data sheets
FS-11	Site and sample naming convention
FS-12	Ambient creek status monitoring site evaluation
FS-13	QA/QC data review

3.2.1 Bioassessments

In accordance with the RMC QAPP (BASMAA, 2016a), bioassessments were conducted during the spring index period (approximately April 15 to July 15) and at a minimum of 30 days after any significant storm (roughly defined as at least 0.5 inch of rainfall within a 24-hour period).

Each bioassessment monitoring site consisted of an approximately 150-meter stream reach divided into 11 equidistant transects placed perpendicular to the direction of flow. The sampling position within each transect alternated between 25, 50 and 75 percent distance of the wetted width of the stream (see SOP FS-1, BASMAA, 2016b).

3.2.1.1 Benthic Macroinvertebrates (BMI)

BMIs were collected via kick net sampling using the reach-wide benthos method described in RMC SOP FS-1 (BASMAA, 2016b), based on the SWAMP bioassessment procedures (Ode et al., 2016a and 2016b). Samples were collected from a one square foot area approximately one meter downstream of each transect. The benthos was disturbed by manually rubbing areas of coarse substrate, followed by disturbing the upper layers of finer substrate to a depth of 4 to 6 inches to dislodge any remaining invertebrates into the net. Slack water habitat procedures were used at transects with deep and/or slow-moving water. Material collected from the 11 subsamples was composited in the field by transferring the entire sample into one to two 1,000 mL wide-mouth jar(s), and the samples were preserved with 95 percent ethanol.

3.2.1.2 Algae

Filamentous algae and diatoms also were collected using the reach-wide benthos method described in SOP FS-1 (BASMAA, 2016b), based on the SWAMP bioassessment procedures (Ode et al., 2016a and 2016b). Algae samples were collected synoptically with BMI samples. The sampling position within each transect was the same as used for BMI sampling, except algae samples were collected 6 inches upstream of the BMI sampling position and following BMI collection from that location. The algae were collected using a range of methods and equipment, depending on the substrate occurring at the site (e.g., erosional, depositional, large and/or immobile) per RMC SOP FS-1. Erosional substrates included any material (substrate or organics) small enough to be removed from the stream bed, but large enough to isolate an area equal to a rubber delimiter (12.6 cm^2 in area).

When a sample location along a transect was too deep to sample, a more suitable location was selected, either on the same transect or from one further upstream. Algae samples were collected at each transect prior to moving on to the next transect. Sample material (substrate and water) from all 11 transects was combined in a sample bucket, agitated, and a suspended algae sample was then poured into a 500 mL cylinder, creating a composite sample for the site. A 45 mL subsample was taken from the algae composite sample and combined with 5 mL glutaraldehyde into a 50 mL sample tube for taxonomic identification of soft algae. Similarly, a 40 mL subsample was taken from the algae composite sample and combined with 10 mL of 10 percent formalin into a 50 mL sample tube for taxonomic identification of diatoms.

The algae composite sample also was used for collection of chlorophyll-*a* and ash-free dry mass (AFDM) samples following methods described in Fetscher et al. (2009). For the chlorophyll-*a* sample, 25 mL of the algae composite volume was removed and run through a glass fiber filter (47 mm, 0.7 µm pore size) using a filtering tower apparatus in the field. The AFDM sample was collected using a similar process which employs pre-combusted filters. Both filter samples were placed in Whirl-Pak® bags, covered in aluminum foil, and immediately placed on ice for transport to the analytical laboratory.

3.2.1.3 Physical Habitat (PHab)

PHab assessments were conducted during each BMI bioassessment monitoring event using the SWAMP PHab protocols (Ode et al., 2016a and 2016b) and RMC SOP FS-1 (BASMAA, 2016b). PHab data were collected at each of the 11 transects and 10 additional inter-transects (located between each main transect) by implementing the “Full” SWAMP level of effort (as prescribed in the MRP). At algae sampling locations, additional assessment of the presence of micro- and macroalgae was conducted during the pebble counts. In addition, water velocities were measured per SWAMP protocols at a single location in the sample reach (when possible).

3.2.2 Physicochemical Measurements

Dissolved oxygen, temperature, conductivity, and pH were measured during bioassessment monitoring using a multi-parameter probe (see SOP FS-3, BASMAA, 2016b). Dissolved oxygen, specific conductivity, water temperature, and pH measurements were made either by direct submersion of the instrument probe into the sample stream or by collection and immediate analysis of grab sample in the field. Physicochemical measurements were taken approximately 0.1m below the water surface at locations of the stream appearing to be completely mixed, ideally at the centroid of the stream. Measurements took place upstream of sampling personnel and equipment and upstream of areas where bed sediments have been disturbed or prior to such bed disturbance.

3.2.3 Chlorine

Water samples were collected and analyzed for free and total chlorine using CHEMetrics test kits (K-2511 for low range and K-2504 for high range). Chlorine measurements in water were conducted during bioassessment monitoring and again during dry season monitoring for sediment chemistry, sediment toxicity, and water toxicity.

3.2.4 Nutrients and Conventional Analytes (Water Chemistry)

Water samples were collected during bioassessment monitoring for nutrient analyses using the standard grab sample collection method, as described in SOP FS-2 (BASMAA, 2016b). Sample containers were rinsed using ambient water and filled and recapped below the water surface whenever possible. An intermediate container was used to collect water for all sample containers containing preservative added in advance by the laboratory. Sample container size and type, preservative type, and associated holding times for each analyte are described in Table 1 of SOP FS-9 (BASMAA, 2016b). The syringe filtration method was used to collect samples for analyses of dissolved orthophosphate and dissolved organic carbon. All sample containers were labeled and stored on ice for transport to the analytical laboratory, except for analysis of AFDM and chlorophyll-*a* samples, which were field-frozen on dry ice by sampling teams, where appropriate.

3.2.5 Water Toxicity

Samples were collected using the standard grab sample collection method described above, filling the required number of labeled 2.25-liter amber glass bottles with ambient water, putting them on ice to cool to 4° C ± 2° C, and delivered to the laboratory within the required hold time. The laboratory was notified of the impending sample delivery to ensure meeting the 24-hour sample delivery time requirement. Procedures used for sample collection and transport are described in SOP FS-2 (BASMAA, 2016b).

3.2.6 Sediment Chemistry and Sediment Toxicity

In the case where sediment samples and water samples and measurements were collected at the same event, sediment samples were collected after water samples were collected. Before conducting sediment sampling, field personnel surveyed the proposed sampling area to identify appropriate fine-sediment depositional areas and to avoid disturbing possible sediment collection sub-sites. Personnel carefully entered the stream and began sampling at the closest appropriate reach, continuing upstream. Sediment samples were collected from the top 2 cm of sediment in a compositing container, thoroughly homogenized, and then aliquoted into separate jars for chemical and toxicological analysis using standard clean sampling techniques (see SOP FS-6, BASMAA, 2016b). Sample jars were submitted to the respective laboratories per SOP FS-9 (BASMAA, 2016b).

3.3 Laboratory Analysis Methods

RMC participants agreed to use the same set of analytical laboratories for regional/probabilistic parameters, developed standards for contracting with the labs, and coordinated quality assurance issues.

All samples collected by RMC participants sent to laboratories for analysis were analyzed and reported per SWAMP-comparable methods, as described in the RMC QAPP (BASMAA, 2016a). The following analytical laboratory contractors were used for biological, chemical and toxicological analysis:

BioAssessment Services, Inc. – BMI taxonomic identification

The laboratory performed taxonomic identification nominally on a minimum of 600 BMI individuals for each sample, per standard taxonomic effort Level 1, as established by the Southwest Association of Freshwater Invertebrate Taxonomists, with additional identification of chironomids to subfamily/tribe level (corresponding to a Level 1a standard taxonomic effort).

EcoAnalysts, Inc. – Algae taxonomic identification

Samples were processed in the laboratory following draft SWAMP protocols to provide count (diatom and soft algae), biovolume (soft algae), and presence (diatom and soft algae) data. Laboratory processing included identification and enumeration of 300 natural units of soft algae and 600 diatom valves to the lowest practical taxonomic level. Diatom and soft algae identifications were not fully harmonized with the California Algae and Diatom Taxonomic Working Group's Master Taxa List, and 12 taxa were not included in the data analysis.

Caltest Analytical Laboratory, Inc. – Water chemistry (nutrients, etc.), sediment chemistry, chlorophyll-a, AFDM

Upon receipt at the laboratory, samples were immediately logged and preserved as necessary. USEPA-approved testing protocols were then applied for analysis of water and sediment samples.

PHYSIS Environmental Laboratories, Inc. – Water chemistry (pyrethroids, imidacloprid, fipronil and degradates, total and dissolved organic carbon, and suspended sediment concentration)

Upon receipt at the laboratory, samples were immediately logged and preserved as necessary. USEPA-approved testing protocols were then applied for analysis of water samples and modified as necessary.

Pacific EcoRisk, Inc. – Water and sediment toxicity

Testing of water and sediment samples was performed per species-specific protocols published by USEPA.

3.4 Data Analysis – Water Year 2019 Data

Only data collected by CCCWP during water year 2019 for regional/probabilistic parameters are presented and analyzed in this report. This includes data collected during bioassessment monitoring, including BMI and algae taxonomy, water chemistry, and physical habitat evaluations at 10 sites, as well as dry weather water and sediment toxicity and sediment chemistry data from one additional site. The bioassessment data are used to evaluate stream conditions, and the associated physical, chemical and toxicity testing data are then analyzed to identify potential stressors which may impact water quality and biological conditions. For the comprehensive, multi-year analysis required for the IMR, the accumulated data (water years 2012-2019) were used to develop a statistically representative data set for the RMC region to address management questions related to condition of aquatic life (see Section 3.5).

Creek status monitoring data generated by CCCWP for local/targeted parameters (not included in the probabilistic design), per MRP provision C.8.d, are reported in Local/Targeted Creek Status Monitoring Report: Water Year 2019, found in Appendix 2 of the IMR (CCCWP, 2020).

The creek status monitoring results are subject to potential follow-up actions, per MRP provisions C.8.d and C.8.g, if they meet certain specified threshold triggers, as shown in Table 3.3 for the regional/ probabilistic parameters. If monitoring results meet the requirements for follow-up actions as shown in Table 3.3, the results are compiled on a list for consideration as potential stress/source identification (SSID) projects, per MRP provision C.8.e, and used by RMC programs to help inform the SSID project selection process.

As part of the stressor assessment for this report, water and sediment chemistry and toxicity data generated during water year 2019 also were analyzed and evaluated against these threshold triggers to identify potential stressors which might contribute to degraded or diminished biological conditions.

In addition to those threshold triggers for potential SSID projects, the results are compared to other regulatory standards, including Basin Plan water quality objectives, where available and applicable.

Table 3.3 Requirements for Follow-up for Regional/Probabilistic Creek Status Monitoring Results Per MRP Provisions C.8.d and C.8.g

Constituent	Threshold Trigger Level	MRP Provision	Provision Text
CSCI Score	< 0.795 (plus see provision text =>)	C.8.d.i.(8)	Sites scoring less than 0.795 per CSCI are appropriate for an SSID project, as defined in provision C.8.e. Such a score indicates a substantially degraded biological community relative to reference conditions. Sites where there is a substantial difference in CSCI score observed at a location relative to upstream or downstream sites are also appropriate for an SSID project. If many samples show a degraded biological condition, sites where water quality is most likely to cause and contribute to this degradation may be prioritized by the permittee for an SSID project.
Chlorine	> 0.1 mg/L	C.8.d.ii.(4)	The permittees shall immediately resample if the chlorine concentration is greater than 0.1 mg/L. If the resample is still greater than 0.1 mg/L, then permittees shall report the observation to the appropriate permittee central contact point for illicit discharges, so the illicit discharge staff can investigate and abate the associated discharge in accordance with provision C.5.e (Spill and Dumping Complaint Response Program).
Toxicity	TST "fail" on initial and follow-up sample test; both results have > 50 percent effect	C.8.g.iv	The permittees shall identify a site as a candidate SSID project when analytical results indicate any of the following: (1) a toxicity test of growth, reproduction, or survival of any test organism is reported as "fail" in both the initial sampling, and (2) a second, follow up sampling, and both have ≥ 50 percent effect. Note: Applies to dry and wet weather, water column and sediment tests.
Pesticides (Water)[1]	> Basin Plan water quality objectives	C.8.g.iv	The permittees shall identify a site as a candidate SSID project when analytical results indicate a pollutant is present at a concentration exceeding its water quality objective in the Basin Plan.
Pesticides and Other Pollutants (Sediment)	Result exceeds PCE or TCE (per MacDonald et al., 2000)	C.8.g.iv	The permittees shall identify a site as a candidate SSID project when analytical results indicate any of the following: (1) A pollutant is present at a concentration exceeding its water quality objective in the Basin Plan, and (2) for pollutants without water quality objectives, results exceed PEC or TEC.

1 Per RMC decision, with Water Board staff concurrence, in accordance with MRP provision C.8.g.iii.(3), this monitoring commenced in water year 2017.

PEC probable effects concentrations

TEC threshold effects concentrations

Note: Per MRP provision C.8.d. and C.8.g., these are the data thresholds which trigger listings as candidate SSID projects.

3.4.1 Biological Data

The biological condition of each probabilistic site monitored by CCCWP in water year 2019 was evaluated principally through analysis of BMI and algal taxonomic metrics, and calculation of associated index of biological integrity (IBI) scores. An IBI is an analytical tool involving calculation of a site condition score based on a compendium of biological metrics.

3.4.1.1 Benthic Macroinvertebrate (BMI) Data Analysis

Under the MRP, the BMI taxonomic data are evaluated principally through calculation of the CSCI, a recently developed bioassessment index (Rehn et al., 2015; Rehn, 2016; Mazor et al., 2016). The CSCI scores evaluate stream health based on comparison of the observed BMI taxonomy (as reported by the lab) versus the expected BMI community characteristics that would, in theory, be present in a reference stream with similar geographic characteristics as the monitored stream, based on a specific set of watershed parameters.

The CSCI score is computed as the average of two other indices: O/E, the observed (O) taxonomic diversity at the monitoring site divided by the taxonomic composition expected (E) at a reference site with similar geographical characteristics, and MMI, a multi-metric index incorporating several metrics reflective of BMI community attributes (such as measures of assemblage richness, composition, and diversity), as predicted for a site with similar physical characteristics. The six metrics selected for inclusion in the MMI calculations were taxonomic richness, number of shredder taxa, percent clinger taxa, percent Coleoptera taxa, percent EPT (Ephemeroptera, Plecopter, and Trichoptera) taxa, and percent intolerant taxa (Rehn et al., 2015; Rehn, 2016).

CSCI scores run from a minimum of 0 (indicating no correspondence to modeled reference site conditions) to a maximum of 1 (perfect correspondence with modeled reference site conditions). A CSCI score below 0.795 indicates biological degradation and a potential candidate site for an SSID project, per the MRP. This index produces conservative values relative to urban creeks.

Prior to the adoption of the first MRP, work was initiated on a San Francisco Bay Region B-IBI in a collaborative effort by BASMAA participants and others, and the results were provisionally tested in Contra Costa (CCCWP, 2007) and Santa Clara (SCVURPPP, 2007) Counties. The Contra Costa County version of the Bay Area B-IBI was subsequently used in analysis and reporting of BMI data over the course of several years for the annual Contra Costa Monitoring and Assessment Program (CCMAP) bioassessment monitoring (see summary, Ruby, 2012). Calculation of the preliminary Contra Costa B-IBI is also presented for CCCWP's BMI data in this report, to allow for comparisons with the historical CCMAP data set. For consistency and comparison with the 2012 regional UCMR (BASMAA, 2013), subsequent urban creeks monitoring reports, and other RMC programs, the Southern California B-IBI score (per Ode et al., 2005) is also computed for condition assessment in this report.

3.4.1.2 Algae Data Analysis

Algae taxonomic data are evaluated through a variety of metrics and indices. MRP 2.0 does not specify threshold trigger levels for algae data. For the comprehensive analysis, both the standard algal indices of biotic integrity (A-IBIs) and the recently developed Algae Stream Condition Index (ASCI) multi-metric index (MMI) metrics were calculated for the water year 2019 data and for the multi-year (2012-2019) analysis.

Eleven diatom metrics, 11 soft algae metrics, and five algal IBIs (A-IBI; D18, H20, H21, H23 and S2) were calculated for this report following protocols developed from work in Southern California streams

(Fetscher et al., 2013 and 2014), as reported in prior urban creeks monitoring reports. These A-IBIs were not tested for Bay Area waters; however, because the Southern California A-IBI D18 (per Fetscher et al., 2013 and 2014) relies only on diatoms and is thought to be more transferable to other areas of the state (Marco Sigala, personal communication), the D-18 A-IBI has been used in recent years by CCCWP and other RMC Programs provisionally for assessment of stream conditions.

Diatom and soft algae metrics fall into five categories:

Tolerance/Sensitivity: association with specific water-quality constituents like nutrients; tolerance to low dissolved oxygen; tolerance to high-ionic-strength/saline waters

Autoecological Guild: nitrogen fixers; saprobic/heterotrophic taxa

Morphological Guild: sedimentation indicators; motility

Taxonomic Groups: Chlorophyta, Rhodophyta, Zygnemataceae, heterocystous cyanobacteria

Relationship to Reference sites

IBI scoring ranges and values were provided by Dr. A. Elizabeth Fetscher (Marco Sigala, personal communication). After each metric was scored, values were summed and then converted to a 100-point scale by multiplying the sum by the number of metrics (e.g., sum x [100/50] if five metrics included in the IBI).

California SWAMP is currently developing a set of algae indices meant to be more robust in assessing biointegrity in wadable streams in California across a broad range of environmental conditions. Three ASCI MMIs are currently under development, and the methods have been made available to scientists working with algae data (specifically, MMIs for diatoms, soft algae, and a diatom/soft algae hybrid).

As of the comprehensive multi-year analysis (Section 5 of this report), the analysis will focus less on the older A-IBIs, such as the D18, S2, and H20 indices, as they were developed for Southern California streams, and have become deficient since 2013 due to the lack of updated attribute traits (Marco Sigala. personal communication). The ASCI MMIs were developed for statewide use and are expected to be more robust across a wider range of environmental conditions.

3.4.1.3 Biological Condition Categories

During development of the CSCI and ASCI indices, the range of possible scores for each index was divided into categories to represent the likelihood that the biota were intact or altered, with respect to conditions judged to prevail in similar creeks under unimpacted conditions (Rehn et al., 2015; Theroux et al., in prep). Those condition categories are defined in Table 3.4 for the CSCI and the three ASCI MMI algae indices.

Table 3.4 CSCI and ASCI Multi-metric Scoring ranges by Condition Category

	Likely Intact	Possibly Altered	Likely Altered	Very Likely Altered
B-IBI (BMI) Index				
CSCI	≥ 0.92	≥ 0.79 and < 0.92	≥ 0.63 and < 0.79	< 0.63
ASCI (Algae) Indices				
Diatom MMI	≥ 0.92	≥ 0.81 and < 0.92	≥ 0.66 and < 0.81	< 0.66
Soft Algae MMI	≥ 0.92	≥ 0.80 and < 0.92	≥ 0.65 and < 0.80	< 0.65
Hybrid MMI	≥ 0.95	≥ 0.88 and < 0.95	≥ 0.78 and < 0.88	< 0.78

3.4.2 Physical Habitat (PHab) Condition

PHab condition was assessed for the CCCWP bioassessment monitoring sites using “mini-PHab” scores. Mini-PHab scores range from 0 to 60, representing a combined score of three physical habitat sub-categories (epifaunal substrate/cover, sediment deposition, and channel alteration), each of which can be scored on a range of 0 to 20 points. Higher PHab scores reflect higher quality habitat.

PHab condition also was assessed for the CCCWP bioassessment monitoring sites using the Index of Physical Habitat Integrity (IPI), a multi-metric index recently developed by the State of California (SWAMP) to characterize physical habitat condition for streams in California (Rehn et al., 2018a). The IPI is based on the concept that physical habitat characteristics have a profound effect on stream health, and that high-quality physical habitat is essential for maintaining beneficial uses. Interim instructions for calculating IPI using GIS and the analytical software platform “R” were published by SWAMP in 2018 (Rehn et al., 2018b).

The IPI is calculated from empirical data organized into two input files: the “stations” data, which are derived from the GIS characteristics associated with each monitoring site, and “PHab” data, which include about a dozen physical habitat characteristics derived from present in the bioassessment EDD produced from the bioassessment fieldwork. The State has provided guidance on four IPI score condition categories that can be used to facilitate interpretation of the calculated IPI scores. See details with discussion of results, section 4.3.1.

3.4.3 Water and Sediment Chemistry and Toxicity

As part of the stressor assessment for this report, water and sediment chemistry and toxicity data generated during water year 2019 were analyzed and evaluated to identify potential stressors that may contribute to degraded or diminished biological conditions. Results were evaluated in relation to MRP threshold triggers, and water chemistry results were evaluated with respect to applicable water quality objectives, where feasible.

For sediment chemistry trigger criteria, comparisons to threshold effects concentrations (TECs) and probable effects concentrations (PECs) are calculated as defined in MacDonald et al. (2000). For each constituent for which there is a published TEC or PEC value, the ratio of the measured concentration to the respective TEC or PEC value was computed as the TEC or PEC quotient, respectively. All results where a TEC quotient was equal to or greater than 1.0 were identified. For each site, the mean PEC quotient was then computed, and any sites where mean PEC quotient was equal to or greater than 0.5 were identified.

Toxic unit equivalents also were computed for pyrethroid pesticides in sediment, based on available literature LC_{50} values (LC_{50} is the concentration of a chemical which is lethal on average to 50 percent of test organisms). Because organic carbon mitigates the toxicity of pyrethroid pesticides in sediments, the LC_{50} values were derived based on organic carbon-normalized pyrethroid concentrations. Therefore, the RMC pyrethroid concentrations reported by the lab also were divided by the measured total organic compound (TOC) concentration at each site (as a percentage), and the TOC-normalized concentrations were then used to compute toxic unit (TU) equivalents for each pyrethroid. For each site, the TU equivalents for the individual pyrethroids were summed, and sites where the summed TU equivalents were equal to or greater than 1.0 were identified.

3.5 Quality Assurance/Quality Control (QA/QC)

Data quality assurance and quality control (QA/QC) procedures are described in detail in the BASMAA RMC QAPP (BASMAA, 2016a) and in RMC SOP FS13, QA/QC Data Review (BASMAA, 2016b).

Data quality objectives were established to ensure the data collected were of sufficient quality for the intended use. Data quality objectives include both quantitative and qualitative assessment of the acceptability of data. The qualitative goals include representativeness and comparability. The quantitative goals include completeness, sensitivity (detection and quantitation limits), precision, accuracy, and contamination. To ensure consistent and comparable field techniques, pre-monitoring field training and *in situ* field assessments were conducted.

Data were collected per the procedures described in the relevant SOPs (BASMAA, 2016b), including appropriate documentation of data sheets and samples, and sample handling and custody. Laboratories providing analytical support to the RMC were selected based on demonstrated capability to adhere to specified protocols.

All data were thoroughly reviewed by the programs responsible for collecting them, for conformance with QAPP requirements, and review of field procedures for compliance with the methods specified in the relevant SOPs. Data review was performed per protocols defined in RMC SOP FS13, QA/QC Data Review (BASMAA, 2016b). Data quality was assessed, and qualifiers were assigned, as necessary, in accordance with SWAMP requirements.

3.6 Comprehensive, Multi-Year Data Analysis

The multi-year analysis nominally covers water years 2014-2019, as required by MRP provision C.8.h.v. (the current IMR is required to cover the years since the previous IMR, which covered water years 2012 and 2013). However, because metrics were available for a wide range of physical, chemical and biological metrics for water years 2012-2016 in the BASMAA five-year bioassessment report, CCCWP has included data and metrics from water years 2012-2019 for parts of the current analysis.

More detail regarding the compiled data, available metrics, and analytical methods is presented in section 5.1 of this report.

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4 Results and Discussion

4.1 Statement of Data Quality

The RMC established a set of guidance and tools to help ensure data quality and consistency implemented through the collaborating programs. Additionally, the RMC participants continue to meet and coordinate on an ongoing basis to plan and coordinate monitoring, data management, and reporting activities, among others.

A comprehensive QA/QC program was implemented by each of the RMC programs, each of which is solely responsible for the quality of the data submitted on its behalf, covering all aspects of the regional/probabilistic monitoring. In general, QA/QC procedures were implemented as specified in the RMC QAPP (BASMAA, 2016a), and monitoring was performed per protocols specified in the RMC SOPs (BASMAA, 2016b) and in conformity with SWAMP protocols. QA/QC issues noted by the laboratories and/or RMC field crews are summarized below.

4.1.1 Bioassessment

Field duplicate BMI samples were collected at Wildcat Creek (site 206R02455). An analysis of the comparative results produced the following:

- The average relative percent difference (RPD) between the duplicate samples for 21 individual BMI taxonomic metrics was 36 percent
- The CSCI scores computed for this duplicate data set produced RPD of just 2.5 percent, with an average RPD of 9 percent for the several component CSCI metric scores
- RPD for each of the three ASCI scores was 6.7 percent (diatoms MMI), 23.5 percent (soft algae MMI), and 16.6 percent (hybrid MMI)

The RPD results for the CSCI and ASCI metrics are considered to represent an acceptable level of variation between duplicate sets of taxonomic data.

Taxonomic procedures for BMI identification and enumeration included components identified in the QAPP:

- Minimum 600 organism subsample when possible
- Sorting measurement quality objective: a check of remnants for organisms missed by original subsampler
- Interlaboratory quality control: submission of 10 percent of processed samples (one sample for this project) to an independent lab for review of taxonomic accuracy/precision and conformance to standard taxonomic level

All water year 2019 samples met the minimum sample count threshold of 600 individuals specified in the QAPP.

The New Zealand mudsnail (*Potamopyrgus antipodarum*), a non-native invasive species, was confirmed at several sites: Refugio, Franklin, Moraga, Alamo and Rodeo creeks.

The interlaboratory quality control review revealed no taxonomic discrepancies and two minor discrepancies in the BMI counts at the selected site; the slight corrections were reflected in the final EDD used in the data analysis.

4.1.2 Sediment Chemistry

The sample was diluted by the laboratory prior to analysis in an effort to reduce matrix interferences, resulting in higher reporting limit(s).Otherwise, no significant quality control issues were reported by the laboratory (Caltest) for the sediment sample analyses (Marsh Creek, site 544MSH045).

A field duplicate sediment sample was collected from Marsh Creek (site 544MSH045) on Jul. 23, 2019 and analyzed for a suite of metals and organic compounds. The average RPD for all detected analytes was 11.9 percent. RPD was within QAPP limits for all constituents except cyfluthrin (RPD 38.1 percent) and cyhalothrin/lambda (RPD 26.1 percent). These RPD values otherwise indicate acceptable precision from field collection and laboratory analysis.

4.1.3 Water Chemistry

Field duplicate samples were collected for water quality analysis as part of the bioassessment field work from Franklin Creek (site 207R01280) on May 9, 2019. The average RPD between the duplicate samples for the 10 water quality analytes was 27.8 percent, driven high principally due to the unusually high RPD for TKN. RPD was within QAPP limits for all constituents, except AFDM (RPD 37.4 percent), Ammonia as N (RPD 48.2 percent), Chlorophyll-*a* (RPD 34.9 percent), and TKN (RPD 140 percent). The water quality RPD results otherwise are considered to represent an acceptable level of variation between duplicates.

4.1.4 Sediment Toxicity

For the sediment sample collected from Marsh Creek (site 544MSH045) on Jul. 23, 2019, the *Chironomus* test was initiated on Jul. 29, 2019, within the required holding time.

The *Hyalella* sediment test for the same sample was initiated on Jul. 27, 2019, also within the required holding time.

4.1.5 Water Toxicity

No significant issues were reported in the laboratory analysis.

The water toxicity tests were within required holding time, initiated on Jul. 24, 2019.

Pathogen-related mortality was not observed in any sample replicates tested for water year 2019.

4.2 Biological Condition Assessment

Biological condition assessment addresses the RMC's core management question: what is the condition of aquatic life in creeks in the RMC area and are aquatic life beneficial uses supported? The designated beneficial uses listed in the San Francisco Bay Region Basin Plan (SFBRWQCB, 2015) for RMC creeks monitored by CCCWP for bioassessment in water year 2019 are shown in Table 4.1.

The BASMAA Five-Year Bioassessment Report, included as Appendix 8 of the water year 2018 Urban Creeks Monitoring Report, provides additional analysis at the countywide program and regional levels, as well as comparisons between urban and non-urban land use sites.

Table 4.1 Designated Beneficial Uses Listed in the San Francisco Bay Region Basin Plan or CCCWP Bioassessment Sites Monitored in Water Year 2019

Site Code	Creek Name	Human Consumptive Uses							Aquatic Life Uses									Recreational Uses		
		AGR	MUN	FRSH	GWR	IND	PROC	COMM	SHELL	COLD	EST	MAR	MIGR	RARE	SPWN	WARM	WILD	REC-1	REC-2	NAV
204R02180	Alamo Creek															E	E	E	E	
204R02587	Moraga Creek			E						E					E	E	E	E	E	
206R01792	Refugio Creek															E	E	E	E	
206R02048	Rodeo Creek									E					E	E	E	E	E	
206R02455	Wildcat Creek												E		E	E	E		E	
206R02560	Refugio Creek															E	E	E	E	
207R01280	Franklin Creek									E			E	E	E	E	E	E	E	
207R01655	E Branch Grayson Creek									E			E	E		E	E	E	E	
544R02037	Marsh Creek							E						E		E	E	E	E	
544R02505	Marsh Creek							E						E		E	E	E	E	

E existing beneficial use

Note: Per Basin Plan Ch. 2 (SFBRWQCB, 2015), beneficial uses for freshwater creeks include municipal and domestic supply (MUN), agricultural supply (AGR), industrial process supply (PRO), groundwater recharge (GWR), water contact recreation (REC1), noncontact water recreation (REC2), wildlife habitat (WILD), cold freshwater habitat (COLD), warm freshwater habitat (WARM), fish migration (MIGR), and fish spawning (SPWN). The San Francisco Bay Estuary supports estuarine habitat (EST), industrial service supply (IND), and navigation (NAV) in addition to all the uses supported by streams. Coastal waters' beneficial uses include water contact recreation (REC1); noncontact water recreation (REC2); industrial service supply (IND); navigation (NAV); marine habitat (MAR); shellfish harvesting (SHELL); ocean, commercial and sport fishing (COMM); and preservation of rare and endangered species (RARE).

4.2.1 Benthic Macroinvertebrate (BMI) Metrics

BMI taxonomic metrics are shown in Table 4.2 for the CCCWP creek status sites monitored in the spring index period of water year 2019. For consistency with the 2012 regional UCMR, subsequent urban creeks monitoring reports, and other RMC programs, the SoCal B-IBI score is included in the condition assessment analysis in this report. The preliminary Contra Costa B-IBI also is reported for purposes of comparison with the extensive historical database of bioassessment data produced by CCCWP during 2001-2011, as well as recent urban creeks monitoring reports. The condition category based on the Contra Costa B-IBI score is also shown for each bioassessment site at the bottom of Table 4.2.

CSCI scores were computed from the BMI taxonomy data and site-specific watershed characteristics for each bioassessment monitoring site. The CSCI score is computed as the average of the observed-to-expected score (O/E; the observed taxonomic diversity at the monitoring site divided by the taxonomic composition expected at a reference site with similar geographical characteristics), and the MMI score (a multi-metric index incorporating several metrics reflective of BMI community attributes, such as measures of assemblage richness, composition, and diversity, as predicted for a site with similar physical characteristics). CSCI scores run from a minimum of 0 (indicating no correspondence to modeled reference site conditions) to a maximum of 1 (perfect correspondence with modeled reference site conditions). Per the MRP, a CSCI score of less than 0.795 is degraded, and should be evaluated for consideration as a possible SSID study location.

The essential results of the CSCI calculations are presented in Table 4.3. As shown in Table 4.3, every CCCWP bioassessment site monitored in water year 2019 except Wildcat Creek (site 206R02455) produced a CSCI score below the MRP threshold of 0.795, indicating a degraded biological community relative to reference conditions. These sites consequently may be listed as potential candidates for SSID studies.

The water year 2019 CSCI scores ranged from a low of 0.315 at Marsh Creek (site 544R02505) to a high of 0.891 at Wildcat Creek (site 206R02455). Marsh Creek (site 544R02505) was also the only site monitored in water year 2019 to rate a “poor” CC-IBI score.

Table 4.2 Benthic Macroinvertebrate Metrics for CCCWP Bioassessment Sites Monitored in Water Year 2019

BMI Metrics for CCCWP Bioassessment Sites, Spring 2019										
Site Code:	204R02180	204R02587	206R01792	206R02048	206R02455	206R02560	207R01280	207R01655	544R02037	544R02505
Creek Name:	Alamo	Moraga	Refugio	Rodeo	Wildcat	Refugio	Franklin	Grayson	Marsh	Marsh
Richness										
Taxonomic	26	21	17	19	33	12	19	10	18	9
EPT	4	5	2	3	14	2	4	1	4	1
Ephemeroptera	1	2	1	1	5	1	2	1	3	0
Plecoptera	0	1	0	0	4	0	0	0	0	0
Trichoptera	3	2	1	2	5	1	2	0	1	1
Coleoptera	0	2	0	0	2	0	1	0	2	0
Predator	9	4	4	6	12	1	4	1	4	0
Diptera	9	7	7	5	11	5	7	5	6	2
Composition										
EPT Index (%)	9.1	5.3	4.5	1.1	49	1.3	34	3.4	7.5	2.3
Sensitive EPT Index (%)	0.2	1.0	0.0	0.3	14	0.0	1.3	0.0	0.2	0.0
Shannon Diversity	2.03	1.68	1.91	1.08	2.52	0.42	1.99	1.62	1.95	0.26
Dominant Taxon (%)	40	53	29	73	19	93	27	43	29	95
Non-insect Taxa (%)	42	33	41	47	12	42	32	30	33	67
Tolerance										
Tolerance Value	6.7	6.8	6.0	7.7	4.7	7.9	5.3	5.5	6.8	6.0
Intolerant Organisms (%)	0.0	0.8	0.0	0.0	9.3	0.0	0.7	0.0	0.0	0.0
Intolerant Taxa (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tolerant Organisms (%)	47	54	18	88	1.6	95	11	2.9	48	1.2
Tolerant Taxa (%)	35	19	35	42	12	25	42	10	22	33
Functional Feeding Groups										
Collector-Gatherers (%)	44	25	52	22	49	5	65	96	41	96
Collector-Filterers (%)	8.3	18	29	1.2	19	1.8	29	0.7	29	3.1
Scrapers (%)	40	53	15	73	14	93	2.4	2.9	28	0.5
Predators (%)	5.5	2.0	1.1	2.6	4.6	0.2	2.9	0.2	2.5	0.0
Shredders (%)	0.0	1.0	0.0	0.0	12	0.0	1.3	0.0	0.0	0.0
Other (%)	2.0	0.8	2.9	1.2	0.3	0.5	0.0	0.2	0.2	0.0

Table 4.2 Benthic Macroinvertebrate Metrics for CCCWP Bioassessment Sites Monitored in Water Year 2019

BMI Metrics for CCCWP Bioassessment Sites, Spring 2019										
Site Code:	204R02180	204R02587	206R01792	206R02048	206R02455	206R02560	207R01280	207R01655	544R02037	544R02505
Creek Name:	Alamo	Moraga	Refugio	Rodeo	Wildcat	Refugio	Franklin	Grayson	Marsh	Marsh
Estimated Abundance										
Composite Sample (11 ft^2)	3,467	2,923	8,846	25,574	884	59,712	3,509	4,912	6,144	12,971
#/ft^2	315	266	804	2,325	80	5,428	319	447	559	1,179
#/m^2	3,366	2,838	8,588	24,830	858	57,973	3,406	4,769	5,965	12,593
Supplemental Metrics										
Collectors (%)	52	43	81	23	69	6.8	93	97	70	99.5
Non-Gastropoda Scrapers (%)	0.0	0.3	0.0	0.0	14	0.0	0.0	0.0	0.0	0.0
Shredder Taxa (%)	0.0	14	0.0	0.0	12	0.0	11	0.0	0.0	0.0
Diptera Taxa[a]	6	4	4	2	8	2	4	3	3	1
IBI Scores										
SoCal IBI Score	27	37	10	20	67	21	11	14	30	3
CC B-IBI Score	38	36	29	31	50	26	28	18	35	3
CC B-IBI Category	Good	Good	Fair	Fair	Very Good	Fair	Fair	Marginal	Good	Poor

a Calculated based on Chironomids identified to family level

Notes: Metrics are calculated from standard classifications, based on level I standard taxonomic effort, except Chironomids, which are identified to subfamily/ tribe. Standard taxonomic effort source: Southwest Association of Freshwater Invertebrate Taxonomists (http://www.waterboards.ca.gov/swamp/docs/safit/ste_list.pdf).

The CC B-IBI scoring ranges for the condition categories are as follows: Poor: 0-10; Marginal: 11-22; Fair: 23-34; Good: 35-42; Very Good: 43-50

Table 4.3 Results of CSCI Calculations for Water Year 2019 CCCWP Bioassessment Sites

Site Code	Creek Name	Sample Date	BMI Count	O/E	MMI	CSCI
204R02180	Alamo Creek	06/12/19	614	0.752	0.349	0.550
204R02587	Moraga Creek	06/11/19	609	0.676	0.453	0.564
206R01792	Refugio Creek	05/08/19	645	0.660	0.266	0.463
206R02048	Rodeo Creek	06/13/19	666	0.609	0.318	0.464
206R02455	Wildcat Creek	05/07/19	626	1.067	0.715	0.891
206R02560	Refugio Creek	05/08/19	622	0.544	0.343	0.443
207R01280	Franklin Creek	05/09/19	614	0.690	0.325	0.507
207R01655	E Branch Grayson Creek	05/06/19	614	0.465	0.180	0.322
544R02037	Marsh Creek	05/06/19	640	0.757	0.483	0.620
544R02505	Marsh Creek	06/12/19	608	0.222	0.407	0.315

Note: CSCI scores less than 0.795 indicate a substantially degraded biological community relative to reference conditions, and such sites are candidates for SSID projects.

4.2.2 Algae Metrics

Soft algae and diatom taxonomy samples were collected at 10 sites in Contra Costa County in water year 2019, as part of the RMC program. Samples (including a field duplicate at Wildcat Creek, site 206R02455) were collected following the SWAMP Bioassessment Wadable Streams Protocol (Ode et al.,2016). Samples were processed in the laboratory by EcoAnalysts following SWAMP protocols (Stancheva et al., 2015) to provide count (diatom and soft algae), biovolume (soft algae), and “presence” (diatom and soft algae) data. Diatom and soft algae identifications matched the California Algae and Diatom Taxonomic Working Group’s Master Taxa List, and all taxonomic “FinalIDs” currently included in the SWAMP database were included in the calculations.

Pre-ASCI Algal IBI Metrics

Eleven diatom metrics, 11 soft algae metrics, and five IBIs (D18, H20, H21, H23, and S2) were calculated following work performed on Southern California streams (Fetscher et al., 2013 and 2014). Diatom and soft algae metrics fall into five categories:

- Tolerance/sensitivity: association with specific water-quality constituents like nutrients; tolerance to low dissolved oxygen; tolerance to high-ionic-strength/saline waters
- Autecological guild: nitrogen fixers; saprobic/heterotrophic taxa
- Morphological guild: sedimentation indicators; motility
- Taxonomic groups: Chlorophyta, Rhodophyta, Zygnemataceae, heterocystous cyanobacteria
- Relationship to reference sites

IBI scoring ranges and values were provided by Dr. A. Elizabeth Fetscher (personal communication). After each metric was scored, values were summed and then converted to a 100-point scale by multiplying the sum by the number of metrics (e.g., sum x [100/50] if five metrics included in the IBI). IBIs are not calculated for field duplicates per the setup of the SWAMP Reporting Module.

The five calculated A-IBI scores are shown in summary in Table 4.4 for each bioassessment site monitored in water year 2019, with the highest and lowest scores highlighted for each of the IBIs. Additional tables containing detailed results for the A-IBI calculations and discussion of the results for each of the five IBIs are provided in Appendix A.

Table 4.4 Algal-IBI Scores for the Diatom (D18), Soft Algae (S2) and Hybrid (H20, H21, H23) Indices for Contra Costa Stations Sampled in 2019

Site Code	Creek Name	Sample Date	D18 A-IBI Score	S2 A-IBI Score	H20 A-IBI Score	H21 A-IBI Score	H23 A-IBI Score
204R02180	Alamo Creek	06/12/19	64	27	42	60	58
204R02587	Moraga Creek	06/11/19	56	40	40	69	65
206R01792	Refugio Creek	05/08/19	26	35	22	33	39
206R02048	Rodeo Creek	06/13/19	34	40	31	37	39
206R02455	Wildcat Creek	05/07/19	36	73	48	41	52
206R02560	Refugio Creek	05/08/19	66	40	58	47	54
207R01280	Franklin Creek	05/09/19	30	17	19	36	31
207R01655	E Br Grayson Creek	05/06/19	6	7	9	4	9
544R02037	Marsh Creek	05/06/19	54	2	34	39	35
544R02505	Marsh Creek	06/12/19	18	22	21	14	21

D18 diatom IBI #18
H20 hybrid algae IBI #20
H21 hybrid algae IBI #21
H22 hybrid algae IBI #22
S2 soft algae IBI #2
Note: Highest score for each A-IBI is highlighted in green; lowest score for each A-IBI is shown in orange

Overall, sites 204R02180 in Alamo Creek, 204R02587 in Moraga Creek, and 206R02560 in Refugio Creek had the highest scores for four of the five IBIs (D18, H20, H21, H23), while site 206R02455 in Wildcat Creek had the highest score for the S2 IBI. Site 207R01655 in East Branch Grayson Creek scored the lowest at four of the five IBIs (D18, H20, H21, H23), while site 544R02037 in Marsh Creek had the lowest S2 IBI score (Table 4.4). The proportion of diatom and algae species indicative of low total phosphorous concentrations was low or nonexistent at all 10 sites, suggesting elevated levels of phosphorous. The presence of halobiontic, dissolved oxygen sensitive, and sediment tolerant, highly motile diatom species affected scores across IBIs, suggesting the importance of low ionic strength/salinities, dissolved oxygen concentrations, and sediment qualities on a stronger diatom community, which is consistent with previous years. Soft algae scores were affected by the proportion of taxonomic groups and lack of species found within sites, indicating an impacted community for all sites. However, it is difficult to assess the contribution of some metrics, as the lack of assigned attributes in the database excludes new (since 2013) taxonomic “FinalIDs” from the calculations.

ASCI MMI Scores

The three multi-metric indices (MMIs) included in the Algae Stream Condition Index (ASCI), recently developed by SWAMP, also were calculated for the water year 2019 CCCWP bioassessment sites. Because of questions regarding the soft algae MMI, only the diatoms MMI and hybrid MMI are reported here. (The ASCI developers have been contacted regarding potential issues with the soft algae MMI calculations.)

With the exception of the Wildcat Creek site, which scored “Likely intact” on the diatoms MMI and “Possibly altered” on the hybrid MMI, all sites scored either “Likely altered” or “Very likely altered” on the diatoms MMI and hybrid MMI ASCI metrics (Table 4.5).

Table 4.5 ASCI MMI Scores

Site Code	Creek Name	Diatoms MMI	Diatoms Status	Hybrid MMI	Hybrid Status
204R02180	Alamo Creek	0.56	Very Likely Altered	0.60	Very Likely Altered
204R02587	Moraga Creek	0.69	Likely Altered	0.63	Very Likely Altered
206R01792	Refugio Creek	0.77	Likely Altered	0.52	Very Likely Altered
206R02048	Rodeo Creek	0.50	Very Likely Altered	0.57	Very Likely Altered
206R02455	Wildcat Creek	0.92	Likely Intact	0.92	Possibly Altered
206R02560	Refugio Creek	0.55	Very Likely Altered	0.65	Very Likely Altered
207R01280	Franklin Creek	0.80	Likely Altered	0.68	Very Likely Altered
207R01655	E Branch Grayson Creek	0.58	Very Likely Altered	0.47	Very Likely Altered
544R02037	Marsh Creek	0.49	Very Likely Altered	0.66	Very Likely Altered
544R02505	Marsh Creek	0.53	Very Likely Altered	0.67	Very Likely Altered

Note: Highest score for each MMI is highlighted in green; lowest score for each MMI is shown in orange

The ASCI MMI results (Table 4.5) substantially agree with the other A-IBI results (Table 4.4). It is expected that the ASCI MMI scores will replace the older A-IBI scores for algae-based biological condition assessments in subsequent years.

4.3 Stressor Assessment

This section addresses the question: what are the major stressors to aquatic life in the RMC area? The biological, physical, chemical, and toxicity testing data produced by CCCWP during water year 2019 were compiled, evaluated, and analyzed against the threshold trigger criteria shown in Table 3.3. When the data analysis indicated the associated trigger criteria were exceeded, those sites and results were identified as potentially warranting further investigation.

When interpreting analytical chemistry results, it is important to account for laboratory data reported as either below method detection limits (MDLs) or between detection and reporting limits (RLs). Dealing with data in this range of the analytical spectrum introduces some level of uncertainty, especially when attempting to generate summary statistics for a data set. In the following compilation of statistics for analytical chemistry, in some cases non-detect data (ND) were substituted with a concentration equal to half of the respective MDL, as reported by the laboratory.

4.3.1 Physical Habitat Parameters

An array of physical habitat characteristics is recorded on the SWAMP field data sheets during bioassessment monitoring. A selected few are used to compile a “mini-PHab score”. The mini-PHab scores and associated metrics are summarized in Table 4.6 for bioassessment sites monitored in water year 2019. The Wildcat, Alamo and Moraga Creek sites had the highest mini-PHab scores, while the Rodeo, East Branch Grayson, and Marsh Creek (544R02505) sites had the lowest mini-PHab scores in 2019.

The California IPI score also was calculated for Contra Costa bioassessment sites monitored in water year 2019, using the new SWAMP IPI protocols (Rehn et al., 2018b). During method development, the IPI model was calibrated such that:

- the mean score of reference sites is 1

- scores near 0 indicate substantial departure from reference condition and serious degradation of physical condition
- scores greater than 1 indicate greater physical complexity than predicted for a site, given its natural environmental setting

The SWAMP IPI protocols established thresholds based on the 30th, 10th, and 1st percentiles of IPI scores at reference sites, to divide the IPI scoring range into four categories of physical condition as follows:

- IPI ≥ 0.94 = likely intact condition
- IPI 0.84 to 0.93 = possibly altered condition
- IPI 0.71 to 0.83 = likely altered condition
- IPI ≤ 0.70 = very likely altered condition

The IPI scores calculated from the 2019 PHab data, compiled from bioassessment monitoring conducted during spring 2019, are shown in Table 4.7. Three sites were rated as “Likely intact” (Wildcat Creek, Marsh Creek (544R02505), and Moraga Creek), while only one (Rodeo Creek) ranked as “Very likely altered”.

The IPI scores correspond well with the 2019 mini-PHab scores, as the creek sites with the higher IPI scores generally correspond with the sites with the highest mini-PHab scores, and the creek sites with lower IPI scores generally are also the sites with the lowest mini-PHab scores. A notable exception is the Marsh Creek (544R02505) site, which has the second highest IPI score, and one of the lowest mini-PHab scores.

The Wildcat Creek site had both the highest mini-PHab score and IPI, while the Rodeo Creek site had the lowest score in both cases.

Table 4.6 Physical Habitat Metrics and Mini-PHab Scores for CCCWP Bioassessment Sites Monitored in Water Year 2019

Site Code	Creek Name	Sample Date	Epifaunal Substrate	Sediment Deposition	Channel Alteration	Mini-PHab Score
204R02180	Alamo Creek	06/12/19	15	10	20	45
204R02587	Moraga Creek	06/11/19	13	15	15	43
206R01792	Refugio Creek	05/08/19	11	12	15	38
206R02048	Rodeo Creek	06/13/19	10	9	5	24
206R02455	Wildcat Creek	05/07/19	16	15	19	50
206R02560	Refugio Creek	05/08/19	9	12	12	33
207R01280	Franklin Creek	05/09/19	10	10	13	33
207R01655	E Branch Grayson Creek	05/06/19	9	9	8	26
544R02037	Marsh Creek	05/06/19	13	11	12	36
544R02505	Marsh Creek	06/12/19	11	10	5	26

Note: Highest mini-PHab score is highlighted in green; lowest score is shown in orange

Table 4.7 Index of Physical Habitat Integrity (IPI) Scores for CCCWP Bioassessment Sites Monitored in Water Year 2019

Site Code	Creek Name	Sample Date	IPI Score	IPI Category
204R02180	Alamo Creek	06/12/19	0.89	Possibly altered
204R02587	Moraga Creek	06/11/19	0.96	Likely intact
206R01792	Refugio Creek	05/08/19	0.92	Possibly altered
206R02048	Rodeo Creek	06/13/19	0.68	Very likely altered
206R02455	Wildcat Creek	05/07/19	1.03	Likely intact
206R02560	Refugio Creek	05/08/19	0.93	Possibly altered
207R01280	Franklin Creek	05/09/19	0.93	Possibly altered
207R01655	E Branch Grayson Creek	05/06/19	0.71	Likely altered
544R02037	Marsh Creek	05/06/19	0.81	Likely altered
544R02505	Marsh Creek	06/12/19	0.90	Likely intact

Note: Highest IPI score is highlighted in green; lowest score is shown in orange

4.3.2 Correlations of Biological and Physical Habitat Parameters

The principal biological and physical habitat condition scores are shown together in Table 4.8, and correlations between the key biological and physical habitat condition scores are shown in Table 4.9 The Wildcat Creek site had the highest scores on all metrics, for biological condition and physical habitat.

For the 2019 analysis, there was good correlation among the various biological and physical habitat indices, with the exception of the Contra Costa B-IBI, which did not correlate well with the diatoms MMI, the hybrid MMI, or the IPI. The CSCI was well correlated with all tested biological and physical habitat indices.

The diatoms MMI and hybrid MMI algal community indices were moderately well correlated with each other, and each algal index correlated well with the CSCI and physical habitat indices.

These results support the idea that there may be an observable connection between stream physical habitat condition and benthic and algal biological community health.

Table 4.8 Summary of PHab and Biological Condition Scores for CCCWP Bioassessment Sites Monitored in Water Year 2019

Site Code	Creek Name	CSCI Score	Diatoms MMI ASCI Score	Hybrid MMI ASCI Score	Contra Costa IBI	Mini-PHab Score	IPI Score
204R02180	Alamo Creek	0.550	0.56	0.60	38	45	0.89
204R02587	Moraga Creek	0.564	0.69	0.63	36	43	0.96
206R01792	Refugio Creek	0.463	0.77	0.52	29	38	0.92
206R02048	Rodeo Creek	0.464	0.50	0.57	31	24	0.68
206R02455	Wildcat Creek	0.891	0.92	0.92	50	50	1.03
206R02560	Refugio Creek	0.443	0.55	0.65	26	33	0.93
207R01280	Franklin Creek	0.507	0.80	0.68	28	33	0.93
207R01655	E Branch Grayson Creek	0.322	0.58	0.47	18	26	0.71
544R02037	Marsh Creek	0.620	0.49	0.66	35	36	0.81
544R02505	Marsh Creek	0.315	0.53	0.67	3	26	0.90

Note: Highest score for each index is highlighted in green; lowest score for each metric is shown in orange

Table 4.9 Correlations for PHab and Biological Condition Scores for CCCWP Sites Monitored in Water Year 2019

Comparison	Correlation Coefficient	R Squared
CSCI:Diatoms MMI	0.58	0.33
CSCI:Hybrid MMI	0.79	0.63
CSCI:Contra Costa-IBI	0.90	0.80
CSCI:Mini-PHab	0.82	0.67
CSCI:IPI	0.53	0.28
Diatoms MMI:Hybrid MMI	0.51	0.26
Diatoms MMI:Contra Costa-IBI	0.47	0.22
Diatoms MMI:Mini-PHab	0.59	0.35
Diatoms MMI:IPI	0.68	0.46
Hybrid MMI:Contra Costa-IBI	0.48	0.23
Hybrid MMI:Mini-PHab	0.57	0.32
Hybrid MMI:IPI	0.67	0.45
Contra Costa B-IBI:Mini-PHab	0.79	0.63
Contra Costa B-IBI:IPI	0.33	0.11
Contra Costa B-IBI:SoCal B-IBI	0.84	0.71
Mini-PHab:IPI	0.74	0.54

Note: Correlations are based on scores shown in Table 4.15. Well correlated results (correlated coefficient greater than 0.50) are highlighted in green.

4.3.3 Water Chemistry Parameters

At all 10 bioassessment sites, water samples were collected for nutrient and other conventional analyses using the standard grab sample collection method, as described in SOP FS-2 (BASMAA, 2016b). Standard field parameters (temperature, dissolved oxygen, pH, and specific conductance) were also measured in the field using a portable multi-meter and sonde.

Of the 12 water quality constituents monitored in association with the bioassessment monitoring, water quality standards or established thresholds are available only for ammonia (un-ionized form[4]), chloride[5], and nitrate + nitrite[6] – the latter for waters with MUN beneficial use only, as indicated in Table 4.10.

[4] For ammonia, the standard provided in the Basin Plan (SFBRWQCB, 2017, section 3.3.20) applies to the un-ionized fraction, as the underlying criterion is based on un-ionized ammonia, which is the more toxic form. Conversion of RMC monitoring data from the measured total ammonia to un-ionized ammonia was based on a formula provided by the American Fisheries Society, which calculates un-ionized ammonia in freshwater systems from analytical results for total ammonia and field-measured pH, temperature, and electrical conductivity (see: http://fisheries.org/hatchery).

[5] For chloride, a Secondary Maximum Contaminant Level (MCL) of 250 mg/L applies to those waters with MUN beneficial use, per the Basin Plan (Table 3-5), Title 22 of the California Code of Regulations, and the USEPA drinking water quality standards, and per the Basin Plan (Table 3-7) applies to waters in the Alameda Creek watershed above Niles. Per RMC decision as noted in the UCMR for WY 2012 (BASMAA, 2012), for all other waters, the Criterion Continuous Concentration (CCC) of 230 mg/L (USEPA Water Quality Criteria*) for the protection of aquatic life is used as a conservative benchmark for comparison for all locations not specifically identified within the Basin Plan (i.e., sites not within the Alameda Creek watershed above Niles nor identified as MUN).

*See: http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm

[6] The nitrate + nitrite primary MCL applies to those waters with MUN beneficial use, per the Basin Plan (Table 3-5), Title 22 of the California Code of Regulations, and the USEPA Drinking Water Quality Standards.

Table 4.10 Water Quality Thresholds Available for Comparison to Water Year 2019 Water Chemistry Constituents

Sample Parameter	Threshold	Units	Frequency/Period	Application	Source
Ammonia	0.025	mg/L	Annual Median	Un-ionized ammonia, as N (maxima also apply to Central Bay and u/s [0.16] and Lower Bay [0.4])	Basin Plan (Ch. 3)
Chloride	230	mg/L	Criterion Continuous Concentration	Freshwater aquatic life	USEPA National Recreation Water Quality Criteria, Aquatic Life Criteria
Chloride	860	mg/L	Criteria Maximum Concentration	Freshwater aquatic life	USEPA National Recreation Water Quality Criteria, Aquatic Life Criteria Table
Chloride	250	mg/L	Secondary Maximum Contaminant Level	Alameda Creek watershed above Niles and MUN waters; Title 22 drinking waters	SF Bay Basin Plan (Ch. 3); California Title 22; USEPA Drinking Water Standards Secondary MCL
Nitrate + Nitrite (as N)	10	mg/L	Maximum Contaminant Level	Areas designated as MUN	Basin Plan (Ch. 3)

The comparisons of the measured nutrients data to the thresholds listed in Table 4.10 are shown in Table 4.11. There were no exceedances of the applicable criteria for chloride or nitrate+nitrite at any of the 10 sites monitored in water year 2019, but there were two exceedances of the Basin Plan standard for unionized ammonia, at Wildcat Creek (site 206R02455), and Marsh Creek (site 544R02037), which exhibited a particularly high concentration (168 µg/L). These are highly unusual results, as elevated ammonia levels are not expected in these urban creeks, but they also reflect the 2018 results, in which four of ten sites exceeded the unionized ammonia standard. The samples were collected across separate dates, in different watersheds, and in each year were all analyzed on the same date by the lab, but further investigation did not reveal any clear evidence of laboratory error. These results will be flagged as questionable in the database.

Table 4.11 Comparison of Water Quality (Nutrient) Data to Associated Water Quality Thresholds for Water Year 2019 Water Chemistry Results

Site Code	Creek Name	MUN?	Parameter and Threshold			Number of Parameters > Threshold/ Water Body
			Un-ionized Ammonia (as N)	Chloride	Nitrate + Nitrite (as N)	
			25 µg/L	230/250 mg/L[1]	10 mg/L[2]	
204R02180	Alamo Creek	No	16.5	64	0.244	0
204R02587	Moraga Creek	No	1.19	25	0.063	0
206R01792	Refugio Creek	No	9.94	46	0.144	0
206R02048	Rodeo Creek	No	7.96	70	0.155	0
206R02455	Wildcat Creek	No	29.1	37	0.055	1
206R02560	Refugio Creek	No	7.42	47	0.163	0
207R01280	Franklin Creek	No	6.71	25	0.253	0
207R01655	E Branch Grayson Creek	No	12.8	86	0.058	0
544R02037	Marsh Creek	No	168	74	0.776	1
544R02505	Marsh Creek	No	16.0	140	4.942	0
Number of Values > Threshold			2	0	0	2
Percent of Values > Threshold			20%	0%	0%	

1 250 mg/L threshold applies for sites with MUN beneficial use and Alameda Creek above Niles per Basin Plan

2 Nitrate + nitrite threshold applies only to sites with MUN beneficial use. No water year 2019 sites have MUN beneficial use.

Bolded values indicate results above applicable thresholds

Water samples also were collected and analyzed for free and total chlorine in the field using CHEMetrics test kits during bioassessment monitoring. As shown in Table 4.12, no water year 2019 water samples produced measured levels of free or total chlorine above the 0.08 mg/L threshold.

Table 4.12 Summary of Chlorine Testing Results for Samples Collected in Water Year 2019 in Comparison to Municipal Regional Permit Trigger Criteria

Site Code	Creek Name	Sample Date	Chlorine, Free	Chlorine, Total	Exceeds Trigger Threshold?
204R02180	Alamo Creek	06/12/19	0.0	0.0	No
204R02587	Moraga Creek	06/11/19	0.0	0.0	No
206R01792	Refugio Creek	05/08/19	0.0	0.0	No
206R02048	Rodeo Creek	06/13/19	0.0	0.0	No
206R02455	Wildcat Creek	05/07/19	0.0	0.0	No
206R02560	Refugio Creek	05/08/19	0.0	0.0	No
207R01280	Franklin Creek	05/09/19	0.0	0.0	No
207R01655	E Branch Grayson Creek	05/06/19	0.0	0.0	No
544R02037	Marsh Creek	05/06/19	0.0	0.04	No
544R02505	Marsh Creek	06/12/19	0.0	0.04	No
Number of Samples Exceeding 0.08 mg/L			0	0	
Percentage of Samples Exceeding 0.08 mg/L			0%	0%	

4.3.4 Water Column Toxicity and Chemistry (Wet Weather)

Wet weather samples were not collected during water year 2019, as the relevant MRP monitoring requirement had already been fulfilled in previous monitoring years.

4.3.5 Water Column Toxicity (Dry Weather)

Water samples were collected on Jul. 23, 2019 from one site on Marsh Creek (site 544R02505), and tested for toxicity to several different aquatic species, as required by the MRP. The dry weather water toxicity test results are shown in Table 4.13. All of the dry weather water toxicity test results were determined not to be toxic. The sample testing was initiated within required holding times. Water chemistry testing was not required for the dry season sample.

Table 4.13 Summary of CCCWP Water Year 2019 Dry Season Water Toxicity Results

Dry Season Water Samples			Toxicity Test Results						
			S. capricornutum	*C. dubia*		*C. dilutus*	*H. azteca*	*P. promelas*	
Site Code	Creek Name	Sample Collection Date	Growth (cells/mL x 10^6)	Survival (%)	Reproduction (No. of neonates/ female)	Survival (%)	Survival (%)	Survival (%)	Growth (mg)
Lab Control			3.56	100	32.0	97.5	100	100	0.77
544R02505	Marsh Creek	07/23/19	6.92	100	32.0	100	100	100	0.87

Note: No test treatment was determined to be significantly less than the lab control treatment response at $p < 0.05$

4.3.6 Sediment Toxicity and Sediment Chemistry

Sediment samples were collected on Jul. 23, 2019 after water samples were collected at the same site sampled for water column toxicity (Marsh Creek, site 544R02505), and tested for acute toxicity (survival) to *Hyalella azteca* and *Chironomus dilutus*.

The Jul. 23, 2019 sediment sample was determined to be highly toxic to *Chironomus dilutus*, but not toxic to *Hyalella azteca*.

Because of the high degree of toxicity to *Chironomus*, the site was resampled on Sept. 18, 2019, and retested for *Chironomus* toxicity. The retest also was highly toxic to *Chironomus*. The sediment toxicity test results are shown in Table 4.14.

Table 4.14 Summary of CCCWP Water Year 2019 Dry Season Sediment Toxicity Results

Dry Season Sediment Samples			Toxicity Test Results	
			Hyalella azteca	*Chironomus dilutus*
Site Code	Creek Name	Sample Collection Date	Survival (%)	Survival (%)
Lab Control			97.5	80.0
544R02505	Marsh Creek	07/23/19	80.0	13.8*
Lab Control			NA	90.0
544R02505	Marsh Creek	09/18/19	NA	8.75*

* The response at this test treatment was significantly less than the lab control treatment response at $p < 0.05$ and was determined to be toxic, and the test result was less than 50 percent of the control.

The sediment sample also was tested for a suite of potential sediment pollutants, as required by the MRP, and the results were compared to the trigger threshold levels specified for follow-up in MRP provision C.8.g.iv. (see Table 3.3). The complete sediment chemistry results are shown in Table 4.15, and the results are shown in comparison to the applicable MRP threshold triggers in Table 4.16.

Sediment chemistry results (Tables 4.15 and 4.16) are summarized as follows:

- Three metal constituents (copper, nickel, zinc) had a TEC ≥1.0 (nickel is a naturally occurring element throughout much of the San Francisco Bay area, and commonly occurs at elevated levels in creek status monitoring)
- Only one PAH compound was detected (Dimethylnaphthalene, 2,6-)
- Five of the seven pyrethroid pesticides were detected; the highest was bifenthrin at 18 ng/g

Table 4.15 CCCWP Water Year 2019 Sediment Chemistry Results

Analyte	Units[1]	Site 544R02505 Marsh Creek		
		Result	MDL	RL
Metals				
Arsenic	mg/Kg	6.4	0.22	0.6
Cadmium	mg/Kg	0.14	0.011	0.09
Chromium	mg/Kg	31	0.55	1.1
Copper	mg/Kg	34	0.082	0.44
Lead	mg/Kg	9.3	0.044	0.09
Nickel	mg/Kg	43	0.033	0.09
Zinc	mg/Kg	130	0.88	0.9
Polycyclic Aromatic Hydrocarbons (PAHs)				
Acenaphthene	ng/g	ND	3.3	5.5
Acenaphthylene	ng/g	ND	3.3	5.5
Anthracene	ng/g	ND	3.3	5.5
Benz(a)anthracene	ng/g	ND	3.3	5.5
Benzo(a)pyrene	ng/g	ND	16	19
Benzo(b)fluoranthene	ng/g	ND	16	19
Benzo(e)pyrene	ng/g	ND	16	19
Benzo(g,h,i)perylene	ng/g	ND	16	19
Benzo(k)fluoranthene	ng/g	ND	16	19
Biphenyl	ng/g	ND	3.6	5.5
Chrysene	ng/g	ND	16	19
Dibenz(a,h)anthracene	ng/g	ND	16	19
Dibenzothiophene	ng/g	ND	3.6	5.5
Dimethylnaphthalene, 2,6-	ng/g	11	3.3	5.5
Fluoranthene	ng/g	ND	3.3	5.5
Fluorene	ng/g	ND	3.3	5.5
Indeno(1,2,3-c,d)pyrene	ng/g	ND	16	19
Methylnaphthalene, 1-	ng/g	ND	3.3	5.5
Methylnaphthalene, 2-	ng/g	ND	3.3	5.5
Methylphenanthrene, 1-	ng/g	ND	3.3	5.5
Naphthalene	ng/g	ND	3.3	5.5
Perylene	ng/g	ND	16	19
Phenanthrene	ng/g	ND	3.3	5.5
Pyrene	ng/g	ND	3.3	5.5
Pyrethroid Pesticides				
Bifenthrin	ng/g	18	0.55	1.4
Cyfluthrin, total	ng/g	2.5	0.6	1.4
Cyhalothrin, Total lambda-	ng/g	1.0	0.33	1.4
Cypermethrin, total	ng/g	ND	0.55	1.4
Deltamethrin/Tralomethrin	ng/g	6.8	0.66	1.4
Esfenvalerate/Fenvalerate, total	ng/g	ND	0.71	1.4
Permethrin	ng/g	0.77	0.6	1.4
Other Pesticides				
Carbaryl	ng/g	ND	0.022	0.033

Table 4.15 CCCWP Water Year 2019 Sediment Chemistry Results

Analyte	Units[1]	Site 544R02505 Marsh Creek		
		Result	MDL	RL
Fipronil	ng/g	ND	0.55	1.4
Fipronil Desulfinyl	ng/g	ND	0.55	1.4
Fipronil Sulfide	ng/g	ND	0.55	1.4
Fipronil Sulfone	ng/g	ND	0.55	1.4
Organic Carbon				
Total Organic Carbon	%	2.6	0.022	0.055

1 All measurements reported as dry weight
MDL method detection limit
ND not detected
RL reporting limit

Table 4.16 Threshold Effect Concentration (TEC) and Probable Effect Concentration (PEC) Quotients for Water Year 2019 Sediment Chemistry Constituents

		Site 544R02505		
		Marsh Creek		
	Sample Units[1]	Sample	TEC Ratio	PEC Ratio
Metals				
Arsenic	mg/Kg	6.4	0.65	0.19
Cadmium	mg/Kg	0.14	0.14	0.03
Chromium	mg/Kg	31	0.71	0.28
Copper	mg/Kg	34	1.08	0.23
Lead	mg/Kg	9.3	0.26	0.07
Nickel	mg/Kg	43	1.89	0.88
Zinc	mg/Kg	130	1.07	0.28
Polycyclic Aromatic Hydrocarbons (PAHs)				
Anthracene	ng/g	ND		
Fluorene	ng/g	ND		
Naphthalene	ng/g	ND		
Phenanthrene	ng/g	ND		
Benz(a)anthracene	ng/g	ND		
Benzo(a)pyrene	ng/g	ND		
Chrysene	ng/g	ND		
Fluoranthene	ng/g	ND		
Pyrene	ng/g	ND		
Total PAHs[a]	ng/g	50	0.031	0.0022
		Statistics		
		Number with TEC > 1.0	3	
		Combined TEC Ratio	5.84	
		Average TEC Ratio	0.73	
		Combined PEC Ratio		1.97
		Average PEC Ratio		0.25

a Total PAHs include 24 individual PAH compounds; NDs were substituted at 1/2 MDL to compute total PAHs
Bold TEC or PEC ratio indicates ratio ≥1.0
ND not detected
Note: All measurements reported as dry weight. TECs and PECs per MacDonald et al. (2000).

Sediment TU equivalents were calculated for the pyrethroid pesticides for which there are published LC_{50} levels, and a sum of the calculated TU equivalents was computed for the dry season sediment chemistry results from the monitored site (Marsh Creek, site 544R02505; see Table 4.17). Because organic carbon mitigates the toxicity of pyrethroid pesticides in sediments, the LC_{50} values are based on organic carbon-normalized pyrethroid concentrations. Therefore, the pyrethroid concentrations as reported by the lab were divided by the measured TOC concentration (as a percentage) at each site, and the TOC-normalized concentrations were then used to compute TU equivalents for each pyrethroid (Table 4.17).

Several of the common urban pyrethroid pesticides were detected at the water year 2019 sediment monitoring site (see Table 4.15, above). The calculated TU equivalent of 1.84 (Table 4.17) is sufficient to have caused the observed toxicity to *Chironomus dilutus* in the sediment toxicity testing for this sample. The TU equivalent calculated for bifenthrin (1.33) alone is sufficient to have caused the observed toxicity.

Table 4.17 Calculated Pyrethroid Toxic Unit Equivalents, Water Year 2019 Sediment Chemistry Data

Pyrethroid Pesticides	LC_{50} (µg/g organic carbon)	Site 544R01737 Marsh Creek Sample (ng/g)	Sample (µg/g organic carbon)	TU Equivalents[1]
Bifenthrin	0.52	18	0.69	1.33
Cyfluthrin	1.08	2.5	0.10	0.09
Cyhalothrin, lambda	0.45	1.0	0.04	0.09
Cypermethrin	0.38	ND		
Deltamethrin/Tralomethrin	0.79	6.8	0.26	0.33
Esfenvalerate/Fenvalerate	1.54	ND		
Permethrin	10.8	0.77	0.03	0.00
			Sum (Pyrethroid TUs)	1.84

1 Toxic unit equivalents (TU) are calculated as ratios of organic carbon-normalized pyrethroid sample concentrations to published *H. azteca* LC_{50} values. See http://www.tdcenvironmental.com/resources/Pyrethroids-Aquatic-Tox-Summary.pdf for associated references.

ND not detected

Note: All sample measurements reported as dry weight.

4.3.7 Analysis of Condition Indicators and Stressors – WY 2019

During water year 2019, 10 sites were monitored by CCCWP under the RMC regional/probabilistic design for bioassessment, physical habitat, and water chemistry parameters. One site also was monitored for water and sediment toxicity and sediment chemistry.

The bioassessment and related data are used to develop a preliminary condition assessment for the monitored sites. The water and sediment chemistry and toxicity data are used in conjunction with physical habitat data to evaluate potential stressors which may affect aquatic habitat quality and beneficial uses. Various metrics and indices are also computed to aid in the condition assessment and stressor analysis.

Biological Conditions

CSCI scores are calculated from the CCCWP bioassessment data beginning in water year 2016. The CSCI uses location-specific GIS data to compare the observed BMI taxonomic data to expected BMI assemblage characteristics from reference sites with similar geographical characteristics. The calculated CSCI scores for 2019 samples are again below the MRP 2.0 threshold of 0.795 for nine of the 10 sites monitored, indicating degraded benthic biological communities at those nine sites. Additional work will need to be done with the CSCI scores in relation to this threshold to make a clearer assessment of relative biological conditions for these urban streams.

For the 2019 analysis, the benthic invertebrate community indices (CSCI, Contra Costa B-IBI, SoCal B-IBI) correlated well with each other, and the CSCI correlated well with all biological and physical habitat indices. All 2019 bioassessment sites, except Wildcat Creek, had CSCI scores less than 0.795, indicating a substantially degraded biological community relative to reference conditions.

ASCI scores were calculated for CCCWP bioassessment sites for the first time in water year 2019; the results were well correlated with the CSCI and the physical habitat indices. With the exception of the Wildcat Creek site, which scored “Likely intact” on the diatoms MMI and “Possibly altered” on the hybrid MMI, all sites scored either “Likely altered” or “Very likely altered” on the diatoms MMI and hybrid MMI ASCI metrics.

Based on both the BMI and algal community indices, the biological community conditions of all CCCWP sites monitored in 2019 can be considered to be impacted.

The Marsh Creek sediment sample was determined to be highly toxic to *Chironomus dilutus* in both the original (Jul. 23, 2019) dry weather sample, and in the follow-up retest (sample collected Sept. 18, 2019). The dry weather water sample was not toxic to any of the four test species. As in prior years, the principal stressors affecting water and sediment quality – specifically causing toxicity – appear to be pesticides.

Based on an analysis of the regional/probabilistic data collected by CCCWP during water year 2019, the stressor analysis is summarized as follows:

Physical Habitat (PHab) Conditions

IPI scores were again calculated from the PHab data compiled during the spring 2019 bioassessment monitoring. Two sites ranked as “Likely intact” (Wildcat Creek and Moraga Creek), while only one (Rodeo Creek) ranked as “Very likely altered”.

The IPI scores correspond fairly well with the 2019 mini-PHab scores, as the creek sites with the higher IPI scores generally correspond with the sites with the highest mini-PHab scores, and the creek sites with lower IPI scores generally are also the sites with the lowest mini-PHab scores. A notable exception is the Marsh Creek (544R02505) site, which has the second highest IPI score, and one of the lowest mini-PHab scores.

The four biological metrics tested (CSCI, Contra Costa B-IBI, diatoms MMI, hybrid MMI) generally correlated well with each other and with both the mini-PHab index and the IPI scores, and the two PHab indices correlated well with each other. The Contra Costa B-IBI had weaker correlations with the two ASCI indices and the IPI. These results support the idea that there may be an observable connection between stream physical habitat condition and benthic biological community health.

Water Quality

Of 12 water quality parameters required in association with bioassessment monitoring, applicable water quality standards were only identified for ammonia, chloride, and nitrate+nitrite (for sites with MUN beneficial use only). Two of the results generated at the 10 sites monitored for un-ionized ammonia during water year 2019 exceeded the applicable water quality standard; all water year 2019 chloride and nitrate+nitrite results met the applicable standards.

Water Toxicity

The dry weather water sample was not toxic to any of the four test species.

Sediment Toxicity

The Marsh Creek sediment sample was determined to be highly toxic to *Chironomus dilutus* in both the original (Jul. 23, 2019) dry weather sample, and in the follow-up retest (sample collected Sept. 18, 2019). Pyrethroid pesticide concentrations were determined to be more than sufficient to have caused the observed sediment toxicity.

Sediment Chemistry

Several of the common urban pyrethroid pesticides were detected at the water year 2019 sediment monitoring site. The calculated TU equivalent of 1.84 is sufficient to have caused the observed toxicity to

Chironomus dilutus in the sediment toxicity testing for this sample. The TU equivalent calculated for bifenthrin (1.33) alone is sufficient to have caused the observed sediment toxicity.

Sediment Triad Analyses

Bioassessment, sediment toxicity, and sediment chemistry results from water year 2019 were evaluated as the three lines of evidence used in the triad approach for assessing overall stream condition and added to the compiled results for water years 2012-2019. Good correlation is observed throughout that period in the triad analysis between pyrethroid concentrations with TU ≥1 and sediment toxicity.

Chemical stressors, particularly pesticides, may be contributing to the degraded biological conditions indicated by the low B-IBI scores in many of the monitored streams. The principal stressors identified in the chemical analyses from the 2019 monitoring are pesticides, specifically bifenthrin and other pyrethroid

5 Comprehensive Multi-Year Analysis

The multi-year analysis nominally must cover water years 2014-2019, as required by MRP provision C.8.h.v. (the current IMR is required to cover the years since the previous IMR, which was submitted in spring of 2014 and covered water years 2012 and 2013). However, because metrics were available for a wide range of physical, chemical and biological metrics for water years 2012-2016 in the BASMAA Five-Year Bioassessment Report, CCCWP has included data and metrics from water years 2012-2019 for parts of the current analysis.

5.1 Methods

The data used in the comprehensive multi-year analysis encompassed bioassessment monitoring data from sites monitored by CCCWP during water years 2012-2019, inclusive.

Data from four CCCWP sites and five SFBRWQCB sites were classified as non-urban and were excluded from the analysis. After excluding those sites, there were 76 samples available for the current analysis. The monitoring sites and location characteristics included in the multi-year analysis are listed in Table 5.1 and shown graphically in Figure 5.1

The BASMAA five-year bioassessment report (BASMAA, 2019) compared results from urban sites to non-urban sites across the RMC region, but for the current analysis there were insufficient data from non-urban sites to perform that comparison for sites within Contra Costa County. The BASMAA five-year bioassessment report conclusively demonstrated that non-urban sites generally produced higher biological quality scores than urban sites.

A number of biological metrics were available for the CCCWP data analysis, including indices based on both BMI and algal community composition. Results for nine of the available indices are shown for the eight-year period in Table 5.2

Based on an evaluation of the relative strengths and weaknesses of the various available metrics, the biological indices selected for in-depth assessment in the multi-year analysis included the CSCI scores, diatoms MMI (ASCI) scores, and hybrid algae MMI (ASCI) scores. These parameters are considered the dependent or response variables in the analysis.

Many possibilities exist for factors that may affect in-stream biological conditions as independent variables. This analysis incorporates the 49 independent variables included in the BASMAA five-year bioassessment report, as well as several additional rainfall parameters. The factors are categorized as physical habitat parameters (n=20), most of which are derived from the SWAMP reporting module; rainfall parameters (n=5), derived as described below; water quality parameters (n=14), derived from a combination of field-measured and laboratory data; and watershed or land use parameters, derived from GIS analysis. The lists of parameters included in the analysis from each of these categories are shown in Table 5.3.

For the rainfall parameters, rain gauge data were retrieved from the California Data Exchange Center. As noted in Table 5.4, the county was split into four regions along geographic boundaries (East County, West County, South County and Central County), and the 76 bioassessment sites were each assigned to their respective region. To provide for an assessment of the degree to which biological community data may have been affected by antecedent rainfall, rainfall amounts were derived for 30 days, 60 days and 90 days prior to each bioassessment monitoring date, and for the seasonal total to date. Rainfall recorded within 90 days of the bioassessment monitoring date was also analyzed as a percentage of seasonal rainfall.

Figure 5.1 Urban Bioassessment Monitoring Sites – Water Years 2012-2019

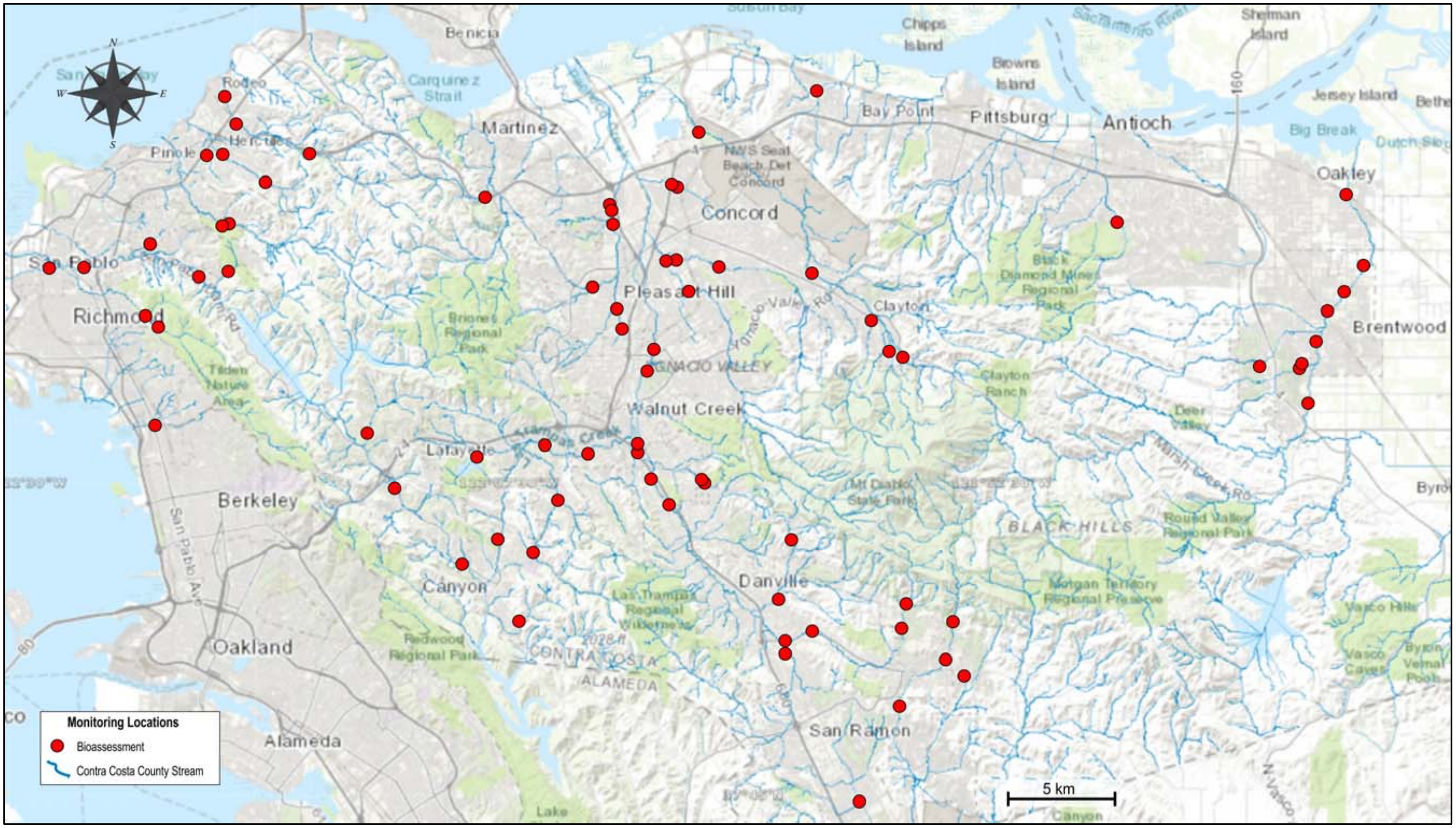


Table 5.1 Monitoring Sites and Location Characteristics Included in the Multi-Year Analysis

RMC Station	Watershed	Creek Name	Year	Sample Date	Flow	Land Use
203R00039	Baxter / Cerrito Richmond Drainages	Cerrito Creek	2012	05/14/12	P	U
206R00155	San Pablo Creek	San Pablo Creek	2012	05/16/12	P	U
206R00215	San Pablo Creek	San Pablo Creek	2012	05/23/12	P	U
207R00011	Grayson Creek / Murderers Creek	Grayson Creek	2012	05/22/12	P	U
207R00139	Las Trampas Creek	Las Trampas Creek	2012	05/17/12	P	U
207R00247	Pine Creek / Galindo Creek	Walnut Creek	2012	05/22/12	P	U
543R00137	Lower Marsh Creek	Deer Creek	2012	05/15/12	P	U
544R00025	Lower Marsh Creek	Dry Creek	2012	05/15/12	P	U
206R00727	Pinole Creek	Pinole Creek	2013	05/13/13	P	U
207R00271	San Ramon Creek	Sycamore Creek	2013	04/29/13	P	U
207R00375	Pine Creek / Galindo Creek	Galindo Creek	2013	05/01/13	P	U
207R00395	Las Trampas Creek	Las Trampas Creek	2013	05/14/13	P	U
207R00503	Pine Creek / Galindo Creek	Pine Creek	2013	05/02/13	P	U
207R00532	San Ramon Creek	Trib to Sycamore Creek	2013	04/29/13	P	U
207R00567	Concord	Walnut Creek	2013	04/30/13	P	U
207R00631	Grayson Creek / Murderers Creek	Grayson Creek	2013	05/16/13	P	U
207R00788	San Ramon Creek	San Ramon Creek	2013	05/15/13	P	U
544R00281	Lower Marsh Creek	Marsh Creek	2013	05/15/13	P	U
206R00407	Wildcat Creek	Wildcat Creek	2014	04/24/14	P	U
206R00551	San Pablo Creek	San Pablo Creek	2014	04/30/14	P	U
206R00599	San Pablo Creek	Appian Creek	2014	05/05/14	P	U
206R00919	San Pablo Creek	Castro Creek	2014	05/14/14	P	U
207R00379	San Ramon Creek	Green Valley Creek	2014	04/21/14	P	U
207R00619	Mt. Diablo Creek	Donner Creek	2014	04/23/14	NP	U
207R00651	San Ramon Creek	Sans Crainte Creek	2014	04/21/14	P	U
207R00823	Pine Creek / Galindo Creek	Galindo Creek	2014	04/23/14	NP	U
207R00843	Las Trampas Creek	Grizzly Creek	2014	04/22/14	P	U
207R00880	Willow Creek and Coastal Drainages	Unnamed Flood Control Channel	2014	05/05/14	P	U
204R00388	Alamo Creek / Tassajara Creek	West Branch Alamo Creek	2015	05/06/15	P	U
204R01156	Alamo Creek / Tassajara Creek	Tributary to Alamo Creek	2015	05/06/15	P	U
206R00960	Rodeo Creek	Rodeo Creek	2015	04/22/15	NP	U

Table 5.1 Monitoring Sites and Location Characteristics Included in the Multi-Year Analysis

RMC Station	Watershed	Creek Name	Year	Sample Date	Flow	Land Use
206R01024	Rodeo Creek	Rodeo Creek	2015	05/05/15	P	U
207R00891	San Ramon Creek	Green Valley Creek	2015	04/22/15	P	U
207R01163	San Ramon Creek	San Ramon Creek	2015	05/04/15	P	U
207R01227	San Ramon Creek	San Ramon Creek	2015	05/04/15	P	U
543R01103	West Antioch Creek	West Antioch Creek	2015	04/21/15	NP	U
544R01049	Lower Marsh Creek	Dry Creek	2015	04/20/15	P	U
544R01305	Lower Marsh Creek	Marsh Creek	2015	04/23/15	P	U
204R01412	Alamo Creek / Tassajara Creek	West Branch Alamo Creek	2016	05/09/16	SP	U
204R01519	San Leandro Creek / Moraga Creek	Rimer Creek	2016	04/28/16	P	U
204R01604	Alamo Creek / Tassajara Creek	West Branch Alamo Creek	2016	04/26/16	P	U
206R01536	Refugio Creek	Ohlone Creek	2016	04/27/16	P	U
207R00779	Las Trampas Creek	Las Trampas Creek	2016	05/10/16	NP	U
207R01271	San Ramon Creek	Walnut Creek	2016	05/11/16	P	U
207R01291	Grayson Creek / Murderers Creek	Grayson Creek	2016	05/11/16	P	U
207R01307	Las Trampas Creek	Lafayette Creek	2016	04/28/16	P	U
207R01447	Alhambra Creek	Franklin Creek	2016	05/12/16	SP	U
207R01611	San Ramon Creek	San Ramon Creek	2016	05/10/16	P	U
204R01819	San Leandro Creek / Moraga Creek	Tributary of Laguna Creek	2017	06/01/17	SP	U
207R01547	Grayson Creek / Murderers Creek	Grayson Creek	2017	05/31/17	P	U
207R01591	Concord	Tributary of Walnut Creek	2017	05/17/17	P	U
207R01595	Mt. Diablo Creek	Mt. Diablo Creek	2017	05/17/17	NP	U
207R01643	Mt. Diablo Creek	Mt. Diablo Creek	2017	05/15/17	NP	U
207R01675	San Ramon Creek	Sans Crainte Creek	2017	05/15/17	P	U
207R01812	San Ramon Creek	Sycamore Creek	2017	05/18/17	P	U
207R01847	Pine Creek / Galindo Creek	Pine Creek	2017	05/30/17	SP	U
207R01860	San Ramon Creek	Sycamore Creek	2017	05/16/17	NP	U
207R01931	San Ramon Creek	San Ramon Creek	2017	06/15/17	P	U
204R02068	South San Ramon Creek	South San Ramon Creek	2018	05/31/18	P	U
206R01495	Pinole Creek	Pinole Creek	2018	05/29/18	P	U
206R02203	San Pablo Creek	Lauterwasser Creek	2018	05/30/18	SP	U
206R02343	Wildcat Creek	Wildcat Creek	2018	05/15/18	NP	U

Table 5.1 Monitoring Sites and Location Characteristics Included in the Multi-Year Analysis

RMC Station	Watershed	Creek Name	Year	Sample Date	Flow	Land Use
207R01600	Mt. Diablo Creek	Mt. Diablo Creek	2018	05/14/18	NP	U
207R01899	Mt. Diablo Creek	Mitchell Creek	2018	05/14/18	NP	U
207R02315	Grayson Creek / Murderers Creek	Grayson Creek	2018	05/30/18	P	U
544R01737	Lower Marsh Creek	Marsh Creek	2018	05/16/18	P	U
544R01993	Lower Marsh Creek	Marsh Creek	2018	05/16/18	P	U
204R02180	Alamo Creek / Tassajara Creek	Alamo Creek	2019	06/12/19	P	U
204R02587	San Leandro Creek / Moraga Creek	Moraga Creek	2019	06/11/19	SP	U
206R01792	Refugio Creek	Refugio Creek	2019	05/08/19	SP	U
206R02048	Rodeo Creek	Rodeo Creek	2019	06/13/19	P	U
206R02455	Wildcat Creek	Wildcat Creek	2019	05/07/19	NP	U
206R02560	Refugio Creek	Refugio Creek	2019	05/08/19	P	U
207R01655	Grayson Creek / Murderers Creek	East Branch Grayson Creek	2019	05/06/19	NP	U
544R02037	Lower Marsh Creek	Marsh Creek	2019	05/06/19	P	U
544R02505	Lower Marsh Creek	Marsh Creek	2019	06/12/19	P	U
CCCWP	NON-URBAN SITES (not included in analysis)					
543R00219	Upper Marsh Creek	Marsh Creek	2012	05/21/12	P	NU
543R00245	Upper Marsh Creek	Marsh Creek	2012	05/21/12	P	NU
207R04027	Pine Creek / Galindo Creek	Pine Creek	2018	05/17/18	SP	NU
207R01280	Alhambra Creek	Franklin Creek	2019	05/09/19	NP	NU
SFBRWQCB	NON-URBAN SITES (not included in analysis)					
206R00055	San Pablo Creek	Bear Creek	2012	06/27/12	P	NU
207R00075	Las Trampas Creek	Las Trampas Creek	2012	06/12/12	P	NU
206R00471	Pinole Creek	Pinole Creek	2013	06/03/13	NP	NU
206R00487	Pinole Creek	Pinole Creek	2013	05/22/13	NP	NU
207R00251	Pine Creek / Galindo Creek	Little Pine Creek	2014	05/13/14	NP	NU

Table 5.2 Biological Metrics Available for the Multi-Year Analysis

Station ID	Creek Name	Sample Date	O/E (CSCI)	pMMI (CSCI)	CSCI	Diatoms MMI (ASCI)	Soft Algae MMI (ASCI)	Hybrid MMI (ASCI)	D18 (A-IBI)	H20 (A-IBI)	S2 (A-IBI)
203R00039	Cerrito Creek	05/14/12	0.71	0.27	0.490	0.84	0.98	1.01	40	30	7
206R00155	San Pablo Creek	05/16/12	0.66	0.24	0.451	0.37	1.01	0.79	40	50	67
206R00215	San Pablo Creek	05/23/12	0.44	0.23	0.335	0.59	0.94	0.79	34	34	50
207R00011	Grayson Creek	05/22/12	0.54	0.28	0.409	0.43	0.75	0.76	70	49	13
207R00139	Las Trampas Creek	05/17/12	0.39	0.29	0.342	0.66	0.94	0.51	40	34	23
207R00247	Walnut Creek	05/22/12	0.67	0.38	0.526	0.60	0.77	0.81	28	16	0
543R00137	Deer Creek	05/15/12	0.53	0.30	0.413	0.37	0.98	0.52	4	2	2
544R00025	Dry Creek	05/15/12	0.53	0.20	0.368	0.50	0.91	0.69	4	2	0
206R00727	Pinole Creek	05/13/13	0.59	0.23	0.410	0.69	0.88	0.55	24	22	20
207R00271	Sycamore Creek	04/29/13	0.53	0.12	0.326	0.75	0.84	0.66	38	26	8
207R00375	Galindo Creek	05/01/13	0.32	0.26	0.290	0.61	0.85	0.62	42	26	2
207R00395	Las Trampas Creek	05/14/13	0.57	0.33	0.450	0.51	1.03	0.40	46	28	0
207R00503	Pine Creek	05/02/13	0.67	0.30	0.485	0.60	0.66	0.58	58	35	2
207R00532	Tributary to Sycamore Creek	04/29/13	0.54	0.24	0.388	0.49	0.69	0.44	20	16	13
207R00567	Walnut Creek	04/30/13	0.53	0.23	0.381	0.51	0.76	0.45	30	32	40
207R00631	Grayson Creek	05/16/13	0.70	0.35	0.525	0.76	0.85	0.57	30	21	8
207R00788	San Ramon Creek	05/15/13	0.66	0.48	0.572	0.73	1.03	0.51	48	31	2
544R00281	Marsh Creek	05/15/13	0.61	0.37	0.494	0.36	0.90	0.41	56	38	5
206R00407	Wildcat Creek	04/24/14	0.89	0.68	0.787	0.69	1.11	0.88	38	44	48
206R00551	San Pablo Creek	04/30/14	0.53	0.32	0.430	0.55	1.11	0.66	18	36	67
206R00599	Appian Creek	05/05/14	0.55	0.16	0.354	0.62	0.83	0.58	50	44	33
206R00919	Castro Creek	05/14/14	0.82	0.27	0.546	0.91	1.11	0.93	26	29	33
207R00379	Green Valley Creek	04/21/14	0.57	0.19	0.379	0.87	0.89	0.79	56	52	40
207R00619	Donner Creek	04/23/14	0.59	0.39	0.492	0.94	0.90	1.05	72	74	73
207R00651	Sans Crainte Creek	04/21/14	0.52	0.12	0.316	0.86	0.97	0.74	48	36	33
207R00823	Galindo Creek	04/23/14	0.59	0.34	0.466	0.70	0.87	0.72	14	15	18
207R00843	Grizzly Creek	04/22/14	0.49	0.19	0.340	0.61	1.01	0.66	54	38	5
207R00880	Unnamed Flood Control Ch	05/05/14	0.45	0.17	0.310	0.63	0.81	0.51	20	28	33
204R00388	West Branch Alamo Creek	05/06/15	0.62	0.22	0.418	0.44	0.91	0.58	64	62	68
204R01156	Tributary to Alamo Creek	05/06/15	0.45	0.20	0.327	0.22	0.67	0.44	10	12	20

Table 5.2 Biological Metrics Available for the Multi-Year Analysis

Station ID	Creek Name	Sample Date	O/E (CSCI)	pMMI (CSCI)	CSCI	Diatoms MMI (ASCI)	Soft Algae MMI (ASCI)	Hybrid MMI (ASCI)	D18 (A-IBI)	H20 (A-IBI)	S2 (A-IBI)
206R00960	Rodeo Creek	04/22/15	0.72	0.23	0.476	0.40	0.99	0.52	10	19	25
206R01024	Rodeo Creek	05/05/15	0.46	0.08	0.274	0.45	0.97	0.56	44	62	97
207R00891	Green Valley Creek	04/22/15	0.47	0.24	0.358	0.54	0.89	0.48	14	15	10
207R01163	San Ramon Creek	05/04/15	0.83	0.41	0.620	0.78	0.99	0.76	58	48	28
207R01227	San Ramon Creek	05/04/15	0.60	0.40	0.497	0.47	0.94	0.58	62	52	33
543R01103	West Antioch Creek	04/21/15	0.67	0.30	0.485	0.36	0.78	0.39	40	35	47
544R01049	Dry Creek	04/20/15	0.43	0.12	0.275	0.66	0.95	0.48	52	41	23
544R01305	Marsh Creek	04/23/15	0.44	0.29	0.367	0.24	0.80	0.36	20	20	22
204R01412	West Branch Alamo Creek	05/09/16	0.48	0.22	0.352	0.69	1.07	0.52	32	20	17
204R01519	Rimer Creek	04/28/16	0.71	0.23	0.469	0.59	1.28	0.62	48	30	17
204R01604	West Branch Alamo Creek	04/26/16	0.61	0.22	0.414	0.45	0.65	0.41	20	12	0
206R01536	Ohlone Creek	04/27/16	0.93	0.41	0.666	0.84	1.28	0.68	46	38	50
207R00779	Las Trampas Creek	05/10/16	0.71	0.51	0.612	0.81	1.12	0.77	72	48	3
207R01271	Walnut Creek	05/11/16	0.53	0.33	0.428	0.54	0.29	0.45	52	32	0
207R01291	Grayson Creek	05/11/16	0.56	0.34	0.449	0.49	0.40	0.37	16	10	3
207R01307	Lafayette Creek	04/28/16	0.69	0.43	0.557	0.86	1.28	0.80	52	32	17
207R01447	Franklin Creek	05/12/16	0.59	0.37	0.480	0.76	1.07	0.71	54	42	17
207R01611	San Ramon Creek	05/10/16	0.82	0.38	0.600	0.61	0.98	0.51	42	26	0
204R01819	Tributary of Laguna Creek	06/01/17	0.64	0.50	0.571	0.69	1.07	0.70	64	40	0
207R01547	Grayson Creek	05/31/17	0.39	0.17	0.282	0.79	0.82	0.78	92	58	0
207R01591	Tributary of Walnut Creek	05/17/17	0.59	0.29	0.439	0.46	0.87	0.59	42	29	13
207R01595	Mt. Diablo Creek	05/17/17	0.55	0.28	0.414	0.64	0.87	0.71	74	46	0
207R01643	Mt. Diablo Creek	05/15/17	0.57	0.39	0.482	0.79	1.28	0.68	62	39	17
207R01675	Sans Crainte Creek	05/15/17	0.57	0.23	0.399	0.89	0.96	0.64	60	38	0
207R01812	Sycamore Creek	05/18/17	0.46	0.34	0.403	0.36	0.86	0.58	30	32	35
207R01847	Pine Creek	05/30/17	0.73	0.44	0.585	0.56	0.67	0.42	34	24	3
207R01860	Sycamore Creek	05/16/17	0.47	0.26	0.367	0.83	0.82	0.81	62	38	2
207R01931	San Ramon Creek	06/15/17	0.81	0.44	0.626	0.67	0.79	0.61	6	9	7
204R02068	South San Ramon Creek	05/31/18	0.421	0.296	0.359	0.62	0.81	0.55	56	35	18
206R01495	Pinole Creek	05/29/18	0.889	0.486	0.688	0.67	1.07	0.64	24	15	0

Table 5.2 Biological Metrics Available for the Multi-Year Analysis

Station ID	Creek Name	Sample Date	O/E (CSCI)	pMMI (CSCI)	CSCI	Diatoms MMI (ASCI)	Soft Algae MMI (ASCI)	Hybrid MMI (ASCI)	D18 (A-IBI)	H20 (A-IBI)	S2 (A-IBI)
206R02203	Lauterwasser Creek	05/30/18	0.718	0.365	0.541	0.58	0.50	0.48	44	29	18
206R02343	Wildcat Creek	05/15/18	0.829	0.489	0.659	0.74	1.07	0.72	36	28	7
207R01600	Mt. Diablo Creek	05/14/18	0.482	0.178	0.330	0.49	0.74	0.54	16	10	0
207R01899	Mitchell Creek	05/14/18	0.798	0.504	0.651	0.64	0.96	0.77	72	45	0
207R02315	Grayson Creek	05/30/18	0.388	0.242	0.315	0.59	0.79	0.51	32	29	22
544R01737	Marsh Creek	05/16/18	0.497	0.227	0.362	0.68	0.71	0.56	32	20	5
544R01993	Marsh Creek	05/16/18	0.448	0.150	0.299	0.57	0.67	0.54	30	18	25
204R02180	Alamo Creek	06/12/19	0.75	0.35	0.550	0.56	1.20	0.60	64	42	27
204R02587	Moraga Creek	06/11/19	0.68	0.45	0.564	0.69	1.28	0.63	56	40	40
206R01792	Refugio Creek	05/08/19	0.66	0.27	0.463	0.77	1.28	0.52	26	22	35
206R02048	Rodeo Creek	06/13/19	0.61	0.32	0.464	0.50	1.06	0.57	34	31	40
206R02455	Wildcat Creek	05/07/19	1.07	0.71	0.891	0.92	1.01	0.92	36	48	73
206R02560	Refugio Creek	05/08/19	0.54	0.34	0.443	0.55	0.91	0.65	66	58	40
207R01655	East Branch Grayson Creek	05/06/19	0.46	0.18	0.322	0.58	1.04	0.47	6	9	7
544R02037	Marsh Creek	05/06/19	0.76	0.48	0.620	0.49	0.75	0.66	54	34	2
544R02505	Marsh Creek	06/12/19	0.22	0.41	0.315	0.53	1.11	0.67	18	21	22
CCCWP	NON-URBAN SITES (not included in analysis)										
543R00219	Marsh Creek	05/21/12	0.80	0.72	0.759	0.71	0.90	0.81	60	38	2
543R00245	Marsh Creek	05/21/12	0.91	0.60	0.754	0.63	0.76	0.70	42	29	8
207R04027	Pine Creek	05/17/18	0.758	0.566	0.662	0.64	0.54	0.53	28	18	32
207R01280	Franklin Creek	05/09/19	0.69	0.32	0.507	0.80	1.28	0.68	30	19	17
SFBRWQCB	NON-URBAN SITES (not included in analysis)										
206R00055	Bear Creek	06/27/12	0.90	0.75	0.824				22	31	40
207R00075	Las Trampas Creek	06/12/12	1.06	0.77	0.918				50	44	33
206R00471	Pinole Creek	06/03/13	0.79	0.40	0.594				32	28	38
206R00487	Pinole Creek	05/22/13	0.56	0.45	0.509				16	29	53
207R00251	Little Pine Creek	05/13/14	0.63	0.30	0.463				50	51	57

Table 5.3. Physical Habitat, Rainfall, Water Quality and Watershed/Land Use Parameters Included in the Multi-Year Analysis

PHab Parameters Produced by the SWAMP Reporting Module

- Combined Riparian Human Disturbance Index (HDI) - SWAMP
- Evenness of Flow Habitat Types
- Evenness of Natural Substrate Types
- Mean Boulders cover
- Mean Filamentous Algae Cover
- Mean Wetted Width/Depth Ratio
- Mean Woody Debris <0.3m cover
- Natural Shelter cover - SWAMP
- Percent Boulders – large
- Percent Boulders – large and small
- Percent Boulders - small
- Percent Fast Water of Reach
- Percent Fines
- Percent Gravel - coarse
- Percent Sand
- Percent Slow Water of Reach
- Percent Substrate Smaller than Sand (<2 mm)
- Shannon Diversity (H) of Aquatic Habitat Types
- Shannon Diversity (H) of Natural Substrate Types

PHab Parameters Computed from Field Data

- Mini-PHab Score (= sum of field observations for Epifaunal Substrate + Sediment Deposition + Channel Alteration)

Rainfall Parameters

- Antecedent Rainfall (30 days)
- Antecedent Rainfall (60 days)
- Antecedent Rainfall (90 days)
- Rainfall Total (Season to Date)
- 90 Day Rainfall as % Season Total

Water Quality Parameters

- AFDM (g/m2)
- Chloride (mg/L)
- Chlorophyll a (mg/m2)
- Dissolved Oxygen (mg/L)
- Nitrate + Nitrite (mg/L)
- OrthoPhosphate as P (mg/L)
- pH
- Phosphorus as P (mg/L)
- Silica as SiO2 (mg/L)
- Specific Conductivity (uS/cm)
- Temperature (C)
- TKN (mg/L)
- Total Nitrogen (mg/L)
- Unionized Ammonia (UIA) (ug/L)

Watershed / Land Use Parameters Derived from the CSCI "Stations" File and GIS

- Drainage Area (km2)
- Elevation (m)
- Percent Impervious 1K
- Percent Impervious 5K
- Percent Impervious Watershed
- Percent Urban 1K
- Percent Urban 5K
- Percent Urban Watershed
- Road Crossings 1K
- Road Crossings 5K
- Road Crossings Watershed
- Road Density 1K
- Road Density 5K
- Road Density Watershed

Table 5.4 Descriptions and Locations of Rain Gauges Used to Derive Rainfall Parameters Used in the Multi-Year Analysis

Rain Gauge Name (Abbrev.)	Region	Geographic Boundaries	Cities Included in Region
Richmond City Hall (RHL)	West County	West of Franklin Range and Briones	Richmond, El Cerrito, Pinole, Rodeo
Ironhouse Sanitary District (ISD)	East County	East of Mt. Diablo	Antioch, Pittsburg, Oakley, Brentwood
Briones (BNE)	Central County	North of SR 24 and I-680 junction, between Briones/Franklin Range and Mt. Diablo	Walnut Creek, Concord, Pleasant Hill, Martinez
Grayson Creek at City Yard (GCC)	Central County Alternate*	North of SR 24 and I-680 junction, between Briones/Franklin Range and Mt. Diablo (used for 2017 only)	Walnut Creek, Concord, Pleasant Hill, Martinez
Rocky Ridge (RKY)	South County	South of SR 24	Lafayette, Moraga, Danville, San Ramon

5.2 Results/Comprehensive Analysis

5.2.1 Biological Condition Analysis

Three of the biological condition metrics were determined to be sufficiently robust and reliable and were selected for further evaluation: CSCI, as a broad-based indicator of BMI community health, and two of the ASCI metrics – diatoms MMI and hybrid MMI – both as indicators of in-stream algal community health.

Initially, for those three indicator indices, the eight years of assembled data from CCCWP bioassessment monitoring were assessed with respect to their condition category ranges (per Table 3.4).

Based on the scoring ranges shown in Table 3.4, the numbers of samples accruing to each of the four biological condition categories are shown in Table 5.5 for the three biological indices selected for the comprehensive analysis (CSCI, diatoms MMI/ASCI, and hybrid algae MMI/ASCI). The results are also illustrated graphically in Figures 5.2 and 5.3.

Taken together, these results reinforce the notion that urban streams in Contra Costa County are generally impacted form the standpoint of biological communities, specifically BMI and algae. The BASMAA five-year bioassessment report analysis produced the same conclusion.

Table 5.5 Numbers of CCCWP Samples in CSCI and ASCI MMI Categories, 2012-2019

	Likely Intact	Possibly Altered	Likely Altered	Very Likely Altered	Total
CSCI	0	1	5	70	76
Diatom MMI	2	9	20	45	76
Hybrid MMI	2	2	8	64	76

Figure 5.2 CCCWP CSCI Scores by Biological Condition Category, WY 2012-2019

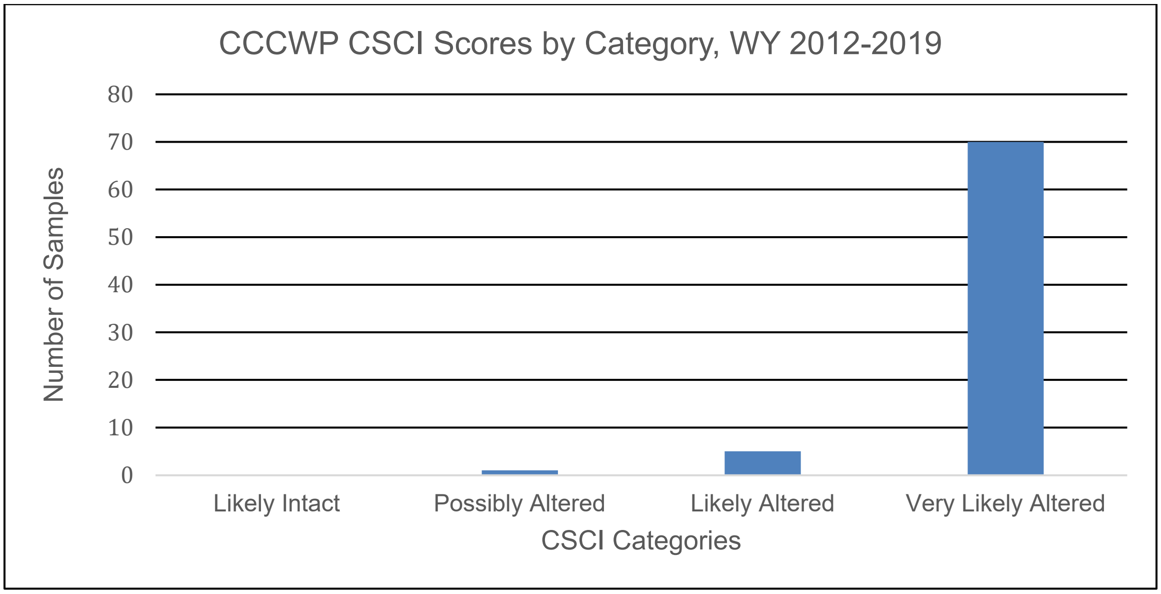
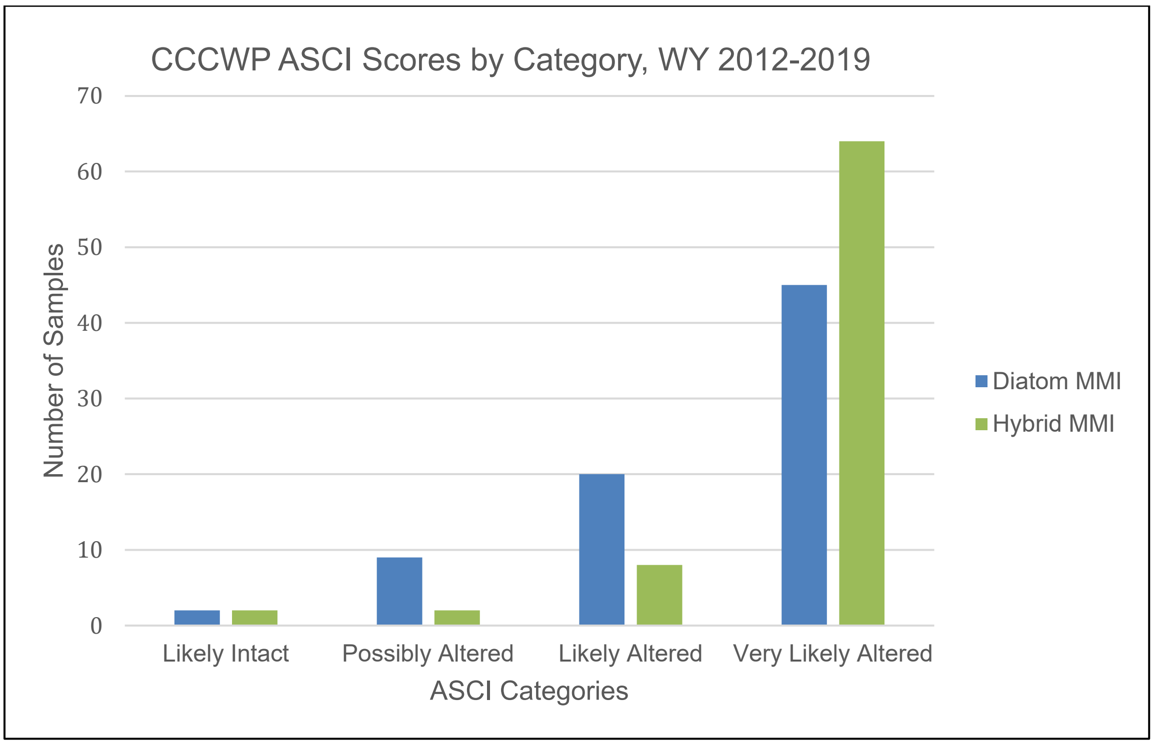


Figure 5.3 CCCWP ASCI Scores by Biological Condition Category, WY 2012-2019



5.2.2 Correlation Analysis

Correlation coefficients were computed for each of the three biological condition response variables and the 53 independent variables identified as potential factors influencing the biological condition scores. For each response variable, the factors were ranked by the absolute values of the correlation coefficients to identify the factors by the strength of their relationships with the response variables, irrespective of direction (positive or negative). The top 15 factors (by correlation coefficient) are listed in Table 5.6 (CSCI), Table 5.7 (diatoms MMI) and Table 5.8 (hybrid MMI).

The parameters that correlated best with CSCI scores (Table 5.6) were dominated by physical habitat factors, and secondarily by water quality factors.

Physical habitat factors also were predominant for the correlations with ASCI indices, but the top 15 correlations for both ASCI indices also included at least two rainfall factors and at least three water quality factors.

The rankings for the top 15 factors were then pooled from the three biological condition variables, and those independent variables were further ranked to illustrate the combined relative effect of the individual factors on biological condition status (Table 5.9).

Table 5.6 Factors with 15 Highest Correlation Coefficients for CSCI Scores, WY 2012-2019, Ranked by Absolute Value of Strength of Correlation Coefficient

Correlation Coefficient CSCI Factor	Factor	Factor Category
0.46	Dissolved Oxygen (mg/L)	WATER QUALITY
-0.46	Percent Substrate Smaller than Sand (<2 mm)	PHAB (SWAMP)
0.41	Percent Boulders - small	PHAB (SWAMP)
0.41	Percent Boulders - large & small	PHAB (SWAMP)
-0.39	Percent Fines	PHAB (SWAMP)
-0.38	Chloride (mg/L)	WATER QUALITY
0.34	pH	WATER QUALITY
0.34	Mini-PHab Score	PHAB (FIELD)
0.33	Percent Fast Water of Reach	PHAB (SWAMP)
0.32	Percent Gravel - coarse	PHAB (SWAMP)
-0.30	Percent Slow Water of Reach	PHAB (SWAMP)
-0.29	Specific Conductivity (uS/cm)	WATER QUALITY
0.29	Shannon Diversity (H) of Natural Substrate Types	PHAB (SWAMP)
0.28	Mean Wetted Width/Depth Ratio	PHAB (SWAMP)
0.28	Evenness of Natural Substrate Types	PHAB (SWAMP)

Table 5.7 Factors with 15 Highest Correlation Coefficients for Diatoms MMI (ASCI) Scores, WY 2012-2019, Ranked by Absolute Value of Strength of Correlation Coefficient

Correlation Coefficient D-MMI (ASCI) Factor	Factor	Factor Category
0.37	Percent Fast Water of Reach	PHAB (SWAMP)
0.36	Shannon Diversity (H) of Aquatic Habitat Types	PHAB (SWAMP)
-0.36	Temperature (C)	WATER QUALITY
-0.34	Chloride (mg/L)	WATER QUALITY
0.34	Mini-PHab Score	PHAB (FIELD)
-0.33	Percent Slow Water of Reach	PHAB (SWAMP)
-0.33	Specific Conductivity (uS/cm)	WATER QUALITY
0.32	Antecedent Rainfall (90 days)	RAINFALL
0.30	Antecedent Rainfall (60 days)	RAINFALL
0.26	Mean Woody Debris <0.3m cover	PHAB (SWAMP)
0.26	Shannon Diversity (H) of Natural Substrate Types	PHAB (SWAMP)
-0.25	Percent Substrate Smaller than Sand (<2 mm)	PHAB (SWAMP)
-0.25	Percent Fines	PHAB (SWAMP)
0.25	Percent Gravel - coarse	PHAB (SWAMP)
-0.25	Mean Filamentous Algae Cover	PHAB (SWAMP)

Table 5.8 Factors with 15 Highest Correlation Coefficients for Hybrid Algae MMI (ASCI) Scores, WY 2012-2019, Ranked by Absolute Value of Strength of Correlation Coefficient

Correlation Coefficient H-MMI (ASCI) Factor	Factor	Factor Category
0.54	Percent Fast Water of Reach	PHAB (SWAMP)
-0.50	Percent Slow Water of Reach	PHAB (SWAMP)
0.47	90 Day Rainfall as % Season Total	RAINFALL
0.46	Antecedent Rainfall (90 days)	RAINFALL
0.42	Antecedent Rainfall (60 days)	RAINFALL
0.39	Percent Gravel - coarse	PHAB (SWAMP)
-0.38	Specific Conductivity (uS/cm)	WATER QUALITY
-0.37	Chloride (mg/L)	WATER QUALITY
0.37	Mini-PHab Score	PHAB (FIELD)
-0.37	Percent Substrate Smaller than Sand (<2 mm)	PHAB (SWAMP)
-0.34	Temperature (C)	WATER QUALITY
-0.31	Percent Fines	PHAB (SWAMP)
-0.31	Road Crossings 5K	WATERSHED
-0.27	Chlorophyll a (mg/m2)	WATER QUALITY
0.26	Mean Wetted Width/Depth Ratio	PHAB (SWAMP)

Table 5.9 Factors Scored by Relative Rankings Based on Strength of CSCI and ASCI Correlations, WY 2012-2019

Factor	Factor Category	CSCI Rank	D-MMI (ASCI) Rank	H-MMI (ASCI) Rank	CSCI Points	D-MMI Points	H-MMI Points	Average Score (CSCI, ASCI)	Average ASCI Score
Percent Fast Water of Reach	PHAB (SWAMP)	9	1	1	7	15	15	12.3	15.0
Chloride (mg/L)	WATER QUALITY	6	4	8	10	12	8	10.0	10.0
Percent Slow Water of Reach	PHAB (SWAMP)	11	6	2	5	10	14	9.7	12.0
Mini-PHab Score	PHAB (FIELD)	8	5	9	8	11	7	8.7	9.0
Percent Substrate Smaller than Sand (<2 mm)	PHAB (SWAMP)	2	12	10	14	4	6	8.0	5.0
Specific Conductivity (uS/cm)	WATER QUALITY	12	7	7	4	9	9	7.3	9.0
Antecedent Rainfall (90 days)	RAINFALL		8	4	0	8	12	6.7	10.0
Temperature (C)	WATER QUALITY		3	11	0	13	5	6.0	9.0
Antecedent Rainfall (60 days)	RAINFALL		9	5	0	7	11	6.0	9.0
Percent Fines	PHAB (SWAMP)	5	13	12	11	3	4	6.0	3.5
Percent Gravel - coarse	PHAB (SWAMP)	10	14	6	6	2	10	6.0	6.0
Dissolved Oxygen (mg/L)	WATER QUALITY	1			15	0	0	5.0	0
Shannon Diversity (H) of Aquatic Habitat Types	PHAB (SWAMP)		2		0	14	0	4.7	7.0
Percent Boulders - small	PHAB (SWAMP)	3			13	0	0	4.3	0
90 Day Rainfall as % Season Total	RAINFALL			3	0	0	13	4.3	6.5
Percent Boulders - large & small	PHAB (SWAMP)	4			12	0	0	4.0	0
pH	WATER QUALITY	7			9	0	0	3.0	0
Shannon Diversity (H) of Natural Substrate Types	PHAB (SWAMP)	13	11		3	5	0	2.7	2.5
Mean Woody Debris <0.3m cover	PHAB (SWAMP)		10		0	6	0	2.0	3.0
Road Crossings 5K	WATERSHED			13	0	0	3	1.0	1.5
Mean Wetted Width/Depth Ratio	PHAB (SWAMP)	14		15	2	0	1	1.0	0.5
Chlorophyll a (mg/m2)	WATER QUALITY			14	0	0	2	0.7	1.0
Evenness of Natural Substrate Types	PHAB (SWAMP)	15			1	0	0	0.3	0
Mean Filamentous Algae Cover	PHAB (SWAMP)		15		0	1	0	0.3	0.5

It is evident from this analysis that for all three of the biological condition indices, physical habitat factors are generally most highly correlated with biological condition, followed by water quality and rainfall factors. The lack of influence of the watershed factors on the biological condition scores is perhaps surprising. Only one watershed factor – Road Crossings within 5 km – appeared in the top 15 factors, and only for the H-MMI/ASCI index, with a rank of 13. In the BASMAA five-year bioassessment report, four of the eight highest ranked factors for CSCI scores were watershed parameters.

On the other hand, for the algal IBI evaluated in the BASMAA five-year bioassessment report (the D18 A-IBI), four of the top six ranked factors were water quality parameters.

Eight factors were included on the top 15 correlation lists for all three of the biological condition variables:

- Percent fast water of reach
- Chloride (mg/L)
- Percent slow water of reach
- Mini-PHab score
- Percent substrate smaller than sand (<2 mm)
- Specific conductivity (uS/cm)
- Percent fines
- Percent gravel – coarse

Certain of these variables are clearly related. For example, Percent Fast Water of Reach and Percent Slow Water of Reach had correlations with similar magnitude for each of the three biological condition variables, but Fast Water is positively correlated, and Slow Water is negatively correlated with biological condition for each of the three indices. Both factors are related to stream slope and flow.

Percent Substrate Smaller than Sand (<2 mm) and Percent Fines would seem to measure similar parameters and, as such, they are both negatively correlated to each of the biological condition indices. Similarly, chloride and conductivity are both related to salinity, and both are negatively correlated with each of the three biological condition indices.

The numbers and percentages of factors appearing in at least one top-15 list of factors for the CCCWP assessment are shown by category in Table 5.10. Again, only one of 14 watershed factors received a top-15 ranking, while 70 percent (14 of 20) of the physical habitat factors were included in one or more of the top 15 lists.

Table 5.10 Numbers and Percentages of Factors Included in Top 15 Correlation Coefficient Rankings for CCCWP Biological Condition Variables, by Category

Category	No. of Factors Per Category	No. of Ranked Factors*	Percent Ranked
Physical Habitat	20	14	70%
Water Quality	14	6	43%
Rainfall	5	3	60%
Watershed	14	1	7%
Overall	53	24	45%

* Factors included in the top 15 correlation coefficient rankings for one or more of the three biological condition variables

Regression equations were derived for the top three ranked factors for each of the three response variables (CSCI, diatoms MMI, hybrid algae MMI), and the results are plotted in Figures 5.4-5.12).

All nine regressions were statistically significant.

Figure 5.4 Regression Plot for CSCI vs. Dissolved Oxygen – WY 2012-2019

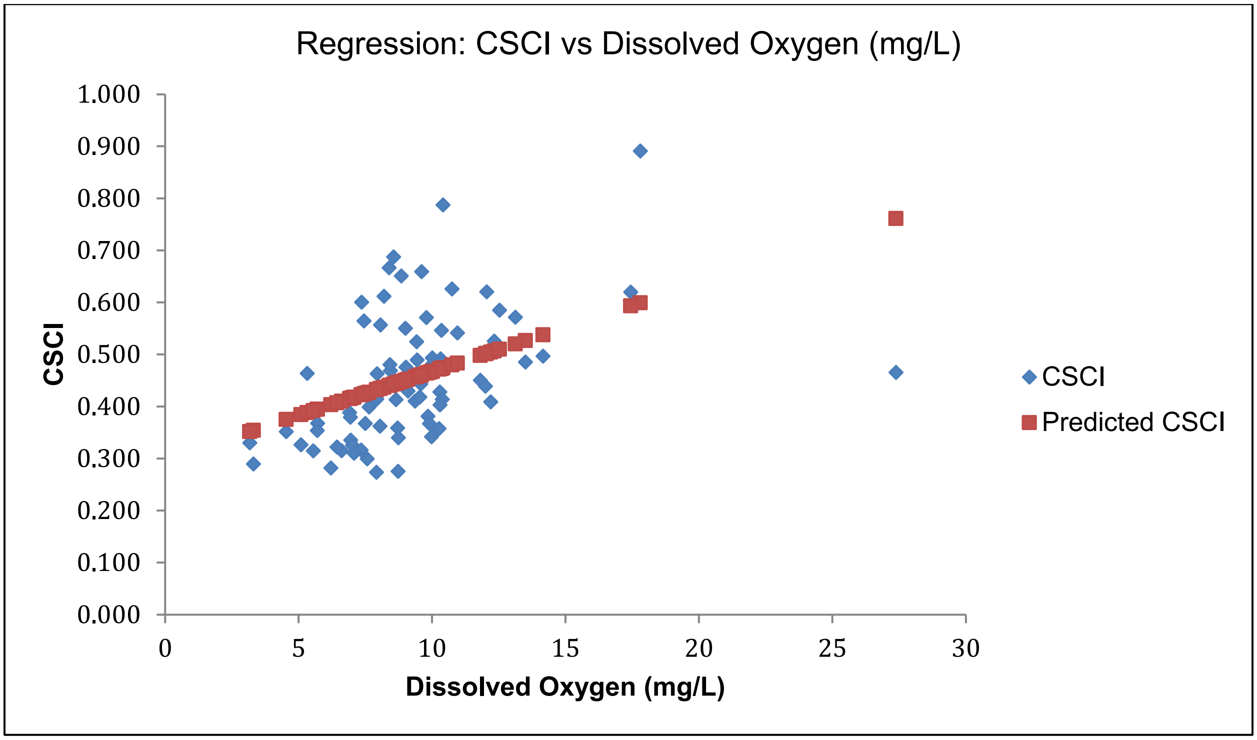


Figure 5.5 Regression Plot for CSCI vs. Percent Substrate Smaller than Sand (<2 mm), WY 2012-2019

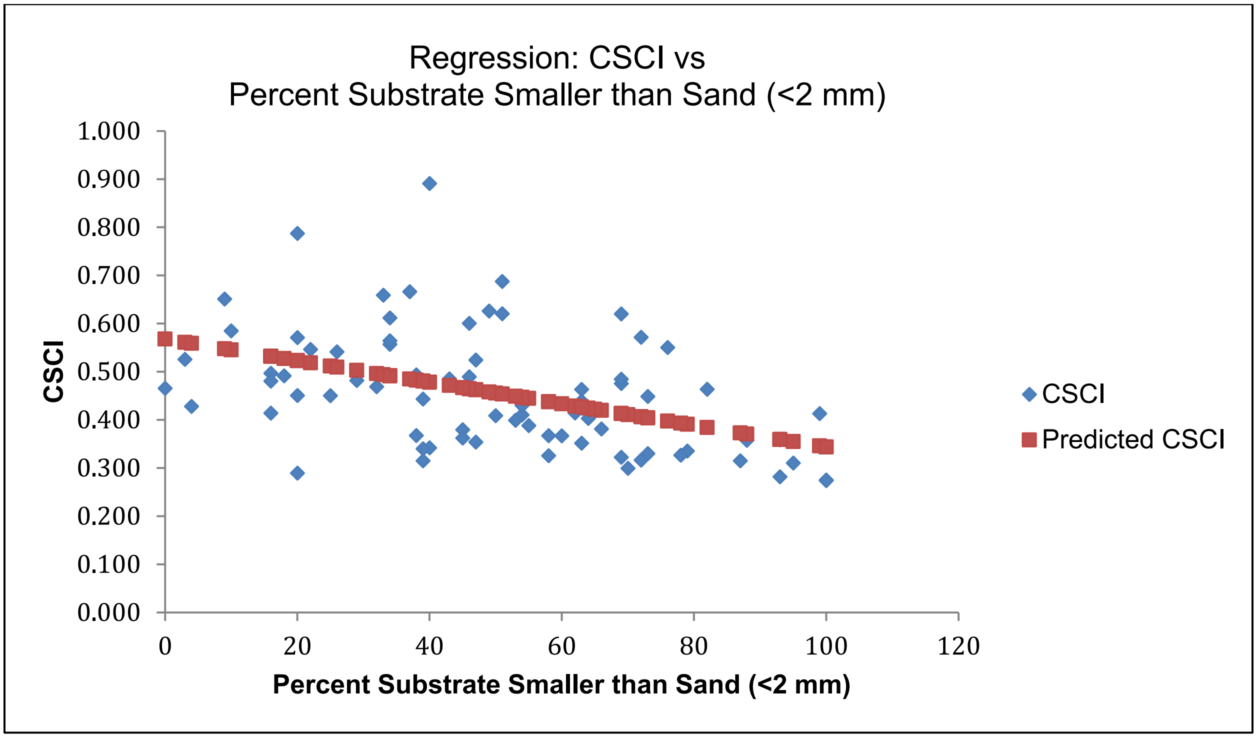


Figure 5.6 Regression Plot for CSCI vs. Percent Boulders (Small), WY 2012-2019

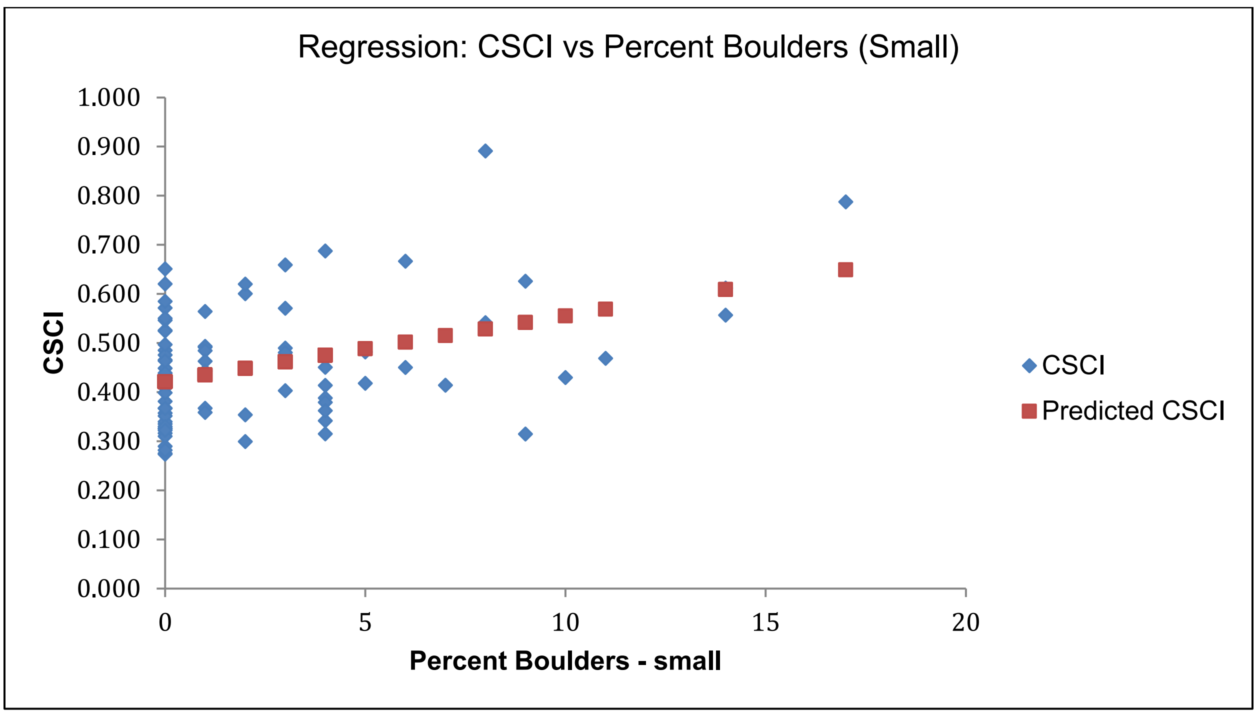


Figure 5.7 Regression Plot for Diatoms MMI (ASCI) vs. Percent Fast Water of Reach, WY 2012-2019

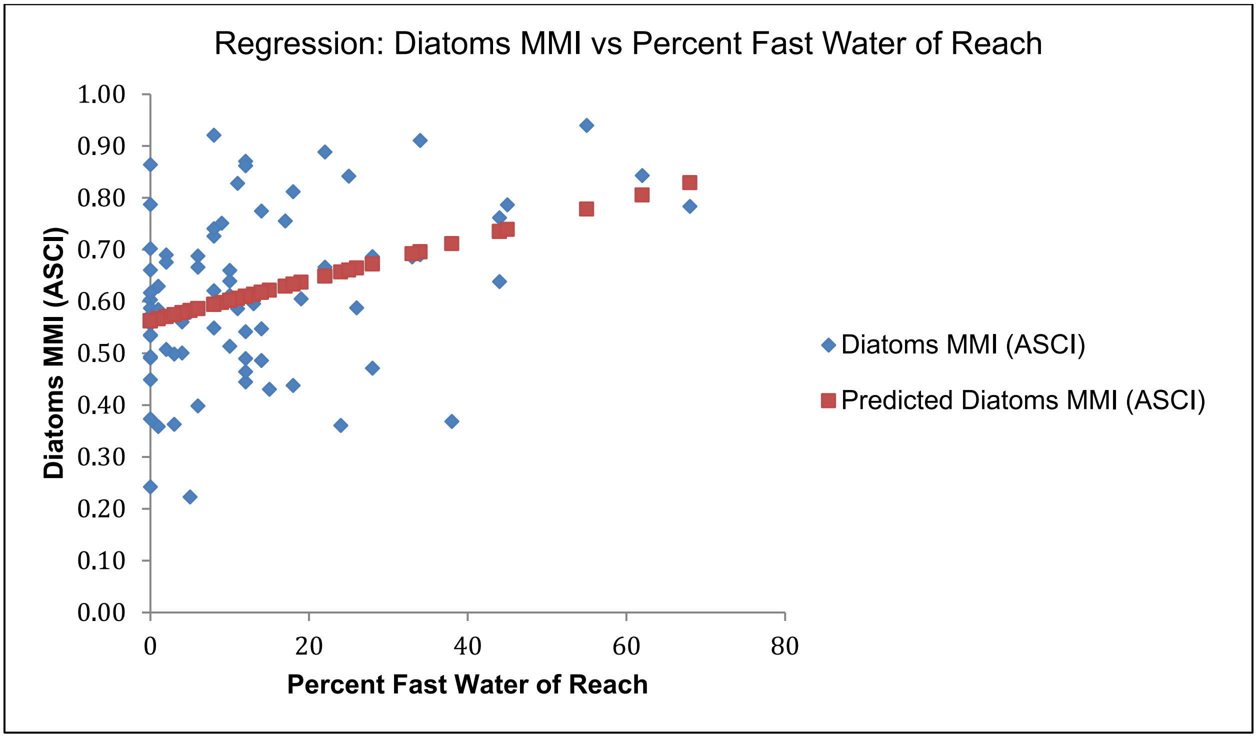


Figure 5.8 Regression Plot for Diatoms MMI (ASCI) vs. Shannon Diversity of Aquatic Habitat Types, WY 2012-2019

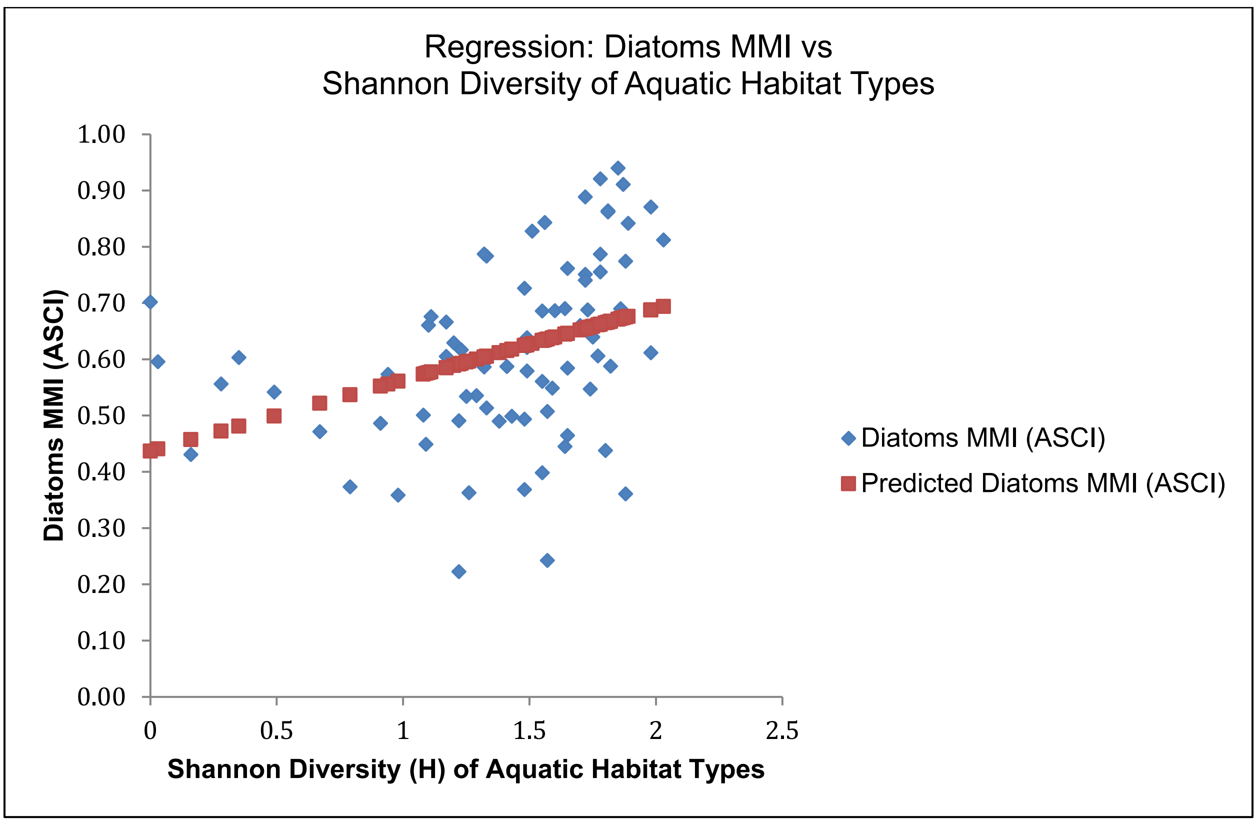


Figure 5.9 Regression Plot for Diatoms MMI (ASCI) vs. Temperature (C), WY 2012-2019

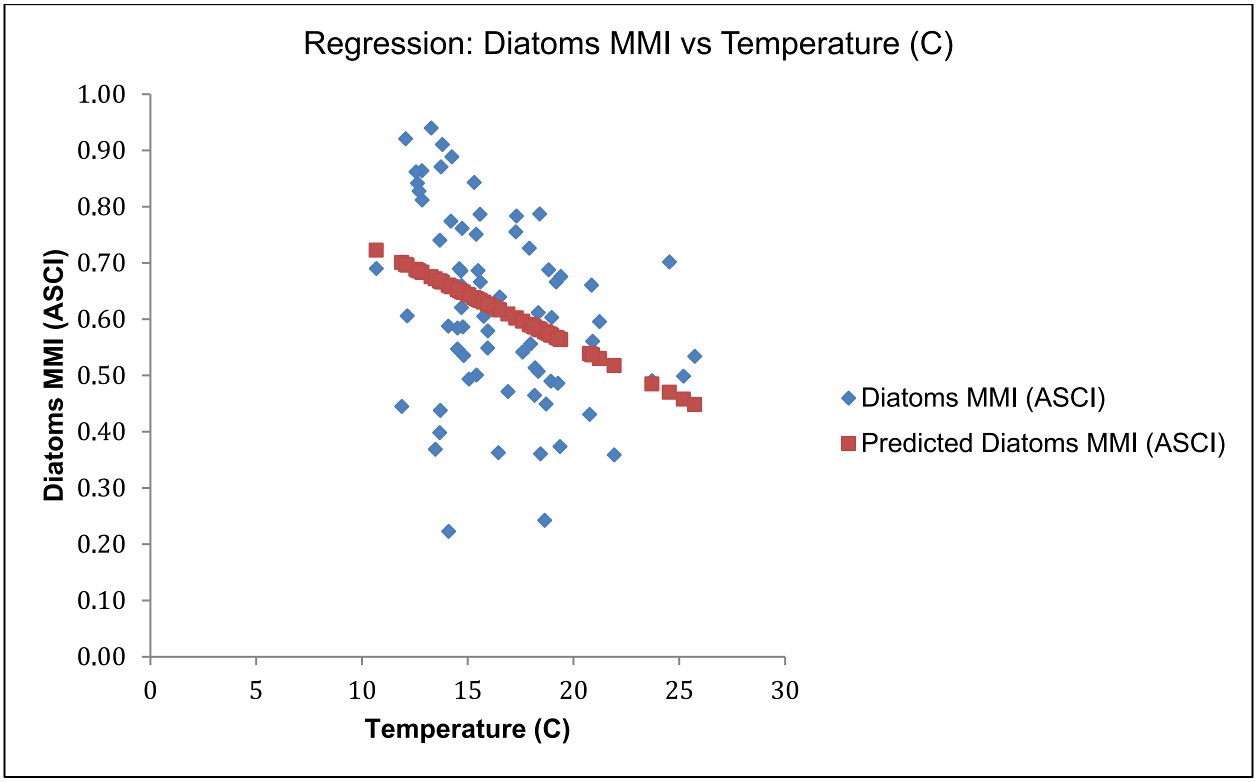


Figure 5.10 Regression Plot for Hybrid Algae MMI (ASCI) vs. Percent Fast Water of Reach, WY 2012-2019

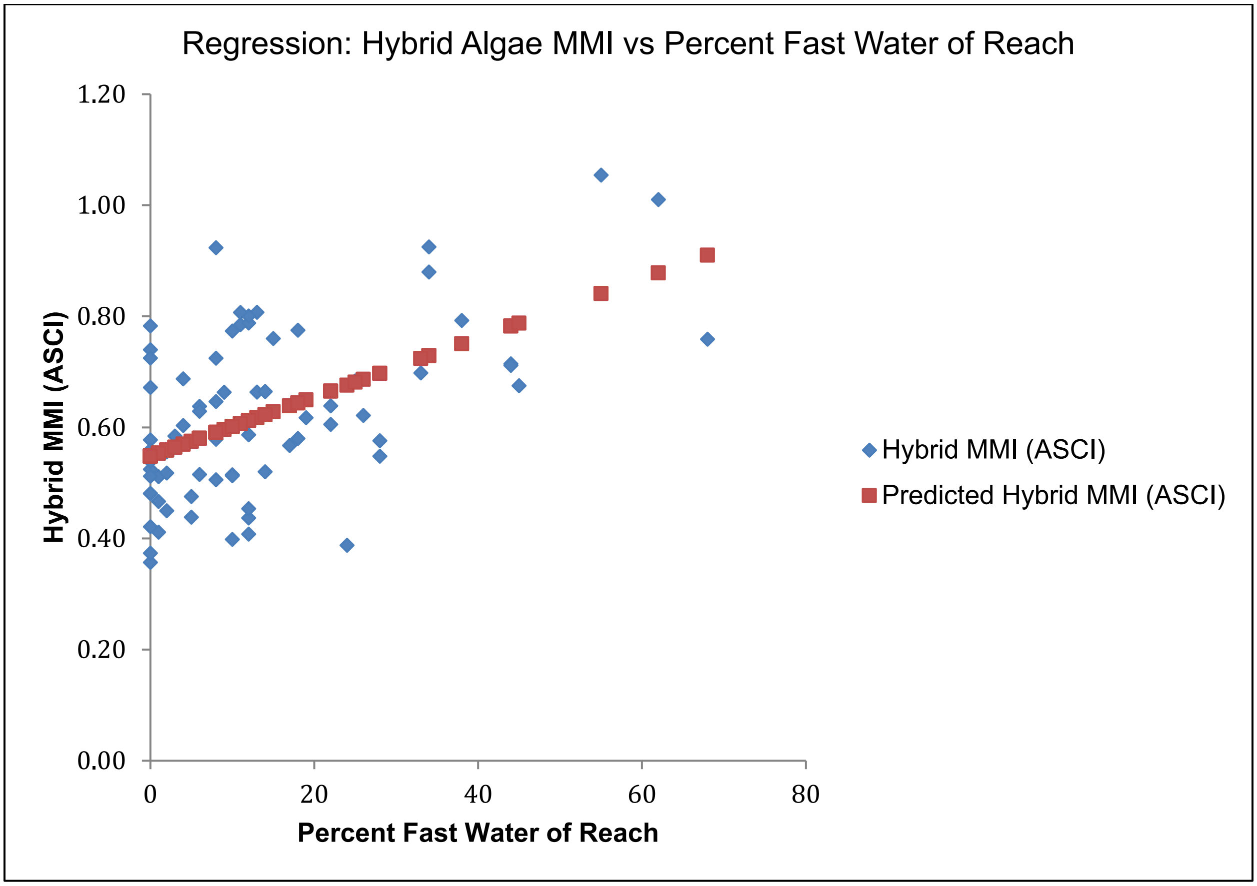


Figure 5.11 Regression Plot for Hybrid Algae MMI (ASCI) vs. Percent Slow Water of Reach, WY 2012-2019

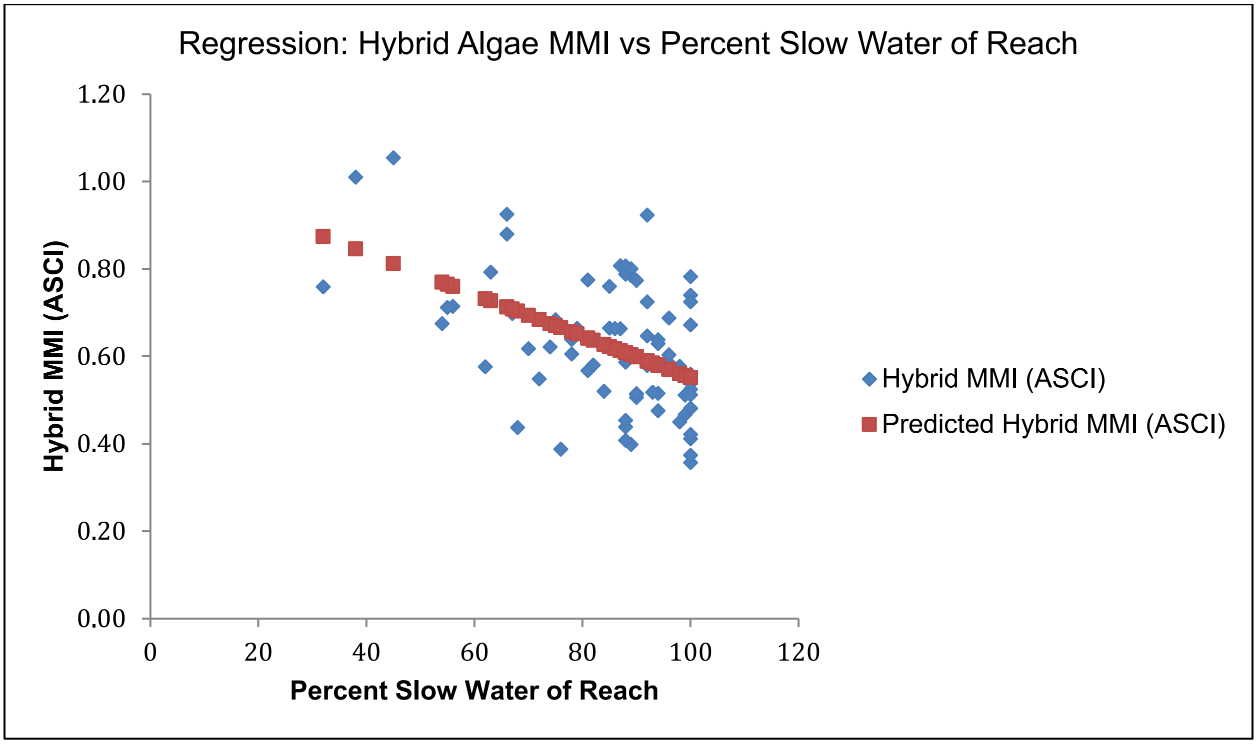
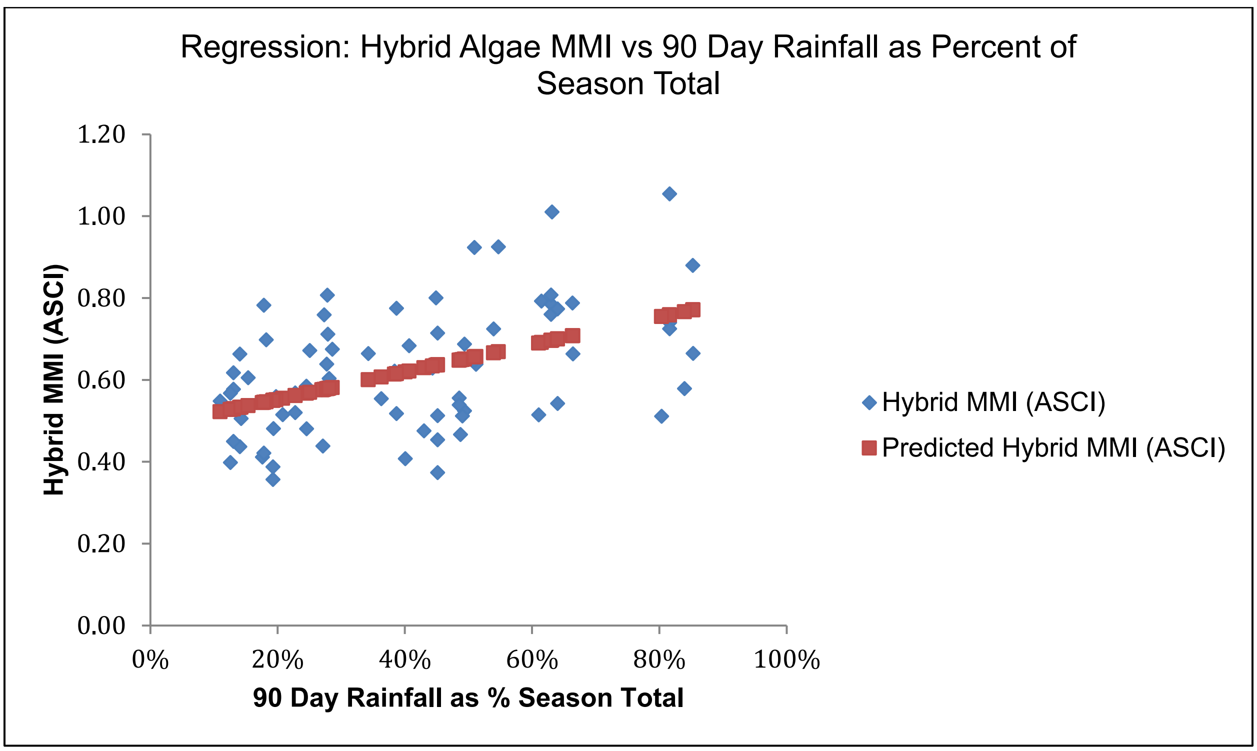
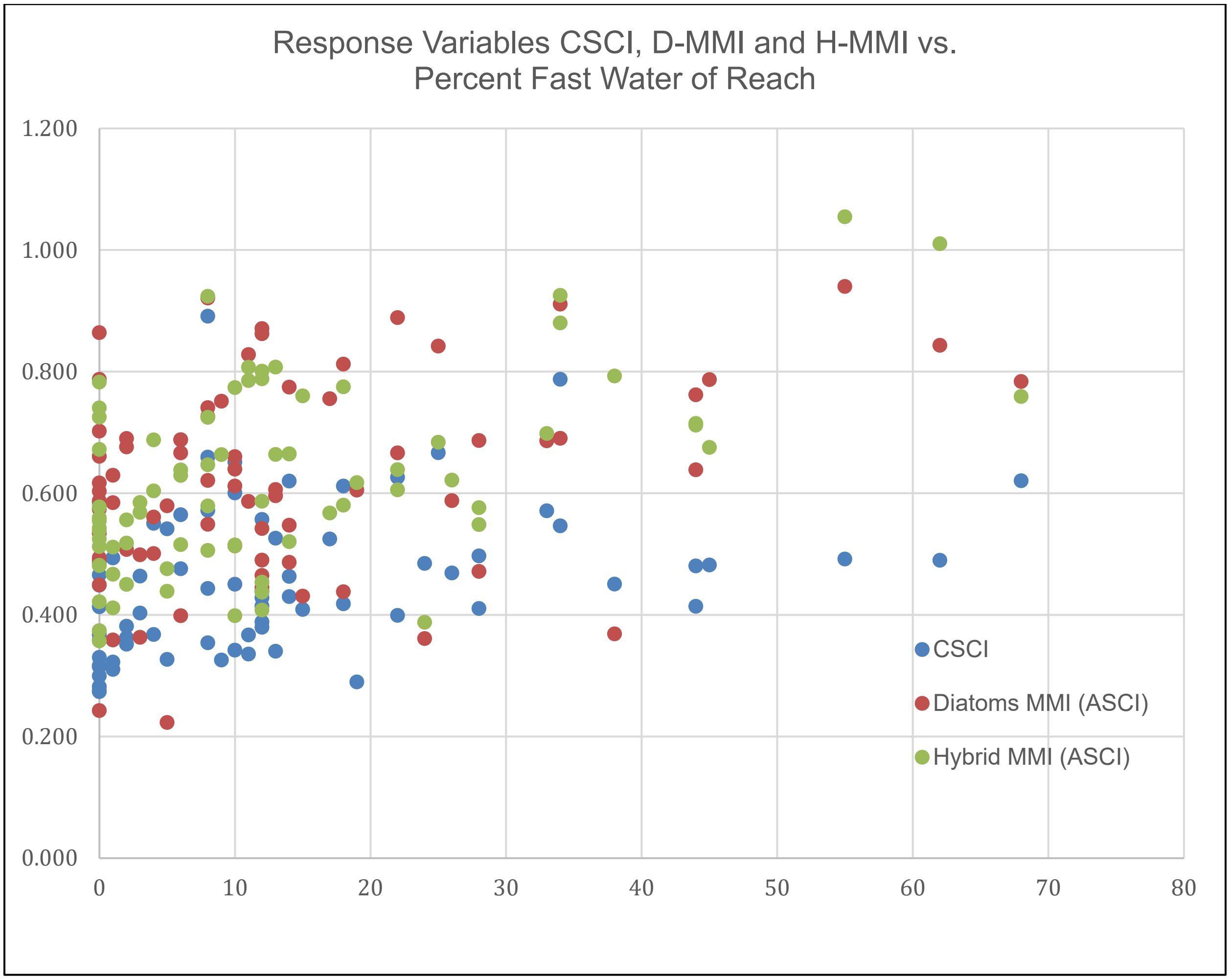


Figure 5.12 Regression Plot for Hybrid Algae MMI (ASCI) vs. 90 Day Rainfall as Percent of Season Total, WY 2012-2019



For factors that appeared in top 15 lists of correlations for all three response variables, the patterns were similar, as illustrated in Figure 5.13 for the Percent Fast Water of Reach factor.

Figure 5.13 Plot of Response Variables CSCI, D-MMI and H-MMI vs. Percent Fast Water of Reach – WY 2012-2019



5.2.3 Sediment Triad Analysis

Table 5.11 summarizes stressor evaluation results for sites with data collected for sediment chemistry, sediment toxicity, and bioassessment parameters by CCCWP over the first eight years of the RMC regional/probabilistic monitoring effort (water years 2012-2019).

Pyrethroid pesticide sediment concentrations appear to be potent predictors of sediment toxicity, as samples with calculated pyrethroid TU equivalents greater than 1.0 exhibited significant sediment toxicity. The samples with TU equivalents less than 1.0 generally did not exhibit sediment toxicity, as shown in Table 5.11 (the 2018 sample being the exception, as the calculated TU equivalent was 0.95, and toxicity was observed to *Hyalella azteca* in the sediment sample).

Table 5.11 Summary of Sediment Quality Triad Evaluation Results – WY 2012-2019 Data

Water Year	Water Body	Site ID	B-IBI Condition Category	Sediment Toxicity	No. of TEC Quotients > 1.0	Mean PEC Quotient	Sum of TU Equivalents
2012	Grayson Creek	207R00011	Very Poor	Yes	10	0.14	2.17
2012	Dry Creek	544R00025	Very Poor	Yes	11	0.51	3.62
2013	Sycamore Creek	207R00271	Very Poor	Yes	0	0.04	10.5
2013	Marsh Creek	544R00281	Very Poor	Yes	4	0.13	1.03
2014	San Pablo Creek	206R00551	Very Poor	No	1	0.09	.016
2014	Grizzly Creek	207R00843	Very Poor	No	1	0.12	.11
2015	Rodeo Creek	206R01024	Poor	No	1	0.11	0.32
2015	Green Valley Creek	207R00891	Very Poor	Yes	3	0.12	1.11
2016	Rimer Creek	204R01519	Degraded (CSCI)	No	1	0.12	0.89
2017	West Branch Alamo Creek	204R01412	Degraded (CSCI)[1]	No	3	0.21	0.255
2018	Marsh Creek	544R01737		Yes	1	0.09	0.95
2019	Marsh Creek	544R02505		Yes	3	0.25	1.84

1 Based on water year 2016 bioassessment data

Note: Yellow-highlighted cells indicate results exceed permit trigger threshold.

5.2.4 Conclusions of the Comprehensive Multi-Year Analysis

Biological conditions in Contra Costa County urban creeks are generally impacted, as indicated by analysis of bioassessment results from 76 monitoring sites over the course of eight years, 2012-2019. Physical habitat factors play a significant role in degradation of in-stream biota, with water quality factors and antecedent rainfall also contributing to in-stream conditions.

Factors that have a positive influence on in-stream biological conditions for BMI and algae include higher percentages of fast water within the reach, higher percentages of coarse gravel, and higher diversity of natural substrate types.

Factors that tend to negatively impact in-stream biota include higher percentages of fines or substrate smaller than sand, higher percentages of slow water in the reach, and elevated chloride or conductivity.

Algae assemblages tend to benefit from higher antecedent rainfall in the 60- to 90-day range and are negatively impacted by elevated temperatures.

Throughout the study period, sediment toxicity and occasional water toxicity are chronic occurrences, with toxicity typically attributable to the presence of pyrethroid and sometimes other pesticides, including the recent presence of fipronil and imidacloprid.

6 Conclusions, Lessons Learned, Recommendations for MRP 3.0

6.1 Water Year 2019

The water year 2019 data were fairly consistent with the results of previous creek status monitoring performed by CCCWP under the MRP. Physical habitat conditions were again compromised at most of the 10 bioassessment sites monitored in 2019. IPI scores were calculated from the PHab data compiled during the spring 2019 bioassessment monitoring. Two sites ranked as “Likely intact” (Wildcat Creek and Moraga Creek), while only one (Rodeo Creek) ranked as “Very likely altered”. The remaining seven sites are rated as “Possibly altered” or “Likely altered”.

The four biological metrics tested (CSCI, Contra Costa B-IBI, diatoms MMI, hybrid MMI) generally correlated well with each other and with both the mini-PHab index and the IPI scores, and the two PHab indices correlated well with each other. These results support the idea that there is a likely connection between stream physical habitat condition and benthic biological community health.

Of the 12 water quality parameters required in association with bioassessment monitoring, applicable water quality standards were only identified for ammonia, chloride, and nitrate+nitrite (for sites with MUN beneficial use only). Two of the results generated at the 10 sites monitored for un-ionized ammonia during water year 2019 exceeded the applicable water quality standard; all water year 2019 chloride and nitrate+nitrite results met the applicable standards.

The dry weather water sample was not toxic to any of the four test species. However, the Marsh Creek sediment sample was determined to be highly toxic to *Chironomus dilutus* in both the original (Jul. 23, 2019) dry weather sample, and in the follow-up retest (sample collected Sep. 18, /2019). Several of the common urban pyrethroid pesticides were detected at the water year 2019 sediment monitoring site. The calculated TU equivalent of 1.84 is sufficient to have caused the observed toxicity to *Chironomus dilutus* in the sediment toxicity testing for this sample. The TU equivalent calculated for bifenthrin (1.33) alone is sufficient to have caused the observed sediment toxicity.

Comprehensive Multi-Year Analysis

Bioassessment, sediment toxicity, and sediment chemistry results from water years 2012-2019 were evaluated as the three lines of evidence used in the triad approach for assessing overall stream condition. Good correlation between pyrethroid concentrations with TU ≥1 and sediment toxicity is observed throughout that period.

Chemical stressors, particularly pesticides, may be contributing to the degraded biological conditions indicated by the low B-IBI scores in many of the monitored streams. The principal stressors identified in the chemical analyses from the 2019 monitoring are pesticides, specifically bifenthrin and other pyrethroid pesticides in sediments.

Physical habitat factors are generally most highly correlated with biological conditions, followed by water quality and rainfall factors. The assessments provided in the comprehensive analysis may be used to guide creek restoration efforts.

6.2 Lessons Learned

6.2.1 Lessons Learned from Regional/Probabilistic Monitoring

Are water quality objectives, both numeric and narrative, being met in local receiving waters, including creeks, rivers and tributaries?

The very few numeric water quality objectives applicable to regional/probabilistic monitoring are generally attained, except for ammonia. The only water quality parameters monitored concurrent with site bioassessments with applicable water quality objectives are ammonia, chloride and nitrate+nitrite. Looking back on the water quality monitoring results from bioassessment sites in Contra Costa County for water years 2012-2019, chloride and nitrate+nitrite generally met water quality objectives at all times and locations sampled. The same was true for ammonia, except in water year 2018 when ammonia exceedances began to occur. Four of 10 sites sampled exceeded the 25 µg/L ammonia water quality objective in water year 2019 and two of 10 exceeded the objective in water year 2019. Ammonia concentrations above the 25 µg/L water quality objective ranged from 29 to 169 µg/L.

The narrative water quality objective for toxicity is directly relevant to bioassessment, pesticide, and toxicity monitoring:

> *All waters shall be maintained free of toxic substances in concentrations that are lethal to or that produce other detrimental responses in aquatic organisms. Detrimental responses include, but are not limited to, decreased growth rate and decreased reproductive success of resident or indicator species. There shall be no acute toxicity in ambient waters. Acute toxicity is defined as a median of less than 90 percent survival, or less than 70 percent survival, 10 percent of the time, of test organisms in a 96-hour static or continuous flow test.*
>
> *There shall be no chronic toxicity in ambient waters. Chronic toxicity is a detrimental biological effect on growth rate, reproduction, fertilization success, larval development, population abundance, community composition, or any other relevant measure of the health of an organism, population, or community.*
>
> *Attainment of this objective will be determined by analyses of indicator organisms, species diversity, population density, growth anomalies, or toxicity tests (including those described in Chapter 4), or other methods selected by the Water Board. The Water Board will also consider other relevant information and numeric criteria and guidelines for toxic substances developed by other agencies as appropriate.*
>
> *The health and life history characteristics of aquatic organisms in waters affected by controllable water quality factors shall not differ significantly from those for the same waters in areas unaffected by controllable water quality factors.*

The first two paragraphs of the narrative directly address toxicity test results as well as pesticide concentration monitoring. Toxicity is detected in sediments of Contra Costa County creeks, and when it is detected the evidence consistently points to concentrations of pesticides that are high enough to cause a toxic response. The last two paragraphs of the narrative objective address benthic invertebrate and algal communities as they are affected by controllable water quality factors.

The meaning of bioassessment scores helps interpret whether or not the narrative is attained. Benthic indices of biological integrity (IBI) reflect the composition of the biological communities of invertebrates living in creek beds. Low scores indicate poor creek health – the communities are dominated by organisms such as blood worms and crayfish which have a high tolerance for pollutants and physical stressors, such as high temperature and low dissolved oxygen (DO). High scores indicate relatively greater species richness and abundance and/or the presence of more sensitive species (e.g., water boatmen). A statewide IBI system, known as the California Stream Condition Index (CSCI), references in-stream conditions to expected conditions based on climate and geography. The Contra Costa IBI (CC-IBI) provides the same value of contextualized interpretation of IBI data, but specific to Contra Costa County.

In addition to benthic IBIs, IBIs have been developed for algal communities. Similar to benthic IBI scores, high scores indicating good creek health results from high algal species richness and presence of algal species that are more pollutant-sensitive, whereas lower scores generally reflect a much lower rich species composition and higher abundance of pollutant-tolerant species. Like benthic IBI metrics, multi-metric index (MMI) algal species composition indices (ASCIs) have been developed for quantitative assessments of stream health. This report deals with a diatoms-only MMI-ASCI and a hybrid MMI-ASCI, following SWAMP guidance.

Finally, physical habitat measurements (e.g., how much cobble is present and how embedded in sediments are cobbles, water velocities) are also used to develop stream condition indices. In this report, a "mini-PHab score" and an index of physical integrity score are used to quantify physical habitat condition.

In this monitoring program, much of the effort performing analyses and developing graphics, tables, and narratives supporting the evaluation of creek health focuses on the question of where creek health is better or worse, and do the various indices tell a consistent story about creek health. At present, the comparison thresholds in the MRP are not by themselves numeric water quality objectives. The California State Water Resources Control Board is developing water quality objectives for biological endpoints that may be applied in the future to compare against numeric measures of creek health.

At present, the comparison thresholds in the MRP are not by themselves numeric water quality objectives. The California State Water Resources Control Board is developing water quality objectives for biological endpoints that may be applied in the future to compare against numeric measures of creek health. Until statewide objectives are adopted, CCCWP uses the CSCI, ASCI and related metrics as indicators of creek status with respect to the elements of the narrative objective addressing "species diversity, population density" and the "health and life history characteristics of aquatic organisms." Analysis of physical habitat measures, physical and chemical water quality parameters, and watershed and land use factors helps us quantify which of those factors influence metrics of biological community health. To the extent that any of these water quality factors are controllable, this information can guide restoration planning.

In comparison to the various indices discussed above, CCCWP's bioassessment data shows that biological conditions in urban creeks in Contra Costa County are generally impacted. Physical habitat plays a significant role in this degradation of creek health. Water quality and antecedent rainfall also contribute to in-stream conditions.

The various indices as measures of creek health tend to agree, especially when the indices point to good creek health. Where the indices at times differ, it is usually a matter of degree (i.e., how bad is the bad and how good is the good). The CSCI tends to assign poor conditions everywhere. In contrast, the CC-IBI offers more of a gradient in stream conditions, which helps prioritize impacted areas for follow-up.

Are conditions in local receiving waters supportive of or likely supportive of beneficial uses?

The numeric water quality objectives for ammonia, chloride, and nitrate+nitrite cited above pertain to municipal potable water supply. Except for the limited subset of ammonia exceedances, this beneficial use is generally attained. The potential impact on groundwater quality of the limited elevated ammonia concentrations detected is unknown. The creeks in question with elevated ammonia are not known to be intentionally used by a municipal water supplier for groundwater recharge.

The evidence from creek status monitoring shows that aquatic life beneficial uses are not fully supported due to a variety of physical habitat, climatic (rainfall), and watershed/land use factors.

The numeric analysis and narrative discussion of bioassessment data indicates that the beneficial uses of wildlife habitat (WILD), warm water fisheries habitat (WARM), and cold-water fisheries habitat (COLD) are attained to varying degrees in Contra Costa County streams. This finding is consistent with more detailed analysis of temperature and dissolved oxygen through local/targeted monitoring programs.

Is the regional/probabilistic monitoring approach generally useful to addressing those two questions?

The data developed through the regional/probabilistic creek status monitoring approach has provided a robust baseline characterization of creek health in Contra Costa County and context with Bay Area and California streams. Work done so far has been useful; however, the value of adding more probabilistic data in the near term is questionable. Rather than continuing the program of probabilistic sampling, CCCWP would prefer to focus resources on monitoring to detect change and where change occurs. This means identifying known or potential future creek restorations, green infrastructure projects, or other watershed management actions that may be expected to improve creek health. Before and after monitoring will help test management hypotheses about the expected magnitude and timing of stream condition in response to management actions.

The RMC approach to draw a random sample of candidate bioassessment sites, and then revise the random draw based on owner permissions and safe access, may have skewed the representativeness of the bioassessment data. Specifically, streams that are accessed only by permission of the East Bay Municipal Utility District (EBMUD) have not been well sampled in Contra Costa County because the permissions process presents schedule challenges. Owing to the surrounding land use, these streams may have better creek health compared to the population of sites monitored to date. CCCWP seeks to iterate the RMC site selection protocols during MRP 3.0 so that future bioassessment monitoring efforts can more directly target known data gaps, as well as areas where potential future changes may lead to potential future improvements in bioassessment scores.

6.2.2 Lessons Learned from Pesticides/Toxicity Monitoring

Are water quality objectives, both numeric and narrative, being met in local receiving waters, including creeks, rivers, and tributaries?

Numeric water quality objectives for diazinon and chlorpyrifos are consistently attained in the creeks monitored by CCCWP in water years 2012-2019. This monitoring was performed in Marsh Creek in compliance with CVRWQCB's TMDL requirements. The outcome of no detections is attributed to a phaseout of consumer use of these pesticides.

Narrative water quality objectives for "no toxic substances in toxic amounts" are not consistently attained. Toxicity in sediments was observed in seven of the 12 assessments of the sediment quality triad performed in Contra Costa County. Chemical analysis shows that pyrethroid pesticides are present in sufficient concentrations to account for observed toxicity.

Are conditions in local receiving waters supportive of or likely supportive of beneficial uses?

The evidence from pesticide and toxicity monitoring shows that aquatic life beneficial uses are not fully supported due to pesticide impacts. Conditions can improve in response to control measures, as evidenced by lessons learned from diazinon and chlorpyrifos.

Is the Pesticide/Toxicity Monitoring approach generally useful to addressing those two questions?

The pesticide and toxicity monitoring approach has established links between observed toxicity and pesticides. As evidenced by lessons learned from diazinon and chlorpyrifos, this type of evidence can be used by regulatory agencies to establish meaningful control programs that make a difference. Data from CCCWP, other Bay Area stormwater programs, and statewide efforts can help build a record to support future regulatory controls of pesticides that have emerged to replace diazinon and chlorpyrifos.

6.3 Recommendations for MRP 3.0

Based on the lessons learned summarized above, CCCWP makes the following recommendations for the creek status monitoring program established in Provision C.8 of the MRP:

- Replace the probabilistic sampling design for bioassessment in MRP 3.0 with a targeted sampling design. The review of data gathered to date shows that baseline conditions have been reasonably well characterized at this point. Future deployment of CCCWP monitoring resources should address the following priorities:
  - Filling data gaps in areas that have heretofore been difficult to access (i.e., EBMUD-owned lands). In addition to identifying problem areas, CCCWP also seeks to identify high-value stream habitat resources that merit protection and/or enhancement.
  - Characterizing before and after conditions where restoration or other watershed management actions are expected to improve creek health.
- Where Water Board has the discretion, consider prescribing minimum numbers of samples for the permit term, rather than annually. The total number of samples required for the permit terms establishes a floor of sampling effort. CCCWP requests some flexibility to plan monitoring efforts so that they are optimized to gain maximum value for the effort and cost applied.
  - Often, the best approach is a monitoring effort concentrated over one to three years, rather than spreading the effort equally over five years.
  - Overly prescribing the monitoring frequency at the annual interval can diminish the quality of the monitoring design and resulting outcomes, or cause CCCWP to seek exceptions.
  - This was a lesson learned during MRP 1.0. The requirement to sample a minimum number of storms per year forced monitoring contractors to sample any available storm event to meet the minimum number, regardless of storm size. This skewed the monitoring toward more frequent, less intense storms. Recognizing that under those conditions, Marsh Creek monitoring was not capturing important flow events from the upper watershed, where the

historic Mount Diablo Mercury mine is located, CCCWP sought and obtained an exception to eliminate the minimum number in favor of conserving resources to sample Marsh Creek when flows from large, later season events convey water from the upper watershed past Marsh Creek Reservoir. This approach has provided important evidence that mercury-impacted sediments do not appear to be transported into lower Marsh Creek during large storm events.

– Seeking exceptions takes time and effort. If MRP 3.0 monitoring requirements constrain the monitoring design to less than optimum, CCCWP and the Water Board may need to accept that the outcomes and insights gained from the monitoring effort may be diminished compared to a monitoring design that allows flexibility for timing and focusing resources.

6.4 Next Steps

The analysis presented in this report identifies a number of potentially impacted sites which might deserve further evaluation and/or investigation to provide better understanding of the sources/stressors which contribute to reduced water quality and lower biological conditions.

Efforts are currently underway by the RMC to implement a new set of SSID projects for implementation during the current MRP term. CCCWP will continue to collaborate in this regional effort. Eight SSID projects are required regionally per MRP 2.0, if performed within a regional collaborative. Per agreement within the RMC, CCCWP will perform one new SSID project during the MRP 2.0 permit term and will participate in one regionally coordinated project, which may not involve toxicity. The current list of potential SSID projects is included as Appendix 3A of the IMR (CCCWP, 2020).

The RMC programs have undertaken a comprehensive, regional analysis of the first five years of bioassessment monitoring performed under the MRP as a BASMAA regional project. In addition to the regional data analysis, complemented by the analysis contained in the various water year 2019 IMRs, RMC programs will evaluate the existing Creek Status Monitoring Plan and probabilistic design and consider appropriate next steps to recommend for the monitoring design in the future.

Candidate probabilistic sites previously classified with “unknown" sampling status in the RMC probabilistic site evaluation process may continue to be evaluated for potential sampling in water year 2020.

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Appendix A: Algae IBI – Detailed Metrics and Discussion

The highest D-18 A-IBI scores occurred at sites 204R02180 (64) in Alamo Creek and 206R02560 (66) in Refugio Creek, while site 207R01655 in East Branch Grayson Creek had the lowest score at 6 (Table A-1). Half of the sites scored between 30 and 56. Higher scores tended to be associated with a lower proportion of halobiontic species, nitrogen heterotrophic species, and sediment tolerant, highly motile species but higher proportion of species requiring >50 percent dissolved oxygen saturation (Tables A-1 and A-2), which is consistent with previous years. Eight of ten sites scored 0 or 1 and the other two sites scored 2 for the proportion of diatom species indicative of low total phosphorous levels, suggesting phosphorous is not a limiting factor in these streams. The proportion of diatom species requiring >50 percent DO saturation exceeded 0.74 at nine sites, but the proportion of species requiring nearly 100 percent DO saturation dropped to below 0.05 for all ten sites, suggesting lower DO levels in the 50-75 percent range compared to near 100 percent consistently. *Nitzschia spp* and *Cocconeis spp*, were the dominant diatom species found at seven of the ten sites, with *Cocconeis spp*. representing over 50 percent of the sample at three sites (204R02180, 206R02560, 544R02037). *Cyclotella meneghiniana* (26.3 percent) and *Nitzschia dubia* (17.2 percent) were the dominant diatom species at the lowest scoring site 207R01655 in East Branch Grayson Creek, while *Cocconeis placentula* (50.7 percent) and *Rhoicosphenia abbreviata* (22.3 percent) were dominant at the highest scoring site 206R02560 in Refugio Creek. Two creeks (Refugio Creek and Marsh Creek) had two sites sampled with differing scores (26 and 66 on Refugio and 18 and 54 on Marsh) due to different species abundances and compositions. Site characteristics including location, physical habitat, and chemical concentrations should be examined in greater detail. Fetscher et al. (2014) found the diatom IBI (D18) to be responsive to stream order, watershed area and percent fines, so these values could also play a role in IBI scores.

The soft algae S2 and related metrics are shown in Tables A-3 and A-4. The highest S2 score occurred at site 206R02455 (73) in Wildcat Creek while sites 544R02037 (2) in Marsh Creek and 207R01655 (7) in East Branch Grayson Creek scored the lowest (Table A-4). Site 206R02455 scored higher because it had a higher proportion of “ZHR” taxa (Zygnemataceae, heterocystous cyanobacteria, Rhodophyta) and no soft algae species belonging to the green algae “CRUS” group (*Cladophora glomerata*, *Rhizoclonium hieroglyphicum*, *Ulva flexuosa*, and *Stigeoclonium spp*; see Tables A-3, A-4). In contrast, sites with lower scores were dominated by taxa belonging to CRUS and Chlorophyta, indicative of high copper and DOC concentrations, and no ZHR taxa. This result is a little inconclusive because SWAMP has not updated the Algae Attribute list since March 2013, and some organisms with SWAMP database taxonomic “FinalIDs” (e.g., *Heteroleibleinia* or *Leptolyngbya*) have not been assigned trait characteristics for copper or DOC, so they are not included in the calculations. All ten sites had zero species indicative of low total phosphorous concentrations. The biovolume at five sites was dominated by *Cladophora glomerata* (42.8 percent and 94.8-100 percent at four sites) while species richness was dominated by *Heteroleibleinia*, *Chamaesiphon*, or *Leptolyngbya* (note, six sites did not have algae in the count samples). Fetscher et al. (2014) found soft algae IBIs were most responsive (negatively) to canopy cover and slope.

The hybrid IBIs (H20, H21, and H23) consisting of both soft algae and diatom metrics produced similar results in determining the lowest scoring site (207R01655 in East Branch Grayson Creek), while H21 and H23 scored higher at sites 204R02180 in Alamo Creek and 204R02587 in Moraga Creek and H20 scored higher at sites 206R02455 in Wildcat Creek and 206R02560 in Refugio Creek (Tables A-5, A-6, A-7). The average IBI score varied slightly among the three IBIs (H20 = 32.4, H21 = 38.0, H23 = 40.3), similar to previous years. The main differences in the H20 IBI scores among sites were due to the proportion of high copper and high DOC diatoms, highly motile diatoms, heterotroph diatoms, and diatoms requiring >50 percent dissolved oxygen saturation. H21 and H23 IBI scores were driven by the proportion of halobiontic diatoms, nitrogen heterotrophs, diatoms requiring >50 percent dissolved oxygen saturation, and sediment tolerant, highly motile diatoms. Fetscher et al. (2014) designated H20 as the overall top performing IBI for Southern California streams, although differences with H23 were not pronounced. H21 and H23 scores have scored closer together in the current and previous years for Contra Costa County streams.

Table A-1 Diatom IBI (D18) and Individual Metric Scores for CCCWP Sites Sampled in 2019

Site Code	Creek Name	Sample Date	D18 IBI Score	Proportion Halobiontic (d) Score	Proportion Low TP Indicators (d) Score	Proportion N Heterotrophs (d) Score	Proportion Requiring >50% DO Saturation (d) Score	Proportion Sediment Tolerant (Highly Motile) (d) Score
204R02180	Alamo Creek	06/12/19	64	7	1	8	8	8
204R02587	Moraga Creek	06/11/19	56	7	0	7	8	6
206R01792	Refugio Creek	05/08/19	26	1	2	3	7	0
206R02048	Rodeo Creek	06/13/19	34	1	2	7	3	4
206R02455	Wildcat Creek	05/07/19	36	2	0	7	7	2
206R02560	Refugio Creek	05/08/19	66	8	0	8	8	9
207R01280	Franklin Creek	05/09/19	30	2	1	4	5	3
207R01655	E Br Grayson Cr	05/06/19	6	0	1	2	0	0
544R02037	Marsh Creek	05/06/19	54	0	1	8	9	9
544R02505	Marsh Creek	06/12/19	18	0	1	0	8	0

D18 diatom IBI #18
H20 hybrid algae IBI #20
H21 hybrid algae IBI #21
H22 hybrid algae IBI #22
S2 soft algae IBI #2
(d) diatom
(b) biovolume
(m) mean of the species results
(s) soft algae, further defined as:
(sp) species counts

Note: Metric scores were assigned based on metric results, as shown in Table A-2, using scoring ranges and values provided by Dr. A. Elizabeth Fetscher (personal communication). The overall IBI score was calculated by converting the sum of individual scores to a 100-point scale by summing the scores and multiplying by the number of metrics (sum x [100/50]).

Table A-2 Diatom Metric Results for CCCWP Sites Sampled in 2019

Site Code	Sample Date	Proportion A Minutissimum (d)	Proportion Halobiontic (d)	Proportion Highly Motile (d)	Proportion Low TN Indicators (d)	Proportion Low TP Indicators (d)	Proportion N Heterotrophs (d)	Proportion oligo- & beta-Mesosaprobic (d)	Proportion poly- & eutrophic (d)	Proportion Requiring >50% DO Saturation (d)	Proportion Requiring Nearly 100% DO Saturation (d)	Proportion Sediment Tolerant (Highly Motile) (d)
204R02180	06/12/19	0.005	0.179	0.095	0.014	0.019	0.074	0.826	0.955	0.944	0.014	0.095
204R02587	06/11/19	0	0.156	0.192	0.009	0.003	0.139	0.708	0.873	0.921	0.047	0.192
206R01792	05/08/19	0.003	0.49	0.493	0.064	0.102	0.34	0.502	0.898	0.878	0.027	0.497
206R02048	06/13/19	0	0.483	0.295	0.148	0.135	0.123	0.433	0.873	0.744	0.004	0.314
206R02455	05/07/19	0	0.428	0.429	0.003	0	0.145	0.598	0.898	0.906	0.037	0.429
206R02560	05/08/19	0.002	0.085	0.059	0.004	0.004	0.056	0.897	0.994	0.952	0.002	0.059
207R01280	05/09/19	0	0.445	0.368	0.041	0.047	0.282	0.411	0.811	0.82	0.005	0.372
207R01655	05/06/19	0	0.696	0.424	0.013	0.014	0.412	0.442	0.91	0.563	0.02	0.696
544R02037	05/06/19	0.007	0.629	0.052	0.012	0.024	0.06	0.918	0.985	0.981	0.01	0.052
544R02505	06/12/19	0.027	0.578	0.558	0.033	0.034	0.62	0.356	0.955	0.946	0.045	0.566

D18 diatom IBI #18
H20 hybrid algae IBI #20
H21 hybrid algae IBI #21
H22 hybrid algae IBI #22
S2 soft algae IBI #2
(b) biovolume
(d) diatom
(m) mean of the species results
(s) soft algae, further defined as:
(sp) species counts
Note: All calculations based on count data; proportions are individual counts/total count for each sample

Table A-3 Soft Algae IBI (S2) and Individual Metric Scores for CCCWP Sites Sampled in 2019

Site Code	Creek Name	Sample Date	S2 IBI Score	Proportion High Cu Indicators (s, sp) Score	Proportion High DOC Indicators (s, sp) Score	Proportion Low TP Indicators (s, sp) Score	Proportion Non-Reference Indicators (s, sp) Score	Proportion Green Algae Belonging to CRUS (s, b) Score	Proportion ZHR (s, m) Score
204R02180	Alamo Creek	06/12/19	27	0	2	0	2	10	2
204R02587	Moraga Creek	06/11/19	40	0	4	0	0	10	10
206R01792	Refugio Creek	05/08/19	35	0	6	0	3	10	2
206R02048	Rodeo Creek	06/13/19	40	3	5	0	7	4	5
206R02455	Wildcat Creek	05/07/19	73	10	10	0	10	10	4
206R02560	Refugio Creek	05/08/19	40	6	7	0	8	0	3
207R01280	Franklin Creek	05/09/19	17	0	0	0	0	10	0
207R01655	E Branch Grayson Creek	05/06/19	7	0	4	0	0	0	0
544R02037	Marsh Creek	050/6/19	2	0	0	0	0	1	0
544R02505	Marsh Creek	06/12/19	22	0	8	0	5	0	0

D18 diatom IBI #18
H20 hybrid algae IBI #20
H21 hybrid algae IBI #21
H22 hybrid algae IBI #22
S2 soft algae IBI #2
(b) biovolume
(d) diatom
(m) mean of the species results
(s) soft algae, further defined as:
(sp) species counts
Note: The overall IBI score was calculated by converting the sum of individual scores to a 100-point scale by summing the scores and multiplying by the number of metrics (sum x [100/60]).

Table A-4 Soft Algae Metric Results for CCCWP Sites Sampled in 2019

Site Code	Sample Date	Proportion High Cu Indicators (s, sp)	Proportion High DOC Indicators (s, sp)	Proportion Low TP Indicators (s, sp)	Proportion Non-Reference Indicators (s, sp)	Proportion ZHR (s, sp)	Proportion Chlorophyta (s, b)	Proportion High DOC Indicators (s, b)	Proportion Non-Reference Indicators (s, b)	Proportion Green Algae Belonging to CRUS (s, b)	Proportion ZHR (s, b)	Proportion ZHR (s, m)
204R02180	06/12/19	0.5	0.6	0	0.4	0.143	0	1	0	0	0	0.071
204R02587	06/11/19	0.5	0.5	0	0.5	0.5	0	0	0	0	1	0.75
206R01792	050/8/19	0.5	0.333	0	0.333	0.25	0	0	0	0	0	0.125
206R02048	06/13/19	0.25	0.4	0	0.2	0.286	0.428	1	0.6	0.6	0.286	0.286
206R02455	05/07/19	0	0	0	0	0.333	0.043	0	0	0	0.187	0.26
206R02560	05/08/19	0.143	0.286	0	0.143	0.375	1	0.999	0.999	1	0	0.188
207R01280	05/09/19	1	1	0	1	0	0	0	0	0	0	0
207R01655	05/06/19	1	0.5	0	0.5	0	1	1	1	1	0	0
544R02037	05/06/19	0.5	1	0	0.75	0	1	1	1	0.996	0	0
544R02505	06/12/19	0.667	0.25	0	0.25	0	0.994	0.995	0.995	1	0	0

D18 diatom IBI #18
H20 hybrid algae IBI #20
H21 hybrid algae IBI #21
H22 hybrid algae IBI #22
S2 soft algae IBI #2
(b) biovolume
(d) diatom
(m) mean of the species results
(s) soft algae, further defined as:
(sp) species counts
Note: Calculations based on either species counts (sp) or biovolume (b); proportion ZHR (s, m) was based on the mean of the species and biovolume results.

Table A-5 Hybrid (diatom and soft algae) IBI (H20) and Individual Metric Scores for CCCWP Sites Sampled in 2019

Site Code	Creek Name	Sample Date	H20 IBI Score	Proportion Halobiontic (d) Score	Proportion High Cu Indicators (s, sp) Score	Proportion High DOC Indicators (s, sp) Score	Proportion Low TN Indicators (d) Score	Proportion Low TP Indicators (s, sp) Score	Proportion N Heterotrophs (d) Score	Proportion Requiring >50% DO Saturation (d) Score	Proportion Sediment Tolerant (Highly Motile) (d) Score
204R02180	Alamo Creek	6/12/19	42	7	0	2	1	0	8	8	8
204R02587	Moraga Creek	6/11/19	40	7	0	4	0	0	7	8	6
206R01792	Refugio Creek	5/8/19	22	1	0	6	1	0	3	7	0
206R02048	Rodeo Creek	6/13/19	31	1	3	5	2	0	7	3	4
206R02455	Wildcat Creek	5/7/19	48	2	10	10	0	0	7	7	2
206R02560	Refugio Creek	5/8/19	58	8	6	7	0	0	8	8	9
207R01280	Franklin Creek	5/9/19	19	2	0	0	1	0	4	5	3
207R01655	E Branch Grayson Creek	5/6/19	9	0	0	4	1	0	2	0	0
544R02037	Marsh Creek	5/6/19	34	0	0	0	1	0	8	9	9
544R02505	Marsh Creek	6/12/19	21	0	0	8	1	0	0	8	0

D18 diatom IBI #18
H20 hybrid algae IBI #20
H21 hybrid algae IBI #21
H22 hybrid algae IBI #22
S2 soft algae IBI #2
(b) biovolume
(d) diatom
(m) mean of the species results
(s) soft algae, further defined as:
(sp) species counts
Note: The overall IBI score was calculated by converting the sum of individual scores to a 100-point scale by summing the scores and multiplying by the number of metrics (sum x [100/80]).

Table A-6 Hybrid (diatom and soft algae) IBI (H21) and Individual Metric Scores for CCCWP Sites Sampled in 2019

Site Code	Creek Name	Sample Date	H21 IBI Score	Proportion Chlorophyta (s, b) Score	Proportion Halobiontic (d) Score	Proportion Low TP Indicators (d) Score	Proportion N Heterotrophs (d) Score	Proportion Requiring >50% DO Saturation (d) Score	Proportion Sediment Tolerant (Highly Motile) (d) Score	Proportion ZHR (s, b) Score
204R02180	Alamo Creek	06/12/19	60	10	7	1	8	8	8	0
204R02587	Moraga Creek	06/11/19	69	10	7	0	7	8	6	10
206R01792	Refugio Creek	05/08/19	33	10	1	2	3	7	0	0
206R02048	Rodeo Creek	06/13/19	37	6	1	2	7	3	4	3
206R02455	Wildcat Creek	05/07/19	41	9	2	0	7	7	2	2
206R02560	Refugio Creek	05/08/19	47	0	8	0	8	8	9	0
207R01280	Franklin Creek	05/09/19	36	10	2	1	4	5	3	0
207R01655	E Branch Grayson Creek	05/06/19	4	0	0	1	2	0	0	0
544R02037	Marsh Creek	05/06/19	39	0	0	1	8	9	9	0
544R02505	Marsh Creek	06/12/19	14	1	0	1	0	8	0	0

D18 diatom IBI #18
H20 hybrid algae IBI #20
H21 hybrid algae IBI #21
H22 hybrid algae IBI #22
S2 soft algae IBI #2
(b) biovolume
(d) diatom
(m) mean of the species results
(s) soft algae, further defined as:
(sp) species counts
Note: The overall IBI score was calculated by converting the sum of individual scores to a 100-point scale by summing the scores and multiplying by the number of metrics (sum x [100/70]).

Table A-7 Hybrid (diatom and soft algae) IBI (H23) and Individual Metric Scores for CCCWP Sites Sampled in 2019

Site Code	Creek Name	Sample Date	H23 IBI Score	Proportion Halobiontic (d) Score	Proportion High DOC Indicators (s, sp) Score	Proportion Low TP Indicators (d) Score	Proportion N Heterotrophs (d) Score	Proportion Green Algae Belonging to CRUS (s, b) Score	Proportion Requiring >50% DO Saturation (d) Score	Proportion Sediment Tolerant (Highly Motile) (d) Score	Proportion ZHR (s, m) Score
204R02180	Alamo Creek	06/12/19	58	7	2	1	8	10	8	8	2
204R02587	Moraga Creek	06/11/19	65	7	4	0	7	10	8	6	10
206R01792	Refugio Creek	05/08/19	39	1	6	2	3	10	7	0	2
206R02048	Rodeo Creek	06/13/19	39	1	5	2	7	4	3	4	5
206R02455	Wildcat Creek	05/07/19	52	2	10	0	7	10	7	2	4
206R02560	Refugio Creek	05/08/19	54	8	7	0	8	0	8	9	3
207R01280	Franklin Creek	05/09/19	31	2	0	1	4	10	5	3	0
207R01655	E Branch Grayson Creek	05/06/19	9	0	4	1	2	0	0	0	0
544R02037	Marsh Creek	05/06/19	35	0	0	1	8	1	9	9	0
544R02505	Marsh Creek	06/12/19	21	0	8	1	0	0	8	0	0

D18 diatom IBI #18
H20 hybrid algae IBI #20
H21 hybrid algae IBI #21
H22 hybrid algae IBI #22
S2 soft algae IBI #2
(b) biovolume
(d) diatom
(m) mean of the species results
(s) soft algae, further defined as:
(sp) species counts
Note: The overall IBI score was calculated by converting the sum of individual scores to a 100-point scale by summing the scores and multiplying by the number of metrics (sum x [100/80]).

Contra Costa Clean Water Program

Integrated Local/Targeted Creek Status Monitoring Report: Water Years 2014-2019

(October 2013-September 2019)

March 18, 2020

Submitted to

Contra Costa Clean Water Program
255 Glacier Drive
Martinez, California 94553

Submitted by

ADH Environmental
3065 Porter Street, Suite 101
Soquel, California 95073

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Acronyms and Abbreviations

ACCWP	Alameda Countywide Clean Water Program
ADH	ADH Environmental
ARC	Armand Ruby Consulting
BASMAA	Bay Area Stormwater Management Agencies Association
CCCWP	Contra Costa Clean Water Program
CFU	colony forming units
COLD	cold freshwater habitat (steelhead stream)
CRAM	California Rapid Assessment Method
CVRWQCB	Central Valley Regional Water Quality Control Board
DO	dissolved oxygen
EBMUD	East Bay Municipal Utility District
FSURMP	Fairfield-Suisun Urban Runoff Management Program
GM	geometric mean
MPN	most probable number
MQO	measurement quality objective
MRP	municipal regional stormwater permit
MWAT	maximum weekly average temperature
NPDES	National Pollutant Discharge Elimination System
pH	hydrogen ion concentration
QAPP	quality assurance project plan
Region 2	San Francisco Bay Regional Water Quality Control Board
Region 5	Central Valley Regional Water Quality Control Board
RMC	Regional Monitoring Coalition
RPD	relative percent difference
RWQC	recreational water quality criteria
SCVURPPP	Santa Clara Valley Urban Runoff Pollution Prevention Program
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SMCWPPP	San Mateo Countywide Water Pollution Prevention Program
SOP	standard operating procedure
SSID	stressor/source identification
STV	statistical threshold value
SWAMP	Surface Water Ambient Monitoring Program
USEPA	U.S. Environmental Protection Agency
WARM	warm water habitat (non-steelhead streams)
WAT	weekly average temperature
WQOs	water quality objectives
WY	water year
YSI	Yellow Springs Instrument Company

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Preface

In early 2010, several members of the Bay Area Stormwater Management Agencies Association (BASMAA) joined to form the Regional Monitoring Coalition (RMC) to coordinate and oversee water quality monitoring required by the Municipal Regional Stormwater Permit (MRP). The RMC includes the following stormwater program participants:

- Alameda Countywide Clean Water Program
- Contra Costa Clean Water Program
- San Mateo Countywide Water Pollution Prevention Program
- Santa Clara Valley Urban Runoff Pollution Prevention Program
- Fairfield-Suisun Urban Runoff Management Program
- City of Vallejo and Vallejo Sanitation and Flood Control District

In accordance with the BASMAA RMC Creek Status and Long-Term Trends Monitoring Plan (EOA and ARC, 2011), monitoring data were collected following methods and protocols specified in the BASMAA RMC Quality Assurance Project Plan (QAPP; BASMAA, 2016a) and BASMAA RMC Standard Operating Procedures (BASMAA, 2016b). Where applicable, monitoring data were derived using methods comparable with methods specified by the California Surface Water Ambient Monitoring Program (SWAMP) QAPP. Data presented in this report were also submitted to the Moss Landing Marine Laboratories Regional Data Center for submittal to the State Water Resources Control Board on behalf of the Contra Costa Clean Water Program's permittees and pursuant to permit provision C.8.h.ii requirements for electronic data reporting.

This Integrated Local/Targeted Creek Status Monitoring Report documents the results of targeted (non-probabilistic) monitoring performed by the Contra Costa Clean Water Program in water year 2019 (Oct. 1, 2018-Sep. 30, 2019) and presents detailed comprehensive analyses of results from previous creek status monitoring years (Oct. 1, 2013-Sep. 30, 2018). Together with the creek status monitoring data reported in Integrated Regional/Probabilistic Creek Status Monitoring Report: Water Years 2014-2019 (ARC, 2020), this submittal fulfills monitoring requirements specified in provision C.8.d and C.8.g of the permit, and complies with reporting provision C.8.h.v of the MRP (SFBRWQCB, 2015a).

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Executive Summary

This Integrated Local/Targeted Creek Status Monitoring Report was prepared by the Contra Costa Clean Water Program (CCCWP) in compliance with the National Pollutant Discharge Elimination System (NPDES) Municipal Regional Stormwater Permit (MRP) issued by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB; Order No. R2-2015-0049). This report documents the results of targeted (non-probabilistic) monitoring performed by CCCWP in water year 2019 (Oct. 1, 2018-Sep. 30, 2019) and presents a detailed comprehensive analysis of results from previous creek status monitoring years (Oct. 1, 2013-Sep. 30, 2018). Together with the creek status monitoring data reported in Integrated Regional/Probabilistic Creek Status Monitoring Report: Water Years 2014-2019 (ARC, 2020), this submittal fulfills monitoring requirements specified in provision C.8.d and C.8.g of the permit, and complies with reporting provision C.8.h.v of the MRP (SFBRWQCB, 2015a).

Within Contra Costa County, targeted monitoring was conducted at:

- Four continuous water temperature monitoring locations
- Two continuous general water quality monitoring locations
- Five pathogen indicator monitoring locations
- Ten riparian assessment monitoring locations (CRAM stream surveys)

Continuous Water Temperature

Hourly water temperature measurements were recorded at 60-minute intervals using Onset® HOBO® data loggers (HOBOs) deployed in two creeks at four separate locations on Apr. 9, 2019. One device was deployed in Rodeo Creek, and three devices were deployed in San Pablo Creek. The HOBOs were retrieved on Oct. 3, 2019. As the permit term reporting requirements apply only to the extent of a given water year, all data collected after Sep. 30, 2019 are not included in this report.

Pathogen Indicators

Samples were collected on Jun. 26, 2019 at five stations along five separate creeks in Contra Costa County. Samples were analyzed for enterococci and *E. coli.* The five sampling locations were located at Alhambra Creek, Pinole Creek, Marsh Creek, Baxter Creek and East Antioch Creek.

General (Continuous) Water Quality

Temperature, dissolved oxygen (DO), hydrogen ion concentration (pH), and specific conductance were continuously monitored at 15-minute intervals by sonde devices during two time periods (May 7-21, 2019 and Aug. 13-23, 2019) at one location along Rodeo Creek (206R00960) and one location along San Pablo Creek (206SPA230).

Results of Targeted Monitoring Data

All targeted monitoring data were evaluated against numeric trigger thresholds, as described in MRP provision C.8.d. These thresholds, which include applicable numeric water quality objectives or other applicable criteria, indicate levels at which additional follow-up may be required under the MRP. Targeted monitoring locations for water year 2019 were located within both SFBRWQCB Region 2 and CVRWQCB Region 5 boundaries. Numeric thresholds are discussed in this report as they are stated in MRP provision C.8.d and are summarized below.

Temperature – HOBOs and Sondes

The trigger threshold for temperature is defined in the MRP for all streams as 20 percent or more of instantaneous results exceeding 24° C. For streams documented to support steelhead fisheries (i.e., steelhead streams), a maximum weekly average temperature (MWAT) of 17° C is used as the applicable criterion to evaluate temperature data. Per the MRP, for the HOBO temperature data, a maximum of one weekly average temperature (WAT) can exceed the threshold of 17° C during the deployment period. For temperature data recorded by sonde devices, which are deployed for a much briefer period (one to two weeks), all WATs must be below 17° C.

For the purpose of this report, creeks with designated beneficial uses listed in Table i as cold freshwater habitat (COLD) are evaluated as steelhead streams, while creeks designated only as warm freshwater habitat (WARM) are referred to as non-steelhead streams.

For water year 2019, per permit guidelines, only streams designated as COLD freshwater habitat were targeted for temperature monitoring.

At the four locations with continuously recorded HOBO temperature data from April until September, both creeks (Rodeo Creek and San Pablo Creek) are classified as steelhead streams.

Temperature was continuously monitored by sonde device during two time periods (May 7-21, 2019 and Aug. 13-23, 2019) in Rodeo Creek and San Pablo Creek.

No water year 2019 temperature monitoring location recorded more than 20 percent instantaneous results above 24° C; therefore, there were no exceedances of this criterion.

There were exceedances of the 17° C WAT threshold in five of eight cases. These locations were Rodeo Creek and all three locations along San Pablo Creek for the HOBO data, and San Pablo Creek for the sondes data during the August deployment. No temperature exceedance occurred for the sondes data during the Rodeo Creek deployment period.

Dissolved Oxygen (DO)

The MRP trigger threshold for dissolved oxygen in non-tidal waters is applied as follows: for waters designated as steelhead streams, no more than 20 percent of instantaneous dissolved oxygen results may drop below 7.0 mg/L.

During the May monitoring period, the 20 percent threshold was not exceeded (DO results of less than 7.0 mg/L) for dissolved oxygen measurements in Rodeo Creek and San Pablo Creek. During the August deployment at Rodeo Creek, dissolved oxygen measurements were recorded below the MRP trigger threshold 100 percent of the time. For San Pablo Creek, the 20 percent threshold was not exceeded during the August deployment.

Table i. Designated Beneficial Uses Listed in the Basin Plan for CCCWP Targeted Monitoring Sites – Water Years 2014-2019

			Human Consumptive Uses							Aquatic Life Uses									Recreational Uses		
Water Year	Site ID	Water Body	AGR	MUN	FRSH	GWR	IND	PROC	COMM	SHELL	COLD	EST	MAR	MIGR	RARE	SPWN	WARM	WILD	REC-1	REC-2	NAV
2014	206RO025	Rodeo Creek									E					E	E	E	E	E	
	206R01024	Rodeo Creek									E					E	E	E	E	E	
	206RO003	Rodeo Creek									E					E	E	E	E	E	
	206R00551	San Pablo Creek			E						E			E	E	E	E	E	E*	E	
2015	204R00388	West Branch Alamo Creek				E					P			E	E	E	E	E	E	E	
	207R00891	Green Valley Creek															E	E	E	E	
	206R01319	San Pablo Creek			E						E			E	E	E	E	E	E*	E	
	207R01163	San Ramon Creek															E	E	E	E	
2016	207R01307	Lafayette Creek									E						E	E	E	E	
	204R01412	West Branch Alamo Creek				E					P			E	E	E	E	E	E	E	
	204R01519	Rimer Creek			E						E					E	E	E	E	E	
	204R01604	West Branch Alamo Creek				E					P			E	E	E	E	E	E	E	
2017	207R01447	Franklin Creek									E			E	E	E	E	E	E	E	
	207R02635	Las Trampas Creek									E				E		E	E	E	E	
	207R02891	Las Trampas Creek									E				E		E	E	E	E	
	207R04544	Alhambra Creek									E			E	E	E	E	E	E	E	
2018	207ALH015	Alhambra Creek									E			E	E		E	E	E	E	
	207ALH110	Alhambra Creek									E						E	E	E	E	
	206SPA125	San Pablo Creek			E						E			E	E	E	E	E	E*	E	
	206R01495	Pinole Creek									E			E	E	E	E	E	E	E	
2019	206R00551	San Pablo Creek			E						E			E	E	E	E	E	E*	E	
	206R01319	San Pablo Creek			E						E			E	E	E	E	E	E*	E	
	206SPA230	San Pablo Creek			E						E			E	E	E	E	E	E*	E	
	206R00960	Rodeo Creek									E					E	E	E	E	E	

E Existing beneficial use
E* Water quality objectives apply; water contact recreation is prohibited or limited to protect public health
P Potential beneficial use

Notes:

Per Basin Plan Ch. 2 (SFBRWQCB, 2015b), beneficial uses for freshwater creeks include municipal and domestic supply (MUN), agricultural supply (AGR), industrial process supply (PRO), groundwater recharge (GWR), water contact recreation (REC1), noncontact water recreation (REC2), wildlife habitat (WILD), cold freshwater habitat (COLD), warm freshwater habitat (WARM), fish migration (MIGR), and fish spawning (SPWN). The San Francisco Bay Estuary supports estuarine habitat (EST), industrial service supply (IND), and navigation (NAV) in addition to all uses supported by streams. Beneficial uses for coastal waters include water contact recreation (REC1); noncontact water recreation (REC2); industrial service supply (IND); navigation (NAV); marine habitat (MAR); shellfish harvesting (SHELL); ocean, commercial and sport fishing (COMM); and preservation of rare and endangered species (RARE).

pH

The MRP trigger threshold for pH in surface waters is applied as follows: no more than 20 percent of instantaneous pH results may fall outside the range of 6.5 to 8.5. This range was used to evaluate the pH data collected at all targeted locations over water year 2019.

During the May monitoring period at San Pablo Creek, 21 percent of results failed to meet pH criterion, exceeding the MRP threshold of 20 percent of instantaneous results. During the August monitoring period, the pH of San Pablo Creek always met the MRP criterion. During both the May and August deployment periods, the pH of Rodeo Creek always met MRP criterion.

Specific Conductance

The MRP trigger threshold for specific conductance in surface waters is applied as follows: no more than 20 percent of instantaneous specific conductance results may exceed 2,000 µS/cm, and readings should not indicate a spike in specific conductance with no obvious natural explanation.

During the May monitoring period, specific conductance measurements in Rodeo Creek and San Pablo Creek always met MRP criterion. During the August deployment period in Rodeo Creek, specific conductance measurements were recorded above the 2,000 µS/cm threshold 100 percent of the time. For San Pablo Creek, the 20 percent threshold was not exceeded during the August deployment.

Pathogen Indicator Bacteria

The single sample maximum concentrations of 130 CFU/100 ml for enterococci and 410 CFU/100 ml for *E. coli* were used as water contact recreation evaluation thresholds for the purposes of this evaluation, based on an adaptation of the recommended water quality criteria established by U.S. Environmental Protection Agency (USEPA) to protect recreational uses (USEPA, 2012).

For enterococci, three out of five single sample concentrations (Alhambra Creek, Marsh Creek and Pinole Creek) exceeded the single sample threshold concentration. For *E. coli,* three of the five stations (Alhambra Creek, Marsh Creek and Pinole Creek) exceeded the threshold concentration for water contact recreation criteria.

Exceedances for each of the above parameters are summarized in Table ii.

Table ii. CCCWP Threshold Exceedances – Water Year 2019

Creek	Index Period	Parameter	Threshold Exceedance
Rodeo Creek at Franklin Canyon Golf Course	08/21/19-09/03/19	Continuous Water Temperature (HOBO)	Two or more WATs exceed 17° C
San Pablo Creek at Fred Jackson Way (Richmond)	06/05/19-07/02/19 07/10/19-09/03/19 09/11/19-09/17/19	Continuous Water Temperature (HOBO)	Two or more WATs exceed 17° C
San Pablo Creek at Church Lane (San Pablo)	06/05/19-06/11/19 08/07/19-09/24/19	Continuous Water Temperature (HOBO)	Two or more WATs exceed 17° C
San Pablo Creek at Santa Maria Way (Orinda)	06/05/19-06/18/19 07/10/19-09/17/19	Continuous Water Temperature (HOBO)	Two or more WATs exceed 17° C
San Pablo Creek at Santa Maria Way (Orinda)	08/13/19-08/23/19	Continuous Water Temperature (sonde)	One WAT exceeds 17° C
San Pablo Creek at Santa Maria Way (Orinda)	05/07/19-05/21/19	Continuous Water Quality – pH	20% of instantaneous results below 6.5 or above 8.5
Rodeo Creek at Franklin Canyon Golf Course	08/13/19-08/23/19	Continuous Water Quality – DO	20% of instantaneous results below 7.0 mg/L
Rodeo Creek at Franklin Canyon Golf Course	08/13/19-08/23/19	Continuous Water Quality – Specific Conductance	20% of instantaneous results above 2,000 µS/cm
Alhambra Creek	06/26/19	Enterococci	Single grab sample exceeded USEPA criterion of 130 CFU/100 ml
Marsh Creek	06/26/19	Enterococci	Single grab sample exceeded USEPA criterion of 130 CFU/100 ml
Pinole Creek	06/26/19	Enterococci	Single grab sample exceeded USEPA criterion of 130 CFU/100 ml
Alhambra Creek	06/26/19	*E. coli*	Single grab sample exceeded USEPA criterion of 410 CFU/100 ml
Marsh Creek	06/26/19	*E. coli*	Single grab sample exceeded USEPA criterion of 410 CFU/100 ml
Pinole Creek	06/26/19	*E. coli*	Single grab sample exceeded USEPA criterion of 410 CFU/100 ml

CFU colony forming unit
DO dissolved oxygen
WAT weekly average temperature

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1. Introduction

Contra Costa County lies within both the Region 2 and Region 5 jurisdictions of the State Water Resources Control Board. The countywide stormwater program is subject to both the Region 2 municipal regional stormwater National Pollutant Discharge Elimination System (NPDES) permit (MRP) and the Region 5 permit (Central Valley Permit). Municipal stormwater discharges in Contra Costa County are regulated by the requirements of both the municipal regional permit (MRP) for urban stormwater in Region 2 (Order No. R2-2015-0049)[1] and the East Contra Costa County municipal National Pollutant Discharge Elimination System (NPDES) permit (Central Valley Permit) in Region 5 (Order No. R5-2010-0102)[2]. Prior to the reissuance of MRP Order No. R2-2015-0049, the requirements of the two permits were effectively identical. With the reissued MRP in 2015, some differences between the permits led to an agreement between the Central Valley and San Francisco Bay Regional Water Quality Control Boards, where sites in the Central Valley Region (Region 5) will continue to be sampled as part of the creek status monitoring required by both permits, with monitoring and reporting requirements prevailing under the jurisdiction of the Region 2 MRP (Order No. R2-2019-0004)[3].

Beginning in 2010, members of the Bay Area Stormwater Management Agencies Association (BASMAA) formed the Regional Monitoring Coalition (RMC) to collaboratively implement the monitoring requirements found in provision C.8 of the MRP. The participants of the RMC are listed in Table 1. The BASMAA RMC developed a quality assurance project plan (QAPP) (BASMAA, 2016a), standard operating procedures (SOPs) (BASMAA, 2016b), data management tools, and reporting templates and guidelines. Costs for these activities are shared among RMC members on a population-weighted basis by direct contributions and provision of in-kind services by RMC members to complete required tasks. Participation in the RMC is facilitated through the BASMAA Monitoring and Pollutants of Concern Committee.

The goals of the RMC are to:

1. Assist RMC permittees in complying with requirements of MRP provision C.8 (water quality monitoring);
2. Develop and implement regionally consistent creek monitoring approaches and designs in the Bay Area through improved coordination among RMC participants and other agencies (e.g., regional water quality control boards, Regions 2 and 5, and the State Water Resources Control Water Board), which share common goals; and
3. Stabilize the costs of creek monitoring by reducing duplication of efforts and streamlining reporting.

The RMC divided the creek status monitoring requirements specified by permit provisions into those parameters which could reasonably be included within a regional/probabilistic design, and those which,

[1] The SFBRWQCB issued the five-year municipal regional permit for urban stormwater (MRP, Order No. R2-2015-0049) to 76 cities, counties and flood control districts (i.e., permittees) in the Bay Area on Nov. 19, 2015 (SFBRWQCB, 2015a). The BASMAA programs supporting MRP regional projects include all MRP permittees, as well as the cities of Antioch, Brentwood, and Oakley, which are not named as permittees under the MRP but have voluntarily elected to participate in MRP-related regional activities.

[2] The CVRWQCB issued the East Contra Costa County municipal NPDES permit (Central Valley Permit, Order No. R5-2010-0102) on September 23, 2010 (CVRWQCB, 2010). This permit is now superseded by Order R2-2019-0004, incorporating the eastern portion of Contra Costa County within the requirements of the MRP (Order No. R2-2015-0049).

[3] The SFBRWQCB, per agreement with the CVRWQCB, adopted Order No. R2-2019-004 on Feb. 13, 2019.

for logistical and jurisdictional reasons, should be implemented locally using a targeted (non-probabilistic) design. The monitoring elements included in each design category are specified in Table 2.

Table 1. Regional Monitoring Coalition Participants

Stormwater Programs	RMC Participants
Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)	Cities of Campbell, Cupertino, Los Altos, Milpitas, Monte Sereno, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, Sunnyvale, Los Altos Hills, and Los Gatos; Santa Clara Valley Water District; and Santa Clara County
Alameda Countywide Clean Water Program (ACCWP)	Cities of Alameda, Albany, Berkeley, Dublin, Emeryville, Fremont, Hayward, Livermore, Newark, Oakland, Piedmont, Pleasanton, San Leandro, and Union City; Alameda County; Alameda County Flood Control and Water Conservation District; and Zone 7
Contra Costa Clean Water Program (CCCWP)	Cities of Antioch, Brentwood, Clayton, Concord, Town of Danville, El Cerrito, Hercules, Lafayette, Martinez, Town of Moraga, Oakley, Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon, Walnut Creek; Contra Costa County Flood Control and Water Conservation District; and Contra Costa County Watershed Program
San Mateo County Wide Water Pollution Prevention Program (SMCWPPP)	Cities of Belmont, Brisbane, Burlingame, Daly City, East Palo Alto, Foster City, Half Moon Bay, Menlo Park, Millbrae, Pacifica, Redwood City, San Bruno, San Carlos, San Mateo, South San Francisco, Atherton, Colma, Hillsborough, Portola Valley, and Woodside; San Mateo County Flood Control District; and, San Mateo County
Fairfield-Suisun Urban Runoff Management Program (FSURMP)	Cities of Fairfield and Suisun City
Vallejo Permittees	City of Vallejo and Vallejo Sanitation and Flood Control District

Table 2. Creek Status Monitoring Elements per MRP Provisions C.8.d. and C.8.g., Monitored as Either Regional/Probabilistic or Local/Targeted Parameters

Biological Response and Stressor Indicators	Monitoring Design	
	Regional (Probabilistic)	Local (Targeted)
Bioassessment, physical habitat assessment, CSCI	X	X[1]
Nutrients (and other water chemistry associated with bioassessment)	X	X[1]
Chlorine	X	X[2]
Stream Surveys (CRAM)		X[3,4]
Water toxicity (wet and dry weather)	NA	NA
Water chemistry (pesticides, wet weather)	NA	NA
Sediment toxicity (dry weather)	NA	NA
Sediment chemistry (dry weather)	NA	NA
Continuous water quality (sondes data: temperature, dissolved oxygen, pH, specific conductance)		X
Continuous water temperature (data loggers)		X
Pathogen indicators (bacteria)		X

CSCI California Stream Condition Index

CRAM California Rapid Assessment Method

1 Provision C.8.d.i.(6) allows for up to 20 percent of sample locations to be selected under a targeted monitoring design. This design change was made under MRP Order No. R2-2015-0049.

2 Provision C.8.d.ii.(2) provides options for probabilistic or targeted site selection. In water years 2014-2019, chlorine was measured at probabilistic sites.

3 Under MRP Order No. R2-2009-0074, stream surveys (stream walking and mapping) were required and sampled under a probabilistic monitoring design. The sampling method specified is the United Stream Assessment or equivalent. In water years 2014-2015, the California Rapid Assessment Method was selected.

4 The stream survey requirement was removed under MRP Order No. R2-2015-0049; therefore, data presented in this report were collected pursuant to MRP Order No. R2-2009-0074 and is applicable to water years 2014 and 2015 only.

NA Monitoring parameter not specific to either monitoring design

This report focuses on the creek status and long-term trends monitoring activities conducted to comply with provision C.8.d using a targeted (non-probabilistic) monitoring design (see Table 2). The report documents the results of targeted monitoring performed by Contra Costa Clean Water Program (CCCWP) during water year (WY) 2019 and provides a comprehensive analysis of all local/targeted data collected pursuant to MRP Provision C.8.d since the previous Integrated Monitoring Report (water years 2014-2019). Together with the creek status monitoring data reported in Integrated Regional/Probabilistic Creek Status Monitoring Report: Water Years 2014-2019 (ARC, 2020), this submittal fulfills monitoring and reporting requirements for creek status monitoring in provisions C.8.d and C.8.g of the permit, and complies with reporting provision C.8.h.v of the MRP (SFBRWQCB, 2015a). The remainder of this report describes the study area and design (Section 2), monitoring methods (Section 3), results and discussion (Section4), and next steps (Section 5).

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2. Study Area and Design

2.1. Regional Monitoring Coalition Area

The RMC area encompasses 3,407 square miles of land in the San Francisco Bay Area. This includes the portions of the five participating counties which fall within the jurisdiction of the SFBRWQCB. Figure 1 displays the BASMAA RMC area and illustrates the boundary of the State Water Resources Control Board (Regions 2 and 5) within Contra Costa County. The eastern portion of Contra Costa County drains to the CVRWQCB region (Region 5), while the rest of the county drains into Region 2. Status and trends monitoring is conducted in flowing water bodies (i.e., creeks, streams and rivers) interspersed among the RMC area, including perennial and non-perennial creeks and rivers running through both urban and non-urban areas.

Contra Costa County has 31 major watersheds and sub-watersheds containing more than 1,300 miles of creeks and drainages (CCCDD, 2003). The county's creeks discharge into the Sacramento-San Joaquin Delta in the east, along the series of bays to the north (including Suisun and San Pablo bays), and to North San Francisco Bay in the west. In addition, two watersheds (Upper San Leandro and Upper Alameda Creek) originate in Contra Costa County and continue through Alameda County before reaching San Francisco Bay.

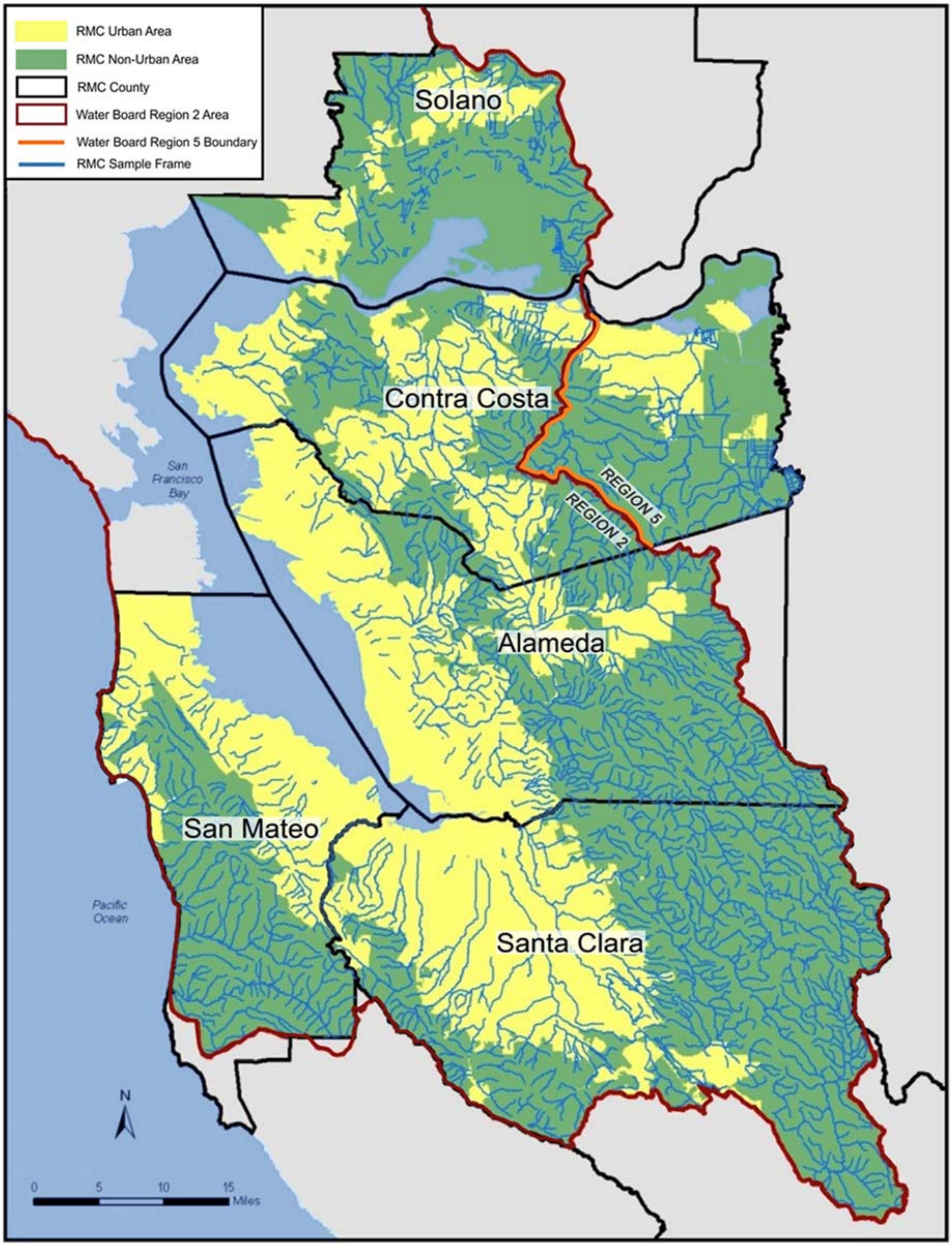
2.2. Contra Costa County Targeted Monitoring Areas and Siting Rationale – Water Year 2019

In water year 2019, two of the county's watersheds were the focus of targeted general water quality and water temperature monitoring, while five locations (each in individual watersheds) were selected for pathogen indicator sampling. In Region 2, the Rodeo Creek and San Pablo Creek watersheds were selected for continuous water quality and water temperature monitoring, while the Alhambra Creek, Baxter Creek and Pinole Creek watersheds were sampled for pathogen indicators. In Region 5, the East Antioch Creek and Marsh Creek watersheds were targeted for pathogen indicators sampling. Details discussing the water year 2019 siting rationale and watershed overview are discussed below, while further discussion about targeted sampling rationale and watershed overview of previous water year monitoring locations can be found in the Integrated Monitoring Report Bibliography (2014-2018).

2.2.1. Alhambra Creek

The Alhambra Creek watershed is in the northwestern part of Contra Costa County, spanning 10,735 acres. The watershed originates in the Briones Hills, encompassed by Briones Regional Park, and travels 7.88 miles to the Carquinez Strait in the City of Martinez. From the Briones Hills, the upper watershed retains a rural character, traveling through open tracts and agricultural lands. Upon its descent, the lower watershed maintains a rural feeling at higher elevations, while the flood plain at lower elevations is defined by a heavily urbanized area driven by 100 years of industrialization in the City of Martinez (CCCDD, 2003).

Figure 1. Map of BASMAA RMC Area, County Boundaries, and Major Creeks



The Alhambra Creek watershed has two major tributaries – Franklin Creek and Arroyo Del Hambre – which help comprise the watershed's total channel length of 48.08 miles. The watershed is predominantly natural, with 87 percent of the channel length containing no obvious reinforcements and 13 percent containing either concrete or earthen reinforcements (CCCDD, 2003).

CCCWP sampled one location in the Alhambra Creek watershed during water year 2019, which was targeted for pathogen indicator sampling. Located on Alhambra Creek between Main Street and Ward Street, the sampling location was selected for its proximity to downtown Martinez and easy stream access points for the general public. In addition to available general public access points, a network of homeless encampments in the riparian corridor were identified as having the possibility to negatively impact the designated beneficial uses of Alhambra Creek.

2.2.2. Baxter Creek

The Baxter Creek watershed is in western Contra Costa County, with headwaters in the northern extent of the East Bay Hills. Baxter Creek and its tributaries (14.44 miles) originate in underground springs beneath El Cerrito's Berkeley Country Club and flow down from the hills in three branches. After running through a series of neighborhood parks, the creeks join near the Gateway property at San Pablo and Macdonald Avenues. The creek then flows through Richmond into Stege Marsh and San Francisco Bay (CCCWP, 2004).

Many areas in the Baxter Creek watershed were lined or culverted during the first half of the twentieth century to accommodate the new urbanization and prevent flooding in the lower watersheds. This relatively level area between the Berkeley Hills and Point Richmond is now drained by an extensive municipal stormwater system, leaving only 41.2 percent of the Baxter Creek watershed in a natural state containing no obvious reinforcements (CCCWP, 2004).

CCCWP sampled one location in the Baxter Creek watershed during water year 2019, which was targeted for pathogen indicator sampling. The area of Baxter Creek near Gateway Park along the western side of San Pablo Avenue was selected for its proximity to the Richmond Greenway Trail and evidence of high impact use of in-stream homeless encampments. The site along Baxter Creek was targeted for pathogen indicator sampling to determine if the presence of homeless encampments in the area negatively impacts the stream's designated beneficial uses.

2.2.3. East Antioch Creek

The East Antioch Creek watershed is in the northeastern part of Contra Costa County. It is part of the creek system in this region which drains from the hills south of Antioch to the Sacramento-San Joaquin River Delta. The main stem of East Antioch Creek flows from its low elevation headwaters near Lone Tree Way in Antioch along a 7.87-mile branch which passes through various detention basins, levees, and culverts. The vast majority of the 7,261-acre watershed consists of low topography, with the highest elevation in the East Antioch Creek system near the headwaters at 327 feet (CCCDD, 2003).

For water year 2019, one location was selected for targeted monitoring along East Antioch Creek. The sampling location was selected at the outflow of Lake Alhambra, a small man-made lake upstream of the tidal boundary with the Sacramento-San Joaquin River Delta. The location was selected to determine how the lake and nearby homeless encampments may be impacting the designated beneficial uses of East Antioch Creek.

2.2.4. Marsh Creek

The Marsh Creek watershed lies in the northeastern part of Contra Costa County. The headwaters flow from the eastern flank of Mount Diablo, across the Morgan Territory preserve and Mount Diablo foothills into Marsh Creek Reservoir. From its headwaters, Marsh Creek experiences a range of hydrologic, geologic and topographic changes as it descends steep rocky terrain and enters the alluvial plain downstream of the Marsh Creek Reservoir. The second largest watershed in the county, it encompasses over 60,000 acres and flows 34.57 miles before exiting into the Sacramento-San Joaquin River Delta at Big Break Regional Shoreline (CCCWP, 2004).

Historically, Marsh Creek meandered through the alluvial area north of the Marsh Creek reservoir. After the turn of the century however, farmers and flood control authorities altered the channel and surrounding landscape to protect agricultural resources which have served the area since the mid-1800s. This intended alteration of flow, including the building of levees, dams, detention basins and reservoirs, led to a severe reduction in riparian vegetation and habitat, which then led to significant development within the City of Brentwood (CCCWP, 2004). The alteration from the creek's natural state in the lower watershed and active and historic agricultural use made the Marsh Creek watershed a targeted sampling location for CCCWP when determining the urban impacts on receiving waters to the Sacramento-San Joaquin Delta.

CCCWP sampled one location in the Marsh Creek watershed during water year 2019, which was targeted for pathogen indicator sampling. The area of Marsh Creek as it passes under East Cypress Road in the City of Oakley was selected for its proximity to the Marsh Creek Regional Trail and evidence of high impact use of in-stream and near-stream homeless encampments. The site along Marsh Creek was targeted for pathogen indicator sampling to determine if the presence of homeless encampments in the area negatively impacts the stream's designated beneficial uses.

2.2.5. Pinole Creek

Pinole Creek is a perennial stream which drains the 9,705-acre Pinole Creek watershed in western Contra Costa County. With headwaters in the Briones Hills, Pinole Creek flows roughly northwest to San Pablo Bay across oak woodlands, private ranchlands, and lightly developed urban landscapes. The central reaches of Pinole Creek and its tributaries run approximately six miles through a broad, open valley with a relatively intact floodplain until reaching the urbanized area around the Pinole city limits. The City of Pinole occupies the northern third of the watershed, which was originally settled in the broad alluvial floodplain of Pinole Creek. As Pinole Creek descends from the East Bay foothills into the town of Pinole, Interstate 80 forms a man-made margin where the natural stream channel gives way to confined flood control channels. The length of the longest branch of the creek is 10.95 miles with an estimated mean daily flow of 10.4 cubic feet per second (CCCDD, 2003).

CCCWP sampled one location in the Pinole Creek watershed during water year 2019, which was targeted for pathogen indicator sampling. Located on Pinole Creek just north of the San Pablo Avenue culvert in the City of Pinole, the sampling location was selected for its proximity to Fernandez Park and easy stream access points for the general public. The sampling location along Pinole Creek was selected to determine if the location meets pathogen indicator water quality standards for the designated beneficial uses.

2.2.6. Rodeo Creek

Located in the northwest corner of Contra Costa County, the full watershed of Rodeo Creek is 6,657 acres and flows in a northwesterly direction for 8.35 miles before draining into the western end of the Carquinez Strait (CCCDD, 2003). Formed by numerous tributaries flowing off the west slopes of Franklin Ridge, Rodeo Creek has a mean daily flow of 7.0 cubic feet per second with 20 percent of its watershed being impervious surface. The creek's upper watershed is private ranchland and East Bay Regional Park District property, while the lower watershed is characterized by residential housing, industrial zones, and commercial properties in the town of Rodeo.

In 2019, CCCWP monitored Rodeo Creek to determine if water temperature and general water quality criteria were within MRP 2 thresholds, as the stream maintains a current beneficial use as a cold-water habitat (COLD). Located midway up the watershed, roughly four miles from the creek mouth at Carquinez Strait, the 2019 monitoring location was in a perennial section of Rodeo Creek as it parallels Franklin Canyon Golf Course in the City of Hercules.

2.2.7. San Pablo Creek

The full watershed of San Pablo Creek is 27,640 acres, arising in the City of Orinda at a maximum elevation of 1,905 feet and flowing westerly 19.65 miles to San Pablo Bay. After leaving Orinda, San Pablo Creek flows across East Bay Municipal Utility District (EBMUD) land into San Pablo Reservoir. Water released from San Pablo Reservoir flows into lower San Pablo Creek, where it crosses first through rural and then through heavily urbanized residential and commercial property. Earthen or concrete channelized portions of San Pablo Creek amount to 10.6 percent of the entire channel and occur as it passes through the City of San Pablo. Impervious surface in the San Pablo Creek watershed is calculated at 20 percent (CCCDD, 2003).

Covering 43.5 square miles in west Contra Costa County, the San Pablo Creek watershed is characteristic of other west county watersheds, as the lower portions reflect years of occupation and industrialization in the Cities of San Pablo and Richmond, and the headwaters are occupied by semi-rural residential areas in the City of Orinda and unincorporated Contra Costa County. The San Pablo Reservoir, a major feature of the watershed, has a capacity of 38,600 acre-feet of water and is regulated by EBMUD. To the north of the San Pablo Reservoir, tributary headwaters also enter the Briones Reservoir (a reserve to the San Pablo Reservoir) and is regulated by EBMUD. The surrounding lands adjacent to these reservoirs currently maintain a protected watershed status, providing habitat for numerous species of plants and animals in the region. This habitat is further enhanced by the adjacent East Bay Regional Park lands of Briones and Tilden Regional Parks (CCCWP, 2004).

In water year 2019, there were three water temperature monitoring stations on San Pablo Creek: two monitoring stations downstream of San Pablo Reservoir (site IDs 206R01319 and 206R00551) and one location upstream of San Pablo Reservoir (site ID 206SPA230). The upstream monitoring location was also targeted to monitor general water quality criteria and was selected to determine if San Pablo Creek meets water quality standards for the currently designated beneficial use as a steelhead stream.

2.3. Contra Costa Targeted Monitoring Design

In water years 2014 and 2015, stream surveys using the California Rapid Assessment Method (CRAM) were conducted at targeted locations approximately one month following bioassessments at the same locations (Table 3, Figure 2).

Site locations were identified using a targeted monitoring design to address the following management questions:

1. What are the overall physical and/or ecological conditions of creek reaches based on visible indicators within each reach?
2. Do stream surveys using CRAM data provide a useful utility to correlate aquatic biological conditions at reaches scored using the California Stream Condition Index?

In water years 2014-2019, continuous water temperature, continuous water quality measurements, and pathogen indicator bacteria were monitored at the targeted locations listed in Table 3 and illustrated in Figure 3.

Site locations were identified using a targeted monitoring design based on the directed principle[4] to address the following management questions:

1. What is the range of continuous water quality measurements at targeted sites of interest?
2. Do continuous water quality measurements indicate potential impacts to aquatic life?
3. What are the pathogen indicator concentrations at creek sites where water contact recreation may occur?
4. Are conditions in local receiving waters supportive of or likely supportive of beneficial uses?

Within Contra Costa County, the following targeted monitoring was conducted each water year from water year 2014 to water year 2019:

- Four continuous water temperature monitoring locations
- Two continuous water quality monitoring locations
- Five pathogen indicator monitoring locations
- Ten riparian assessment monitoring locations (CRAM stream surveys)[5]

[4] Directed Monitoring Design Principle: A deterministic approach in which points are selected deliberately based on knowledge of their attributes of interest as related to the environmental site being monitored. This principle is also known as "judgmental," "authoritative," "targeted," or "knowledge-based."

[5] Stream surveys (CRAM) required only under MRP Order No. R2-2009-0074 (water years 2014 and 2015).

Table 3. Targeted Sites and Local Reporting Parameters Monitored in Contra Costa County – Water Years 2014-2019

Site Code	Creek Name	Latitude	Longitude	CRAM[1]	Water Temperature[2,3]	Continuous Water Quality[2,3]	Pathogen Indicator Bacteria[2,3]
Water Year 2014							
206RDO003	Rodeo Creek	38.01995	-122.25917		X		X
206RDO025	Rodeo Creek	38.01593	-122.24249		X	X	X
206R00407	Wildcat Creek	37.94274	-122.30593	X			
206R00551	San Pablo Creek	37.96207	-122.33625	X	X	X	X
206R00599	Appian Creek	37.97156	-122.30328	X			
206R00919	Castro Creek	37.96030	-122.26370	X			
206R01024	Rodeo Creek	38.03433	-122.26616		X		X
207R00379	West Branch Green Valley	37.85224	-121.97756	X			
207R00619	Donner Creek	37.92852	-121.92762	X			
207R00651	Sans Crainte Creek	37.87545	-122.02232	X			
207R00823	Galindo Creek	37.96493	-122.03602	X			
207R00843	Grizzly Creek	37.86806	-122.09589	X			X
207R00880	Tributary to Suisan Bay	38.03292	-121.96469	X			
Water Year 2015							
204R00388	West Branch of Alamo Creek	37.80352	-121.89936	X	X	X	X
207R00891	Green Valley	37.82838	-121.98444	X	X		X
206R00960	Rodeo	38.00768	-122.22185	X			
206R01024	Rodeo	38.01993	-122.25920	X			
544R01049	Dry	37.92213	-121.71938	X			
543R01103	West Antioch	37.98026	-121.81226	X			
204R01156	Tributary of Alamo	37.79739	-121.88988	X			
207R01163	San Ramon	37.88713	-122.05534	X	X	X	X
207R01227	San Ramon	37.87703	-122.04847	X			
207R01271	Walnut	37.918973	-122.053884				X
544R01305	Marsh	37.94454	-121.70527	X			
206R01319	San Pablo	37.96689	-122.35916		X		X
Water Year 2016							
207R01307	Lafayette Creek	37.88772	-122.13563		X		
204R01412	West Branch Alamo Creek	37.78795	-121.92410		X	X	
207R01447	Franklin Creek	37.99012	-122.13346				X
206R01495	Pinole Creek	37.97844	-122.26257				X
204R01519	Rimer Creek	37.81545	-122.11620		X	X	X
204R01604	West Branch Alamo Creek	37.81911	-121.89583		X		
206SPA020	San Pablo Creek	37.96283	-122.34562				X
206SPA030	San Pablo Creek	37.96293	-122.34497				X

Table 3. Targeted Sites and Local Reporting Parameters Monitored in Contra Costa County – Water Years 2014-2019

Site Code	Creek Name	Latitude	Longitude	CRAM[1]	Water Temperature[2,3]	Continuous Water Quality[2,3]	Pathogen Indicator Bacteria[2,3]
Water Year 2017							
204R01412	West Branch Alamo Creek	37.78720	-121.92397				X
207R01447	Franklin Creek	37.99104	-122.13245		X		
207R01675	Sans Crainte Creek	37.87695	-122.02433				X
207R02635	Las Trampas Creek	37.89013	-122.07435		X	X	
207R02891	Las Trampas Creek	37.88708	-122.09708		X		X
207R03403	Walnut Creek	37.90314	-122.05892				X
207R04544	Alhambra Creek	37.99977	-122.13044		X	X	X
Water Year 2018							
207ALH015	Alhambra Creek	38.01490	-122.13257		X		
207ALH110	Alhambra Creek	38.00346	-122.12968		X		
206SPA125	San Pablo Creek	37.96621	-122.29918		X	X	
207WAL025	Grayson Creek	37.99699	-122.06491				X
207WAL411	Las Trampas Creek	37.86159	-122.10146			X[4]	
206R00727	Pinole Creek	37.97961	-122.26835				X
206R01495	Pinole Creek	37.97889	-122.26211		X		
207R01675	Sans Crainte Creek	37.87644	-122.02348				X
206R02343	Wildcat Creek	37.96174	-122.35471				X
207R02891	Las Trampas Creek	37.88692	-122.09717			X[5]	
206R03927	San Pablo Creek	37.96480	-122.32364				X
Water Year 2019							
207ALH010	Alhambra Creek	38.01674	-122.13588				X
203BAX045	Baxter Creek	37.93120	-122.32393				X
543EAN010	East Antioch Creek	38.01072	-121.79635				X
544R04613	Marsh Creek	37.99169	-121.69590				X
206PNL010	Pinole Creek	38.00691	-122.28995				X
206R00960	Rodeo Creek	38.00737	-122.22129		X	X	
206SPA230	San Pablo Creek	37.88118	-122.18817		X	X	
206R00551	San Pablo Creek	37.96205	-122.33608		X		
206R01319	San Pablo Creek	37.96744	-122.36554		X		

1 Stream surveys (CRAM) required only under MRP Order No. R2-2009-0074 (water years 2014 and 2015)
2 Monitoring parameters in water years 2014 and 2015 are subject to MRP Order No. R2-2009-0074 criterion
3 Monitoring parameters in water years 2016-2019 are subject to MRP Order No. R2-2015-0049 criterion
4 Las Trampas Creek spring deployment location (2018)
5 Las Trampas Creek fall deployment location (2018)
Values in **bold** exceed MRP criterion. Exceedance details are presented in Table 19.

Figure 2. Overview of CRAM Sites Monitored by CCCWP – Water Years 2014-2015

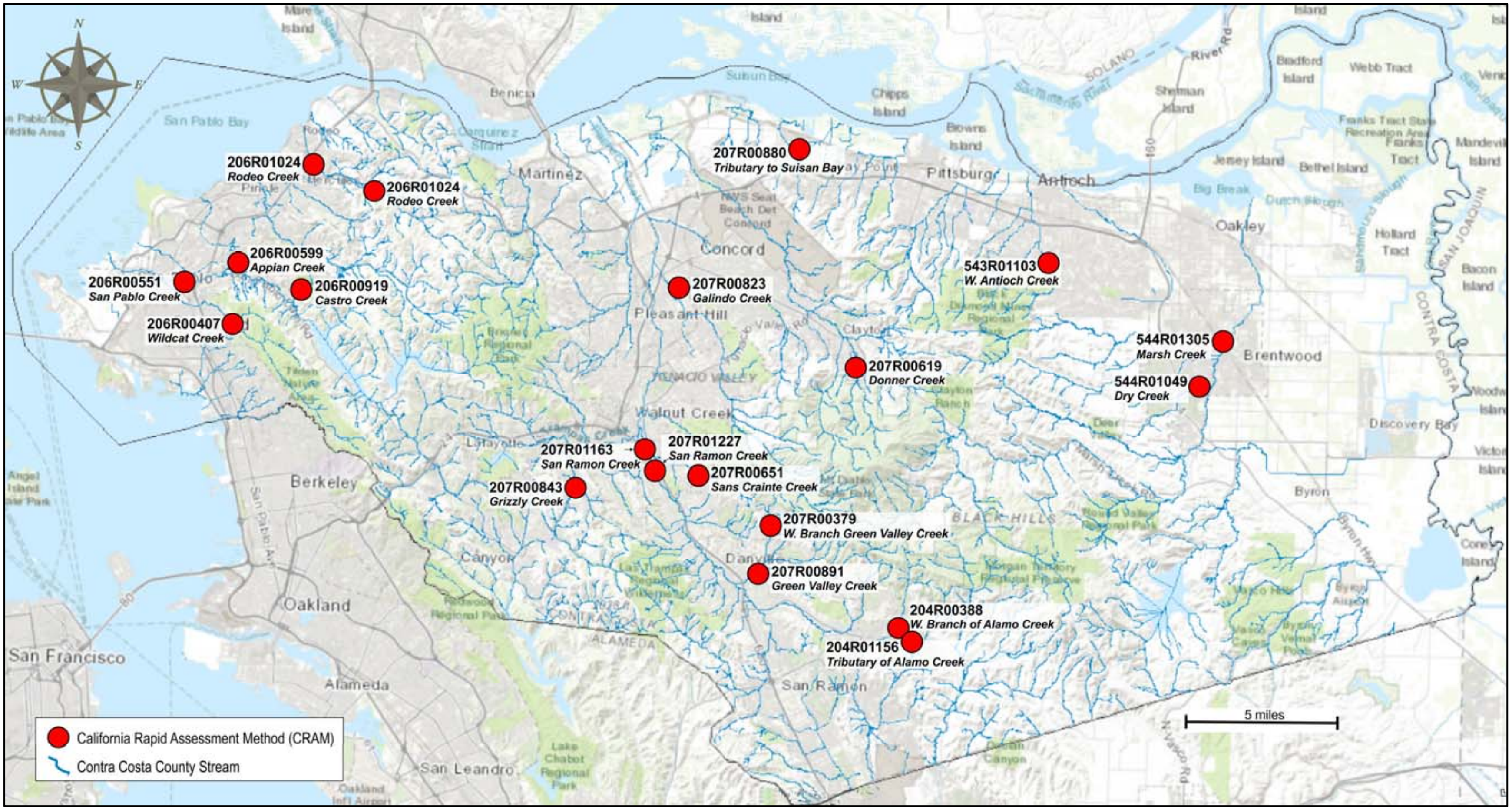
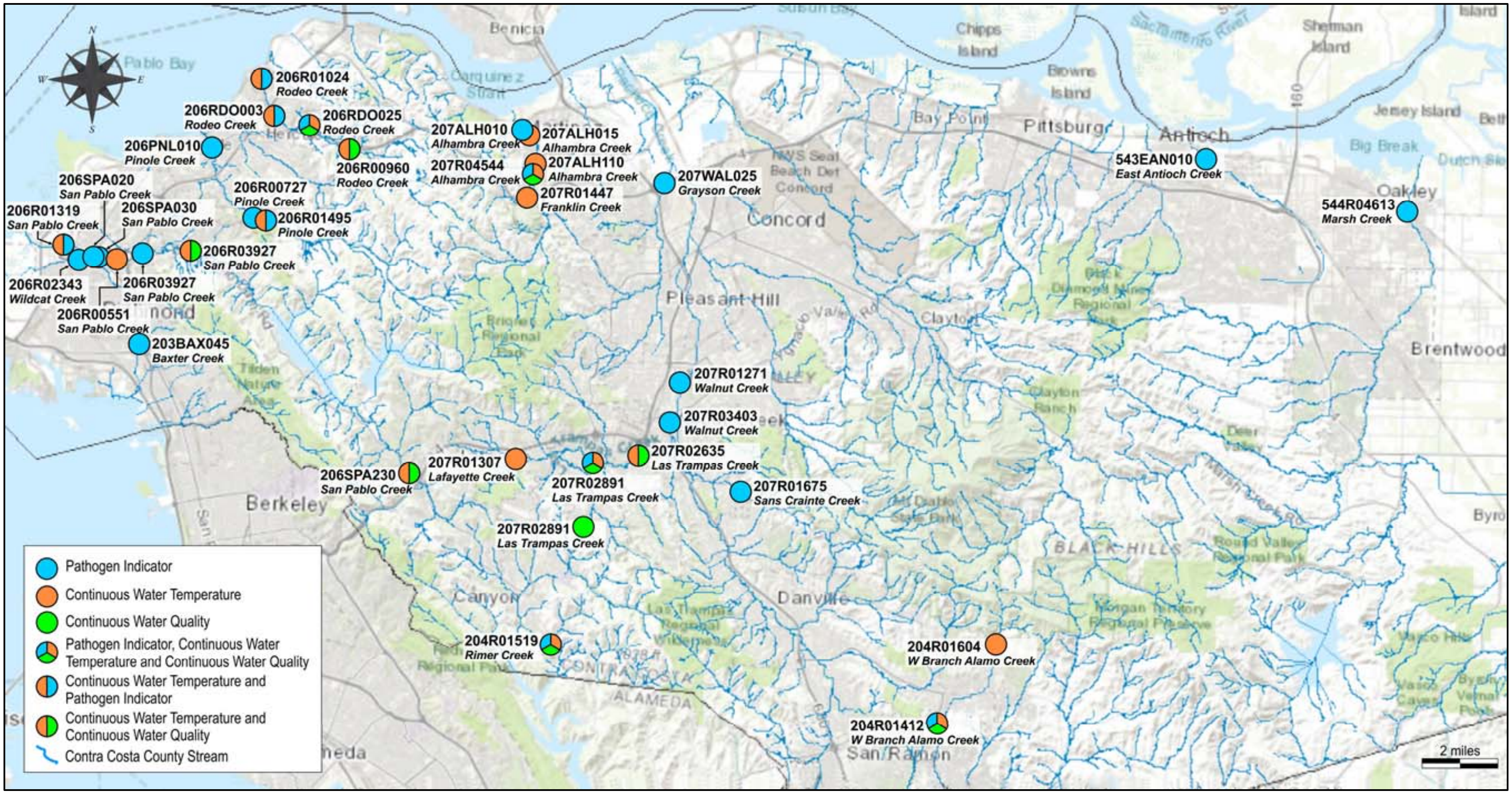


Figure 3. Overview of Targeted Sites Monitored by CCCWP – Water Years 2014-2019



3. Monitoring Methods

Targeted monitoring data were collected in accordance with the BASMAA RMC QAPP (BASMAA, 2016a) and BASMAA RMC SOP (BASMAA, 2016b). Where applicable, monitoring data were collected using methods comparable to those specified by the California Surface Water Ambient Monitoring Program (SWAMP) QAPP[6], and were submitted in SWAMP-compatible format by CCCWP to the SFBRWQCB and the CVRWQCB on behalf of CCCWP permittees and pursuant to provision C.8.h.

3.1. Data Collection Methods

Water quality data were collected in accordance with SWAMP-comparable methods and procedures described in the BASMAA RMC SOPs (BASMAA, 2016b) and associated QAPP (BASMAA, 2016a). These documents are updated as needed to maintain current and optimal applicability. The SOPs were developed using a standard format which describes health and safety precautions and considerations, relevant training, site selection, and sampling methods and procedures, (including pre-fieldwork mobilization activities to prepare equipment), sample collection, and demobilization activities to preserve and transport samples.

Monitoring frequency, timeframe, and number of site details for data evaluated are discussed below.

3.1.1. Continuous Water Quality Measurements

Continuous water quality monitoring equipment (YSI EXO 3, YSI 6600 V2, and Eureka Manta 35+ water probe sondes) were deployed at two targeted locations each water year. Continuous water quality parameters (dissolved oxygen, specific conductivity, pH, and water temperature) were recorded every 15 minutes at two stations over two time periods. The equipment was deployed as follows:

- Once during the spring over one to two weeks concurrent with bioassessment sampling (April-May)
- Once during the summer over one to two weeks at the same sites (late June-September)

Procedures used for calibrating, deploying, programming and downloading data are described in RMC SOP FS-4 (BASMAA, 2016b).

3.1.2. Continuous Water Temperature Monitoring

During each water year, continuous water temperature monitoring was conducted using digital temperature loggers (Onset® HOBO® Water Temp Pro V2) at four locations in the county. Locations were deployed at targeted sites from April-September in stream reaches that are documented to support cold water fisheries or where either past data or best professional judgment indicates that temperatures may negatively affect the designated beneficial use. Digital temperature loggers were set to record at 60-minute intervals over the course of the monitoring period.

[6] The current SWAMP QAPP is available at: https://www.waterboards.ca.gov/water_issues/programs/swamp/qapp/swamp_QAPrP_2017_Final.pdf

Procedures used for calibrating, deploying, programming and downloading data are described in RMC SOP FS-5 (BASMAA, 2016b).

3.1.3. Pathogen Indicator Sampling

In compliance with permit requirements, a set of pathogen indicator samples was collected in the dry season at five targeted locations each year during water years 2014-2019. All five sampling locations were selected for their potential to detect anthropogenic sources of contamination or were targeted due to site location within public parks, given the increased potential of public contact with water bodies. Pathogen indicator samples for enterococci and *E. coli* were analyzed at all sites.

Sampling techniques included direct filling of containers and immediate transfer of samples to analytical laboratories within specified holding time requirements. Procedures used for sampling and transporting samples are described in RMC SOP FS-2 (BASMAA, 2016b).

3.2. Data Analysis and Interpretation Methods

Targeted monitoring data were evaluated against water quality objectives or other applicable thresholds, as described in provision C.8.d of the MRP. Table 4 defines thresholds used for selected targeted monitoring parameters as they apply to water years 2016-2019. The following subsections provide details on MRP thresholds and the underlying rationale.

3.2.1. Dissolved Oxygen (DO)

The Basin Plan (SFBRWQCB, 2015b) lists the applicable water quality objective for dissolved oxygen in non-tidal waters as follows: 7.0 mg/L minimum for waters designated as COLD (i.e., a steelhead stream). Although this water quality objective is a suitable criterion for an initial evaluation of water quality impacts, further evaluation may be needed to determine the overall extent and degree to which cold water beneficial uses are supported at a site. For example, further analyses may be necessary at sites in lower reaches of a water body which may not support salmonid spawning or rearing habitat but may be important for upstream or downstream fish migration. In these cases, dissolved oxygen data will be evaluated for the salmonid life stage and/or fish community expected to be present during the monitoring period. Such evaluations of both historical and current ecological conditions will be made, where possible, when evaluating water quality information.

To evaluate the results against the relevant threshold in MRP section C.8.d, the dissolved oxygen data were evaluated to determine whether 20 percent or more of the measurements were below the 7.0 mg/L minimum.

Table 4. Requirements for Follow-Up for Local/Targeted Creek Status Monitoring Results Per MRP Provision C.8.d

Constituent	Threshold Level[1]	MRP 2 Provision	Provision Text
Water Temperature (continuous, HOBO)	≥ 2 weekly averages > 17° C (steelhead streams); or 20% of results > 24° C instantaneous maximum (per station)	C.8.d.iii.(4)	The temperature trigger is defined as when two or more weekly average temperatures exceed the Maximum Weekly Average Temperature of 17° C for a steelhead stream, or when 20% of the results at one sampling station exceed the instantaneous maximum of 24° C. Permittees shall calculate the weekly average temperature by breaking the measurements into non-overlapping, 7-day periods.
Water Temperature (continuous, sondes)	A weekly average >17° C (steelhead streams); or 20% of results >24° C instantaneous maximum (per station)	C.8.d.iv.(4)a.	The Permittees shall calculate the weekly average temperature by separating the measurements into non-overlapping, 7-day periods. The temperature trigger is defined as any of the following: a. Maximum Weekly Average Temperature exceeds 17° C for a steelhead stream, or 20% of the instantaneous results exceed 24° C.
pH (continuous, sondes)	≥ 20% results < 6.5 or > 8.5	C.8.d.iv.(4)b.	The pH trigger is defined as 20% of instantaneous pH results are < 6.5 or > 8.5.
Specific Conductance (continuous, sondes)	≥ 20% results > 2000 µS	C.8.d.iv.(4)c.	The conductivity trigger is defined as 20% of the instantaneous specific conductance results are >2000 µS, or there is a spike in readings with no obvious natural explanation.
Dissolved Oxygen (continuous, sondes)	≥ 20% results < 7 mg/L (cold water fishery streams)	C.8.d.iv.(4)d.	The dissolved oxygen trigger is defined as 20% of instantaneous dissolved oxygen results are < 7 mg/L in a cold-water fishery stream.
Enterococci	>130 CFU/100 mL	C.8.d.v.(4)	If USEPA's statistical threshold value for 36 per 1000 primary contact recreators is exceeded, the water body reach shall be identified as a candidate SSID project. (Per RMC/SFBRWQCB staff agreement, CFU and MPN units are deemed to be comparable for this purpose.)
E. coli	> 410 CFU/100 mL	C.8.d.v.(4)	If USEPA's statistical threshold value for 36 per 1000 primary contact recreators is exceeded, the water body reach shall be identified as a candidate SSID project. (Per RMC/SFBRWQCB staff agreement, CFU and MPN units are deemed to be comparable for this purpose.)

1 Per MRP provision C.8.d., these are the data thresholds which trigger listings as candidate SSID projects per MRP provision C.8.e.
CFU colony forming unit
MPN most probable number
SSID stressor/source identification

3.2.2. Hydrogen Ion Concentration (pH)

The applicable water quality objective for pH in surface waters is stated in the Basin Plan (SFBRWQCB, 2015b) as follows: the pH shall not be depressed below 6.5 nor raised above 8.5. This range was used in this report to evaluate the pH data collected from creeks.

To evaluate the results against the relevant threshold in MRP provision C.8.d, the pH data were evaluated to determine whether 20 percent or more of the measurements were outside of the water quality objectives.

3.2.3. Specific Conductance

The applicable water quality objective for specific conductance in surface waters is stated in the MRP as follows: 20 percent of instantaneous specific conductance results should not exceed 2,000 µS/cm, or there should not be a spike in readings with no obvious natural explanation.

To evaluate the results against the relevant threshold in MRP provision C.8.d, the specific conductance data were evaluated to determine whether 20 percent or more of instantaneous measurements were outside of the water quality objectives, or if data was determined to have a spike in readings with no obvious natural explanation.

3.2.4. Temperature

Temperature is one indicator of the ability of a water body to support a salmonid fisheries habitat (e.g., a steelhead stream). In California, the beneficial use of a steelhead stream is generally associated with suitable spawning habitat and passage for anadromous fish.

In Section C.8.d.iii.(4) of the MRP, the temperature trigger threshold specification is defined as follows:

> "The permittees shall identify a site for which results at one sampling station exceed the applicable temperature trigger or demonstrate a spike in temperature with no obvious natural explanation as a candidate SSID project. The temperature trigger is defined as when two or more weekly average temperatures exceed … 17° C for a steelhead stream, or when 20 percent of the results at one sampling station exceed the instantaneous maximum of 24° C."

In Section C.8.d.iv.(4).a of the MRP, which deals with continuous monitoring of dissolved oxygen, temperature and pH, the temperature trigger threshold specification is defined as follows:

> "…(the) maximum weekly average temperature (MWAT) exceeds 17° C for a steelhead stream, or 20 percent of the instantaneous results exceed 24° C."

The first cited section applies to temperature data recorded by the HOBO devices through the period of April-September. The second cited section applies to temperature data recorded by sonde devices during the two shorter deployment periods in spring and summer.

In either case, the weekly average temperature was calculated as the average of seven daily average temperatures in non-overlapping seven-day periods. In all cases of the recorded temperature data, the first day's data was not included in the weekly average temperature calculations to eliminate the probable high bias of the average daily temperature of that day, because the recording devices were all deployed during daylight hours (the typically warmer part of a standard 24-hour day). As the weekly average temperatures were calculated over the disjunctive seven-day periods, the last periods not containing a full seven days of data were also excluded from the calculations.

In compliance with the cited sections of the MRP, sites for which results exceeded the applicable temperature trigger can be identified as candidates for a stressor/source identification (SSID) project in the following three ways:

1. If a site had temperature recorded by a HOBO device and two or more weekly average temperatures calculated from the data were above 17° C

2. If a site had temperature recorded by a sonde device and one or more weekly average temperatures calculated from the data were above 17° C (equivalent to determining the MWAT at one of the sites was above 17° C for the period in question)

3. If a site had 20 percent of its instantaneous temperature results above 24° C, regardless of the recording device

3.2.5. Pathogen Indicator Bacteria

In 2012, the U.S. Environmental Protection Agency (USEPA) released its recreational water quality criteria recommendations for protecting human health in all coastal and non-coastal waters designated for primary contact recreation use. The Recreational Water Quality Criteria (RWQC) include two sets of recommendations (Table 5). Primary contact recreation is protected if either set of criteria recommendations are adopted into state water quality standards. However, these recommendations are intended as guidance to states, territories and authorized tribes in developing water quality standards to protect swimmers from exposure to water containing organisms which indicate the presence of fecal contamination. They are not regulations themselves (USEPA, 2012), but are considered to represent established thresholds for the purpose of evaluating threshold triggers per the MRP.

Section C.8.d.v of the MRP requires use of the USEPA statistical threshold value for the 36/1000 illness rate (Recommendation 1; see Table 5) for determining if a pathogen indicator collection sample site is a candidate for a stressor/source identification project. Because the geometric mean (GM) cannot be determined from the data collected, the MRP also requires use of the standard threshold values (STV) shown in Table 5. For data interpretive purposes, colony forming units (CFU) and most probable number (MPN) are considered equivalent.

Table 5. USEPA 2012 Recreational Water Quality Criteria

Criteria Elements	Recommendation 1 Estimated Illness Rate 36/1,000		Recommendation 2 Estimated Illness Rate 32/1,000	
Indicator	GM (CFU/100 mL)	STV[1] (CFU/100 mL)	GM (CFU/100 mL)	STV (CFU/100 mL)
Enterococci	35	130	30	110
E. coli (fresh)	126	410	100	320

1 MRP thresholds
CFU colony forming unit
GM geometric mean
STV standard threshold values

3.3. Quality Assurance/Quality Control Procedures

Data quality assurance and quality control procedures are described in detail in the BASMAA RMC QAPP (BASMAA, 2016a). Data quality objectives were established to ensure data collected are of adequate quality and sufficient for the intended uses. Data quality objectives address both quantitative and qualitative assessment of the acceptability of data. The qualitative goals include representativeness and comparability. The quantitative goals include specifications for completeness, sensitivity (detection and quantization limits), precision, accuracy, and contamination. Data were collected according to the procedures described in the relevant BASMAA RMC SOPs (BASMAA, 2016b), including appropriate documentation of data sheets and samples, and sample handling and custody. Laboratories providing analytical support to the RMC were selected based on the demonstrated ability to adhere to specified protocols.

3.4. Data Quality Assessment Procedures

Following completion of the field and laboratory work, the field data sheets and laboratory reports were reviewed by the local quality assurance officer and compared against the methods and protocols specified in the RMC SOPs and QAPP. The findings and results were then evaluated against the relevant data quality objectives to provide the basis for an assessment of programmatic data quality. A summary of data quality steps associated with water quality measurements is shown in Table 6. The data quality assessment consisted of the following elements:

- Conformance with field and laboratory methods, as specified in RMC SOPs and QAPP (including sample collection and analytical methods, sample preservation, sample holding times, etc.)
- Numbers of measurements/samples/analyses completed versus planned, and identification of reasons for any missed samples
- Temperature data were checked for accuracy by comparing measurements taken by HOBOs with National Institute of Standards Technology thermometer readings in room temperature water and ice water
- Continuous water quality data were checked for accuracy by comparing measurements taken before and after deployment with measurements taken in standard solutions to evaluate potential drift in readings
- Quality assessment laboratory procedures for accuracy, precision, and contamination (i.e., lab duplicates and lab blanks) were implemented for pathogen samples collected

Table 6. Data Quality Steps Implemented for Temperature and Continuous Water Quality Monitoring

Step	Temperature (HOBOs)	Continuous Water Quality (Sondes)
Pre-event calibration / accuracy check conducted	X	X
Readiness review conducted	X	X
Check field datasheets for completeness	X	X
Post-deployment accuracy check conducted		X
Post-sampling event report completed	X	X
Post-event calibration conducted		X
Data review-compare drift against SWAMP measurement quality objectives		X
Data review-check for outliers / out of water measurements	X	X

4. Results

This results section summarizes water quality data monitored by CCCWP in water year 2019, followed by a comprehensive analyses of water quality data collected since the previous integrated monitoring report (water years 2014-2019).

4.1. Statement of Data Quality – Water Year 2019

Field data sheets and laboratory reports were reviewed by the local quality assurance officer and results were evaluated against relevant data quality objectives. Results were compiled for qualitative metrics (representativeness and comparability) and quantitative metrics (completeness, precision and accuracy) in accordance with the BASMAA RMC QAPP (BASMAA, 2016a). Results summarizing the water year 2019 data quality assessment are discussed below, while further details discussing data quality assessments of monitoring results from previous water years can be found in the Integrated Monitoring Report bibliography (CCCWP, 2014; CCCWP, 2015; CCCWP, 2016; CCCWP, 2017; CCCWP, 2018).

The following summarizes the results of the water year 2019 data quality assessment:

- Hourly water temperature data were recorded at 60-minute intervals from digital data loggers deployed in two creeks at four separate locations: one location in Rodeo Creek and three locations in San Pablo Creek. Data loggers were deployed on Apr. 9, 2019 and remained deployed until the pickup date of Oct. 3, 2019. As the permit term reporting requirements apply only to the extent of a given water year, all data collected after Sep. 30, 2019 were not included in this report. One hundred percent of the expected data were collected at all four locations.

- Continuous water quality data (water temperature, pH, dissolved oxygen, and specific conductance) were continuously monitored at 15-minute intervals by sonde devices during two time periods (May 7-21 and Aug. 13-23, 2019) in two locations: one location in Rodeo Creek and one location in San Pablo Creek. One hundred percent of the expected data were collected at both locations; however, continuous dissolved oxygen data during the August deployment period in Rodeo Creek were questionable (see section 4.2.3 for details).

- One laboratory duplicate sample for pathogen indicator analyses was performed and resulted in a relative percent differences (RPD) that exceeded the measurement quality objective of 25 percent. The RPD calculated for enterococci and *E. coli* were 81 and 64 percent, respectively. It is not uncommon for urban surface water to have relatively high RPDs due to the patchy distribution of bacteria in suspension in water samples.

- An assessment of the continuous water quality data related to data quality objectives for accuracy for water year 2019 is presented in Table 7. All accuracy measurements successfully met the data quality objective in water year 2019. In general, all accuracy measurements successfully met data quality objectives in previous water years. Details discussing results of the accuracy of previous water year measurements can be found in the Integrated Monitoring Report bibliography (CCCWP, 2014; CCCWP, 2015; CCCWP, 2016; CCCWP, 2017; CCCWP, 2018).

Table 7. Accuracy[1] Measurements Taken for Dissolved Oxygen, pH and Specific Conductivity – Water Year 2019

Parameter	Measurement Quality Objectives	206R00960 Rodeo Creek		206SPA230 San Pablo Creek	
		May	August	May	August
Dissolved oxygen (mg/l)	± 0.5 or 10%	-0.25	-0.07	-0.42	0.13
pH 7.0	± 0.2	-0.02	-0.12	0.04	0.00
pH 10.0	± 0.2	0.19	-0.10	-0.05	-0.04
Specific conductance (µS/cm)	± 10%	-0.4%	-2.3%	1.7%	0.1%

1 Accuracy of the water quality measurements were determined by calculating the difference between sonde readings using a calibration standard versus the actual concentration of the calibration standard. The results displayed are those taken following measurements within the stream, defined as "post calibration", as opposed to the "pre calibration values", where all the sonde probes were offset to match the calibration standard prior to deployment.

4.2. Water Quality Monitoring Results

All targeted water quality monitoring data were evaluated against numeric trigger thresholds, as described in MRP provision C.8.d. These thresholds, which include applicable numeric water quality objectives or other criteria, indicate levels at which additional follow-up may be required under the MRP. Targeted monitoring locations for water years 2014-2019 were located within both SFBRWQCB Region 2 and CVRWQCB Region 5 boundaries. The results are presented below.

4.2.1. Continuous Water Temperature (HOBO) – Water Year 2019

Summary statistics for continuous water temperature data collected at the four monitoring locations from April -September 2019 are shown in Table 8. At Rodeo Creek and all three San Pablo Creek locations, approximately 175 days of hourly temperature data were collected. All data were collected successfully with no device issues or equipment movement, resulting in 100 percent capture of targeted data.

Table 8. Descriptive Statistics for Continuous Water Temperature Measured at Four Sites in Contra Costa County (Rodeo Creek and San Pablo Creek) – Apr. 9-Sep. 30, 2019

Site Temperature	206R00960 Rodeo Creek (° C)	206R01319 San Pablo Creek (° C)	206R00551 San Pablo Creek (° C)	206SPA230 San Pablo Creek (° C)
Minimum	11.57	9.71	10.39	11.51
Median	15.95	16.96	16.44	14.52
Mean	15.75	16.88	16.31	15.81
Maximum	18.08	24.07	20.60	19.48
MWAT[1]	17.19	18.42	18.00	18.49
Number of Measurements	4,187	4,188	4,190	4,190

1 The maximum of the 7-day average of the daily average temperature

The minimum and maximum temperature for all four stations was 9.71° C and 24.07° C, respectively. The median temperature range for all four stations was 14.52° C to 16.96° C, and the MWAT range was 17.19° C to 18.49° C.

Continuous water temperature data measured at each station are presented in Figure 4. The weekly average temperature (WAT) data, WAT threshold of 17° C and acute threshold of 24° C for juvenile salmonid rearing (steelhead streams) are illustrated in Figures 5 and 6. Figures illustrating water temperature data results of previous water years can be found in the Integrated Monitoring Report bibliography (CCCWP, 2014; CCCWP, 2015; CCCWP, 2016; CCCWP, 2017; CCCWP, 2018).

Figure 4. Water Temperature Data Collected at Four Sites in Contra Costa County (Rodeo Creek and San Pablo Creek) – Apr. 9-Sep. 30, 2019

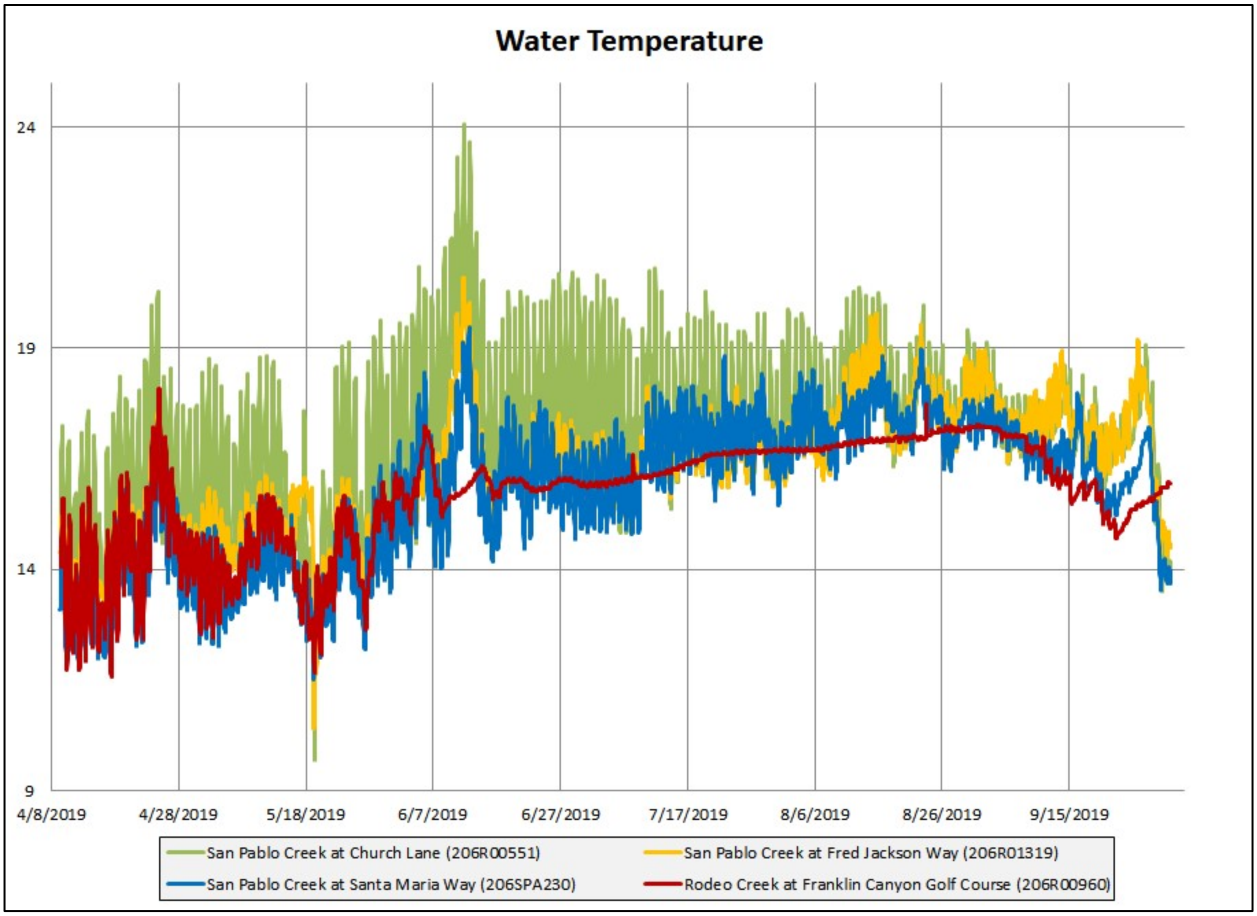


Figure 5. Weekly Average Water Temperature Data Collected at Four Sites (Rodeo Creek and San Pablo Creek) – Apr. 9-Sep. 30, 2019

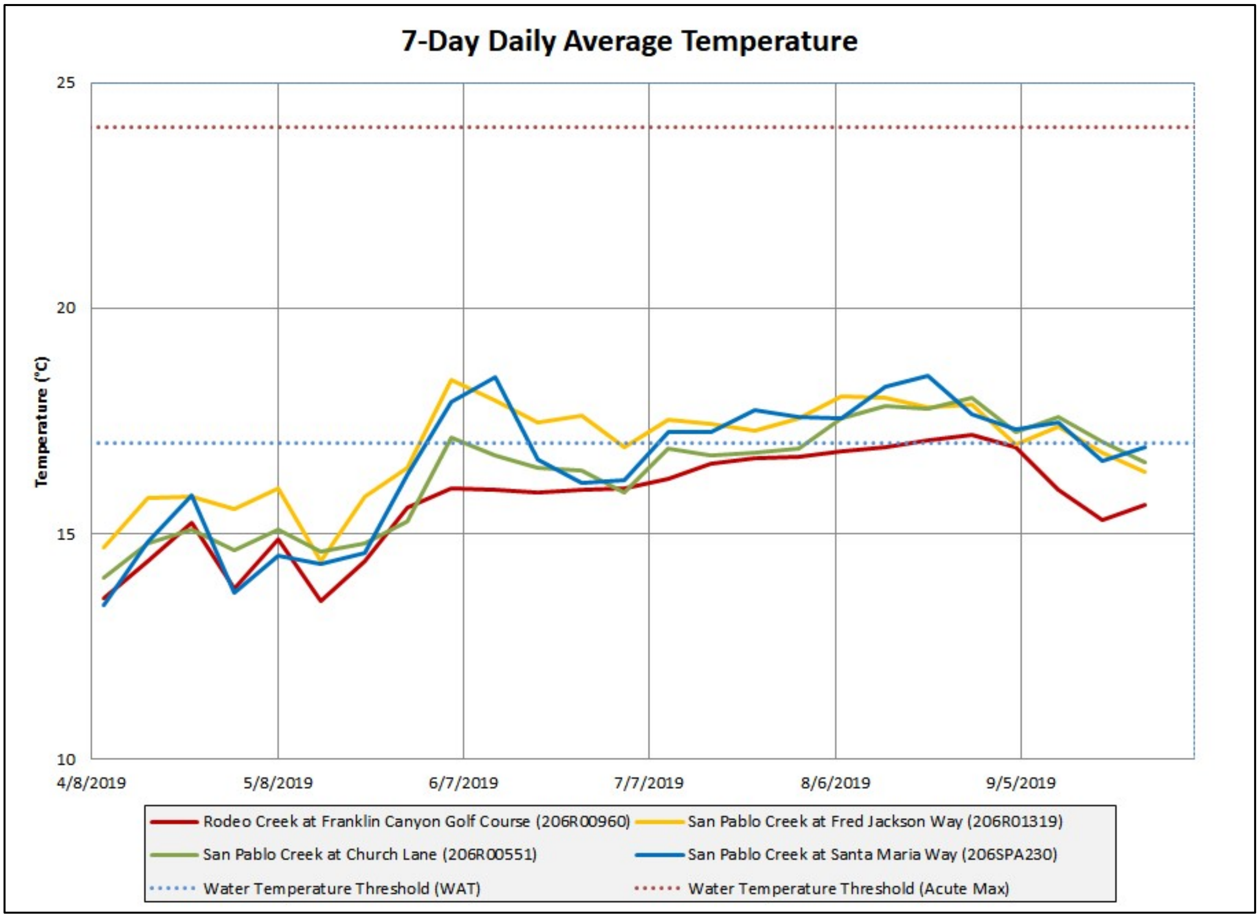
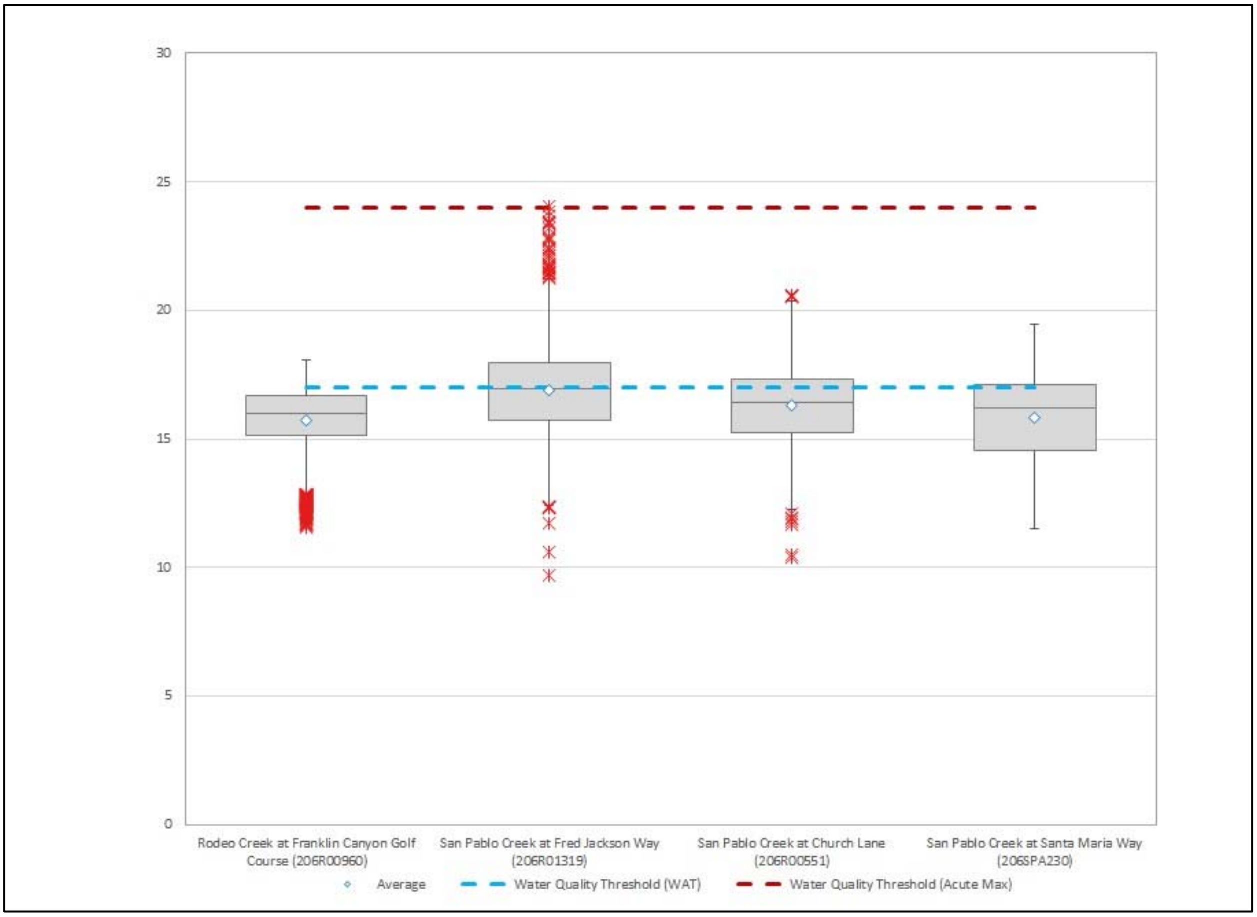


Figure 6. Box Plots of Weekly Average Temperature Data Collected at Four Sites in Contra Costa County (Rodeo Creek and San Pablo Creek) – Apr. 9-Sep. 30, 2019



Over the course of the monitoring period, weekly average temperatures measured at Rodeo Creek and all three San Pablo Creek locations exceeded the threshold for steelhead streams (Table 9). The number of exceedances ranged from two to 13 instances. Therefore, all four stations exceeded the MRP trigger threshold for continuous (HOBO) water temperature (two or more weekly average temperatures over the 17° C threshold; Table 9).

Table 9. Water Temperature Data Measured at Four Sites in Comparison to MRP WAT Trigger Threshold for Steelhead Streams

Site ID	Creek Name[1]	Monitoring Period	Number of Results Where WAT > 17° C
206R00960	Rodeo Creek	04/09/19-09/30/19	2
206R01319	San Pablo Creek	04/09/19-09/30/19	13
206R00551	San Pablo Creek	04/09/19-09/30/19	8
206SPA230	San Pablo Creek[2]	04/09/19-09/30/19	12

1 Site IDs for San Pablo Creek are presented in order of most downstream to upstream location
2 Monitoring station located above San Pablo Reservoir
WAT weekly average temperature
Values in **bold** exceed MRP criterion

4.2.2. Continuous Water Temperature (HOBO) – Water Years 2014-2019

Over the course of the previous six water years, weekly average daily maximum water temperatures (water year 2014 and 2015 criterion) and weekly average temperatures (water years 2016-2019 criterion) consistently measured above MRP trigger thresholds for continuous water temperature (Table 10). Sites with targeted monitoring results exceeding the MRP trigger criterion are identified as candidate SSID projects. Conclusions and recommendations from targeted monitoring in water years 2014-2019 are discussed below.

Throughout the urban stream environment, several factors can contribute to elevated water temperatures. The following factors were evaluated with respect to water temperature exceedances observed in the water years 2014-2019 monitoring period:

- Lack of riparian habitat
- Channel dynamics and channel alteration
- Air temperature (heat conduction)
- Flow conditions
- Non-stormwater related dry weather discharges
- Spatial and temporal variability

Elevated water temperatures were found to occur during periods of elevated air temperatures, as the transfer of heat by conduction from higher temperature air to the surface of lower temperature stream water occurs. The seasonal trend, as discussed in the CCCWP water year 2017 urban creeks monitoring report, suggests air temperature and solar radiation are contributing factors to water temperature exceedances, while noting the effects in this region were likely enhanced as the area experienced higher than normal air temperatures during recent summers. As only one of a number of factors contributing to water temperature exceedances, the impact of solar radiation and conduction heating can increase with the removal of riparian habitat.

Table 10. Water Temperature Data Measured at 24 Sites in Comparison to MRP Trigger Thresholds

Water Year[1,2]	Site ID	Creek Name	Monitoring period	Percent of Results Where WAMT > 20.5° C / Number of Results Where WAT > 17° C
2014[3]	206RDO025	Rodeo Creek	04/14/14-09/3014	0%
	206R01024	Rodeo Creek	04/14/14-09/3014	96%
	206RDO003	Rodeo Creek	06/06/14-09/30/14	100%
	206R00551	San Pablo Creek	04/14/14-09/30/14	0%
2015[4]	204R00388	West Branch of Alamo Creek	04/15/15-05/27/15; 07/17/15-10/03/15	0%
	207R00891	Green Valley Creek	04/15/15-05/27/15; 07/17/15-10/03/15	55%
	206R01319	San Pablo Creek	04/15/15-05/27/15; 07/17/15-10/03/15	0%
	207R01163	San Ramon Creek	04/15/15-05/27/15; 07/17/15-10/03/15	74%
2016[5,6]	207R01307	Lafayette Creek	04/13/16-09/30/16	3
	204R01412	West Branch Alamo Creek	04/13/16-09/30/16	14
	204R01519	Rimer Creek	04/13/16-09/30/16	4
	204R01604	West Branch Alamo Creek	04/13/16-08/11/16	2
2017	207R01447	Franklin Creek	04/26/17-09/30/17	14
	207R02635	Las Trampas Creek	04/26/17-09/30/17	17
	207R02891	Las Trampas Creek	04/26/17-09/30/17	16
	207R04544	Alhambra Creek	04/26/17-09/30/17	15
2018	207ALH015	Alhambra Creek	04/19/18-09/30/18	15
	207ALH110	Alhambra Creek	04/19/18-09/30/18	13
	206SPA125	San Pablo Creek	04/19/18-09/30/18	0
	206R01495	Pinole Creek	04/19/18-09/30/18	9
2019	206R00960	Rodeo Creek	04/09/19-09/30/19	2
	206R01319	San Pablo Creek	04/09/19-09/30/19	13
	206R00551	San Pablo Creek	04/09/19-09/30/19	8
	206SPA230	San Pablo Creek	04/09/19-09/30/19	12

1 Weekly Average Maximum Daily Temperature threshold criterion required under MRP Order No. R2-2009-0074 (water years 2014 and 2015 only)

2 Weekly Average Temperature threshold criterion required under MRP Order No. R2-2015-0074 (water years 2016-2019)

3 Monitoring period at station 206RDO003 reduced due to device theft

4 Water year 2015 experienced an equipment malfunction during data retrieval, resulting in lost data between routine maintenance visits

5 West Branch Alamo Creek is listed by the Basin Plan as having a potential COLD beneficial use. As the creek is not listed as having an existing COLD beneficial use, these results do not constitute an exceedance under MRP criterion

6 Monitoring period at station 204R01604 reduced due to loss of as stream flow during the late summer

WAMT weekly average maximum daily temperature

WAT weekly average temperature

Values in **bold** exceed MRP criterion

During water years 2014-2019 monitoring, the removal of shade-providing riparian vegetation is evident along sections of lower San Pablo Creek, Las Trampas Creek, and Rodeo Creek. The lack of riparian habitat often coincides with flood control infrastructure or artificial stream channelization. Flood control infrastructure or channelization efforts can create substantial changes in stream channel dynamics, which include increasing channel width-to-depth ratios. The artificial increase of stream channel width-to-depth ratios can expose a larger surface area of water to solar radiation, effectively increasing water temperature.

In addition to stream channelization, stream channel alterations also include the construction of artificial impoundments and dams. During water year 2015 and 2016 monitoring, CCCWP selected water temperature monitoring stations above and below a large artificial impoundment located on the West Branch of Alamo Creek. Water temperature data located downstream of the artificial impoundment detected numerous small temperature spikes outside of the typical diurnal cycle, in one case increasing the water temperature by 3° C in one hour in May of 2015. Due to this, follow up monitoring was conducted in 2016 with one location selected for monitoring above the impoundment, and one below. The results for the two HOBO water temperature loggers displayed a significant difference in the total number of WATs that exceed a maximum temperature criterion of 17° C between the station located downstream and station located upstream of the impoundment (Table 10). The exceedances in stream water temperature downstream of the impoundment were explained by the following:

- The impoundment disrupts stream flow, effectively slowing the rate of flow or concentrating the flow into a large pool, where flow rate is stopped altogether. The natural stream canopy is absent in this location, and the water is distributed over a large surface area, where the water is warmed during periods of prolonged exposure to warm temperatures and direct sunlight
- The increases in water temperature spikes downstream of the impoundment occurred during periods directly associated with an increase of air temperature, such as those experienced during local heat waves

The effects of multiple factors on water temperature as described above can have a more pronounced effect when factoring in stream discharge, as suggested by the disruption of flow experienced in the West Branch of Alamo Creek. Artificially reducing, slowing or stopping the streams discharge can increase temperature related effects of solar radiation on reaches with insufficient riparian vegetation or altered stream channel dynamics. At some monitoring sites, discharge naturally decreased due to seasonal conditions, or was lower than average due to the regions experienced drought conditions, such as in the lower end of Alhambra Creek.

Targeted monitoring of water temperature were also conducted at upper watershed locations, in which the vast majority of stream channels are naturally shaded by riparian vegetation and contain minimal to no stream alteration, such as Lafayette Creek in 2016, San Pablo Creek in 2018 and Pinole Creek in 2018. Such locations generally saw fewer WAT exceedances, with the exception of Pinole Creek in 2018, which is targeted for water temperature and general water quality parameters in water year 2020, due to the streams current steelhead run, recent fish passage improvement projects, and detected water temperature exceedances in 2018. Further water temperature monitoring in upper watershed locations is scheduled to occur in future water years to determine spatial variability of stream corridors, however such monitoring may be selective or restricted as many upper reaches of COLD streams in Contra Costa County do not maintain perennial flow. Target locations for future monitoring are presented in Table 11.

Table 11. Designated COLD Beneficial Uses Listed in the Basin Plan

Basin	Water Body	Human Consumptive Uses							Aquatic Life Uses									Recreational Uses		
		AGR	MUN	FRSH	GWR	IND	PROC	COMM	SHELL	COLD	EST	MAR	MIGR	RARE	SPWN	WARM	WILD	REC-1	REC-2	NAV
San Pablo Basin	Rodeo Creek									E					E	E	E	E	E	
	Pinole Creek									E			E	E	E	E	E	E	E	
	San Pablo Creek			E						E			E	E	E	E	E	E*	E	
	Wildcat Creek			E						E			E	E	E	E	E	E	E	
Suisan Basin	Alhambra Creek									E			E	E		E	E	E	E	
	Franklin Creek									E			E	E	E	E	E	E	E	
	Arroyo Del Hambre									E						E	E	E	E	
	Walnut Creek									E			E	E	E	E	E	E	E	
	Grayson Creek									E			E	E		E	E	E	E	
	Pine Creek									E			E	E	E	E	E	E	E	
	Galindo Creek									E						E	E	E	E	
	Bollinger Canyon Creek									E					E	E	E	E	E	
	Las Trampas Creek									E				E		E	E	E	E	
	Lafayette Creek									E						E	E	E	E	
	Mt. Diablo Creek									E			E	E	E	E	E	E	E	
	Mitchell Creek									E			E	E	E	E	E	E	E	
	Donner Creek									E					E	E	E	E	E	
South Bay Basin	Indian Creek			E						E			E	E	E	E	E	E*	E	
	W Branch Alamo Creek				E					P			E	E	E	E	E	E	E	
	Moraga Creek			E						E					E	E	E	E	E	

E Existing beneficial use
E* Water quality objectives apply; water contact recreation is prohibited or limited to protect public health
P Potential beneficial use
Notes:

Per Basin Plan Ch. 2 (SFBRWQCB, 2015b), beneficial uses for freshwater creeks include municipal and domestic supply (MUN), agricultural supply (AGR), industrial process supply (PRO), groundwater recharge (GWR), water contact recreation (REC1), noncontact water recreation (REC2), wildlife habitat (WILD), cold freshwater habitat (COLD), warm freshwater habitat (WARM), fish migration (MIGR), and fish spawning (SPWN). The San Francisco Bay Estuary supports estuarine habitat (EST), industrial service supply (IND), and navigation (NAV) in addition to all uses supported by streams. Beneficial uses for coastal waters include water contact recreation (REC1); noncontact water recreation (REC2); industrial service supply (IND); navigation (NAV); marine habitat (MAR); shellfish harvesting (SHELL); ocean, commercial and sport fishing (COMM); and preservation of rare and endangered species (RARE).

4.2.3. Continuous Water Quality – Water Year 2019

Summary statistics for continuous water quality measurements collected over two time periods (May and August) are shown in Table 12. Weekly average temperature and MWAT for both stations over the same monitoring period are displayed in Table 13. Data collected during both periods, along with the required thresholds, are plotted in Figures 7 through 10.

Table 12. Descriptive Statistics for Daily and Monthly Continuous Water Quality Parameters (Temperature, Dissolved Oxygen, Conductivity and pH) Measured in Contra Costa County (Rodeo Creek and San Pablo Creek) – May 7-21 and Aug. 13-23, 2019

Parameter		206R00960 Rodeo Creek		206SPA230 San Pablo Creek	
		May	August	May	August
Temperature (° C)	Minimum	11.55	16.75	11.13	16.52
	Median	14.28	16.88	13.71	17.62
	Mean	14.09	16.87	13.74	17.64
	Maximum	15.60	17.16	15.62	19.07
Dissolved oxygen (mg/l)	Minimum	7.18	0.00 Q	10.09	7.31
	Median	8.14	0.00 Q	10.82	8.51
	Mean	8.14	0.00 Q	10.83	8.53
	Maximum	9.12	2.00 Q	11.29	9.54
pH	Minimum	8.01	6.84	7.97	7.57
	Median	8.09	6.88	8.47	8.33
	Mean	8.08	6.88	8.44	8.29
	Maximum	8.14	6.93	8.59	8.46
Specific conductance (µS/cm)	Minimum	1445	2635	202	596
	Median	1857	2669	660	666
	Mean	1831	2668	615	664
	Maximum	1895	2692	669	731

Q Continuous dissolved oxygen data in Rodeo Creek were questionable during the month of August due to an unknown physical cause or instrument failure

Table 13. Weekly Average Temperatures and MWAT Measured at Two Sites (Rodeo Creek and San Pablo Creek) for Both Events

Site Name	Creek Name	Monitoring Period	WAT	MWAT
206R00960	Rodeo Creek	05/07/19-05/21/19	14.77	14.77
		08/13/19-08/23/19	16.87	16.87
206SPA230	San Pablo Creek	05/07/19-05/21/19	13.92	13.92
		08/13/19-08/23/19	17.56	17.56

MWAT maximum weekly average temperature

WAT weekly average temperature

Values in **bold** exceed MRP criterion of 17° C for steelhead streams

Figure 7. Continuous Water Quality Data (Temperature) Measured in Rodeo Creek and San Pablo Creek – May 7-21 and Aug. 13-23, 2019

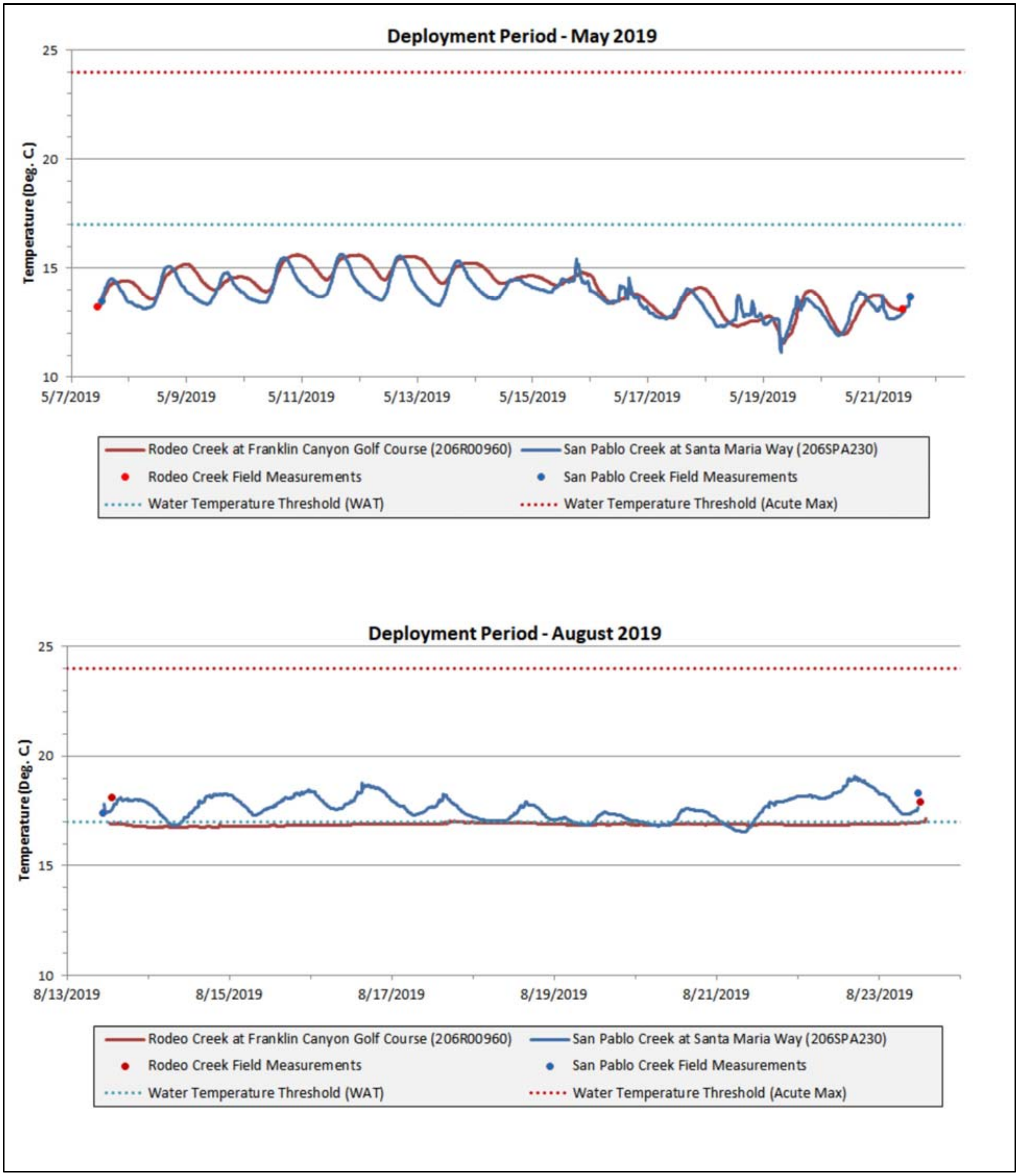
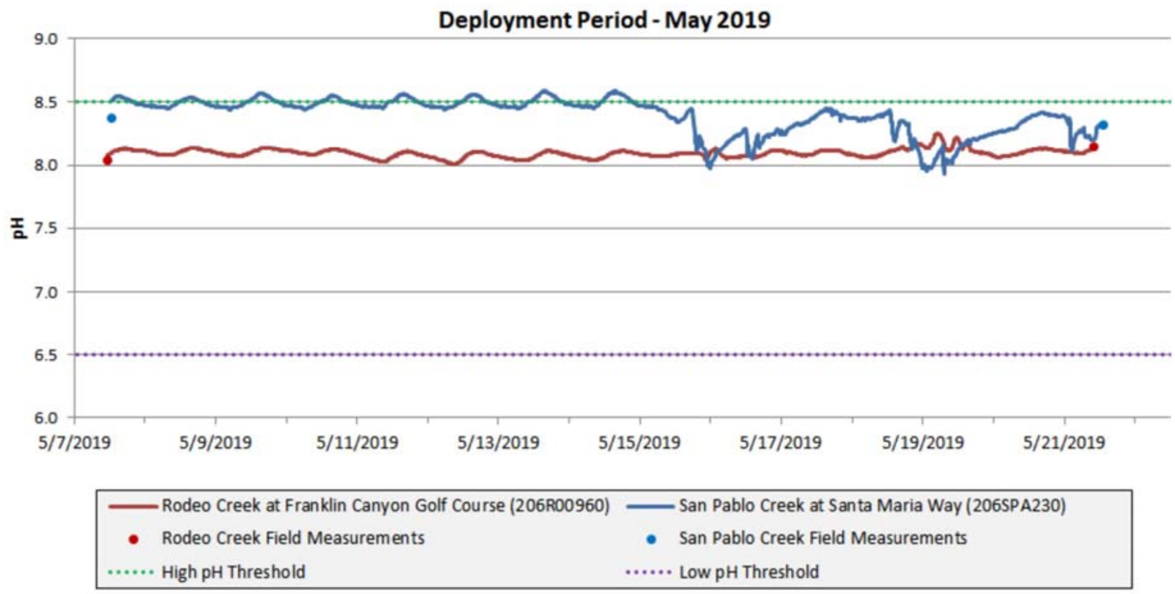


Figure 8. Continuous Water Quality Data (pH) Measured in Rodeo Creek and San Pablo Creek – May 7-21 and Aug. 13-23, 2019



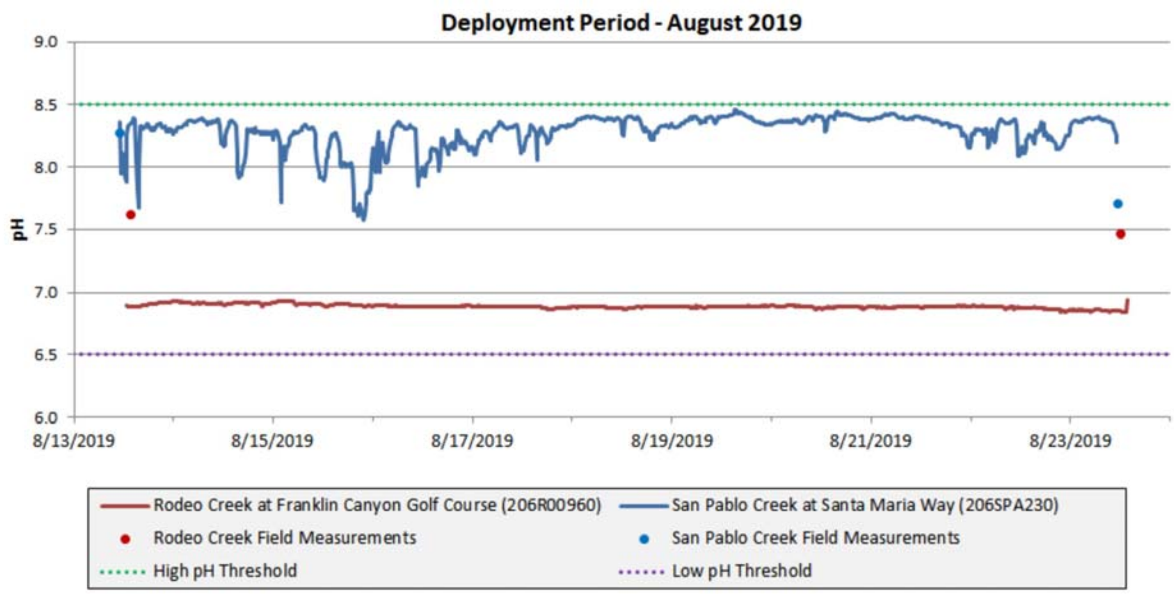
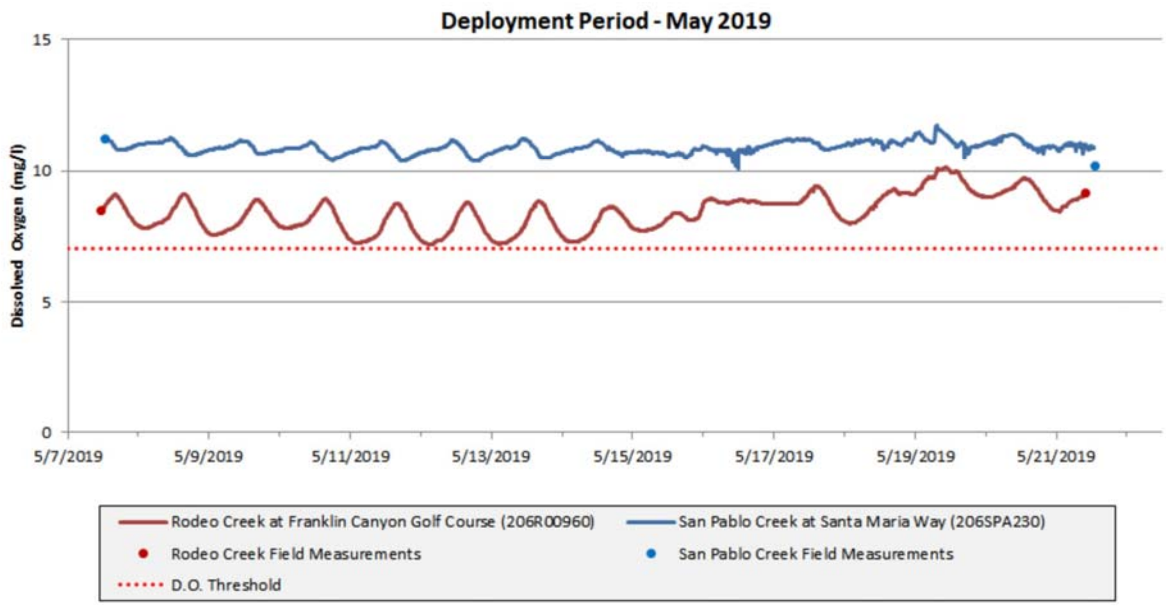


Figure 9. Continuous Water Quality Data (Dissolved Oxygen) Measured in Rodeo Creek and San Pablo Creek – May 7-21 and Aug. 13-23, 2019



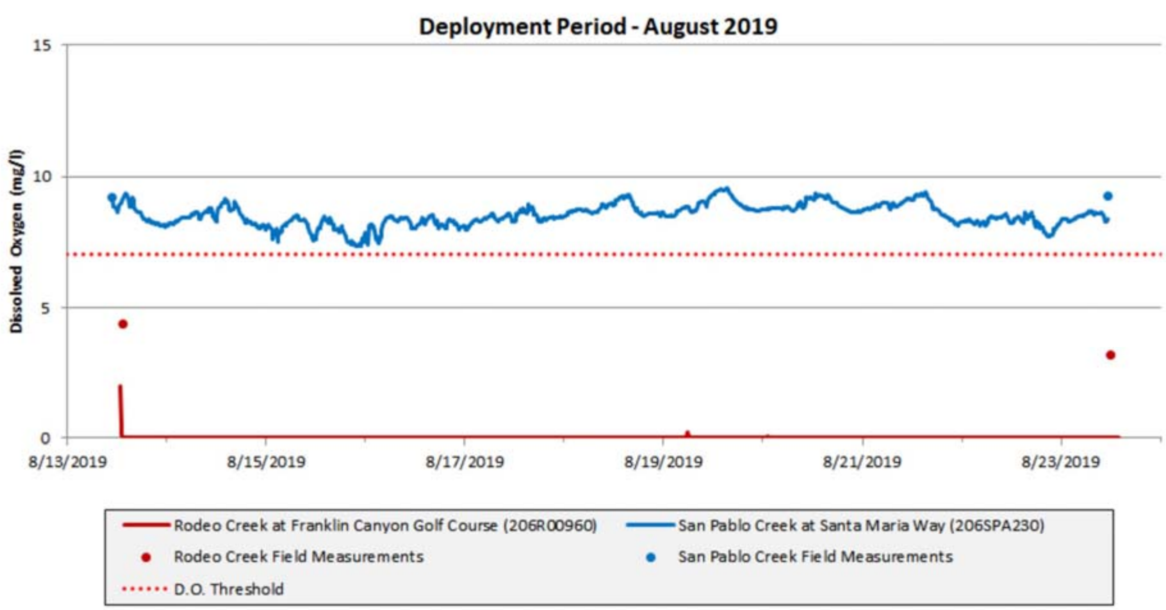
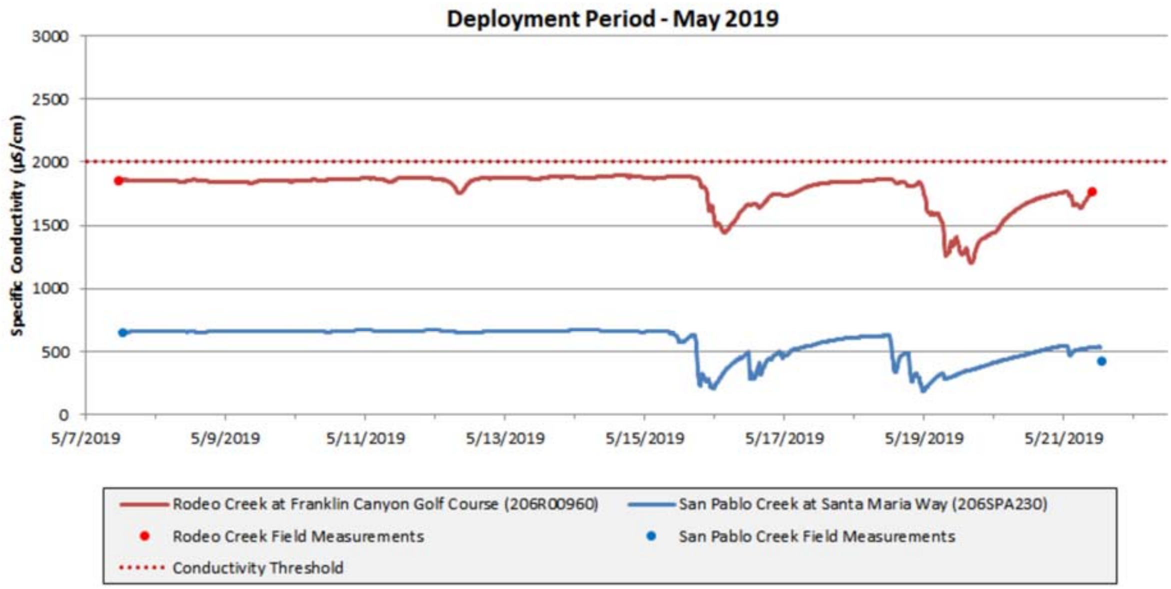
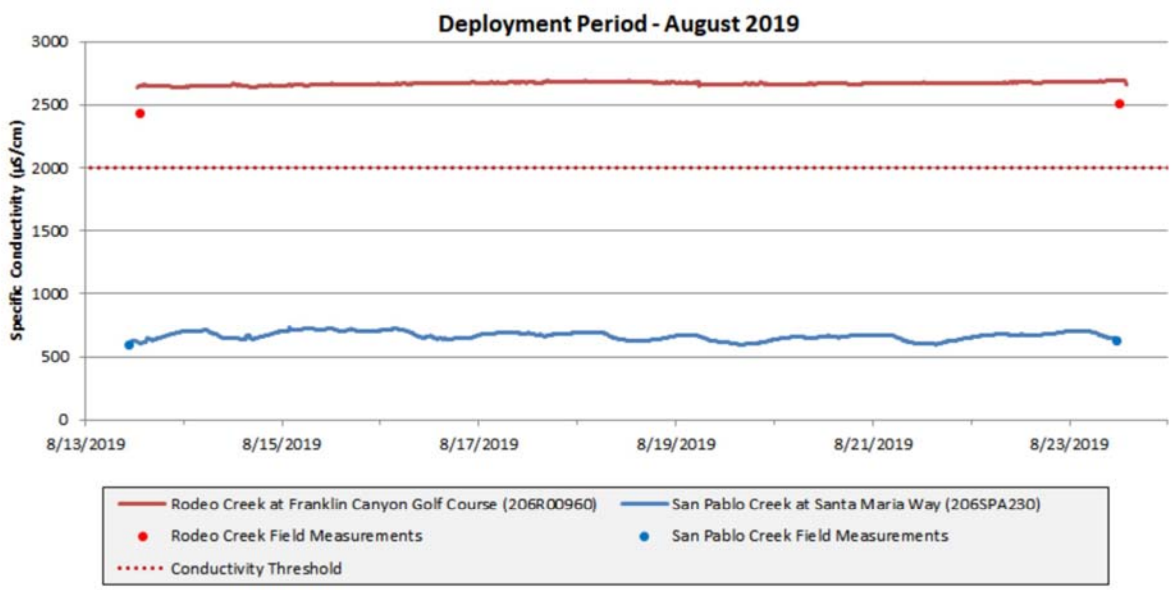


Figure 10. Continuous Water Quality Data (Specific Conductivity) Measured in Rodeo Creek and San Pablo Creek – May 7-21 and Aug. 13-23, 2019





Continuous water temperature data at both stations during the May deployment period display a diurnal cycle typical of the region. For the August deployment, continuous water temperature data at the San Pablo Creek location display a diurnal cycle, while water temperature data at Rodeo Creek lack a diurnal cycle, displaying a more consistent water temperature over the course of the monitoring period (Figure 7). It is possible that the sonde measurement device during the August deployment was inadvertently placed near the bottom of a relatively deep pool in Rodeo Creek which may have accounted for the lack of a discernable diurnal cycle. Placement of the sonde devices near the bottom of a pool may also explain why the continuous temperature measurements were lower than the near-surface temperature field measurements that were collected at the time of deployment and retrieval (lower graph in Figure 7). Field crew observations in August noted a drop of instream surface flow conditions and a heavily shaded riparian canopy suggesting there is no basis to reject the continuous water temperature data as the instrument may have been exposed to a stratified layer of colder water.

During the May deployment period, weekly average temperature measurements at both stations measured below the MRP threshold criterion for steelhead streams. For the August deployment, the weekly average temperature measurement at Rodeo Creek was below the MRP threshold, while the San Pablo Creek station exceeded the MRP threshold (Table 12).

Minimum and maximum pH measurements for San Pablo Creek over both deployment periods (May and August) were 7.57 and 8.59, respectively. Minimum and maximum pH measurements at Rodeo Creek during both periods was 6.84 and 8.14, respectively. During the May deployment period, San Pablo Creek and Rodeo Creek pH data display a classic diurnal curve, before a series of fluctuations from the May 15-21 storm events. During the August deployment period, pH measurements at San Pablo Creek vacillate between 7.9 and 8.5 frequently over the course of the deployment period. As this part of San Pablo Creek contains multiple residential homes, it is possible that runoff from landscape irrigation contributes to the pH oscillations, in contrast to what would normally be expected with typical diurnal pH cycles seen with instream primary production. During the August deployment at Rodeo Creek, pH readings display a relatively consistent value, with measurements within the upper and lower criteria of 8.5 and 6.5 (Figure 8). It is possible that the sonde measurement device during the August deployment was inadvertently placed near the bottom of a relatively deep pool in Rodeo Creek which may have accounted for the lack of pH fluctuations. Placement of the sonde devices near the bottom of a pool may also explain why the continuous pH measurements were lower than the near-surface pH field measurements that were collected at the time of deployment and retrieval (Figure 8, bottom).

The lowest dissolved oxygen concentration at San Pablo Creek (7.31 mg/l) occurred during August 2019. The lowest dissolved oxygen concentration at Rodeo Creek (0.00 mg/l) also occurred in August 2019. Data presented in Table 12 suggest dissolved oxygen data in Rodeo Creek was lost due to an instrument sensor failure or due to an unknown physical cause. To investigate whether dissolved oxygen values being recorded by the sonde device in Rodeo Creek during August could be validated, field crews performed an independent vertical profile for dissolved oxygen in the 4-foot deep pool at the location of the sonde deployment on Nov. 12, 2019, prior to the first rainfall event of the season. The vertical profile results were as follows: 3.5 mg/l near the surface, 2.0 mg/l at mid column, and 0.6 mg/L at the bottom of the 4-foot pool. Although the dissolved oxygen was low at the bottom, this profile confirms a non-zero reading near peak photosynthesis hours, as opposed to the consistent flatlining of data at 0.0 mg/l as recorded by the instrument (Figure 9). Due to field confirmation of non-zero readings at the bottom of the pool, the continuous dissolved oxygen data during the month of August at Rodeo Creek were qualified as “questionable” due to an unknown equipment failure or unknown physical cause.

During the May deployment but prior to the May 15-21 storm events, dissolved oxygen data in both Rodeo Creek and San Pablo Creek display a classic diurnal curve associated with instream primary production.

Continuous conductivity data in San Pablo Creek and Rodeo Creek display readings typical of the region (Figure 10). The median concentration of conductivity in San Pablo Creek between the two deployment periods increased slightly from 660 µS/cm in May to 666 µS/cm in August. The median concentration of conductivity in Rodeo Creek between the two deployment periods increased from 1,857 µS/cm in May to 2,699 µS/cm in August. The increase in conductivity between the two deployment periods can be attributed to a decrease in surface runoff, resulting in an increase of groundwater discharge. Groundwater discharges in the area often percolate through old marine sediment layers, picking up ions and increasing the stream's conductivity in the late summer months. During the entire August deployment, the San Pablo Creek station exceeded the MRP conductivity threshold of 2,000 µS/cm.

On May 15, there was a noticeable change in the data displayed in Figures 7 to 10. This was due to the intrusion of fresh water in Rodeo Creek and San Pablo Creek from a series of storm events which produced about 2.26 inches of rain in the vicinity of the two locations from 05:10 on May 15 to 11:55 on May 21. The net effect of this runoff was the following in both streams:

- A series of temperature fluctuations within the typical diurnal curve (Figure 7, top)
- A decrease and then slight increase in pH (Figure 8, top)
- A series of dissolved oxygen fluctuations within the typical diurnal curve (Figure 9, top)
- A sudden decrease followed by a gradual increase in conductivity (Figure 10, top)

These phenomena are all consistent with fresh water running into the measurement locations from storm rainfall.

Table 14 presents the percentages of continuous water quality data exceeding the water quality evaluation criteria specified in provision C.8.d of the MRP (see Table 6) for specific conductance, dissolved oxygen and pH, as measured at Rodeo Creek and San Pablo Creek stations during both monitoring periods.

Table 14. Percent of Specific Conductance, Dissolved Oxygen and pH Data Measured at Two Sites (Rodeo and San Pablo Creek) for Both Events Exceeding Water Quality Evaluation Criteria Identified in Table 6

Site Name	Creek Name	Monitoring Period	Specific Conductance	DO Percent Results < 7.0 mg/L	pH Percent Results < 6.5 or > 8.5
206R00960	Rodeo Creek	05/07/19-05/21/19	0%	0%	0%
		08/13/19-08/23/19	100%	100%	0%
206SPA230	San Pablo Creek	05/07/19-05/21/19	0%	0%	21%
		08/13/19-08/23/19	0%	0%	0%

Values in **bold** exceed MRP criterion

Following is a summary of water quality evaluation criteria exceedances occurring at either creek.

4.2.3.1. Rodeo Creek

Specific conductance measurements during the August deployment in Rodeo Creek exceeded MRP criterion 100 percent of the time (20 percent of instantaneous results >2,000 µS/cm; see Table 6). Dissolved oxygen measurements during the August deployment period dropped below the minimum steelhead stream criterion of 7.0 mg/L 100 percent of the time.

4.2.3.2. San Pablo Creek

During the May 2019 deployment, pH levels in San Pablo Creek fell below or exceeded MRP threshold criterion (see Table 6) 21 percent of the time, exceeding MRP threshold criterion (20 percent or more of values exceed the applicable threshold).

4.2.4. Continuous Water Quality and Steelhead Suitability – Water Years 2014-2019

Details discussing the comprehensive data analysis of continuous water quality data are discussed below.

4.2.4.1. Alhambra Creek – Water Year 2017

Water Temperature

At the sonde monitoring location, the WAT temperatures recorded for the May and July-August deployment periods was 16.02° C and 19.03° C, respectively. The water temperature measurements therefore exceeded MRP criterion during the July-August 2017 deployment period.

Dissolved Oxygen

Dissolved oxygen levels during May 2017 did not drop below the minimum steelhead stream criterion of 7.0 mg/L. During the July-August 2017 period, 100 percent of results failed to meet the minimum dissolved oxygen criterion, exceeding the MRP threshold of 20 percent of instantaneous results < 7.0 mg/L.

The decrease in dissolved oxygen between the spring and summer deployments is consistent with a warming of water temperature. The decrease in dissolved oxygen is consistent with the reduced solubility of oxygen with increased water temperatures.

pH

The minimum and maximum pH measurements for Alhambra Creek during both 2017 deployment periods were 7.48 and 8.41. Therefore, the pH of Alhambra Creek always met MRP criterion.

Specific Conductance

Continuous conductivity data display readings typical of the region and always met MRP criterion. The median concentration of conductivity in Alhambra Creek between the two deployment periods increased from 1,475 µS/cm in May to 1,762 µS/cm in July-August. This increase can be attributed to a decrease in surface runoff, resulting in an increase of groundwater discharge.

Steelhead Suitability

Alhambra Creek historically supported steelhead and it is assumed a small number of steelhead still ascend the creek to spawn and rear young. Due to temperature criterion exceedances discussed above and presented in Table 10, lower Alhambra Creek provides steelhead migration habitat, but no rearing habitat for salmonids is supported during the summer months.

The dissolved oxygen results further suggest that lower Alhambra Creek provides steelhead migration habitat, but no rearing habitat during the summer. Depressed dissolved oxygen levels suggest steelhead rearing habitat is not present at this location in Alhambra Creek.

4.2.4.2. Las Trampas Creek – Water Years 2017 and 2018

Water Temperature

The 2017 sonde monitoring station at Las Trampas Creek recorded a median temperature of 16.63° C and 20.63° C for the May and July-August deployments, respectively. The MWAT over the two deployment periods was 16.94° C and 21.43° C. Water temperature criterion was exceeded at the sonde monitoring location during the July-August 2017 deployment where the WAT exceeded 17° C.

During the May 2018 deployment, the median water temperature was 14.58° C and the WAT was 15.17° C. Temperature measurements at this monitoring location during the May 2018 deployment did not exceed the 17° C WAT criterion. The median water temperature during the September 2018 deployment, was 17.99° C and the WAT was 18.53° C. The temperature measurements at the sonde monitoring location during the September deployment exceeded the MRP 17° C threshold.

Dissolved Oxygen

During the spring deployment periods (May 2017 and May 2018), no dissolved oxygen measurements fell below the minimum steelhead stream criterion of 7.0 mg/L. Dissolved oxygen measurements during the August 2017 and September 2018 deployment periods fell below steelhead stream criterion 40 percent and 47 percent of the time, respectively, exceeding MRP criterion (Table 15).

pH

The pH during the May 2017 deployment period exceeded Basin Plan criterion during 17 percent of the monitoring period. As this does not exceed MRP trigger thresholds for pH (20 percent or more of values exceed the applicable threshold; Table 6), pH values met MRP criterion during the May 2017 monitoring period.

pH levels during the July-August 2017 deployment and the 2018 spring and summer deployments always met MRP criterion.

Specific Conductance

During both spring and summer monitoring periods of the 2017 and 2018 deployments, specific conductance measurements of Las Trampas Creek always met MRP criterion.

Steelhead Suitability

Although Las Trampas Creek probably once supported steelhead, as did most of the Walnut Creek drainage, the construction of drop structures on Walnut Creek downstream of the City of Walnut Creek prevent steelhead access to the watershed at present. The upper watershed of Las Trampas Creek is thought to support resident rainbow trout, as determined by its proximity to resident rainbow trout located in Lafayette Creek and Lafayette Reservoir, however no steelhead migration is present. As summer temperatures recorded in this portion of creek in 2017 and 2018 consistently exceeded criterion (Table 10), this location on Las Trampas Creek is thought to be marginal or prohibitive for steelhead rearing. Dissolved oxygen results recorded during the 2017 and 2018 summer deployment periods further suggest that this area of Las Trampas Creek may provide steelhead migration, but no rearing habitat during the summer.

4.2.4.3. Rimer Creek – Water Year 2016

Water Temperature

At the sonde monitoring station, Rimer Creek recorded a median temperature of 13.8° C and 16.8° C for the April and August 2016 deployments, respectively. The WAT over the two deployment periods was 17.03° C and 21.7° C. The temperature criterion was therefore exceeded at the sonde monitoring location during both the April and August deployment periods, where the WAT exceeded 17° C.

Dissolved Oxygen

Dissolved oxygen levels in Rimer Creek during the April deployment period did not drop below the minimum in-stream habitat criterion of 7.0 mg/L. During the August period, 47 percent of results failed to meet the minimum dissolved oxygen criterion, exceeding the MRP threshold of 20 percent of instantaneous results < 7.0 mg/L.

pH

The pH of Rimer Creek always met MRP criterion during the monitoring period (Table 15).

Specific Conductance

The specific conductance of Rimer Creek always met MRP criterion during the 2016 monitoring periods. Specific conductance medians for both April and August were within MRP criterion (714-821 μS/cm), respectively.

Steelhead Suitability

While no longer supporting an anadromous steelhead population traveling San Leandro Creek to San Francisco Bay, Rimer Creek likely supports small numbers of resident rainbow trout descended from this steelhead population. Because this creek appears to support a viable population of resident rainbow trout, and likely provides spawning and/or rearing habitat for rainbow trout from Upper San Leandro Reservoir, MRP criterion for a steelhead stream apply to Rimer Creek. As such, this stream should be considered a steelhead stream for the purposes of current or future water quality monitoring status.

4.2.4.4. Rodeo Creek – Water Years 2014 and 2019

Water Temperature

The vast majority of the Rodeo Creek channel upstream of both the 2014 and 2019 monitoring locations is shaded by riparian vegetation. This likely explains why, during both spring and summer deployment periods, Rodeo Creek did not exceed water temperature threshold criterion. The median water temperature under MRP 1 criteria in 2014 was 16.89° C and the WAT values during the May and August 2019 deployment periods were 14.77° C and of 16.87°, respectively.

Dissolved Oxygen

Dissolved oxygen measurements in Rodeo Creek were measured to be in exceedance of Basin Plan objectives 100 percent of the time during the spring and summer deployment of 2014, and 100 percent of the time during the summer deployment of 2019. During both the 2014 and 2019 summer deployments, field crew observations noted minimal or discontinuous surface flow during deployment or retrieval periods. The noted decrease or discontinuation of surface flow is a contributing factor to decreased dissolved oxygen levels in Rodeo Creek. During the August 2019 deployment period, dissolved oxygen measurement data are qualified as questionable, as the mean concentration of data collected is 0.00 mg/L.

pH

The minimum and maximum pH measurements for Rodeo Creek during both 2014 deployment periods were 7.23 and 8.28, respectively. During the 2019 spring and summer deployment periods, the minimum and maximum pH measurements were 6.84 and 8.14, respectively. The pH of Rodeo Creek always met MRP criterion.

Specific Conductance

The median specific conductance in Rodeo Creek during the April and August 2014 deployment periods was 2,750 µS/cm and 3,230 µS/cm, respectively. During the May and August 2019 deployment periods, the median specific conductance was 1,857 µS/cm and 2,669 µS/cm, respectively (Table 12).

During the May 2019 deployment period, the specific conductance of Rodeo Creek always met the MRP criterion (Table 14).

During the August 2019 deployment period, 100 percent of results failed to meet specific conductance criterion, exceeding the MRP threshold of 20 percent instantaneous results > 2,000 µS/cm (Figure 10)

While there was no MRP measurement quality objective for specific conductance monitoring in water year 2014, 100 percent of results during the April and August 2014 deployment periods would have failed to meet current MRP criterion.

Steelhead Suitability

The 2015 edition of the Basin Plan for the San Francisco Bay Region designates Rodeo Creek as having both COLD and WARM existing beneficial uses. This indicates the upstream portion of this creek has year-round water temperatures suitably cold to support salmonids, but the lower portions of the creek are too warm to support salmonids through the summer. Historically, Rodeo Creek has not supported steelhead, and Leidy et al (2005) concluded that Rodeo Creek is not suitable for steelhead at present. Part of this reasoning is due to the short length of Rodeo Creek (8.35 miles) and its small watershed.

4.2.4.5. San Pablo Creek – Water Years 2014, 2018 and 2019

Water Temperature

Water temperature monitoring during the April-May and August 2014 deployment did not exceed MRP 1 criterion. The median water temperature at this location was 16.34 °C. At the 2018 sonde monitoring location at San Pablo Creek, the recorded median temperature was 14.76° C and 15.72° C for the May and September deployments, respectively. The WAT over the two deployment periods was 15.15° C and 15.62° C. The temperature criterion at the sonde monitoring location during the May and September 2018 deployments did not exceed the 17° C threshold criterion. During the 2019 monitoring in San Pablo Creek, the sonde monitoring location recorded a median temperature of 13.71° C and 17.62° C for the May and August deployments, respectively. The WAT over the two deployment periods was 13.92° C and 17.56° C. The temperature criterion at the sonde monitoring location during the May deployment did not exceed 17° C threshold criterion; however, the weekly average temperature recorded during the August 2019 deployment period of 17.56° C exceeded MRP criterion.

Dissolved Oxygen

The lowest dissolved oxygen concentrations recorded during the 2014, 2018 and 2019 deployments occurred during the summer deployments in all years and measured 6.86 mg/l, 0.46 mg/l and 7.31 mg/l, respectively. During the September 2018 deployment, dissolved oxygen fell below the steelhead stream threshold 100 percent of the time. Therefore, San Pablo Creek exceeded MRP trigger thresholds for dissolved oxygen during the September 2018 measurement period.

pH

The minimum and maximum pH measurements during the 2014 deployment periods were 7.72 and 8.01, respectively, while the minimum and maximum pH measurements during the 2018 deployment periods were 7.46 and 8.05, respectively. The pH of San Pablo Creek always met MRP criterion at 2014 and 2018 monitoring locations (Table 15)

During the May 2019 monitoring period, 21 percent of results failed to meet pH criterion, exceeding the MRP threshold of 20 percent of instantaneous results. During the August monitoring period, the pH of San Pablo Creek always met MRP criterion.

Specific Conductance

The median specific conductance in San Pablo Creek during the April-May and August 2014 deployment periods was 1,366 µS/cm and 1,604 µS/cm, respectively. During the May and September 2018 deployment periods, the median specific conductance was 1,102 µS/cm and 1,248 µS/cm, respectively.

Steelhead Suitability

Historically, San Pablo Creek once supported runs of steelhead and Coho salmon. The lower section of San Pablo Creek below the San Pablo Reservoir dam still had runs of steelhead in the 1950s; however, EBMUD currently reports San Pablo Creek below San Pablo Reservoir no longer supports steelhead/rainbow trout. From 2006-2018, EBMUD conducted annual fish sampling of three sites on San Pablo Creek below the reservoir and found no steelhead/rainbow trout other than a few hatchery rainbow trout that appear to have come from San Pablo Reservoir (personal communication between Scott Cressey and Jessica Purifacto, 2018).

Currently, there are three barriers present in lower San Pablo Creek that prevent upstream steelhead migration. The first barrier is located where San Pablo Creek flows under Giant Road in North Richmond, followed by the Interstate 80 culvert barrier, and finally the barrier at El Portal Drive in San Pablo. Although San Pablo Creek does not currently support steelhead/rainbow trout, the Basin Plan designates San Pablo Creek’s existing beneficial uses as both COLD and WARM habitat, showing awareness that the lower end of San Pablo Creek could serve as a winter and spring migration corridor should steelhead/rainbow trout return to San Pablo Creek.

Above the San Pablo Reservoir, rainbow trout from the reservoir can only migrate a short distance (0.5 miles) up San Pablo Creek due to a vertical drop structure near the EBMUD Orinda water treatment facility. The water year 2019 monitoring station at Santa Maria Way is approximately two miles upstream of this drop structure; therefore, San Pablo Creek at this location may contain resident rainbow trout, but not steelhead or migratory trout, from San Pablo Reservoir (Cressey, 2019).

4.2.4.6. San Ramon Creek – Water Year 2015

Water Temperature

During the April and September 2015 monitoring period, San Ramon Creek temperature criterion were subject to MRP 1 threshold values. The maximum MWAT temperature recorded for San Ramon Creek exceeded the 20.5° C criterion during 80 percent of the April deployment period and 75 percent of the September deployment period. San Ramon Creek does not maintain a COLD beneficial use, as monitoring of steelhead streams was not required at the time.

Dissolved Oxygen

Dissolved oxygen levels in San Ramon Creek during the April and September 2015 deployment periods were not subject to minimum COLD dissolved oxygen criterion as this location does not maintain a COLD designated beneficial use.

pH

The minimum and maximum pH measurements for San Ramon Creek during both 2015 deployment periods were 7.70 and 9.25, respectively. During the April-May 2015 monitoring period, 31 percent of results failed to meet pH criterion, exceeding the MRP threshold of 20 percent of instantaneous results. During the September monitoring period, the pH of San Ramon Creek always met MRP criterion.

Specific Conductance

While without specified criterion in water year 2015, the median specific conductivity of 528 µS/cm to 814 µS/cm is normal for this region.

4.2.4.7. West Branch Alamo Creek – Water Years 2015 and 2016

Water Temperature

During the 2015 spring and summer monitoring periods, the maximum MWAT temperature recorded for the West Branch of Alamo Creek was 14.44° C in April and 16.34° C in September. The MRP 1 temperature criterion of 20.5° C was not exceeded in 2015. In 2016, the median water temperature recorded for the April and August deployments was 14.7° C and 18.2° C, respectively. The maximum WAT over the two deployment periods was 15.01° C and 18.51° C, respectively. The temperature criterion was exceeded at the YSI sonde monitoring location during the August deployment where the WAT exceeded 17° C.

Dissolved Oxygen

The lowest 2015 dissolved oxygen concentration (1.67 mg/l) at the West Branch of Alamo Creek occurred during the September deployment, and the lowest 2016 dissolved oxygen concentration (3.03 mg/l) occurred during the August deployment. Continuous general water quality data along the West Branch of Alamo Creek do not follow a diurnal cycle exhibited by primary production. General water quality parameters in most cases met water quality objectives; however, dissolved oxygen exceedances during both deployment periods in 2015 and 2016 could be due to discharge from an artificial impoundment located upstream of sites 204R00388 and 204R01412.

During the April-May and September 2015 deployments, dissolved oxygen levels fell below the COLD threshold criterion 91 and 93 percent of the time, respectively. During the April and August 2016 deployments, dissolved oxygen levels fell below the COLD threshold 58 and 100 percent of the time, respectively.

pH

The minimum and maximum pH measurements for West Branch Alamo Creek during both 2015 deployment periods were 7.66 and 8.06, respectively. The minimum and maximum pH measurements for West Branch Alamo Creek during both 2016 deployment periods were 7.77 and 8.16, respectively. The pH of the West Branch of Alamo Creek always met the Basin Plan criterion during the 2015 and 2016 monitoring periods.

Specific Conductance

The median specific conductance in West Branch Alamo Creek during the April-May and September 2015 deployment periods were 1,003 µS/cm and 1,004 µS/cm, respectively. During the April and August 2016 deployment periods, the median specific conductance was 1,102 µS/cm and 1,248 µS/cm, respectively. Specific conductance in the West Branch of Alamo Creek always met MRP criterion during the monitoring periods.

Steelhead Suitability

The 2015 Basin Plan states Alamo Creek has a potential beneficial use as COLD freshwater habitat (i.e., steelhead stream), but its current designation is listed as WARM freshwater habitat. As there is no historical record of this creek ever supporting a run of steelhead, and it currently does not support either steelhead or resident rainbow trout, the lower West Branch Alamo Creek does not qualify as a steelhead stream as suggested by MRP criterion, despite 2015 Basin Plan designation as a potential cold water fishery.

Table 15. Water Temperature, Specific Conductance, Dissolved Oxygen and pH Data Measured in Contra Costa County Exceeding Water Quality Evaluation Criteria Identified in Table 6

Water Year	Site Code	Creek Name	Monitoring Period	Percent of Results Where WAMT[1] > 20.5° C / WAT[2]	Specific Conductance[3]	DO Percent Results < 7.0 mg/l (COLD)	pH Percent Results < 6.5 or > 8.5
2014	206RDO025	Rodeo Creek[4]	04/14/14-04/25/14	0%	100%	100%	0%
			08/01/14-08/18/14	0%	100%	100%	0%
	206R00551	San Pablo Creek	04/30/14-05/09/14	0%	0%	0%	0%
			08/01/14-08/13/14	0%	0%	0%	0%
2015	204R00388	West Branch of Alamo Creek[5]	04/21/15-05/01/15	0%	0%	91%	0%
			09/02/15-09/15/15	0%	0%	93%	0%
	207R01163	San Ramon Creek[6]	0402/15-05/01/15	80%	0%	0%	30%
			09/02/15-09/15/15	75%	0%	31%	0%
2016	204R01412	West Branch Alamo Creek	04/15/16-04/25/16	15.01	0%	58%	0%
			08/01/16-08/15/16	18.51, 18.15	0%	100%	0%
	204R01519	Rimer Creek	04/15/16-04/25/16	14.07	0%	0%	0%
			08/01/16-08/15/16	17.03, 17.48	0%	47%	0%
2017	207R02635	Las Trampas Creek	05/16/17-05/30/17	16.82, 16.94	0%	0%	17%
			07/31/17-08/11/17	21.43	0%	40%	0%
	207R04544	Alhambra Creek	05/16/17-05/30/17	16.02, 16.01	0%	0%	0%
			07/31/17-08/11/17	19.03	0%	100%	0%
2018	207WAL411	Las Trampas Creek	05/08/18-05/17/18	15.17	0%	0%	0%
	207R02891		09/04/18-09/14/18	18.53	0%	47%	0%
	206SPA125	San Pablo Creek	05/08/18-05/17/17	15.15	0%	9%	0%
			09/04/18-09/14/18	15.62	0%	100%	0%
2019	206R00960	Rodeo Creek	05/07/19-05/21/19	14.77	0%	0%	0%
			08/13/19-08/23/19	16.87	100%	100%	0%
	206SPA230	San Pablo Creek	05/07/19-05/21/19	13.92	0%	0%	21%
			08/13/19-08/23/19	17.56	0%	0%	0%

1 Weekly Average Maximum Daily Temperature (WAMT) threshold criterion required under MRP Order No. R2-2009-0074 (water years 2014 and 2015)

2 Weekly Average Temperature (WAT) threshold criterion required under MRP Order No. R2-2015-0074 (water years 2016-2019)

3 Specific conductance measurements were recorded during water years 2014-2019. Under MRP Order No. R2-2009-0074, no threshold criterion is listed. Therefore, 2014 and 2015 measurements do not have applicable threshold criterion. Results were retroactively evaluated against MRP Order No. R2-2015-0074 criterion for the purpose of this report

4 Surface flow was observed to be discontinuous during the August 2014 deployment period.

Table 15. Water Temperature, Specific Conductance, Dissolved Oxygen and pH Data Measured in Contra Costa County Exceeding Water Quality Evaluation Criteria Identified in Table 6

Water Year	Site Code	Creek Name	Monitoring Period	Percent of Results Where WAMT[1] > 20.5° C / WAT[2]	Specific Conductance[3]	DO Percent Results < 7.0 mg/l (COLD)	pH Percent Results < 6.5 or > 8.5

5 West Branch Alamo Creek maintains a potential beneficial use as a cold-water stream. As this location does not have an existing COLD beneficial use, the results do not constitute an exceedance. Location was monitored to determine if COLD beneficial uses were present.

6 San Ramon Creek does not have either a potential or existing COLD beneficial use. Monitoring of COLD streams was mandated under MRP Order No. R2-2015-0049. Dissolved oxygen results do not constitute an exceedance under MRP Order No. R2-2009-0047 criterion.

Values in **bold** exceed MRP criterion

4.2.5. Water Quality Data Evaluation for Steelhead Suitability – Water Year 2019

The potential responsive action to the analysis of water quality as it relates to fish habitat in Rodeo Creek and San Pablo Creek is discussed below. After a brief discussion of site characteristics and results, the potential responsive action to the analysis of water quality as it relates to fish habitat follows.

4.2.5.1. Rodeo Creek (206R00960)

Water Temperature

The 2015 edition of the Basin Plan for the San Francisco Bay Region designates Rodeo Creek as having both COLD and WARM existing beneficial uses. This indicates the upstream portion of this creek has year-round water temperatures suitably cold to support salmonids, but the lower portions of the creek are too warm to support salmonids through the summer (Cressey, 2019).

The continuous monitoring station on Rodeo Creek in Hercules was located at the Franklin Canyon Golf Course approximately four miles from the mouth of Rodeo Creek where it flows into Carquinez Strait. Located in a natural section of stream, this monitoring station was selected due to its currently designated beneficial use as a steelhead stream.

Historically, Rodeo Creek has not supported steelhead, and (Leidy et al., 2005) concluded that Rodeo Creek is not suitable for steelhead at present. Part of this reasoning is due to the short length of Rodeo Creek (8.35 miles) and its small watershed. Weekly average temperature calculations for the HOBO temperature monitoring station exceeded MRP criterion on two occasions (Table 9), with both weekly average temperature exceedances occurring during the period from Aug. 21-Sep. 3, 2019. Even though the two occasions when weekly average temperature temperatures exceeded the criterion were only slightly above the 17° C threshold, this suggests the Basin Plan's designation of steelhead habitat may better apply upstream of the golf course, while the WARM designated beneficial use applies downstream of the golf course, where less riparian shading is common and the lower 2.75 miles of the creek are channelized (Cressey, 2019).

The sonde monitoring location at Rodeo Creek recorded median temperatures of 14.28° C and 16.88° C for the May and August deployments, respectively (Table 11) and the MWAT over the two deployment periods was 14.77° C and 16.87° C (Table 12). The temperature criterion at the sonde monitoring location during the May and August deployments did not exceed the 17° C threshold criterion.

Dissolved Oxygen

During the May deployment in Rodeo Creek, dissolved oxygen levels never dropped below the minimum steelhead stream criterion of 7.0 mg/L; therefore, no dissolved oxygen measurements exceeded MRP criterion during this deployment.

During the August 2019 deployment, dissolved oxygen data was qualified as "questionable" due to an unknown physical cause or instrument failure (Table 12). However, results of near-surface dissolved oxygen field measurements at the time of sonde deployment and retrieval, and results of an independent dissolved oxygen profile on Nov. 12, 2019, indicate that the dissolved oxygen was very likely below the steelhead stream criterion of 7.0 mg/L 100 percent of the time during the August deployment (Figure 9)

pH

The pH of Rodeo Creek always met the MRP criterion during the monitoring period (Table 13).

Specific Conductance

The median specific conductance in Rodeo Creek during the May and August deployment periods was 1,857 µS/cm and 2,669 µS/cm, respectively (Table 12).

During the May deployment period, the specific conductance of Rodeo Creek always met the MRP criterion (Table 13).

During the August 2019 deployment period, 100 percent of results failed to meet specific conductance criterion, exceeding the MRP threshold of 20 percent instantaneous results > 2,000 µS/cm (Figure 10)

4.2.5.2. San Pablo Creek (206R01319)

Water Temperature

The water year 2019 water temperature monitoring station 206R01319 was in lower San Pablo Creek at Fred Jackson Way in the City of Richmond. Station 206R01319 was the downstream-most monitoring station of three along San Pablo Creek and one of two locations located below San Pablo Reservoir. The HOBO monitoring device was in a section of natural stream, approximately 1.25 miles from the mouth of San Pablo Creek where it enters San Pablo Bay. The Basin Plan (SFBRWQCB, 2015b) designates San Pablo Creek as being both COLD and WARM water habitat, meaning a WARM designation may be more suitable in its lower end where less riparian shading is common (Cressey, 2019).

Historically, San Pablo Creek once supported runs of steelhead and Coho salmon. The lower section of San Pablo Creek below the San Pablo Reservoir dam still had runs of steelhead in the 1950s (Leidy et al., 2005); however, EBMUD currently reports San Pablo Creek below San Pablo Reservoir no longer supports steelhead/rainbow trout. From 2006-2018, EBMUD conducted annual fish sampling of three sites on San Pablo Creek below the reservoir and found no steelhead/rainbow trout other than a few hatchery rainbow trout that appear to have come from San Pablo Reservoir (personal communication between Scott Cressey and Jessica Purifacto, 2018).

Currently, there are three barriers present in lower San Pablo Creek that prevent upstream steelhead migration. The first barrier is located where San Pablo Creek flows under Giant Road in North Richmond, followed by the Interstate 80 culvert barrier, and finally the barrier at El Portal Drive in San Pablo (Cressey, 2018). Although San Pablo Creek does not currently support steelhead/rainbow trout, the Basin Plan designates San Pablo Creek’s existing beneficial uses as both COLD and WARM habitat, showing awareness that the lower end of San Pablo Creek could serve as a winter and spring migration corridor should steelhead/rainbow trout return to San Pablo Creek.

The median water temperature at this location was 16.16° C and the MWAT was 18.42° C (see Table 8). The 17° C weekly average temperature criterion was exceeded on 13 occasions, or 52 percent of the 25-week monitoring period, while the instantaneous water temperature criterion of 24° C was exceeded just once (24.07° C). Due to this, lower San Pablo Creek at Fred Jackson Way (site 206R01319) failed to meet weekly average temperature criteria for a steelhead stream, suggesting summer temperatures recorded at this location are marginal or prohibitive for steelhead rearing.

4.2.5.3. San Pablo Creek (206R00551)

Water Temperature

The second of two monitoring stations along San Pablo Creek below the San Pablo Reservoir (station 206R00551) was located near Church Lane in the City of San Pablo approximately 2 miles upstream of station 206R01319. Located in a natural section of stream with dense riparian cover, the Church Lane HOBO recorded water temperature exceedances on eight occasions, or 32 percent of the 25-week deployment period. The instantaneous water temperature criterion of 24° C was never exceeded, and the maximum weekly average temperature was 18° C. While meeting instantaneous temperature criterion of a steelhead stream, San Pablo Creek at the Church Lane monitoring station failed to meet MRP weekly average temperature criterion, suggesting summer temperatures recorded at this location are marginal or prohibitive for steelhead rearing.

4.2.5.4. San Pablo Creek (206SPA230)

Water Temperature

The 2019 water quality monitoring station of San Pablo Creek at Santa Maria Way in Orinda is upstream of the San Pablo Reservoir and just downstream of Highway 24. While this reach of San Pablo Creek once supported a run of steelhead prior to the construction of San Pablo Reservoir, adult steelhead can presently migrate upstream only as far as the base of San Pablo dam. Above the San Pablo Reservoir, rainbow trout from the reservoir can only migrate a short distance (0.5 miles) up San Pablo Creek due to a vertical drop structure near the EBMUD Orinda water treatment facility. The water year 2019 monitoring station at Santa Maria Way is approximately two miles upstream of this drop structure; therefore, San Pablo Creek at this location may contain resident rainbow trout, but not steelhead or migratory trout, from San Pablo Reservoir (Cressey, 2019). As this section of San Pablo Creek currently maintains a designated beneficial use as a cold-water habitat, water temperature and general water quality parameters were targeted to monitor this current beneficial use.

The median water temperature at this location was 14.52° C and the MWAT was 18.49° C (Table 8). The 17° C weekly average temperature criterion was exceeded on 12 occasions, or 48 percent of the 25-week monitoring period. The instantaneous water temperature criterion of 24° C was never exceeded as the highest recorded temperature was 19.48° C.

As shown in Table 11, the sonde monitoring location at San Pablo Creek recorded a median temperature of 13.71° C and 17.62° C for the May and August deployments, respectively. The MWAT over the two deployment periods was 13.92° C and 17.56° C (Table 12).

The temperature criterion at the sonde monitoring location during the May deployment did not exceed 17° C threshold criterion; however, the weekly average temperature recorded during the August deployment period of 17.56° C exceeded MRP criterion (Table 11). Summer water temperatures recorded by the HOBO monitoring station in this portion of San Pablo Creek exceeded MRP criterion, indicating water temperatures in this location are not suitable for the designated beneficial use for COLD water fisheries.

Dissolved Oxygen

Dissolved oxygen levels during the May and August deployment period never dropped below the minimum steelhead stream criterion of 7.0 mg/L. Therefore, dissolved oxygen levels of San Pablo Creek always met MRP criterion (Table 13).

pH

During the May monitoring period, 21 percent of results failed to meet pH criterion, exceeding the MRP threshold of 20 percent of instantaneous results (Table 13).

During the August monitoring period, the pH of San Pablo Creek always met MRP criterion (Table 13).

Specific Conductance

The specific conductance of San Pablo Creek always met the MRP criterion during the monitoring period (Table 13). The median specific conductance of 660 µS/cm to 666 µS/cm is normal for the region.

4.3. Pathogen Indicator Bacteria – Water Year 2019

In compliance with MRP provision C.8.d, a set of pathogen indicator samples were collected on Jun. 26, 2019 at five stations on creeks in Contra Costa County (Table 16). They were analyzed for enterococci and *E. coli*. The sites were located along Baxter Creek, Pinole Creek, Alhambra Creek, East Antioch Creek and Marsh Creek. Due to their proximity to either a public park or illegal encampment, all sites were targeted to investigate if the water quality could be impacted by regular human recreational activity, such as off-leash dog parks or other activities suspected with illegal encampments. All sites were chosen based upon the likelihood of recreational water contact or to investigate areas of possible anthropogenically-induced contamination.

As described previously (Section 3.2.5), single sample maximum concentrations of 130 CFU/100ml enterococci and 410 CFU/100ml *E. coli* were used for evaluation, based on the most recently published recreational water quality criteria statistical threshold values for water contact recreation (USEPA, 2012). Enterococci concentrations ranged from 86 to 1,733 CFU/100 ml and *E. coli* concentrations ranged from 120 to 11,000 CFU/100 ml. Three enterococci samples exceeded the applicable criterion, while three samples collected for *E. coli* also exceeded the applicable USEPA criterion. Samples collected at 206PNL010 (Pinole Creek), 207ALH010 (Alhambra Creek) and 544R04613 (Marsh Creek) all exceeded criteria for both *E. coli* and enterococci.

Table 16. Fecal Coliform, Enterococci and E. coli Levels Measured from Water Samples Collected at 30 Locations in Creeks in Contra Costa County – Water Years 2014-2019

Water Year	Site ID	Creek Name	Fecal Coliform[1,3] (CFU/100ml)	Enterococci[2,4] (CFU/100ml)	*E. Coli*[5] (CFU/100ml)
2014	207R00843[a]	Grizzly Creek	1,100	NA	1,100
	206RD0025	Rodeo Creek	50	NA	50
	206R01024	Rodeo Creek	110	NA	80
	206RD0003	Rodeo Creek	500	NA	500
	206R00551	San Pablo Creek	300	NA	300
2015	204R00388	West Branch of Alamo	280	NA	280
	207R00891	Green Valley	300	NA	300
	207R01163	San Ramon Creek	300	NA	300
	207R01271	Walnut Creek	14,000	NA	14,000
	206R01319	San Pablo Creek	2,800	NA	2,800
2016	206SPA020	San Pablo Creek	NA	52	300
	206SPA030[b]	San Pablo Creek	NA	31	170
	207R01447	Franklin Creek	NA	63	220
	206R01495	Pinole Creek	NA	52	1100
	204R01519	Rimer Creek	NA	330	700
2017	204R01412	West Branch Alamo Creek	NA	172	300
	207R01675	Sans Crainte Creek	NA	2,419	500
	207R02891	Las Trampas Creek	NA	152	800
	207R03403	Walnut Creek	NA	93	280
	207R04544	Alhambra Creek	NA	365	500
2018	207WAL025[a]	Grayson Creek	NA	63	517
	206R00727	Pinole Creek	NA	28	121
	207R01675	Sans Crainte Creek	NA	579	461
	206R02343	Wildcat Creek	NA	388	59
	206R03927	San Pablo Creek	NA	73	172
2019	203BAX045	Baxter Creek	NA	101	120
	206PNL010	Pinole Creek	NA	1,553	11,000
	207ALH010	Alhambra Creek	NA	1,733	816
	543EAN010	East Antioch Creek	NA	86	228
	544R04613[b]	Marsh Creek	NA	145	820

1 Fecal Coliform analyzed under MRP Order No. R2-2009-0074 (water years 2014 and 2015)
2 Enterococci analyzed under MRP Order No. R2-2015-0049 (water years 2016-2019)
3 **Bold** values exceeded SF Bay Basin Plan water quality objective of 400 MPN/100ml for fecal coliform
4 **Bold** values exceeded USEPA criterion of 130 CFU/100ml for enterococci
5 **Bold** values exceeded USEPA criterion of 410 CFU/100ml for E. coli
a Relative percent differences from a laboratory duplicate sample exceeded the measurement quality objective of 25 percent for *E. coli*
b Relative percent differences from a laboratory duplicate sample exceeded the measurement quality objective of 25 percent for enterococci and *E. coli*
NA Not applicable; enterococci was not analyzed in water years 2014 and 2015; fecal coliform was not analyzed in water years 2016-2019

5. Lessons Learned

Are water quality objectives, both numeric and narrative, being met in local receiving waters, including creeks, rivers, and tributaries?

Local/targeted monitoring using continuous monitoring addresses water temperature, conductivity, pH, turbidity and dissolved oxygen. These parameters have water quality objectives that generally relate to WARM and COLD beneficial uses. Objectives for conductivity are generally attained in most Contra Costa creeks monitored, except for Rodeo Creek. The Rodeo Creek location consistently exceeds the conductivity objective, pointing to the possible influence of groundwater at the location monitored. The pH of water generally stays within bounds established by the Basin Plan (6.5 < pH > 8.5) at frequencies specified in the MRP; exceptions occur at San Ramon and San Pablo Creeks, where the pH exceeded 8.5 30 percent and 21 percent of the time, respectively. The daytime peak of pH values, coincident with daily dissolved oxygen peaks at the locations monitored, point to photosynthetic cycling as a root cause of pH exceedances.

Attainment of dissolved oxygen and temperature thresholds was less widespread throughout the county than conductivity and pH attainment. Of the creeks monitored during MRP 2.0, San Pablo Creek had the most consistent attainment of the dissolved oxygen water quality objective relevant to COLD (> 7 mg/L), although during the summer monitoring period this threshold was never attained at location 206SPA125. Temperatures in San Pablo Creek also generally attained MRP thresholds at most locations and times. Referring back to the Integrated Monitoring Report from MRP 1.0, Wildcat Creek also showed the most favorable temperature conditions of all creeks monitored in Contra Costa County over the past two permit cycles. Thus, the most consistent attainment of temperature and water quality objectives pertinent to COLD in monitored creeks are Wildcat and San Pablo Creeks. This observation is aligned with the land uses and the relatively cooler climate in west county watersheds, as compared to central and eastern county watersheds.

Attainment of the water quality objective for WARM (DO > 5 mg/L) is also variable for the 16 different sonde deployments conducted 2012-2019 (Table 17). The objective is generally attained during the spring deployments. During the summer, at least half of the sonde deployments indicated dissolved oxygen lower than 5 mg/L during isolated incidents. Five of the 16 had more prolonged incidents, including Marsh Creek.

Marsh Creek was selected for a stressor/source identification study in 2017 that was concluded in 2019. The study identified low dissolved oxygen as a root cause of recurrent fish kills. The study is complete and, having identified flow augmentation as a potential corrective action, Permittees are now evaluating the effectiveness of this potential remedy and the implications for longer term strategies to maintain and enhance water quality in Marsh Creek.

Grab sampling for pathogen indicators showed that exceedances can occur downstream of locations where people live outdoors, or in recreational vehicles and other temporary accommodation that lack centralized sanitary sewage services. Not all exceedances were attributed to anthropogenic sources, as the presence of waterfowl on stream banks and in the stream channel were also suspected to contribute to elevated levels of fecal indicator bacteria.

Table 17. Summary of Attainment of DO > 5 mg/L in Contra Costa County Creeks

Creek/Location	Year Monitored	DO > 5 mg/L in Spring?	DO > 5 mg/L in summer?
Rodeo Creek @ Franklin Canyon Golf Course	2019	Yes	Unknown[1]
San Pablo Creek @ Santa Maria Way	2019	Yes	Yes
Las Trampas Creek @ Lafayette Community Park	2018	Yes	Generally, yes; one incident DO < 5 mg/L
San Pablo Creek @ Earth Island Institute	2018	Generally, yes; one incident of DO < 5 mg/L	Generally, no; only during mid-day peaks does DO attain > 5 mg/L
Las Trampas Creek @ Camino Posada Court	2017	Yes	Yes
Alhambra Creek @ F Street	2017	Yes	Generally, no; only during mid-day peaks does DO attain > 5 mg/L; one low DO event lasted 48 hours
West Branch of Alamo Creek @ Red Willow Road	2016	Yes	Generally, no; only during mid-day peaks does DO attain > 5 mg/L; one low DO event lasted 48 hours
Rimer Creek @ Camino Pablo	2016	Yes	Yes
West Branch of Alamo Creek	2015	Generally, yes; with two brief incidents of DO < 5 mg/L	Initially, yes; but DO dropped below 5 mg/L for last 5 days of monitoring
San Ramon Creek	2015	Yes	Yes, with one very brief incident of DO < 5 mg/L
Rodeo Creek @ Muir Land Trust	2014	No	No
San Pablo Creek @ Rock Harbor Church	2014	Yes	Yes
Pinole Creek at Pinole Library	2013	Yes	Generally, yes; four brief incidents DO < 5 mg/L
San Pablo Creek (Camino Encinas @ Moraga Way)	2013	Yes	Yes
Walnut Creek (Arroyo Way @ Civic Drive)	2012	Yes	Yes
Marsh Creek @ Fish Ladder	2012 - Present	SSID study completed that identified low DO as cause of recurrent fish kills. Permittees are evaluating and implementing corrective measures.	

1 Monitoring equipment failed during the summer deployment.

2 Stressor/source identification

Are conditions in local receiving waters supportive of or likely supportive of beneficial uses?

The analysis of water quality objectives – with a focus on dissolved oxygen and temperature – indicates that San Pablo and Wildcat Creeks show the most promise for attaining beneficial use of COLD; however, attainment of COLD water quality objectives for those two creeks is also not 100 percent. Those and other creeks monitored show partial or full attainment of WARM, with the consistent pattern that failure to attain dissolved oxygen > 5 mg/L is most common in summer and is typically driven by day-night photosynthesis/metabolism cycles of in-stream algae and/or macrophytes.

The beneficial use of Water Contact Recreation (REC-1), as assessed by the risks of full immersion (i.e., swimming) are not attained, especially downstream of known human sources of pathogen indicators. The appropriateness of full contact immersion as a risk indicator in streams that are wadable (at most) has not been evaluated.

Is the local/targeted monitoring approach generally useful to address those two questions?

Continuous monitoring is a cost-effective, solutions-oriented approach to characterizing stream health. This approach supported direct understanding of the root causes of low dissolved oxygen and resulting fish kills in Marsh Creek. The insights gained from continuous monitoring also led to flow augmentation as a pilot intervention project. The summary of attainment of COLD and WARM provided above is a useful road map to guide future deployment of monitoring resources in MRP 3.0 and subsequent permit cycles.

Monitoring for pathogen indicators was helpful to verify where human activity, such as off-leash dog parks, duck feeding areas or encampments, could negatively impact the designated beneficial use. Future monitoring for pathogens indicators should focus on effectiveness. The monitoring management question should be, as municipalities define and implement maximum extent practicable measures to manage water quality impacts that result from human activity, how is water quality improved?

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SSID Project ID	Date Updated	County/ Program	Creek/ Channel Name	Site Code(s) or Other Site ID	Project Title	Primary Indicator(s) Triggering Stressor/Source ID Project									Indicator Result Summary	Rationale for Proposing/Selecting Project	Current Status of SSID Project or Date Completed	EO Concurrence of project completion (per C.8.e.iii.(b))
						Bioassess	General WQ	Chlorine	Temp	Water Tox	Sed Tox	Sed Chem	Pathogen Indicators	Other				
AL-1	1/22/20	ACCWP	Palo Seco Creek		Exploring Unexpected CSCI Results and the Impacts of Restoration Activities	X									Sites where there is a substantial difference in CSCI score observed at a location relative to upstream or downstream sites, including sites on Palo Seco Creek upstream of the Sausal Creek restoration-related sites, that had substantial and unexpected differences in CSCI scores.	The project will provide additional data to aid consideration of unexpected and unexplained CSCI results from previous water year sampling on Palo Seco Creek, enable a more focused study of monitoring data collected over many years in a single watershed, and allow analysis of before and after data at sites upstream and downstream of previously completed restoration activities.	In WY 2019, nutrient sampling, bioassessment, and additional DO and temperature monitoring were conducted. The second SSID progress report is included in ACCWP's March 2020 IMR.	
AL-2	1/22/20	ACCWP	Arroyo Las Positas		Arroyo Las Positas Stressor Source Identification Project	X									CSCI scores below the threshold were recorded on Arroyo Las Positas in WYs 2016 and 2017. In 2017, one site exceeded the Basin Plan threshold for chloride. The creek is also listed on the 303(d) list for eutrophication and has an approved TMDL for Diazinon.	The Water Board is conducting sampling in the watershed as part of their TMDL development efforts and an SSID project will supplement those efforts and generate a better overall picture of stressors impacting the waterbody.	In WY 2019, ACCWP conducted bioassessments, nutrient sampling, and continuous monitoring at multiple locations within the watershed over the course of spring and summer months. The first SSID progress report is included in ACCWP's March 2020 IMR.	
CC-1	1/27/20	CCCWP	Lower Marsh Creek		Marsh Creek Stressor Source Identification Study									X	10 fish kills have been documented in Marsh Creek between September 2005 and September 2019. Low dissolved oxygen was proved to be the cause in the most recent (9/17/19) event; circumstances indicate low DO was a likely cause in many if not all of the prior events.	This SSID study addresses the root causes of fish kills in Marsh Creek. Monitoring data collected by CCCWP and other parties are being used to investigate multiple potential causes, including low dissolved oxygen, warm temperatures, daily pH swings, fluctuating flows, physical stranding, and pesticide exposure. During year 2 a pilot test of water storage and night-time flow augmentation was conducted by the City of Brentwood Wastewater Treatment Plant (WWTP).	The CCCWP SSID work plan was submitted in 2018. The Year 2 Status Report is included in CCCWP's March 2020 IMR. The study successfully concluded in Year 2. The final report will recommend project completion. Flow augmentation appears to be a viable means of avoiding lethally low DO in portions of the creek downstream of the WWTP.	

SSID Project ID	Date Updated	County/ Program	Creek/ Channel Name	Site Code(s) or Other Site ID	Project Title	Primary Indicator(s) Triggering Stressor/Source ID Project									Indicator Result Summary	Rationale for Proposing/Selecting Project	Current Status of SSID Project or Date Completed	EO Concurrence of project completion (per C.8.e.iii.(b))
						Bioassess	General WQ	Chlorine	Temp	Water Tox	Sed Tox	Sed Chem	Pathogen Indicators	Other				
SC-1	1/29/20	SCVURPPP	Coyote Creek	NA	Coyote Creek Toxicity SSID Project						X				The SWRCB recently added Coyote Creek to the 303(d) list for toxicity.	This SSID study investigated the extent and magnitude of toxicity in an urban reach of Coyote Creek. Sediment samples (n=8) were collected during the dry season of 2018 and 2019. Samples were generally not toxic, with the exception of one sample that had low levels of toxicity (subsequent re-test of sample was not toxic). Sediment chemistry results were inconclusive (i.e., pesticide concentrations were not at levels suspected of causing toxicity). SSID Project results support similar findings from long term monitoring conducted by the SWAMP SPoT Program of reduced acute toxicity in Coyote Creek over the past 10 years.	The work plan was submitted with SCVURPPP's WY 2017 UCMR. A project report describing the results of the WY 2018 and WY 2019 monitoring will be submitted with the WY 2019 IMR.	
SC-2	1/29/20	SCVURPPP	Lower Silver-Thompson Creek	NA	Lower Silver SSID Project	X								X	Low CSCI scores and high nutrient concentrations at a majority of bioassessment locations.	Evaluate potential causes of reduced biological conditions in Lower Silver-Thompson Creek. The SSID Project is investigating sources of nutrients and assessing the range and extent of eutrophic conditions (if present). The Project will evaluate association between stressor data (e.g., water chemistry, dissolved oxygen and physical habitat) and biological condition indicators (i.e., CSCI and ASCI scores)	The work plan was submitted with SCVURPPP's FY 18-19 Annual Report. It is anticipated to be a two-year project with the project report to be submitted with the WY 2020 UCMR.	
SM-1	1/29/20	SMCWPPP	Pillar Point / Deer Creek / Denniston Creek	NA	Pillar Point Harbor Bacteria SSID Project								X		FIB samples from 2008, 2011-2012 exceeded WQOs.	A grant-funded Pillar Point Harbor MST study conducted by the RCD and UC Davis in 2008, 2011-2012 pointed to urban runoff as a primary contributor to bacteria at Capistrano Beach and Pillar Point Harbor. The study, however, did not identify the specific urban locations or types of bacteria. This SSID project investigated bacteria contributions from the urban areas within the watershed. In WY 2018, Pathogen indicator and MST monitoring was conducted at 14 freshwater sites during 2 wet and 2 dry events. Very few samples contained "controllable" source markers (i.e., human and dog). Additional field studies	The work plan was submitted with SMCWPPP's WY 2017 UCMR. A project report describing the results of the WY 2018 and WY 2019 investigations was submitted on October 28, 2019. SMCWPPP is awaiting Executive Officer concurrence regarding project completion.	

SSID Project ID	Date Updated	County/ Program	Creek/ Channel Name	Site Code(s) or Other Site ID	Project Title	Primary Indicator(s) Triggering Stressor/Source ID Project									Indicator Result Summary	Rationale for Proposing/Selecting Project	Current Status of SSID Project or Date Completed	EO Concurrence of project completion (per C.8.e.iii.(b))
						Bioassess	General WQ	Chlorine	Temp	Water Tox	Sed Tox	Sed Chem	Pathogen Indicators	Other				
																were conducted in WY 2019 to understand hydrology and specific source areas.		
FSV-1	1/16/20	City of Vallejo in assoc. with FSURMP	Rindler Creek	207R03504	Rindler Creek Bacteria and Nitrogen Study								X		E. coli result of 2800 MPN/100mL in Sept. 2017.	A source identification study is warranted in Rindler Creek due to the elevated FIB result, other (non-RMC) monitoring indicating elevated ammonia levels, and the presence of a suspected pollutant source upstream of the data collection point. Rindler Creek is a highly urbanized and modified creek that originates in open space northeast of the City of Vallejo. Monitoring is conducted just downstream of the creek crossing under Columbus Parkway; upstream of this site there is City-owned land that is grazed by cattle roughly from December-June.	Additional monitoring in the spring and summer of 2019 revealed consistently high levels of E coli and enterococci when cattle are present. A Work Plan is in development and will be submitted with the IMR in March 2020.	
RMC-1	1/29/20	RMC/ Regional	NA (entire RMC area)	NA	Regional SSID Project: Electrical Utilities as a Potential PCBs Source to Stormwater in the San Francisco Bay Area									X	Fish tissue monitoring in San Francisco Bay led to the Bay being designated as impaired on the CWA 303(d) list and the adoption of a TMDL for PCBs in 2008. POC monitoring suggests diffuse PCBs sources throughout region.	PCBs were historically used in electrical utility equipment, some of which still contain PCBs. Although much of the equipment has been removed from services, ongoing releases and spills may be occurring at levels approaching the TMDL waste load allocation. This regional SSID project is investigating opportunities for BASMAA RMC partners to work with RWQCB staff to: 1) improve knowledge about the extent and magnitude of PCB releases and spills, 2) improve the flow of information from utility companies, and 3) compel cooperation from utility companies to implement improved control measures.	The work plan was submitted with each countywide stormwater program's WY 2018 UCMR and implementation began in WY 2019. BASMAA RMC partners are reaching out to municipally-owned utilities to gather information. Similarly, RWQCB staff are actively seeking opportunities to communicate with non-municipally-owned utility companies. Ongoing bankruptcy proceedings may prolong project completion.	

PCBs from Electrical Utilities in San Francisco Bay Area Watersheds Stressor/Source Identification (SSID)

Prepared in support of provision C.8.e.iii of NPDES Permit # CAS612008

Project Work Plan

Prepared for:
Bay Area Stormwater Management Agencies Association (BASMAA)

Prepared by:
EOA, Inc.
1410 Jackson St.
Oakland, CA 94612

FINAL March 2019

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1.0 Introduction

This work plan supports the requirement to implement a Stressor/Source Identification (SSID) Project as required by Provision C.8.e.iii of the San Francisco Bay (Bay) Region Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Stormwater Permit (MRP) (Order No. R2-2015-0049, SFRWQCB 2015). Per MRP Provision C.8.e.ii, the Bay Area Stormwater Management Agencies Association (BASMAA) Regional Monitoring Coalition (RMC)[1] members are working to initiate eight SSID projects during the five-year term of the MRP (i.e., 2016 – 2020). The RMC programs have agreed that seven SSID projects will be conducted to address local needs (for Santa Clara, Alameda, San Mateo, Contra Costa, Fairfield/Suisun and Vallejo counties), and one project (this project) will be conducted regionally (on behalf of all RMC members). SSID projects follow-up on monitoring conducted in compliance with MRP Provision C.8 (or monitoring conducted through other programs) with results that exceed trigger thresholds identified in the MRP. Trigger thresholds are not necessarily equivalent to Water Quality Objectives (WQOs) established in the San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan) (SFRWQCB, 2017) by the San Francisco Bay Regional Water Quality Control Board (SF Bay Water Board); however, sites where triggers are exceeded may indicate potential impacts to aquatic life or other beneficial uses.

This SSID work plan describes the steps that will be taken to investigate sources of polychlorinated biphenyls (PCBs) from electrical utility equipment in watersheds draining to the San Francisco Bay Basin. BASMAA will implement the work plan as a regional project. BASMAA retained EOA, Inc., of Oakland, CA to develop this work plan and implement the SSID project under the direction of a BASMAA Project Management Team (PMT). All work on this project is supported by funding provided by BASMAA.

1.1 Overview of SSID Project Requirements

SSID projects focus on taking action(s) to identify and reduce sources of pollutants, alleviate stressors, and address water quality problems. MRP Provision C.8.e.iii requires SSID projects to be conducted in a stepwise process, as described below.

Step 1: Develop a work plan that includes the following elements:

- Define the water quality problem (e.g., magnitude, temporal extent, and geographic extent) to the extent known;
- Describe the SSID project objectives, including the management context within which the results of the investigation will be used;
- Consider the problem within a watershed context and examine multiple types of related indicators, where possible (e.g., basic water quality data and biological assessment results);

[1] The BASMAA RMC is a consortium of San Francisco Bay Area municipal stormwater programs that joined together to coordinate and oversee water quality monitoring and several other requirements of the MRP. Participating BASMAA members include the Alameda Countywide Clean Water Program (ACCWP), Contra Costa Clean Water Program (CCCWP), Fairfield-Suisun Urban Runoff Management Program (FSURMP), San Mateo Countywide Water Pollution Prevention Program (SMCWPPP), Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), and City of Vallejo and Vallejo Flood and Wastewater District (formerly Vallejo Sanitation and Flood Control District).

- List potential causes of the problem (e.g., biological stressors, pollutant sources, and physical stressors);
- Establish a schedule for investigating the cause(s) of the trigger stressor/source which begins upon completion of the work plan. Investigations may include evaluation of existing data, desktop analyses of land uses and management actions, and/or collection of new data; and
- Establish the methods and plan for conducting a site-specific study (or non-site specific if the problem is widespread) in a stepwise process to identify and isolate the cause(s) of the trigger stressor/source.

Step 2: Conduct SSID investigations according to the schedule in the work plan and report on the status of the SSID investigation annually in the Urban Creeks Monitoring Report (UCMR) that is submitted to the SF Bay Water Board on March 31 of each year.

Step 3: Follow-up actions:

- If it is determined that discharges to the municipal separate storm sewer system (MS4) contribute to an exceedance of a water quality standard (WQS) or an exceedance of a trigger threshold such that the water body's beneficial uses are not supported, submit a report in the UCMR that describes Best Management Practices (BMPs) that are currently being implemented and additional BMPs that will be implemented to prevent or reduce the discharge of pollutants that are causing or contributing to the exceedance of WQS. The report must include an implementation schedule.
- If it is determined that MS4 discharges are not contributing to an exceedance of a WQS, the SSID project may end. The Executive Officer must concur in writing before an SSID project is determined to be completed.
- If the SSID investigation is inconclusive (e.g., the trigger threshold exceedance is episodic or reasonable investigations do not reveal a stressor/source), the Permittee may request that the Executive Officer consider the SSID project complete.

1.2 SSID Work Plan Organization

This work plan fulfills **Step 1** of the SSID process described above in Section 1.1. It describes the steps that will be conducted to investigate electrical utility equipment as a source of PCBs to the MS4 in watersheds draining to the Bay. The remainder of this work plan is organized according to the required elements described in Step 1:

Section 2.0 Problem Definition, Study Objectives, and Regulatory Background

Section 3.0 Study Area, Existing Data, and Potential Causes of Water Quality Problem

Section 4.0 SSID Investigation Approach and Schedule

Section 5.0 References

2.0 Problem Definition, Study Objectives, and Regulatory Background

2.1 Problem Definition

Fish tissue monitoring in the Bay has revealed the bioaccumulation of PCBs in Bay sportfish at levels thought to pose a health risk to people consuming these fish. As a result, in 1994, the state of California issued a sport fish consumption advisory cautioning people to limit their consumption of fish caught in the Bay. The advisory led to the Bay being designated as an impaired water body on the Clean Water Act (CWA) "Section 303(d) list" due to elevated levels of PCBs. In response, in 2008, the SF Bay Water Board adopted a Total Maximum Daily Load (TMDL) water quality restoration program targeting PCBs in the Bay[2]. The general goals of the TMDL are to identify sources of PCBs to the Bay, implement actions to control the sources, restore water quality, and protect beneficial uses. The PCBs TMDL estimates baseline loads to the Bay from various source categories. The largest source category, at 20 kilograms (kg) per year, was estimated to be stormwater runoff. This category includes all sources to small tributaries draining to the Bay. The PCBs TMDL indicates that a 90% reduction in PCBs from stormwater runoff to the Bay is needed to achieve water quality standards and restore beneficial uses. The TMDL states that the wasteload allocation for stormwater runoff of 2 kg per year shall be achieved within 20 years (i.e., by March 2030). The PCBs TMDL is being implemented through NPDES permits to discharge stormwater issued to municipalities and industrial facilities in the Bay Area (e.g. the MRP).

This SSID project was triggered by monitoring conducted over the past 15+ years by BASMAA members that demonstrates municipal stormwater runoff is a source of PCBs to the Bay. PCBs are a group of persistent organic pollutants that were historically used in many applications, including electrical utility equipment and caulks and sealants used in building materials. However, the greatest use by far was in electrical equipment such as transformers and capacitors (McKee et al. 2006). Existing electrical utility equipment, which is often located in public rights-of-way (ROWs), may still contain PCBs that can be released to the MS4 when spills and leaks occur. Due to past leaks or spills of PCBs oil from electrical equipment, properties owned and operated by electrical utilities may potentially have elevated concentrations of PCBs in surrounding surface soils that can be released to the MS4. Because the cumulative releases of PCBs-laden soils from these properties, and spills or leaks of PCBs oils from electrical equipment to MS4s across the Bay Area may occur at levels that exceed the 2 kg per year TMDL waste load allocation (see Section 3.2.3), this potential source of PCBs may limit the ability of municipalities to meet the goals of the PCBs TMDL for the Bay. Therefore, this potential source warrants further investigation.

Electrical utility applications present special challenges for source identification and abatement[3] due to the quantity of equipment and facilities, their dispersed nature, and difficulty in sampling discharges when they occur. In addition, municipalities lack control over these properties and

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[2] The PCBs TMDL was approved by the US Environmental Protection Agency (USEPA) on March 29, 2010 and became effective on March 1, 2010.

[3] Source identification and abatement is one type of stormwater control measure that Permittees use to reduce loads of PCBs in urban runoff. This control measure involves investigations of properties with elevated PCBs in stormwater or sediment to identify sources that contribute a disproportionate amount of PCBs to the MS4, and cause the properties to be abated, or refer the properties to the SF Bay Water Board or other regulatory authority for follow-up investigation and abatement. This control measure is described in more detail in the BASMAA Interim Accounting Methodology for TMDL Loads Reduced (BASMAA 2017).

equipment. Permittees have no jurisdiction over many large electrical utilities and therefore no control over the cleanup of PCBs-containing spills (e.g., dielectric fluids from transformers), or prompt notification when they happen. Release of PCBs from electrical utility applications has proved particularly difficult to document, quantify or control when private utility companies such as Pacific Gas and Electric, (PG&E) are involved. To date, neither Permittees nor the Region 2 Water Board have been able to verify that a sound and transparent cleanup protocol is used consistently by PG&E for PCBs spills from their electrical utility equipment and properties across Bay Area cities. Moreover, current state and federal regulatory levels for reporting and cleanup of PCBs spills (e.g., cleanup goals for soils) are higher than cleanup levels recommended by the SF Bay Water Board to meet the objectives of the PCBs TMDL (SFBRWQCB 2016). These differences create potential missed opportunities to cleanup spills to the more stringent levels that are more consistent with the PCBs TMDL requirements, and for Permittees to report the associated PCBs load reductions via the MRP load reduction tracking and reporting processes.

Due to these constraints, it is not feasible or appropriate for municipalities to develop and implement PCBs control and reporting programs for electrical utility companies. Therefore, municipalities will need to work with the SF Bay Water Board to investigate electrical utility operations. The overall goal of this project is to gather the information needed and provide justification for the SF Bay Water Board to compel the utilities to develop and implement improved procedures and practices that will reduce releases of PCBs to stormwater runoff.

2.2 SSID Project Objectives

The overall goal of this SSID project is to investigate electrical utility equipment as a source of PCBs to urban stormwater runoff and identify appropriate actions and control measures to reduce this source. Building on the information presented by SCVURPPP (2018), this project is designed to achieve the following three objectives:

1. Gather information from Bay Area utility companies to improve estimates of current PCBs loadings to MS4s from electrical utility equipment, and document current actions conducted by utility companies to reduce or prevent release of PCBs from their equipment;
2. Identify opportunities to improve spill response, cleanup protocols, or other programs designed to reduce or prevent releases of PCBs from electrical utility equipment to MS4s;
3. Develop an appropriate mechanism for municipalities to ensure adequate clean-up, reporting and control measure implementation to reduce urban stormwater loadings of PCBs from electrical utility equipment.

A possible outcome of this SSID project is a recommendation that Bay Area municipalities submit a referral to designate electrical utility equipment and properties as a *Categorical Source*, which is a type of source property as described in more detail in the BASMAA Interim Accounting Methodology for TMDL Loads Reduced (BASMAA, 2017). A *Categorical Source* designation would facilitate development of a regional approach to abate this source under the regulatory authority of the SF Bay Water Board. The *Categorical Source* designation was developed specifically to address potential sources of PCBs that are widespread and distributed across multiple jurisdictions, such as electrical utility applications. MRP Permittees, as a group, can refer an entire source category to the SF Bay Water Board. Although local agencies may still identify and refer individual electrical utility properties to the Water Board for abatement, addressing these facilities and equipment as a *Categorical Source* may prove to be a more effective and efficient way to reduce PCBs loads from this source category. The information gained during this project will also provide data that municipalities can use to develop a methodology to account for PCBs load reductions that can be achieved through implementation of a regional control measure program for electrical utilities.

2.3 Management Questions

This SSID project will address a number of key management questions regarding electrical utility applications as sources of PCBs to MS4s, including:

1. What is the current magnitude and extent of PCBs stormwater loadings from electrical utility equipment and operations in the San Francisco Bay Area region?
2. What aspects of equipment or operational procedures should electrical utilities be required to report to the SF Bay Water Board?
3. Are improvements to spill and cleanup control measures needed to reduce water quality impacts from the release of PCBs in electrical utility equipment?
4. Are additional proactive management practices needed to reduce releases of PCBs from electrical utility equipment?
5. What are the PCBs load reductions that can be achieved through implementation of a regional reporting and control measure program?

2.4 Regulatory Context of PCBs WQOs

To better understand the issues of PCBs in the Bay, it is important to understand the regulatory context of the PCBs WQOs and human health risks associated with PCBs. The State Water Resources Control Board (SWRCB) is part of the California Environmental Protection Agency and administers water rights, water pollution control, and water quality functions for the state. It shares authority for implementation of the federal CWA and the state Porter-Cologne Act with the nine Regional Water Quality Control Boards. The Regional Water Boards regulate surface water and groundwater quality through development and enforcement of WQOs and implementation of Basin Plans that will protect the beneficial uses of the State's waters. These plans designate beneficial uses, WQOs that ensure the protection of those uses, and programs of implementation to achieve the WQOs.

The Basin Plan for the San Francisco Bay region (SFRWQCB 2017) provides the basis for water quality regulation in the San Francisco Bay region. It is implemented by the SWRCB and the SF Bay Water Board. The Basin Plan identifies beneficial uses of Bay waters, establishes narrative and numerical WQOs protective of those beneficial uses, identifies areas where discharges are prohibited, and sets forth a program of implementation to ensure that the Bay WQOs are achieved and beneficial uses are protected. Several beneficial uses are designated in the San Francisco Bay region including commercial and sport fishing (COMM), defined in the Basin Plan as:

- **COMM:** *"Uses of water for commercial or recreational collection of fish, shellfish, or other organisms, including, but not limited to, uses involving organisms intended for human consumption or bait purposes."*

To protect this beneficial use, the narrative WQO for PCBs in the Bay states that "controllable water quality factors shall not cause a detrimental increase in toxic substances found in bottom sediments or aquatic life". PCBs in Bay sportfish have been found at levels thought to pose a health risk to people consuming these fish. As a result, the COMM beneficial use of the Bay is not currently supported and the narrative WQO for PCBs has not been achieved.

3.0 Study Area, Existing Data, and Potential Causes of Water Quality Problem

3.1 Study Area

The study area for this SSID project is the portion of the San Francisco Bay Area region subject to the MRP. This section provides an overview of electrical utility systems and companies currently operating in the study area, and describes how and where PCBs are used within those systems.

Electrical utilities produce or buy electricity from generating sources, and then distribute that electricity to users through two networks: the transmission system and the distribution system. The **transmission system** carries bulk electricity at high voltages, often across long distances, directly from generation sources to substations via high voltage power lines. Substations connect the transmission and distribution systems. Substations may increase the voltage from nearby generating facilities for more efficient transmission over long distances or lower the voltage for transfer to the distribution system. Electricity at a typical substation flows from incoming transmission lines, to circuit breakers, to transformers (which step down the voltage), to voltage regulators and cut out switches (which protect the system from overvoltage), and finally to outgoing distribution lines.

The **distribution system** delivers lower voltage electricity from substations directly to homes and businesses over shorter distances. This system includes pole-mounted equipment, equipment in underground vaults, and aboveground equipment on cement pads that are often in green boxes in the public right-of-way (ROW). This equipment is smaller, but more numerous in terms of the number of units.

Electrical utility equipment and facilities in both the transmission and distribution systems are distributed across the entire Bay Area region. In the past, PCBs were routinely used in electrical utility equipment that contained dielectric fluid as an insulator. This is because prior to the 1979 PCBs ban, dielectric fluid was typically formulated with PCBs due to a number of desirable properties they have (e.g., high dielectric strength, thermal stability, chemical inertness, and non-flammability). Electrical equipment containing dielectric fluid is typically identified as Oil-Filled Electrical Equipment (OFEE). Any OFEE that contained PCBs in the past could still potentially be in use and contain PCBs today. The most common types of OFEE that may contain PCBs are transformers, capacitors, circuit breakers, reclosers, switches in vaults, substation insulators, voltage regulators, load tap changers, and synchronous condensers (PG&E 2000).

In the Bay Area, there are eight electric utility companies operating as of February 2015 (State Energy Commission 2015):

<u>**Investor-Owned Utilities (IOUs)**</u>

1. Pacific Gas and Electric Company (PG&E)
   77 Beale Street
   San Francisco, CA 94105
   (415) 973-7000 (tel)

Publicly Owned Load Serving Entities (LSEs) and Publicly Owned Utilities (POUs)

2. Alameda Municipal Power
   2000 Grand Street
   Alameda, CA 94501-0263
   510.748.3905 (tel)
3. CCSF (also called the Power Enterprise of the San Francisco Public Utilities Commission)
   1155 Market Street, 4th Floor
   San Francisco, CA 94103
   209.989.2063 (tel)
4. City of Palo Alto, Utilities Department
   P.O. Box 10250
   Palo Alto, CA 94303
   650.329.2161 (tel)
5. Pittsburg Power Company Island Energy-City of Pittsburg,
   65 Civic Drive
   Pittsburg, CA 94565-3814
   925.252.4180 (tel)
6. Port of Oakland
   530 Water Street, Ste 3
   Oakland, CA 94607-3814
   510.627.1100 (tel)
7. Silicon Valley Power (SVP) - City of Santa Clara
   1500 Warburton Avenue
   Santa Clara, CA 95050
   408.615.2300 (tel)

Community Choice Aggregators

8. Marin Clean Energy (MCE)
   781 Lincoln Ave Ste 320
   San Rafael, CA 94901-3379
   888.632.3674 (tel)

PG&E is by far the largest electrical utility company in the Bay Area. PG&E is an investor-owned company that is not under the jurisdiction of any Bay Area municipality[4]. Three small publicly-owned utilities in the Bay Area (Alameda Municipal Power, City of Palo Alto Utilities Department, and Silicon Valley Power owned by the City of Santa Clara) maintain their own substations and distribution lines. The other public utilities partner with PG&E to deliver energy through PG&E's equipment. PG&E owns and operates several hundred electrical substations in the Bay Area, in addition to the smaller electrical utility equipment that is widely disbursed throughout urbanized areas and along rural corridors (e.g., small transformers on utility poles or in utility boxes). The total number of pieces of equipment that is in use across the Bay Area and that contains PCBs is not known but is likely in the range of tens to hundreds of thousands (see Section 3.2.2).

[4] PG&E is regulated by the California Public Utilities Commission (CPUC) and the Federal Energy Regulatory Commission (FERC).

3.2 Existing Data

This section presents an overview of the current state of knowledge about PCBs used by electrical utility companies in the Bay Area, the potential mass of PCBs released into the environment from this source over the past 50+ years, and the regulatory programs currently available for the purposes of managing PCBs and reporting and cleaning up spills. This information focuses on PG&E because this private company owns and operates the vast majority of electrical utility properties and equipment in the Bay Area. This information was originally reported by SCVURPPP (2018).

3.2.1 Regulatory Controls on PCBs in Electrical Utility Equipment

Existing federal and state regulations are primarily focused on controlling the management and handling of in-use PCBs and PCB-containing equipment when the concentrations are above the thresholds for hazardous waste. Under federal regulations, the hazardous waste threshold for PCBs is ≥ 50 parts per million (ppm). Under California regulations, the hazardous waste threshold for PCBs is ≥ 5 ppm in liquids (using the Waste Extraction Test, WET), and ≥ 50 ppm in solids. The allowable post-cleanup concentrations of remaining soils and other surface materials typically range from 10 to 25 ppm, depending on site-specific evaluations of human health risk. As a result, current efforts to control and cleanup PCB releases from electrical utility equipment are focused on these thresholds.

By comparison, Bay Area municipalities are concerned with much lower concentrations of PCBs. For example, currently Bay Area municipalities generally designate a site as a *potential* PCBs source to stormwater runoff if soil or sediment concentrations are ≥ 0.5 ppm and designate a site as a *confirmed* PCBs source to stormwater runoff if soil or sediment concentrations are ≥ 1.0 ppm. Control of PCBs sources at these substantially lower concentrations has been deemed necessary to make progress towards meeting the stringent stormwater runoff wasteload allocations called for in the PCBs TMDL.

3.2.2 PCBs Remaining in Electrical Utility Equipment

Although use of PCBs is highly restricted currently, McKee et al. (2006) estimated that 12.3 million kilograms of PCBs were used in the San Francisco Bay Area between 1950 and 1990. Roughly 65% (8 million kg) was used in electrical transformers and large capacitors (McKee et al. 2006). How much of this mass was released to the environment and how much remains in electrical equipment distributed across the Bay Area today is unknown. While the 1979 ban of PCBs did not require the immediate removal of PCBs from current applications, electrical utilities have made substantial efforts over the past 35+ years to reduce the amount of PCBs still used in their applications in the Bay Area. According to PG&E, the majority of OFEE containing PCBs in the Bay Area has already been removed or refurbished with dielectric fluids that do not contain PCBs through the following actions:

- Voluntary replacement programs;
- Ongoing removal of PCBs from OFEE as units are serviced or replaced due to routine maintenance programs; and
- OFEE replacement due to unplanned actions (e.g., transformer leaks and fires).

Voluntary actions conducted by PG&E, primarily in the mid-1980s, included the PCBs Distribution Capacitor Replacement Program and the PCBs Network Transformer Replacement Program (PG&E 2000). In addition, in the 1990s, PG&E implemented a program to remove oil-filled circuit breakers and replace them with equipment that contains sulfur hexafluoride gas

(PG&E 2000). Current ongoing PG&E efforts to remove PCBs-containing equipment are conducted primarily through maintenance programs. Past maintenance of older equipment may have included draining PCBs-containing oils and refilling the equipment with oils that did not contain PCBs. These refurbished OFEE may still contain PCBs at levels of concern to municipalities due to residual contamination from the original PCB-oil. Currently, as maintenance staff identify older equipment in-use, it is scheduled for replacement. However, PG&E has provided limited documentation of their past and current PCBs removal efforts. There remains much uncertainty on where PCBs transformers, PCBs capacitors, oil-filled circuit breakers, and PCBs-containing distribution system equipment were originally located, and which ones have already been removed or replaced.

Despite the removal efforts described above, PCBs may still be found in older and refurbished OFEE, and particularly OFEE located throughout the distribution system. In a recent meeting with SF Bay Water Board Staff, PG&E noted that any equipment installed prior to 1985 could contain PCBs, as it would have come from equipment stockpiled prior to the 1979 ban and was installed prior to the voluntary replacement programs (*personal communication*, Sanchez 2016). Because OFEE are not typically tested for PCBs until the fluid is removed during servicing or disposal, or in the event of a spill, the total number of PCBs-containing OFEE that remain in use is unknown. However, in a letter to the SF Bay Water Board in 2000, PG&E provided information that can be used to make some preliminary estimates, including the following (PG&E 2000):

- There are over 900,000 pieces of OFEE in service in the distribution system;
- In 1999, 22,000 pieces of equipment were serviced at the main PCBs-handling facilities in Emeryville;
- Approximately 10 percent of the units serviced and tested annually contain PCBs at concentrations of 50 parts per million (ppm) or greater, and fewer than 1 percent contained PCBs at concentrations of 500 ppm or greater; and
- The number of pieces of equipment containing PCBs concentrations > 50 ppm has declined over time.

The information above was used to calculate the following:

- Assuming the count of equipment processed in 1999 in Emeryville represents an average annual processing rate throughout the region and that there are at least 900,000 pieces of equipment in PG&E's distribution system it would take over 40 years at a minimum for all of this equipment to be replaced;
- Assuming the 1999 processing rate and 900,000 pieces of equipment in the distribution system in 1985, approximately 175,000 pieces would not yet have been serviced or replaced as of 2018; and
- Of the approximately 175,000 pieces of equipment remaining in-use in 2018, approximately 17,500 (10%) may contain PCBs concentrations > 50 ppm.

Although based on limited information, the above estimates demonstrate that a potentially large number of pieces of equipment containing PCBs over 50 ppm (i.e., 17,500 as of 2018) may remain in-use in the electrical utility distribution system. And the remaining 90% (roughly 157,000 pieces of equipment) may contain lower concentrations of PCBs that could still be of concern to Permittees in their efforts to meet TMDL requirements.

3.2.3 Estimated Loadings of PCBs from Electrical Utility Equipment to MS4s

Building upon their estimates of the total mass of PCBs used historically in the Bay Area, McKee et al. (2006) developed a transport and fate conceptual model that identified the major sources of PCBs to stormwater conveyances and described mass movement from these sources or source areas into the stormwater conveyance system. McKee et al. (2006) estimated the net mass input of PCBs to MS4s in the Bay Area in 2005 was approximately 28 kg per year.[5] Of this total, roughly 29% (8 kg/yr) was estimated to have originated from controlled closed systems (transformers and large capacitors) and 71% (20 kg/yr) was from dissipative uses (e.g., release of PCBs-containing building materials such as caulks and sealants during demolition and renovation). This includes both current and legacy uses that resulted in widespread distribution of PCBs across watershed surfaces. In other words, these estimates suggest that because of both current and past use, transformers and large capacitors, which are both electrical utility applications, may continue to contribute nearly one-third of the net PCBs mass to MS4s in the Bay Area. As noted earlier, such loadings would exceed the 2 kg per year TMDL waste load allocation for stormwater runoff (see Section 2.3.2) and limit the ability of municipalities to meet the goals of the PCBs TMDL for the Bay. Conversely, reduction of PCBs released to MS4s from electrical utility equipment may support attainment of TMDL goals.

3.2.4 Ongoing Release of PCBs from Electrical Utility Equipment

Although the bulk of PCBs remain contained within OFEE until the equipment is removed from use and transported to proper hazardous waste disposal facilities, releases of PCBs to the environment can and do occur. In order to document current spills, publicly available data in the California Office of Emergency Services (Cal OES) spill report database (Cal OES 2016), as well as internal spill records (PG&E 2000) supplied by PG&E to the SF Bay Water Board in September 2000 (that were provided pursuant to a California Water Code §13267 request for information) were reviewed. The Cal OES database and available PG&E spill records were searched for reports of spill releases related to OFEE in the Bay Area between 1994 and 2017. Over 1,200[6] reported release incidents from PG&E OFEE in the Bay Area were identified. The information provided by these records and a summary of the important issues identified for water quality concerns are summarized in the remainder of this section. It is important to note that current regulations do not require reporting of all releases from OFEE. The information provided below is based only on the reported releases for which records were available, and likely represents an underestimate of actual OFEE releases during the time period of review. However, these reports clearly demonstrate that PCBs may still be present in the electrical transmission and distribution systems in the Bay Area, and that releases from these systems can and do continue to occur.

Generally, the publicly available spill release records provide information about the spill release date, time, location, chemical, quantity released, actions taken, known or anticipated risks posed by the release, and additional comments. Other information that is sometimes reported for OFEE releases includes a description of the causes of the release and the equipment affected, and the concentrations of PCBs in that equipment (if known). Concentration information reported is likely assumed from equipment labels, as ranges are most often provided rather than specific values. Typically, the reports are limited to the information that was

[5] The PCBs TMDL estimates a PCBs loading of 20 kg per year from stormwater runoff (see Section 2.1).

[6] The records span 24 years of spill reports, and include PG&E's own record of releases from 1994 thru 1999 and a portion of 2000. The number of reports PG&E submitted in 2000 represents less than half the number of reports for that year. Records did not include all the districts in the Bay Area. District documents submitted reported releases prior to June of 2000, with the exception of one district that submitted a June report. As a result, the number of additional reports from PG&E's records are assumed to be less than half the number of incidents for 2000.

available at the time the spill was initially reported. In some cases, follow-up information such as the results of analytical testing of the spilled materials is also provided, but this is not typical.

3.2.4.1 Number of Reported OFEE Releases

Between 1994 and 2017, over 1,000 spills from PG&E electrical equipment were reported to Cal OES. PG&E records contain information about 200 additional releases that were not reported to Cal OES between 1994 and 2000. A count of these reports by year is presented in Figure 1.

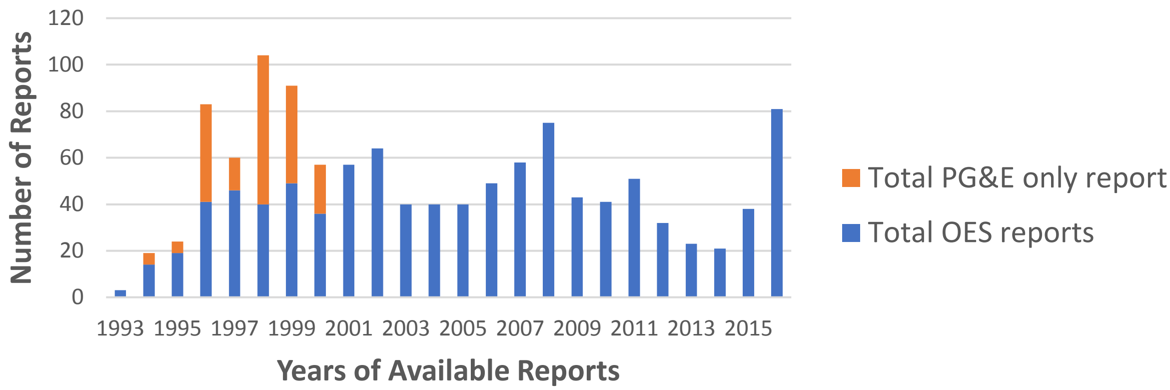

Figure 1. Oil-filled electric equipment spills reported to the California Office of Emergency Services (Cal OES) and/or identified through internal Pacific Gas & Electric (PG&E) reports between 1993 and 2017.

3.2.4.2 Volume of OFEE Releases

The total volume of material released from all reported OFEE spills in a given year in the Bay Area is presented in Figure 2. Mineral oil or transformer oil are the substances identified in over 99% of reported releases from OFEE in the Cal OES spill report database. In a phone conference with SF Bay Water Board staff in 2012, PG&E said they submit written reports to Cal OES for all PCBs spills that meet or exceed the mineral oil federal reportable quantities (RQ) of 42 gallons (*personal communication*, Jan O'Hara 2012). However, the reports reviewed indicate written reports are sometimes submitted for spills that are much less than 42 gallons.

The reported volumes of oil released during a single incident range from less than one gallon up to 5,000 gallons. Nearly half of all OFEE spill reports identify the volume of oil spilled as 5 gallons or less, and more than 90% of all spill reports identify the volume of fluid spilled as less than 100 gallons. Releases as large as 500 gallons from the distribution system and 5,000 gallons from the transmission system have been reported. Only five incidents reported releases that exceeded 1,000 gallons of oil. Nearly all (~99%) of reports provided information on the volume of oil released.

The reported volumes released do not necessarily equate to the volume of the oil that may have reached storm drains or local creeks. Estimates of those volumes were not available.

3.2.4.3 Location of OFEE Releases

Cal OES and PG&E records show releases occurred in all Bay Area counties. Leaks and spills of PCBs from electrical equipment have occurred onto roads, sidewalks, pervious areas, vegetation, structures, vehicles, and even people (Cal OES 2016). Most releases occurred in the distribution system, often from equipment installed in public ROWs such as pole-mounted transformers installed along roadways.

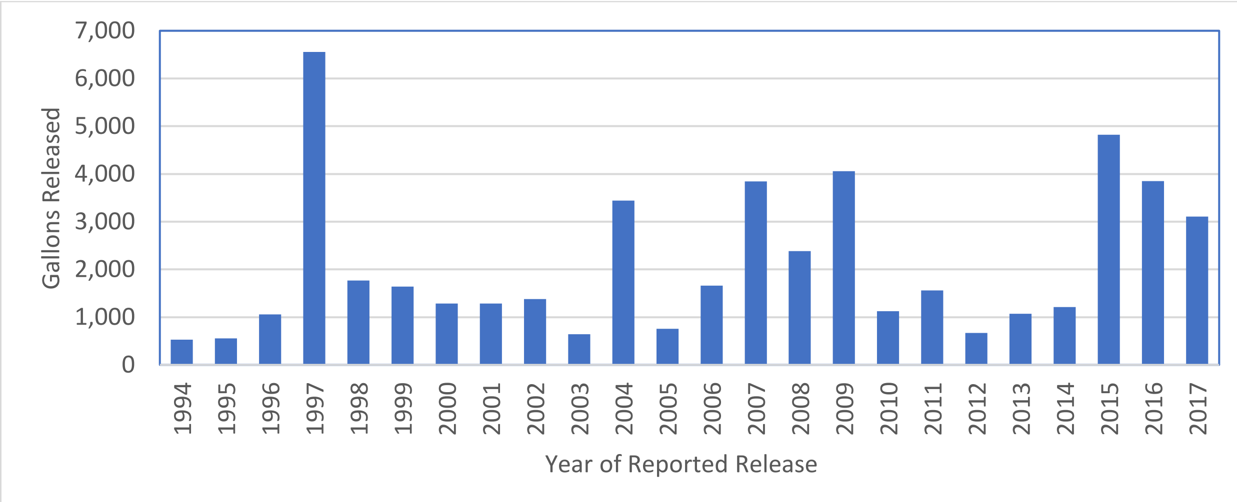

Figure 2. Total reported gallons of oil released each year (1994 – 2017) from spills from PG&E electrical utility equipment in the Bay Area.

A number of reports document direct releases from OFEE to the MS4, and potentially a downstream waterbody (e.g., creek). There are at least 17 incidents identified during the past 15 years that involved direct releases from PG&E OFEE directly to a waterbody or to storm drains that discharge to local creeks (Table 1). The majority of these releases were reported as having unknown PCBs concentrations, and no reports provide any follow-up information on the concentration of PCBs in the spilled materials based on chemical analysis.

It is important to note that in addition to the incidents identified in Table 1, materials spilled during any of the numerous other incidents may (or may not) have entered the MS4 and/or receiving waters such as local creeks directly or been washed into the MS4 and/or creeks by stormwater or irrigation runoff. Generally, the spill reports lack any details regarding this type of information.

Table 1. Examples of Information Reported on Releases of PCBs to Bay Area Storm Drains and Creeks.

Date	Gallons	Reported Concentration	Water Body	Municipality
1/24/2016	Unknown	<50 ppm	Coyote Creek	San José
2/17/2016	Up to 18	Unknown	Los Gatos Creek	Los Gatos
3/7/2016	10	Unknown	Culvert	Concord
8/16/2016	Unknown	<50 ppm	Guadalupe River	San José
11/17/2015	Unknown	Unknown	Cerrito Creek	Richmond
10/4/2015	5	Unknown	Creek	Los Gatos
5/3/2015	30	<2 ppm	Cerrito Creek	Richmond
3/2/2011	30	Unknown	Unknown Marsh	Menlo Park
6/2/2007	40	Unknown	Pond, Marsh Area	Vallejo
2/28/2006	20	<50 ppm	Calara Creek	Pacifica
5/27/2006	1	Unknown	Unknown Creek	Orinda
10/10/2005	Unknown	Unknown	Coyote Creek	San José
7/23/2005	<15	Unknown	Nearby Creek	Walnut Creek
12/8/2004	Small amount	<50 ppm	Moraga Creek	Orinda
3/7/2004	Unknown	Unknown	Blossom Creek	Calistoga
7/14/2003	8	< 50 ppm	Coyote Creek	San José
2/16/2002	15	Unknown	Napa River	Napa

3.2.4.4 Causes of OFEE Releases

Cal OES release reports and PG&E records document a number of causes of PCBs releases from OFEE. Most releases can be attributed to one of the following:

- **Equipment Failure**. This is the cause of the majority of the reported releases. Equipment failure in utility vaults has additional potential as an important source of PCBs because OFEE in these vaults may contain more than 100 gallons of oil. More than 50 release incidents were reported for equipment contained in electrical utility vaults during the time period reviewed. A number of these reports noted the presence of water in the vaults in addition to the PCBs oil released. Releases from equipment failure in utility vaults are mostly contained, but Cal OES spill reports document releases of PCBs oil that breached containment, including discharges that reached water bodies.

- **Accidents**. Approximately 20% of reported releases resulted from equipment knocked over by accident. In the distribution system, reports document 50 to 500 gallons released from poles knocked over during car accidents, by construction equipment, and during tree trimming. On rare occasion PCBs releases have occurred during accidents while equipment is in transport.
- **Storms, Fires, and Overheating from High Summer Temperatures**. These factors are the reported cause of more than 10% of the releases from the distribution system.
- **Field Repairs and Fluid Replacement**. The Cal OES database contains records that indicate draining fluids in the field may have been ongoing as recently as 2007, when a report documented that a valve left open from draining a transformer in the field caused a release. In 2016, Daniel Sanchez, who at the time was PG&E's Manager of Hazardous Materials and Water Quality Environmental Management Programs, informed SF Bay Water Board staff that PG&E does not drain and refill pole mounted PCB transformers in the field any longer; however, it is unclear when this practice ceased, and/or if it still occurs with equipment not mounted on poles.
- **Vandalism**. Between 1997 and 2015, there were at least 25 separate reported incidents of vandalism that resulted in PCBs releases. For example:
  - In 1997, gunshot damage caused the release of 5,000 gallons of oil from a substation transformer and regulators in San Mateo County;
  - In 2011, copper theft at a substation released 750 gallons of oil in Contra Costa County;
  - In 2013, vandalism of pad-mounted transformers resulted in the release of possibly 1,000s of gallons of oil before discovery in San José.

3.2.4.5 PCBs Concentrations in OFEE Releases

Of the more than 1,200 spill reports that were reviewed, approximately one-third identified the PCBs concentration as unknown or did not provide any information on the PCBs concentration of the spilled material (Figure 3). Releases with high PCBs concentrations (> 500 ppm) were infrequently reported, accounting for only 1% of reported spills. Concentrations above 50 ppm represent about 8% of the reported spills. As recently as 2016, failure of a PG&E pole-mounted transformer resulted in release of mineral oil with 280 ppm PCBs to surrounding soils and brick structures. For approximately 44% of the reported releases, the PCBs concentration was identified as less than 50 ppm, based primarily on assumptions associated with a "Non-PCB" label. According to labeling requirements, a "Non-PCB" label indicates the PCBs concentrations in the oil are assumed to be below hazardous waste thresholds of 50 ppm (federal regulations, see Section 3.2.1). However, in most cases, no additional information was provided in the spill reports to indicate how the "Non-PCB" category was arrived at, or whether the federal (> 50 ppm) or state (> 5 ppm in liquid) "Non-PCB" category was assumed. For the vast majority of these reports, no follow-up chemical analysis results were provided that confirmed the "Non-PCB" designations. In a limited number of reports, follow-up PCBs analysis results were provided for materials that were identified as "Non-PCB" during initial reporting. Generally, these results found PCBs concentrations between 5 and 49 ppm, suggesting that the labels were correctly applied. However, any concentration of PCBs in electrical equipment oils is potentially significant in terms of water quality impacts and implementation of the PCBs TMDL. These results clearly demonstrate that the "Non-PCB" designation represents a threshold that is far too high to necessarily be protective of water quality.

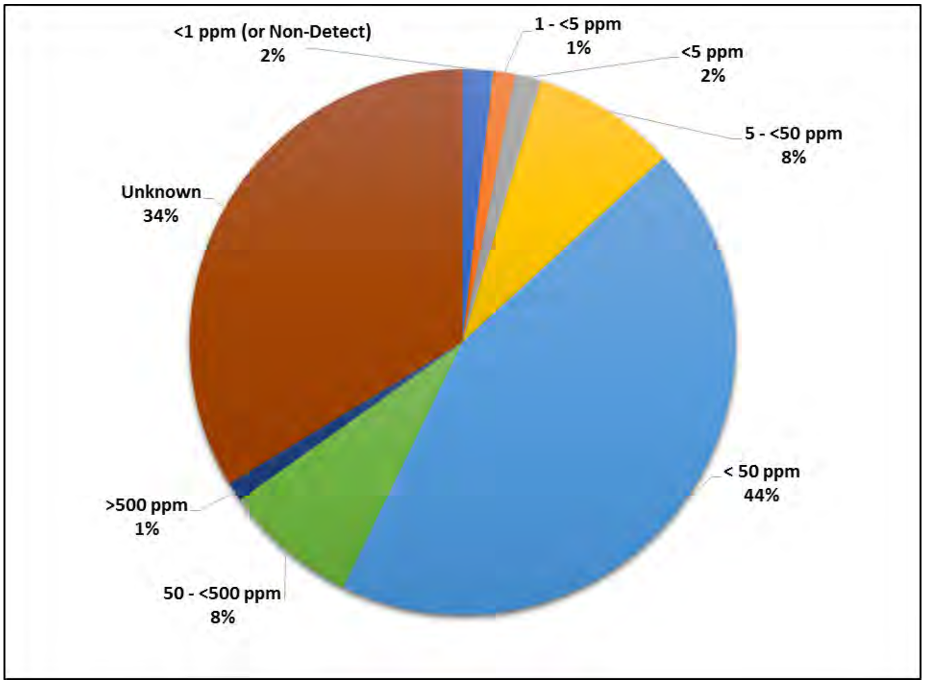

Figure 3. PCB Concentration data reported for releases from PG&E electrical equipment between 1993 and 2016.

Only 1% of the reported releases identified the PCBs concentrations as either below 1 ppm, or below detection limits. Although the quality of the PCBs concentration data in the release reports varies widely, these results clearly demonstrate that PG&E's electrical equipment in the Bay Area can still contain PCBs at concentrations of concern for water quality protection programs.

3.2.5 Cleanup Methods and Actions Taken in Response to OFEE Releases

Limited information is available on the spill response protocols used by electrical utility companies during cleanups. Based on information publicly available, electrical utility companies typically address spills or leaks from their equipment with Standard Operating Procedures (SOPs) that should conform to both State and Federal requirements. According to information provided to the SF Bay Water Board (PG&E 2000), PG&E spill response is guided by internal documents, including:

- ***Utility Operations Standard D-2320*** - for PCBs spills in the distribution system;
- ***PCB Management at Substations -*** for PCBs spills in the transmission system.

However, these documents are not publicly available for review.

The Cal OES reports provide almost no information on actions taken to stop active spills, or the methods used to cleanup spilled materials from surrounding surfaces, storm drain infrastructure, or creeks. Municipalities need this type of information to better understand any potential risks that remain following initial cleanup. Because of the challenges with achieving the stormwater runoff wasteload allocation in the PCBs TMDL, additional remedial actions may be warranted in some cases.

3.3 Potential Causes of Water Quality Problem

Given the history of PCBs use in electrical utility equipment, the current estimates of electrical equipment still in use that contain PCBs, and existing documentation that spills of PCBs from electrical utility equipment continue to occur, electrical utility equipment is likely a significant source of PCBs to stormwater runoff, and ultimately to the Bay. PG&E, the largest electric utility company in the Bay Area, was likely the largest single user of PCBs in the Bay Area, and as such, likely remains the largest current source of PCBs releases to MS4s from electrical utility equipment.

4.0 SSID Investigation Approach and Schedule

The overall approach for this SSID Investigation is to (1) conduct a desktop analysis and (2) propose a source control framework for electrical utility equipment to reduce ongoing PCBs loads to the Bay in stormwater runoff. The purpose of the desktop analysis is to better understand the extent and magnitude of electrical utility equipment as a source of PCBs to urban stormwater runoff, document past and current efforts to reduce PCBs releases from electrical utility equipment during spills or other accidental releases, and document measures already taken or underway to remove PCBs-containing oils and electrical equipment from active service across the Bay Area. The results of the desktop analysis will inform identifying new or improved control measures to avoid/reduce the release of PCBs from this source. This information may also be used to update the estimated PCBs loads to stormwater from this source, and inform development of a load reduction accounting methodology. This project will request the assistance and support of the SF Bay Water Board to gather the information needed from electrical utility companies to conduct the desktop analysis. Based on the outcomes of the desktop analysis, this project will then propose a framework for addressing PCBs from electrical utility equipment. The framework may include a recommendation to designate electrical utilities as a *Categorical Source* of PCBs to stormwater in order to facilitate the development of a comprehensive, regional control measure program to address this source.

This SSID Project is a BASMAA Regional Project. The BASMAA Monitoring and Pollutants of Concern Committee (BASMAA MPC) will oversee implementation of the project. Implementation of this work plan will contribute to fulfillment of MRP Provision C.8.e requirements for all BASMAA co-permittees.

4.1 Task 1: Desktop Analysis

The desktop analysis is designed to gather and evaluate information on electrical utility equipment in the Bay Area to determine if a *Categorical Source* referral is warranted, and to provide the foundation for development of a comprehensive regional control measure program to reduce PCBs loads from this source. The desktop analysis will include the following five sub-tasks:

- **Subtask 1.1 Request information from electrical utility companies.**
  This task will seek the assistance and support of the SF Bay Water Board to: obtain information from private utility companies that is not publicly available but is needed to better understand the extent and magnitude of PCBs releases from OFEE; identify the most appropriate actions to prevent or reduce releases from this source; and develop and implement effective reporting and control measures. For this task, the SF Bay Water Board will be asked to assist BASMAA in compelling electrical utility companies (e.g., PG&E) to provide the necessary information. A preliminary list of information that will be requested includes the following:
  - Spill reporting and notification procedures (both company-wide and location-specific);
  - Spill records NOT reported in Cal OES;
  - SOPs and other documentation used by electrical utilities and their contractors to guide spill response and cleanup actions when releases from OFEE occur;
  - SOPs and documentation, including analytical methods for PCBs used by electrical utilities and their contractors to identify and clean up regular leaks from OFEE during regular maintenance activities

- Measurement data on concentrations of PCBs in OFEE;
- Maintenance records that document when and where PCBs-containing OFEE are removed from the system and how often PCBs containing equipment is inspected for leaks or spills;
- Documentation of past programs to voluntarily remove PCBs-containing oils or OFEE – including what equipment was removed, and the locations from which it was removed; and
- Documentation of where PCBs-containing OFEE were located in the past, and where they are currently located across the Bay Area.

This list will be reviewed prior to making any data requests. Additional data gaps may also be identified and added to the data request based on discussions with SF Bay Water Board staff and/or preliminary information provided by utility companies.

- **Subtask 1.2 Assess current electrical utility data.**
  This task will review, tabulate and analyze the information provided by electrical utility companies as a result of the SF Bay Water Board's request for information, in order to document the following:
  - Measurement data on PCBs concentrations and/or mass in OFEE;
  - Locations of PCBs-containing OFEE;
  - Quantity of PCBs-containing OFEE removed from service annually;
  - Occurrences of spills or releases from OFEE;
  - Current PCBs spill and cleanup reporting requirements; and
  - Current PCBs cleanup protocols.
- **Subtask 1.3 Improve estimates of PCBs loadings.**
  This task will combine the information provided in Subtask 1.2 with all existing data in order to develop improved estimates of current PCBs loadings from electrical utility equipment to MS4s in the study area. The quality of these estimates will partly depend on the quality of the data received from the utility companies.
- **Subtask 1.4 Refine PCBs reporting requirements**
  This task will review all current reporting and notification requirements to identify any improvements or clarifications that the SF Bay Water Board could require of electrical utilities to provide the type of data needed to better quantify the amount of PCBs released from OFEE spills, and to help ensure that adequate cleanup actions are being implemented.
- **Subtask 1.5 Evaluate PCBs cleanup protocols**
  This task will review all documented cleanup protocols that are currently used by electrical utility companies in order to identify any changes or improvements that could be recommended to further reduce the discharge of PCBs to the MS4 when releases occur.

4.2 Task 2: Develop Source Control Framework

Based on the results of the desktop analysis, this task will propose an appropriate framework for managing and implementing control measures to reduce PCBs from electrical utility equipment. The framework should include prescribed methods and procedures for unplanned spills and releases from OFEE, as well as a plan for continued reduction of PCBs from in-use OFEE, and potentially further identification and cleanup of historic release sites. The framework will likely include the following elements:

- Summary of the outcomes of the desktop analysis results, including:
  a. Summary of information provided by electrical utility companies as a result of the SF Bay Water Board's request for information from electrical utilities;
  b. Improved estimates of current PCBs loadings from electrical utility equipment based on information received;
  c. Documentation of current spill clean-up and reporting actions, and existing programs for proactive removal of PCBs-containing oils and equipment conducted by electrical utility companies;
  d. Recommended PCBs spill and cleanup reporting requirements that the SF Bay Water Board could require of electrical utilities;
  e. Recommended improvements to PCBs spill cleanup protocol(s) that would reduce the discharge of PCBs to MS4s that the SF Bay Water Board could require of electrical utilities.
- A recommendation (based on the results of the Task 1 desktop analysis) about designation of electrical utility equipment as a *Categorical Source*.
- Recommended approach to manage and control releases of PCBs from electrical utility companies. For example, if a *Categorical Source* referral is submitted, the recommended approach will focus on development of a comprehensive regional control measure program. The program would include requirements the SF Bay Water Board could impose on electrical utility companies in the Bay Area, such as new spill reporting and cleanup protocols.

4.3 Task 3: Develop methodologies to account for PCB load reductions from new source control measures

BASMAA will further apply the results of the desktop analysis to develop methodologies to account for the PCBs load reductions that can be achieved via the new clean-up and reporting protocols identified above in Task 2.

4.4 Task 3: Develop SSID Project Report

BASMAA will prepare a report describing the desktop analysis and outcomes. The report will summarize the information provided by electrical utility companies and identify recommendations to modify or improve current control measures or management actions that will reduce PCBs released to MS4s. The Management Questions described in Section 2.3 will be addressed:

1. What is the current magnitude and extent of PCBs stormwater loadings from electrical utility equipment and operations in the San Francisco Bay Area region?
2. Are there aspects of equipment or operational procedures that electrical utilities should be required to report to the SF Bay Water Board?
3. Are there additional spill and clean-up controls needed to reduce water quality impacts from the release of PCBs in electrical utility equipment?

4. Are there additional proactive activities needed to avoid releases of PCBs from electrical utility equipment?
5. What are the PCBs load reductions that can be achieved through implementation of a regional reporting and control measure program?

4.5 Project Schedule

Table 2 summarizes the tasks and anticipated outcomes described in this work plan, and the proposed schedule for each task. This is an approximately one-year effort to be conducted primarily in Fiscal Year 2019-2020. However, Task 1 (information request) will likely be made before the end of Fiscal Year 2018-2019. It is anticipated that the SSID project report will be completed in June 2020. The schedule in Table 2 is dependent upon the timing, extent, and format of the data that are received from electrical utility companies based on the SF Bay Water Board's request for information.

Table 2. Tasks, Anticipated Outcomes, and Schedule.

Task Description		Anticipated Outcome(s)	Anticipated Completion Date
Task 1: Desktop Analysis			
1.1	***Request information from electrical utility companies***	Language for information request provided to SF Bay Water Board.	Apr-2019
1.2	***Assess current electrical utility data***	Summary tables of information and analyses of the data received from electrical utility companies.	Oct-2019
1.3	***Improve estimates of PCBs loadings***	Tables with estimated annual PCBs loads to MS4s from electrical utility equipment.	Nov-2019
1.4	***Refine PCBs reporting requirements***	Recommended improved PCBs spill and cleanup reporting requirements for electrical utility companies.	Dec-2019
1.5	***Evaluate PCBs clean-up protocols***	Recommended improved PCBs cleanup protocols for electrical utilities companies.	Dec-2019
Task 2: Develop Source Control Framework		Recommended source control framework for electrical utility equipment.	Jan-2020
Task 3: Develop PCBs Load Reduction Accounting Methodology		Recommended methodology to account for PCBs load reductions achieved through implementation of new source controls.	Jan-2020
Task 4: Reporting		Regional SSID Project Report	Jun-2020

5.0 References

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A change to the scope of this SSID work plan was proposed and accepted, with Water Board concurrence, at the BASMAA Monitoring and Pollutants of Concern Meeting on March 4, 2020. The following revised scope language was provided by BAMSAA contractors on March 25, 2020.

REGIONAL PCBS FROM ELECTRICAL UTILITY EQUIPMENT

In late-2018, BASMAA contracted with EOA, Inc. to develop a work plan for a regional SSID project addressing releases and spills of PCBs from electrical utility equipment. The Regional SSID Project - Electrical Utilities as a Potential PCBs Source to Stormwater in the San Francisco Bay Area – was triggered by fish tissue monitoring in the Bay that led to the Bay being designated as impaired on the Clean Water Act (CWA) Section 303(d) list and the adoption of a TMDL for PCBs in 2008. Subsequent PCBs monitoring by the BASMAA RMC partners and the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) suggests that diffuse sources of PCBs are present throughout the region. One potential source of PCBs to stormwater is releases and spills from electrical utility equipment.

PCBs were historically used in several types of electrical utility equipment, some of which still contain PCBs. Although much of the PCB-containing equipment has been removed from service, some remains in use, and releases and spills from the equipment may be occurring at levels approaching the TMDL waste load allocation. However, the information currently available is not adequate to fully quantify the scope and magnitude of electrical utility applications as a source of PCBs to stormwater. The information gap is partially due to state and federal regulatory levels for reporting and clean-up of PCBs spills that are higher than the PCB levels needed to comply with the PCBs TMDL requirements. Furthermore, stormwater Programs have neither the authority to compel electrical utilities to provide information about spills, equipment replacement programs, and clean-up protocols, nor the authority to require additional controls. Therefore, BASMAA identified a need to develop and implement a regional SSID work plan to further understand the magnitude and extent of this potential PCBs source, and identify controls (if necessary) that could be put into place to reduce the water quality impacts of this source.

The work plan was submitted with each countywide stormwater program's WY 2018 UCMR. It presents a framework for working with the Regional Water Board, which does have jurisdictional authority over electrical utility companies. The overall goal for the regional SSID project is to investigate electrical utility equipment as a source of PCBs to urban stormwater runoff and identify appropriate actions and control measures to reduce this source. Building on the information presented by SCVURPPP (2018b), this project is designed to achieve the following three objectives:

1. Gather information from Bay Area utilities to improve estimates of current PCBs loadings to municipal separate storm sewer systems (MS4s) from electrical utility equipment, and document current actions conducted by utilities to reduce or prevent release of PCBs from their equipment;

2. Identify opportunities to improve spill response, cleanup protocols, or other programs designed to reduce or prevent releases of PCBs from electrical utility equipment to MS4s;

3. Develop an appropriate mechanism for municipalities to ensure adequate clean-up, reporting and control measure implementation to reduce urban stormwater loadings of PCBs from electrical utility equipment.

The information gained during this project will also provide data that municipalities can use to provide better estimates of PCBs load reductions that can be achieved through implementation of a regional control measure program for electrical utilities.

Overview of the Regional SSID Work Plan

The work plan identified 4 project tasks: (1) conduct a desk top analysis; (2) propose a source control framework for electrical utility equipment to reduce ongoing PCBs loads to the Bay in stormwater runoff; (3) develop data inputs to better estimate PCBs load reductions that can be achieved via new source controls; and (4) develop an SSID project report. Each of these tasks are described in more detail below.

Task 1: Desktop Analysis

The desktop analysis is designed to gather and evaluate information on electrical utility equipment in the Bay Area to provide the foundation for development of a comprehensive regional control measure program to reduce PCBs loads from this source. The desktop analysis includes the following five sub-tasks:

- **Subtask 1.1 Request information from electrical utility companies**
  This task will seek the assistance and support of the Regional Water Board to: obtain information from non-municipally owned utility companies that is not publicly available but is needed to better understand the extent and magnitude of PCBs releases from Oil Filled Electrical Equipment (OFEE); identify the most appropriate actions to prevent or reduce releases from this source; and develop and implement effective reporting and control measures. For this task, the Regional Water Board will be asked to assist BASMAA in compelling electrical utility companies (e.g., PG&E) to provide the necessary information. A preliminary list of information that will be requested includes the following:

    - Spill reporting and notification procedures (both region-wide and location-specific);
    - Spill records NOT reported to the California Governor's Office of Emergency Services (Cal OES);
    - SOPs and other documentation used by electrical utilities and their contractors to guide spill response and cleanup actions when releases from OFEE occur;

- SOPs and documentation, including analytical methods for PCBs used by electrical utilities and their contractors to identify and clean up regular leaks from OFEE during regular maintenance activities;
- Measurement data on concentrations of PCBs in OFEE;
- Maintenance records that document when and where PCBs-containing OFEE are removed from the system and how often PCBs containing equipment is inspected for leaks or spills;
- Documentation of past programs to voluntarily remove PCBs-containing oils or OFEE – including what equipment was removed, and the locations from which it was removed; and
- Documentation of where PCBs-containing OFEE were located in the past, and where they are currently located across the Bay Area.

Additional data gaps may also be identified and added to the data request based on discussions with Regional Water Board staff and/or preliminary information provided by utilities.

- **Subtask 1.2 Assess current electrical utility data**
  This task will review, tabulate and analyze the information provided by electrical utilities as a result of the Regional Water Board's request for information, in order to document the following:

  - Measurement data on PCBs concentrations and/or mass in OFEE;
  - Locations of PCBs-containing OFEE;
  - Quantity of PCBs-containing OFEE removed from service annually;
  - Occurrences of spills or releases from OFEE;
  - Current PCBs spill and cleanup reporting requirements; and
  - Current PCBs cleanup protocols.

- **Subtask 1.3 Improve estimates of PCBs loadings**
  This task will combine the information provided in Subtask 1.2 with all existing data in order to develop improved estimates of current PCBs loadings from electrical utility equipment to MS4s in the study area. The quality of these estimates will partly depend on the quality of the data received from the utilities.

- **Subtask 1.4 Refine PCBs reporting requirements**
  This task will review all current reporting and notification requirements to identify any improvements or clarifications that the Regional Water Board could require of electrical utilities to provide the type of data needed to better quantify the amount of PCBs released from OFEE spills, and to help ensure that adequate cleanup actions are being implemented.

- **Subtask 1.5 Evaluate PCBs cleanup protocols**
  This task will review all documented cleanup protocols that are currently used by electrical utilities in order to identify any changes or improvements that could be recommended to further reduce the discharge of PCBs to the MS4 when releases occur.

Task 2: Develop Source Control Framework

Based on the results of the desktop analysis, this task will propose an appropriate framework for managing and implementing control measures to reduce PCBs from electrical utility equipment. The framework should include prescribed methods and procedures for unplanned spills and releases from OFEE, as well as a plan for continued reduction of PCBs from in-use OFEE, and potentially further identification and cleanup of historic release sites. The framework will likely include the following elements:

- Summary of the outcomes of the desktop analysis results, including:
  - Summary of information provided by electrical utilities;
  - Improved estimates of current PCBs loadings from electrical utility equipment based on information received;
  - Documentation of current spill clean-up and reporting actions, and existing programs for proactive removal of PCBs-containing oils and equipment conducted by electrical utilities;
  - Recommended PCBs spill and cleanup reporting requirements that the Regional Water Board could require of electrical utilities;
  - Recommended improvements to PCBs spill cleanup protocol(s) that would reduce the discharge of PCBs to MS4s that the Regional Water Board could require of electrical utilities.
  - Recommended approach to manage and control releases of PCBs from electrical utilities. The approach may include requirements the Regional Water Board could impose on electrical utilities in the Bay Area, such as new spill reporting and cleanup protocols.

Task 3: Develop Data Inputs to Better Account for PCBs Load Reductions from New Source Control Measures

BASMAA will further apply the results of the desktop analysis to develop data inputs to better account for the PCBs load reductions that can be achieved via the new clean-up and reporting protocols identified above in Task 2.

Task 4: Develop SSID Project Report

BASMAA will prepare a report describing the desktop analysis and outcomes. The report will summarize the information provided by electrical utilities and identify recommendations to modify or improve current control measures or management actions that will reduce PCBs released to MS4s. The Management Questions that will be addressed include:

1. What is the current magnitude and extent of PCBs stormwater loadings from electrical utility equipment and operations in the San Francisco Bay Area region?

2. Are there aspects of equipment or operational procedures that electrical utilities should be required to report to the Regional Water Board?

3. Are there additional spill and clean-up controls needed to reduce water quality impacts from the release of PCBs in electrical utility equipment?

4. Are there additional proactive activities needed to avoid releases of PCBs from electrical utility equipment?
5. What are the PCBs load reductions that can be achieved through implementation of a regional reporting and control measure program?

Current Status of the Regional SSID Project

Implementation of the regional SSID work plan began in WY 2019. The Work Plan focused on Pacific Gas and Electric Company (PG&E), the largest electrical utility operating in the MRP area, and the only utility that is not owned by a municipality. The work plan outlined a 2-step process to (1) conduct a desktop analysis using data from PG&E in order to better understand the extent and magnitude of PCBs releases from oil-filled electrical equipment (OFEE) and document current and past efforts to reduce PCBs in OFEE, and (2) propose a source control framework to potentially reduce ongoing PCBs loads to the Bay from electrical utility equipment. The project team developed a letter requesting assistance from the Regional Water Board and outlining the specific data that is needed from PG&E to complete this project. However, PG&E is currently in bankruptcy proceedings, and the outcomes of that process have not yet been determined.

Because of the current situation with PG&E, BASMAA developed a revised approach to the SSID project in early WY 2020 that focuses on municipally-owned electrical utilities in the MRP area. Although these municipally-owned electrical utilities represent a fraction of the electrical utility equipment and properties in the MRP area, BASMAA member agencies have a better opportunity to work with these utilities and gather the type of information needed to conduct the desktop analysis, albeit at a smaller scale. The revised approach will continue to implement the Regional SSID work plan but will focus exclusively on municipally-owned electrical utilities in the Bay Area. The revised approach implements the SSID work plan objectives to develop an appropriate source control framework to inform the development of practices to potentially reduce the release of PCBs from electrical utility equipment; and to develop estimates of PCBs load reductions that could be achieved through implementation of revised management practices, such as improved clean-up and reporting procedures.

In November and December 2019, BASMAA held a series of meetings with representatives from municipally-owned electrical utilities and associated municipal staff in the MRP area to discuss the project and information needs. Based on input provided during these meetings, BASMAA developed an information request for municipally-owned electrical utilities that was similar to the request sent to the Regional Water Board for PG&E data.

BASMAA intends to continue this project during WY 2020. The new request for information will be submitted to each of the municipally-owned electrical utilities in the MRP area in the near future. The BASMAA project team will proceed with the desktop analysis upon receipt of data from these utility partners. It is anticipated that the final project report will be submitted to the Regional Water Board with the Program’s WY 2020 UCMR by March 31, 2021.

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Bay Area Stormwater Management Agencies Association (BASMAA) 2017. Interim Accounting Methodology for TMDL Loads Reduced. Prepared by Geosyntec Consultants and EOA, Inc. March 2017.

Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP). 2018b. Potential Contributions of PCBs to Stormwater from Electrical Utilities in the San Francisco Bay Area. Overview and Information Needs. Prepared by EOA, Inc. September 2018.

Contra Costa Clean Water Program

Marsh Creek Stressor and Source Identification Study:

Year 2 Report

March 18, 2020

Submitted to

CONTRA COSTA CLEAN WATER PROGRAM

Contra Costa Clean Water Program
255 Glacier Drive
Martinez, California 94553

Submitted by

wood.

Wood Environment & Infrastructure Solutions, Inc.
180 Grand Avenue, Suite 1100
Oakland, California 94612

and

ADH Environmental

ADH Environmental
3065 Porter Street, Suite 101
Soquel, California 95073

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Acronyms and Abbreviations

BOD	biochemical oxygen demand
Brentwood	City of Brentwood
CCCWP	Contra Costa Clean Water Program
CDFW	California Department of Fish and Wildlife
DO	dissolved oxygen
mgd	million gallons per day
MRP	Municipal Regional Stormwater NPDES Permit
NPDES	National Pollutant Discharge Elimination System
POC	pollutants of concern
SFBRWQCB	Regional Water Quality Control Board, San Francisco Bay Region
SSC	suspended sediment concentration
SSID	stressor and source identification
TSS	total suspended solids
WWTP	wastewater treatment plant

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EXECUTIVE SUMMARY

This stressor and source identification (SSID) study (study) addresses the causes of fish kills in Marsh Creek, following a work plan approved by the CCCWP Monitoring Committee. The study focuses on low dissolved oxygen (DO) as the primary suspected cause of fish kills. Pesticide toxicity was also evaluated in this study as a potential cause of fish mortality.

Continuous monitoring of water levels, DO, temperature, conductivity, turbidity, and pH at three locations along Marsh Creek helped form our understanding of daily and seasonal factors affecting DO. The locations monitored were just upstream of the City of Brentwood Wastewater Treatment Plant (WWTP), immediately downstream of the WWTP, and about two miles downstream of the WWTP. Dry weather flow event grab samples were tested for pesticides and biochemical oxygen demand (BOD). Additional water level sensors and field investigations helped identify sources of dry weather flow and the response of nightly DO minimum levels to dry weather flow rates.

Continuous DO and water level monitoring demonstrated that a recent (Sep. 17, 2019) fish kill was almost certainly caused by low DO following a first of season rain event. The rain event appears to have mobilized BOD, either from within the stream channel or from watershed sources. In combination with nightly lows in DO that occur naturally due to the photosynthesis/respiration cycle of native algae, this first flush of BOD caused lethally low DO levels.

The mortality event of Sep. 17, 2019 was limited to approximately one hundred fish, found exclusively in areas upstream of the WWTP. In contrast, prior events occurring in late summer and early fall caused thousands of fish to die and extended miles downstream of the WWTP to as far as Cypress Boulevard. The difference in 2019 was a pilot project at the WWTP, at the recommendation of CCCWP, to provide a small amount (250,000 gallons) of water to augment flow between midnight and 6 AM, when nightly DO minima occur. Flow augmentation re-aerates the water by adding well-oxygenated water and increasing stream velocity across the shallow riffles formed by check dams constructed in the creek channel to mitigate erosion. The flow augmentation pilot project by the WWTP was initiated based on the findings from Year 1 of this study, which revealed the link between in-stream dry weather flows and nightly DO minimum levels.

Lethally low DO explains not only the 2019 mortality event but also likely explains several, but not necessarily all, of the prior nine mortality events observed since 2005. At least three prior events had documented low DO in Marsh Creek upstream of the WWTP prior to a first flush rain event, matching the conditions of the 2019 event. Three other prior events occurred in the July-September timeframe and, based on the seasonal timing, are suspected to have been caused by low DO. Three prior events occurred in March and May; the role of DO or other causes for those events is unknown.

Water toxicity to fish in Marsh Creek has been tested seven times through this SSID study and other required monitoring tasks. This includes a fish toxicity bioassay performed on Marsh Creek water collected on the morning of Sep. 19, 2019 as fish were expiring. None of the toxicity tests revealed chemical toxicity to fish (bioassay laboratories prevent lethally low DO levels by aeration during testing).

In May of 2018, crayfish mortality (six crayfish) was noted by field crews upstream of the WWTP. This observation was confirmed by a monitoring team from a local creek group, who found 10 dead crayfish and six dead fish near Creekside Park. The cause of crayfish mortality during that event is unknown. Crayfish are generally hardier than most fish species with respect to extreme aquatic conditions, such as low DO and high temperatures. Around the time of the observed crayfish mortality, DO dipped as low as 5 mg/L and temperatures reached as high as 26.5° C at the monitoring location just upstream of the WWTP, which are conditions that should be tolerable for crayfish. The isolated pools further upstream where the crayfish mortality was noted could possibly have reached more extreme DO and temperature levels. Alternatively, there may be another cause of crayfish mortality, such as pesticide toxicity. As noted in the work plan for this study, crayfish respond to chemical toxicants in a manner more similar to benthic organisms than free-swimming fish. Thus, prior observations of toxicity in Marsh Creek to the benthic amphipod *Hyalella azteca* could be related to the observed crayfish mortality. The two causes are not exclusive: organisms already stressed from pesticide exposure may not be as hardy to extreme conditions of DO and temperature and vice-versa.

Dry weather flows in Marsh Creek come from numerous and variable allowed sources, such as irrigation runoff. None of the analytical results from dry weather flows sampled in this study indicated unusual or concerning water quality characteristics. The main issue with dry weather flows appears to be the intermittent creation and subsequent drying up of wetted pools in the reach of Marsh Creek upstream of the WWTP. Organisms can be lured upstream during dry weather flow events, only to be stranded in pools that eventually become uninhabitable as dry weather flows diminish.

In summary, lessons learned from this study reveal the following:

- Low DO remains the primary suspected cause of recurrent fish mortality in Marsh Creek and was almost certainly the cause of a Sep. 17, 2019 mortality event.
- Dry weather flows directly affect nightly DO minimum levels throughout Marsh Creek – lower flows lead to lower nightly DO minimum levels.
- Flow augmentation at the WWTP appeared to mitigate nightly DO sags downstream of the Brentwood WWTP.
- Marsh Creek below Marsh Creek Reservoir should be considered as two separate reaches for water quality planning purposes. “Reach 1,” downstream of the WWTP to the Delta, has unique water quality characteristics compared to “Reach 2,” from the WWTP upstream to the reservoir. Reach 2 presents much more challenging conditions of DO and temperature because of less consistent flow.

The study is complete, in that it answered the question of current causes of fish mortality in Marsh Creek. The SSID program is intended to provide answers to such questions to permittees via a monitoring study conducted by CCCWP. The new understanding allows CCCWP to end this study, pivoting to Permittees – the City of Brentwood (Brentwood) and the Contra Costa County Flood Control and Water Conservation District – to evaluate and implement appropriate management actions.

CCCWP recommends the following Permittee actions during the 2020-2022 timeframe:

- CCCWP requests that Brentwood continue the flow augmentation pilot for at least two more years (WY 2020-21 and WY 2021-22). Having demonstrated through a single event that this is an effective best practice to ameliorate sudden DO sags, the consistent effectiveness of the intervention needs to be evaluated. Also, the amount and timing of flow needed to maintain acceptable water quality needs to be better defined, so that the most efficient use can be made of valuable, recyclable water.

- CCCWP proposes to continue monitoring water quality (DO, temperature, conductivity and pH) using sondes for at least two more years. This activity was funded by the District in FY 2018-2019. CCCWP is discussing future funding of this monitoring activity with the District and Permittees. Continuous monitoring in conjunction with flow augmentation by Brentwood will allow evaluation of advance warning and responsive actions, whereby baseline augmented flow rates are increased when conditions indicate lethally low DO levels may be reached. This approach will provide a means to find out how augmented flow rates affect minimum DO levels reached after a first flush rain event.

The two Permittee-led actions above (flow augmentation and continuous monitoring) show some potential for an implementable management strategy to prevent or ameliorate fish mortality in Marsh Creek downstream of the WWTP ("Reach 1"). Upstream, from the WWTP to the reservoir ("Reach 2"), episodic fish and crayfish mortality may persist as a result of the intermittency of flow in that reach. CCCWP recommends a planning study could evaluate the best approach, in the consensus view of the community, to improve habitat conditions such that recurrent fish mortality is reduced or prevented. For example, two broad alternatives could be:

- Modify check dams to drain more quickly, so that isolated pools no longer form in Reach 2, upstream of the WWTP; or

- Extend flow augmentation upstream, using District water from Marsh Creek Reservoir, recycled water from the Brentwood WWTP, and/or other water resource partners.

A planning study could evaluate the best approach, in the consensus view of the community, to manage habitat conditions in Reach 2. A key question is whether the greatest net environmental benefit would result from reconfiguring check dams to drain off isolated pools during summer in Reach 2, or alternatively, managing flows in Marsh Creek upstream of the WWTP outfall during critical periods to prevent lethal DO sags. The lead on such a planning study would need to be a community-based group focused on creek restoration and habitat enhancement. This type of water quality and habitat planning is outside the scope of the District's core mission of flood control. The Contra Costa Watershed Forum is an established community-based watershed planning forum where discussion of such a planning process would be appropriate. Findings and recommendations from this will be shared with the Contra Costa Watershed Forum concurrent with release of this report.

Going forward, CCCWP's direct role in relation to this study will be to document the results of Permittee-led activities described above through our annual urban creeks monitoring report. CCCWP will continue to conduct pesticide and toxicity evaluations in Marsh Creek and other Contra Costa County streams, in compliance with MRP provision C.8 and requirements established under Pesticide TMDLs.

While outside the scope of this study, the issue of crayfish mortality is interesting. CCCWP will consider following up on crayfish through a future study, if such a study fulfills requirements of the next re-issuance of the Municipal Regional Stormwater NPDES Permit (expected to be effective in 2021). The need for a crayfish study would be prioritized in consideration of other water quality issues noted in Contra Costa County.

In conclusion, this SSID study successfully identified DO as the most significant controllable water quality factor leading to recurrent fish mortality. While there may be other stressors affecting aquatic life in Marsh Creek, it would be difficult to discern the effects of other stressors until the recurrence of sudden DO crashes is abated. The study also identified short term and long-term management strategies that Permittees can evaluate to address fish mortality related to low DO episodes in Marsh Creek.

1. Introduction and Background

This stressor and source identification (SSID) study (study) addresses the fish kills in Marsh Creek. This study fulfills the requirements of Provision C.8.e of the Municipal Regional Stormwater NPDES Permit (MRP). The primary study objective is to identify causes of fish kills in Marsh Creek. The first step was to determine whether low dissolved oxygen (DO) causes fish kills in Marsh Creek and, if so, determine the causes of the low DO. An alternate hypothesis, not necessarily exclusive of low DO, is that pesticide toxicity causes fish kills. Proving or disproving links to pesticides is more complex compared to identifying low DO as a root cause; therefore, the objective for the pesticide assessment is to provide the most substantive weight of evidence achievable within the schedule and budget of this study.

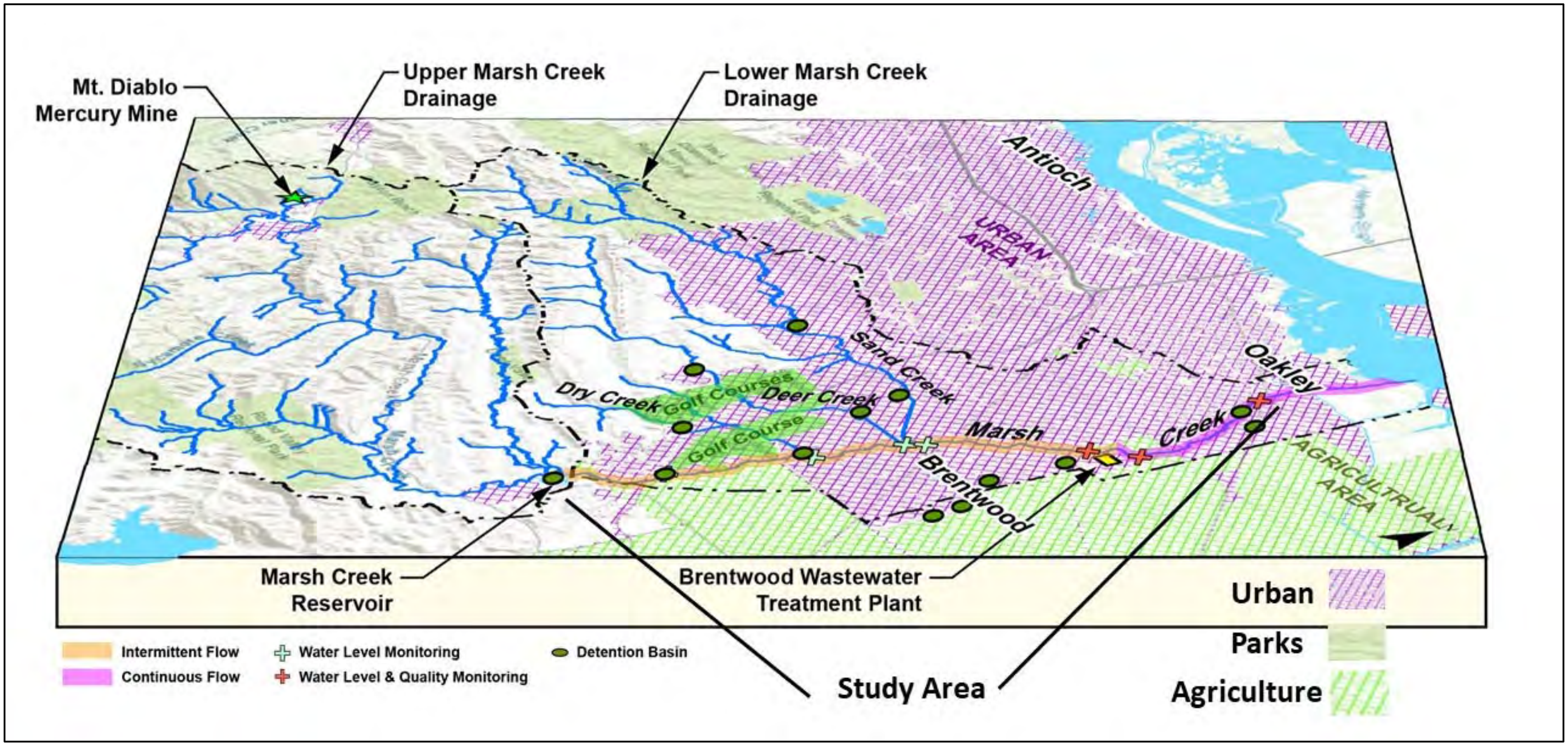
There have been 10 documented fish kills over the past 14 years in Marsh Creek, dating back to 2005 (CCCWP, 2018 and citations therein). These events are often associated with intermittent dry season flows or storm events with varying antecedent dry periods. The most recent event occurred in September 2019.

The study area extends from below Marsh Creek Reservoir downstream to the City of Oakley (Figure 1). Tributaries entering this portion of Marsh Creek include Dry Creek, Sand Creek and Deer Creek. Streamflow in the creek is generally low, but rarely dry, during most of the summer. Known sources of dry weather flow are associated with wastewater treatment plant discharge, agricultural irrigation return flows, and non-stormwater urban drainage from the Brentwood area. Seasonal stormwater flows, the effects of urban development, and agricultural runoff contributions have significant impacts on the quality and quantity of water in Marsh Creek.

The City of Brentwood Wastewater Treatment Plant (WWTP), located approximately 3.6 miles southwest of the Delta at Big Break, treats sanitary wastewater from nearby residential areas and discharges its effluent into Marsh Creek, as authorized by a National Pollutant Discharge Elimination System (NPDES) permit (CA0082660). The WWTP has a design capacity of 5 million gallons per day (mgd); present actual discharge flows are more typically in the range of 3 to 4 mgd, depending in part on recycled water consumption by irrigators. The WWTP creates a relatively constant body of flowing water in Marsh Creek downstream of its outfall. In the region below the WWTP, flow rates tend to peak mid-day, following peaks in early morning residential usage, and are at minimum in the pre-dawn hours. During the summer irrigation season, discharge flow rates can reach near zero every night because of irrigation demand for recycled water.

Upstream of the WWTP outfall, flows are more intermittent, resulting from more intermittent activities. There are a multitude of farms, businesses, and storm drains which discharge stormwater and non-stormwater runoff into Marsh Creek. Agricultural and golf course irrigation, hydrant flushing, planned discharges during water transmission system maintenance, and residential irrigation are all potential sources of non-stormwater flow into Marsh Creek.

Figure 1. Map of Study Area and Relevant Watershed Features



2. Approach

The study approach follows a work plan developed by CCCWP and approved by the CCCWP Monitoring Committee (CCCWP, 2018). Continuous monitoring of water levels, DO, temperature, conductivity, turbidity, and pH at three locations along Marsh Creek helped understand daily and seasonal factors that affect DO. Water levels and quality were successfully monitored using YSI EX03® sonde devices in Marsh Creek at three locations: upstream of the WWTP (Station M2), immediately downstream of the WWTP (Station M1), and two miles downstream at Cypress Boulevard (Station M0). Four Onset Corporation HOBO® U20 water level sensors were deployed at locations on Marsh Creek upstream of station M2: just below the confluence with Sand Creek (Station 544R04189); just below the confluence with Deer Creek (Station M4-A); just below the confluence with Dry Creek (Station 544R05505); and midway between the confluence with Dry Creek and the Marsh Creek Reservoir (Station 544XMCACA). The first three U20 site devices were used for the estimation of dry weather flows from Marsh Creek's major tributaries and the last for any from flows from the reservoir and its environs. Locations of these water quality and water level sensors are indicated in Figure 2.

Figure 2. Marsh Creek and Tributaries with Stations using Water Level and Water Quality Sensors – 2018 and 2019

In 2018 and 2019, field investigations were used to help identify sources of dry weather flow and the potential cause of any fish kills. Grab sampling was performed during dry weather flow events and during a fish kill event to quantify pesticides and biochemical oxygen demand. Constituents analyzed in grab samples are summarized in Table 1. During grab sampling events, field staff also inspected Marsh Creek upstream of the WWTP to attempt to identify sources of dry weather flow. During a single fish kill event that occurred Sep. 17, 2019, water toxicity testing was performed on fathead minnow (*Pimephales promelas*) for survival.

A report on the first year of these activities was issued by CCCWP and approved by the CCCWP Monitoring Committee (CCCWP, 2019). These activities were continued in the second year of the project and the results are presented in this report.

Table 1. Analytical Test Methods, Reporting Limits and Holding Times for Water Chemistry Testing

Analyte	Matrix	Test Method	Reporting Limit	Holding Time
Suspended Sediment Concentration	Water	ASTM D3977-97B	3 mg/L	7 days
Pesticides[1]	Water	EPA 8270M	1.5 ng/L to 2 µg/L	7 days
Ammonia	Water	SM 4500 NH3 C	0.1 mg/L	28 days
Biochemical Oxygen Demand 5-Day	Water	SM 5210B	2 mg/L	48 hours
Total Sulfides	Water	SM 4500-S2	0.1 mg/L	7 days
Total Organic Carbon	Water	SM 5310 B-00/-11	±0.1 %	28 days
Dissolved Organic Carbon	Water	SM 5310 B-00/-11	0.50 mg/L	Filter 48 hours, 28 days

1 Pyrethroids, chlorpyrifos, diazinon, fipronil, and degradants

3. Observations, Results, and Analysis

This section presents the key findings of the study from 2018 and 2019. Grab sample results, HOBO data, and lessons learned from each year set the stage for understanding the causes of the fish kill event that occurred on Sep. 17, 2019. Analysis of continuous monitoring results from that event and a subsequent low DO event that occurred with no fish mortality from Nov. 28 to Dec. 1, 2019, provides solid evidence that DO is the principal cause of fish mortality. More detailed comparison of the very dry base flow conditions of the summer of 2018 to the more continuous base flow during summer 2019 supports the link between flow and minimum DO. This section concludes with a summary of factors which cause low DO in Marsh Creek and relates those factors to the nine prior recorded fish mortality events.

3.1 2018 FIELD OBSERVATIONS, GRAB SAMPLE AND HOBO RESULTS, AND LESSONS LEARNED

While performing bioassessments on May 16, 2018, CCCWP noted six dead crayfish in Marsh Creek in the vicinity of Dainty Avenue. This observation was corroborated by volunteer monitors working with Friends of Marsh Creek Watershed, who were also performing bioassessment surveys May 14-16, 2018. The volunteers reported observation of six dead fish and about 10 dead crayfish in Marsh Creek near Creekside Park. The creek was mostly dry with isolated pools during the previous week; a dry weather flow event peaking around mid-day on May 15, 2018 preceded the May 16 observations of dead crayfish. The dry weather flow entered the creek downstream from the area where the dead crayfish were noted.

Field crews were present for equipment maintenance during two other dry weather flow events on Jul. 17, 2018 and Oct. 4, 2018. On Jul. 17, flows were traced to Deer Creek from evidence of pooled water; in that instance, field crews noted that where their arms had necessarily come into contact with the creek during sampling, they smelled of chlorine, as if they had been in a swimming pool. Field crews did not have chlorine test kits available at that time. The Oct. 4 flows were traced to an irrigation channel discharging to Sand Creek just east of State Highway 4 (located at 37.94747° N, 121.74148° W). Both the Jul. 17 and the Oct. 4 dry weather flow events were sampled for the constituents listed in Table 1.

Other than the minor mortality event of May 16, 2018, no other fish mortality events were noted in 2018. The major lessons learned from 2018 dry season monitoring (CCCWP, 2019) were:

- DO tends to peak by day and reach a minimum level in pre-dawn hours due to algal cycles of photosynthesis and respiration, as previously documented by CCCWP (2018).
- Much of Lower Marsh Creek is a series of interconnected pools created by check dams installed to abate erosive channel scour.

- Downstream of the WWTP, interconnected pools are flushed daily by peak flows from the WWTP; in contrast, upstream of the WWTP, flushing of the pools is entirely dependent on dry weather runoff from a variety of sources.
- The nighttime minimum DO levels reached in Marsh Creek two miles downstream of the WWTP are affected by dry weather flows in Marsh Creek which occur upstream of the WWTP. When dry weather flow is present upstream of the WWTP, minimum DO levels recorded two miles downstream of the WWTP are higher compared to times when no dry weather flow is present upstream of the WWTP at M2. Cessation of dry weather flows upstream of the WWTP at M2 during the summer dry season is generally followed by a substantial decrease in the nightly DO levels reached downstream (i.e., to as low as 3 mg/L) in the summer of 2018.
- None of the pesticides monitored during dry weather flow sampling showed concentrations of concern (Table 2).
- During periods of no flow, water level changes at station M2, just above the fish ladder, match daily stage peaks at M1, downstream of the fish ladder (Figure 3). WWTP flows also tend to peak daily at mid-day, around the same time as the stage peaks at M1 and M2. There appears to be a subsurface hydrologic connection between M2 and M1. The sandy soils beneath Marsh Creek are highly transmissive (City of Brentwood, 2016), allowing water to flow freely back and forth between adjacent ponds as water levels rise and fall.
- Dry weather flow to Marsh Creek comes from a variety of locations (Figure 3).

3.2 SOURCES OF DRY WEATHER FLOW

Water level monitoring upstream of the WWTP using HOBO® data loggers (Figures 3 and 4), combined with observations from the field, confirm there are a variety of dry weather flow sources to Marsh Creek. In the lower portion of Figure 3, stage rises detected by the HOBO® can be tied to stage rises at Station M2 (upper portion of Figure 3) to infer flow sources by a tributary. When the black line in the lower portion of Figure 3 rises, indicating a stage rise in Marsh Creek immediately downstream of Sand Creek, but none of the other three HOBO sensors show significant stage rises, this indicates flow is predominantly from Sand Creek. This was the case in September 2018 and was confirmed by field observation.

On Jul. 17, 2018, when a chlorine smell was noted in dry weather flows sampled, the dry weather flow was predominantly from Deer Creek, again confirmed both by field observation and the fact that HOBOs® downstream of Deer Creek and Sand Creek showed stage rises, but the two HOBO®s located further upstream did not. Around the end of June 2018, Dry Creek contributed dry weather flow. Prior to June 2018, tributary sources of flow varied.

In 2018 and 2019, much of Marsh Creek above its confluence with Deer Creek was dry, as shown by the purplish lines in the lower halves of Figures 3 and 4. During a site visit on Sep. 24, 2919 at HOBO® station

544XMCACA, between the Marsh Creek Reservoir and Dry Creek, all flow in Marsh Creek was observed to be coming from an irrigation pipe just above the deployment point of the device and then going subsurface below a downstream bridge. It is assumed this pipe was the source of any flow detected by this same HOBO® device in this portion of the creek in 2018.

Table 2. Results of Chemical Analysis of Marsh Creek Grab Samples – 2018-2019

Constituent (Units)	Results				MDL	RL
	Marsh Creek at M2 07/17/18	Marsh Creek at M2 10/03/18	Sand Creek at Flow Source 10/04/18	Marsh Creek at M2 09/17/19		
Suspended Sediment Concentration (mg/L)	3.2	<2	<2		2	3
Allethrin (ng/L)	<0.1		<0.1	<0.1	0.1	0.5
Bifenthrin (ng/L)	0.4 J		1.1	<0.1	0.1	0.5
Chlorpyrifos (ng/L)	<0.5		<0.5		0.5	1
Cyfluthrin, total (ng/L)	<0.2		<0.2	<0.2	0.2	0.5
Cyhalothrin, Total lambda- (ng/L)	<0.2		<0.2	<0.2	0.2	0.5
Cypermethrin, total (ng/L)	<0.2		0.4 J	<0.2	0.2	0.5
Diazinon (ng/L)	<0.1		<0.1		0.1	0.5
Deltamethrin/Tralomethrin (ng/L)	<0.2		<0.2	<0.2	0.2	1
Esfenvalerate/Fenvalerate, total (ng/L)	<0.2		<0.2	<0.2	0.2	1
Fenpropathrin (ng/L)	<0.2		<0.2	<0.2	0.2	0.5
Fipronil (ng/L)	<0.5		<0.5	<0.5	0.5	1
Fipronil Desulfinyl (ng/L)	1.2		<0.5	<0.5	0.5	1
Fipronil Sulfide (ng/L)	<0.5		<0.5	<0.6	0.5-0.6	1
Fipronil Sulfone (ng/L)	1.7		0.8J	<0.7	0.5-0.7	1
T-Fluvalinate (ng/L)	<0.2		<0.2	<0.2	0.2	0.5
Permethrin, Total (ng/L)	<2		<2	<2	2	10
Tetramethrin (ng/L)	<0.2		<0.2	<0.2	0.2	0.5
Ammonia as N (mg/L)	0.05		0.032	0.14	0.015	0.02
BOD (mg/L)	6	<5	<5	9	5	5
Sulfide, Total (mg/L)	<0.03		<0.03	<0.03	0.03	0.1
Total Organic Carbon (mg/L)	7.6		2.9	16	0.3	1
Dissolved Organic Carbon (mg/L)	7.3		2.5	14	0.3	1

Figure 3. Stage at Station M2 and at Upstream HOBO Water Level Monitoring Stations – Year 1 Monitoring

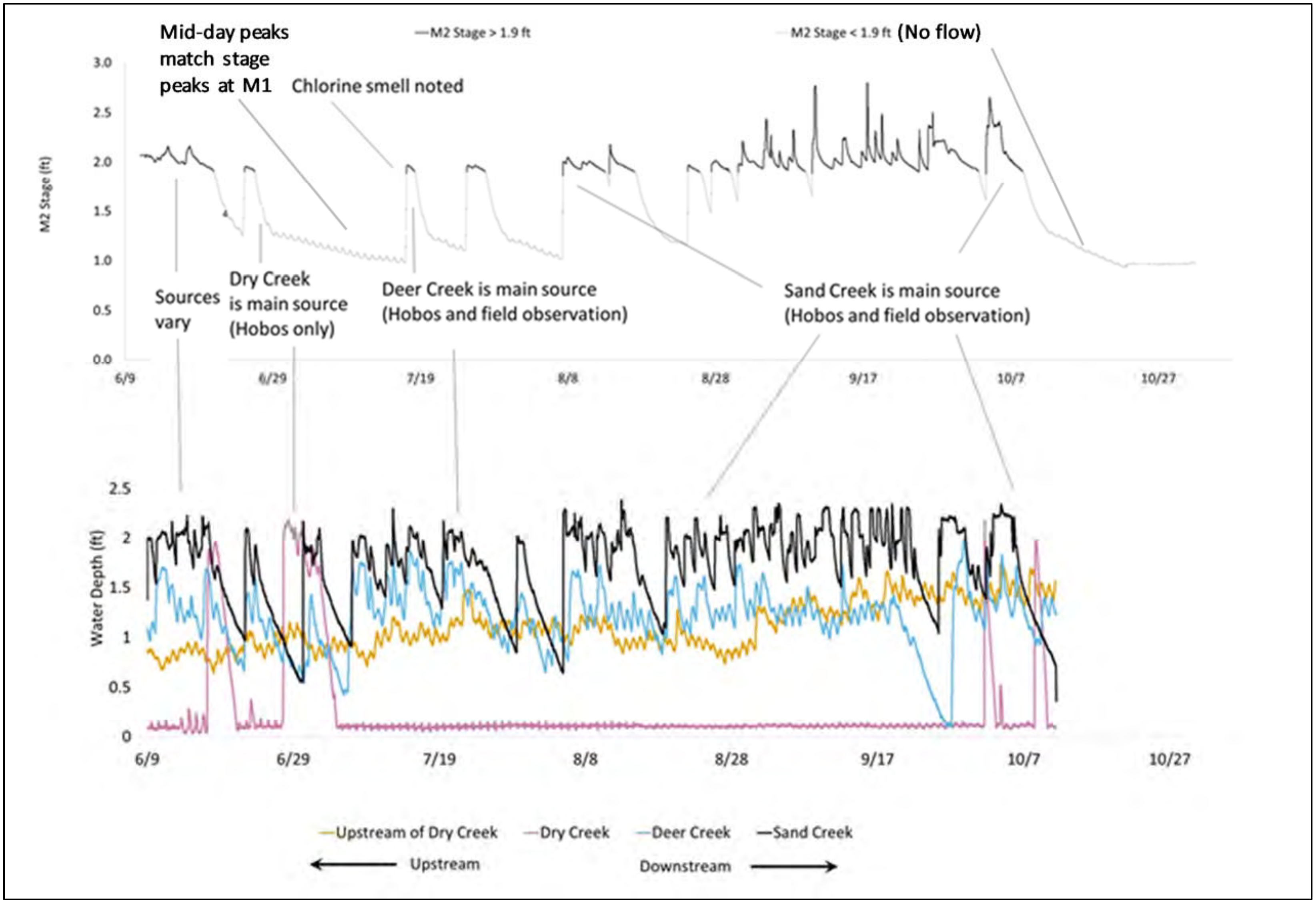
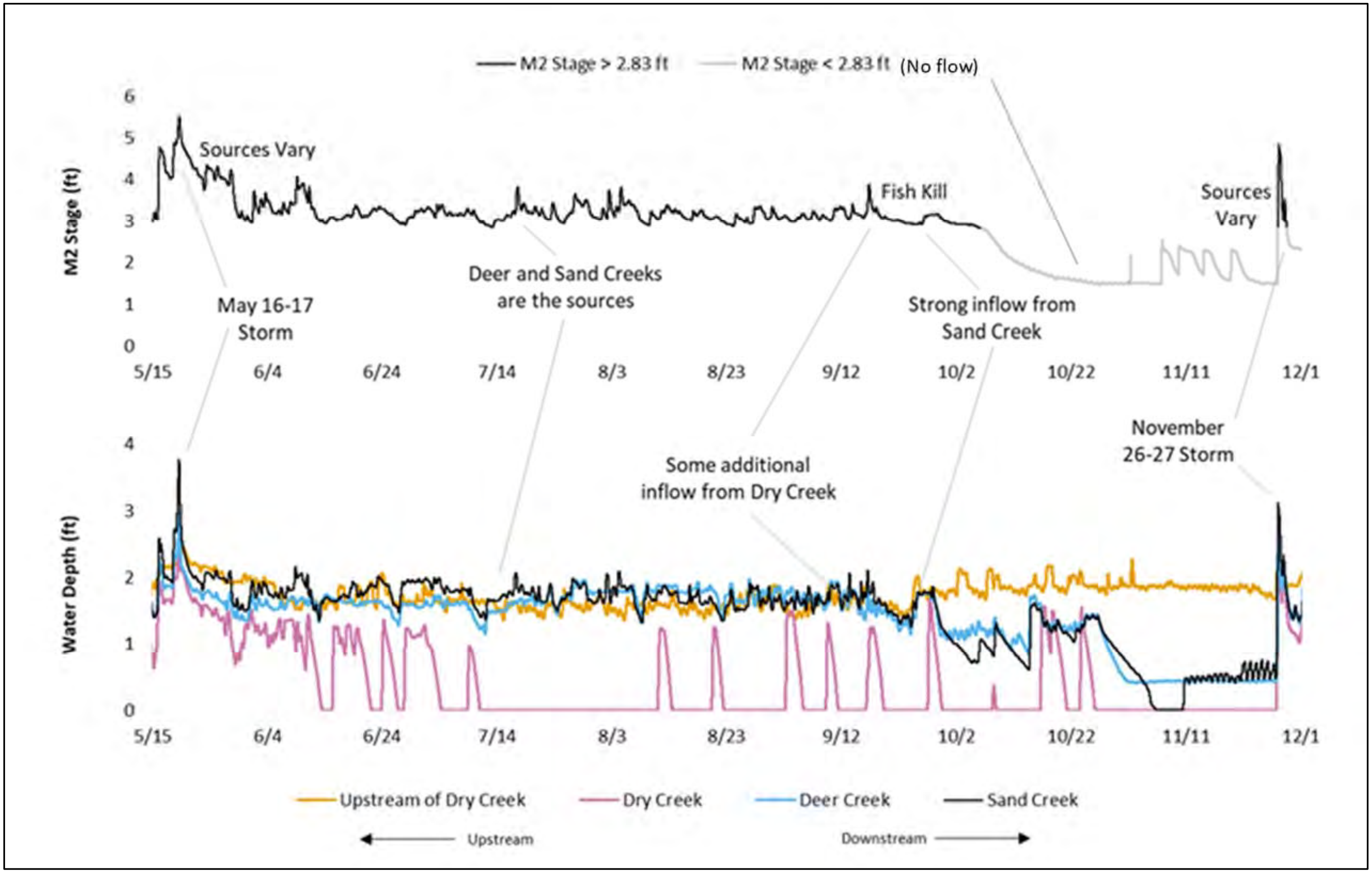


Figure 4. Stage at Station M2 and at Upstream HOBO Water Level Monitoring Stations – Year 2 Monitoring



3.3 2019 OBSERVATIONS BY FIELD STAFF, GRAB SAMPLE RESULTS, AND LESSONS LEARNED

The summer of 2019 had generally more dry weather flow recorded at location M2, upstream of the WWTP, compared to the summer of 2018 (Figure 4). This likely resulted from a much wetter 2018-2019 storm season. During the summer of 2018, there were four discrete periods of no flow upstream of the WWTP that each lasted from one to three weeks (Figure 3). In contrast, Marsh Creek upstream of the WWTP flowed continuously through the summer of 2019 until early October (Figure 4). Other than a river otter spotted at station M2 above the fish ladder, no other notable observations were made on site visits conducted on May 1, May 23, Jun. 19, and Aug. 1, 2019.

Observations and lessons learned from 2018 monitoring led CCCWP to request Brentwood to consider a flow augmentation pilot project during the summer of 2019. The purpose of the pilot project was to determine whether deliberate introduction of flow could increase the level of the nightly DO minimum reached, possibly averting lethally low DO levels. Brentwood had initiated a major capital project at its WWTP to create storage for daytime treated flows, making more recycled water available to irrigators at night. The WWTP agreed to conduct a two-month flow pilot project using storage capacity that was newly available in the summer of 2019. The pilot augmentation project commenced just before midnight on Sep. 16, 2019. The WWTP released 250,000 gallons of recycled water at about 700 gpm into Marsh Creek between midnight and 6 A.M. every night for two months, ending Nov. 14, 2019.

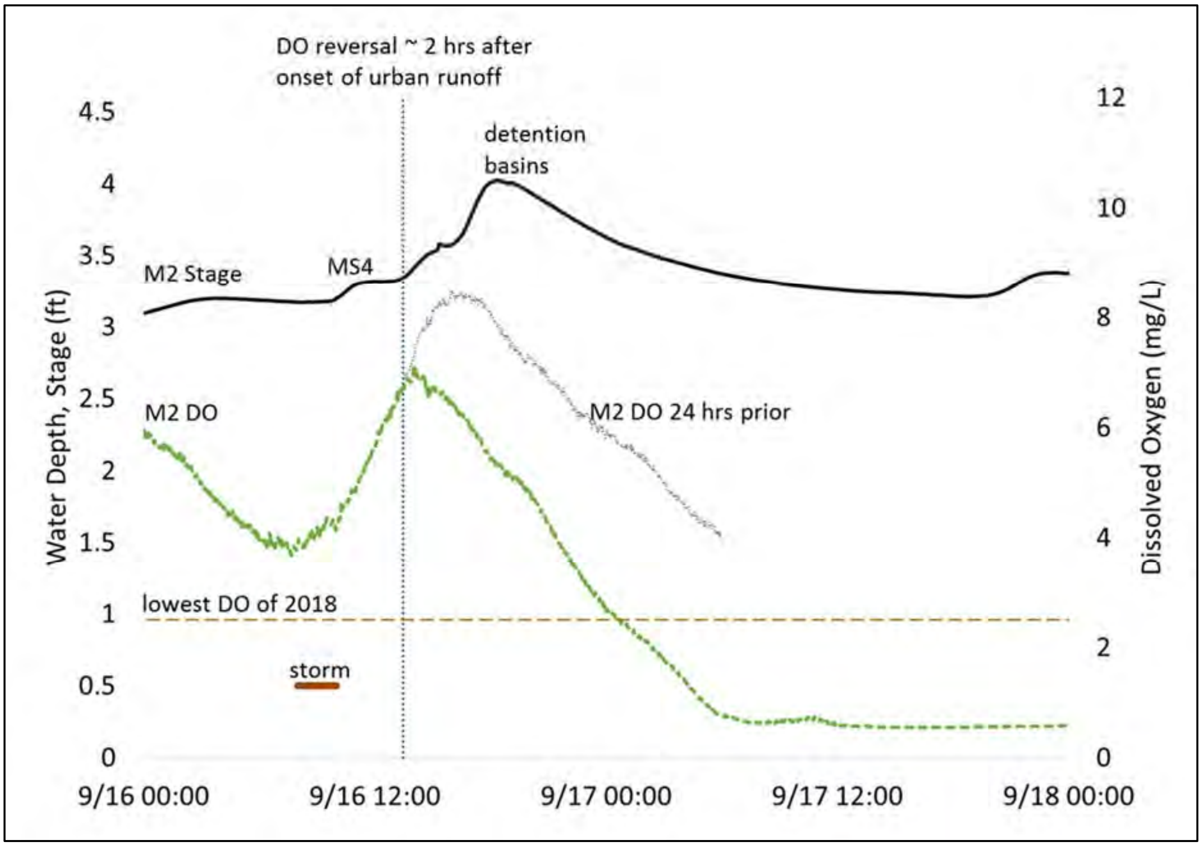
3.3.1 SEPTEMBER 17, 2019 FISH MORTALITY EVENT

During a planned visit for another CCCWP project on Sep. 17 on Marsh Creek, the field crew was notified that a drastic drop in DO had begun at Station M2 the previous night and that they should anticipate performing a grab sample at the station due to a probable fish kill.

Dead fish were observed early that morning in Marsh Creek in the vicinity of the Station M2, upstream of the WWTP. No dead fish were observed downstream of the WWTP outfall, which had been augmenting flow at night starting 36 hours prior to the fish kill event. Marsh Creek water samples were taken for the constituents listed in Table 1 and the results were within normal ranges (Table 2), except biochemical oxygen demand (BOD) was somewhat elevated (9 mg/L). Follow-up toxicity testing on fathead minnow larvae (*Pimephales promelas)* showed no toxic effects of the water to exposed organisms. Detailed field observations of the event are presented in Attachment 1. A summary of additional important data from the event follows below.

Figure 5 helps to understand the response of DO to the storm event of Sep. 16, 2019 on the timeline leading up to the fish kill event of Sep. 17, 2019. The storm occurred in the early morning hours of Sep. 16, 2019. Two stage peaks appear at M2 following the storm. The first, smaller peak represents the flashy response of the urbanized watershed located downstream of detention basins, labeled “MS4” in Figure 5. The second, larger peak represents delayed peak flows from detention basins functioning as designed. Shortly after the “MS4” peak, the daily increase of DO suddenly reversed, showing a marked decline at a time of day when DO would normally increase (i.e., as explicitly compared to 24 hours earlier in Figure 5). A low DO alarm was transmitted to the monitoring team leader at 23:00 on Sep. 16, 2019, who alerted the team that a potential fish kill was imminent.

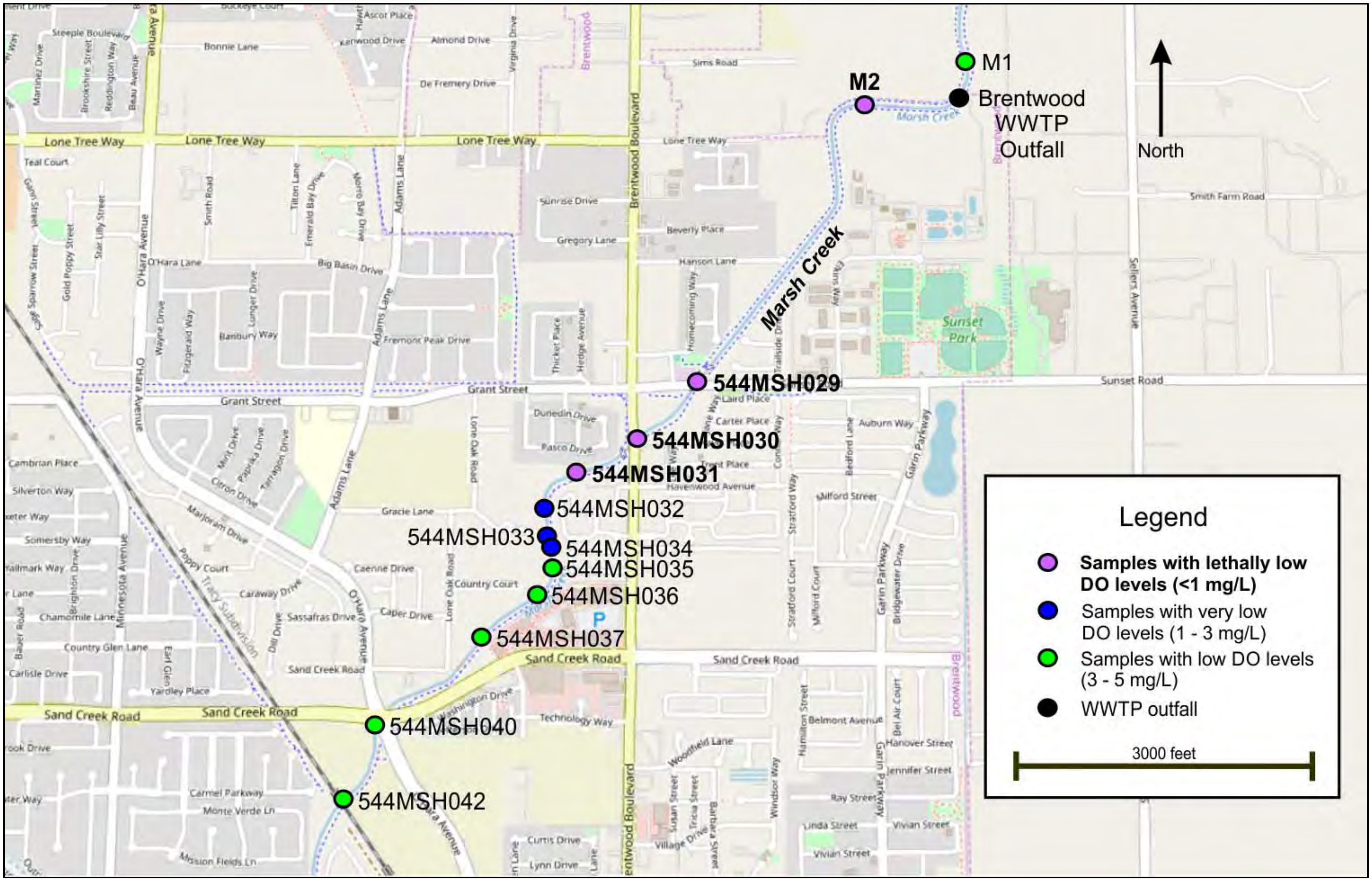
Figure 5. Marsh Creek Station M2 Stage and DO – Sep. 16-17, 2019



Grab field sampling the next day revealed the distribution of low DO water along Marsh Creek. Figure 6 shows the locations and the range of DO measurements taken between 17:00 and 19:00 on Sep. 18, 2019. The steady upward increase from lethally low DO at Station M2 going upstream on Marsh Creek to low but non-lethal levels at Sand Creek Road shows that lethally low DO was limited to a short stretch between where Gracie Lane ends at Marsh Creek and the WWTP outfall. The three stations with lethally low DO also had elevated BOD, ranging from 12-31 mg/L, and increasing from upstream to downstream. Upstream of Gracie Lane, BOD was below 5 mg/L.

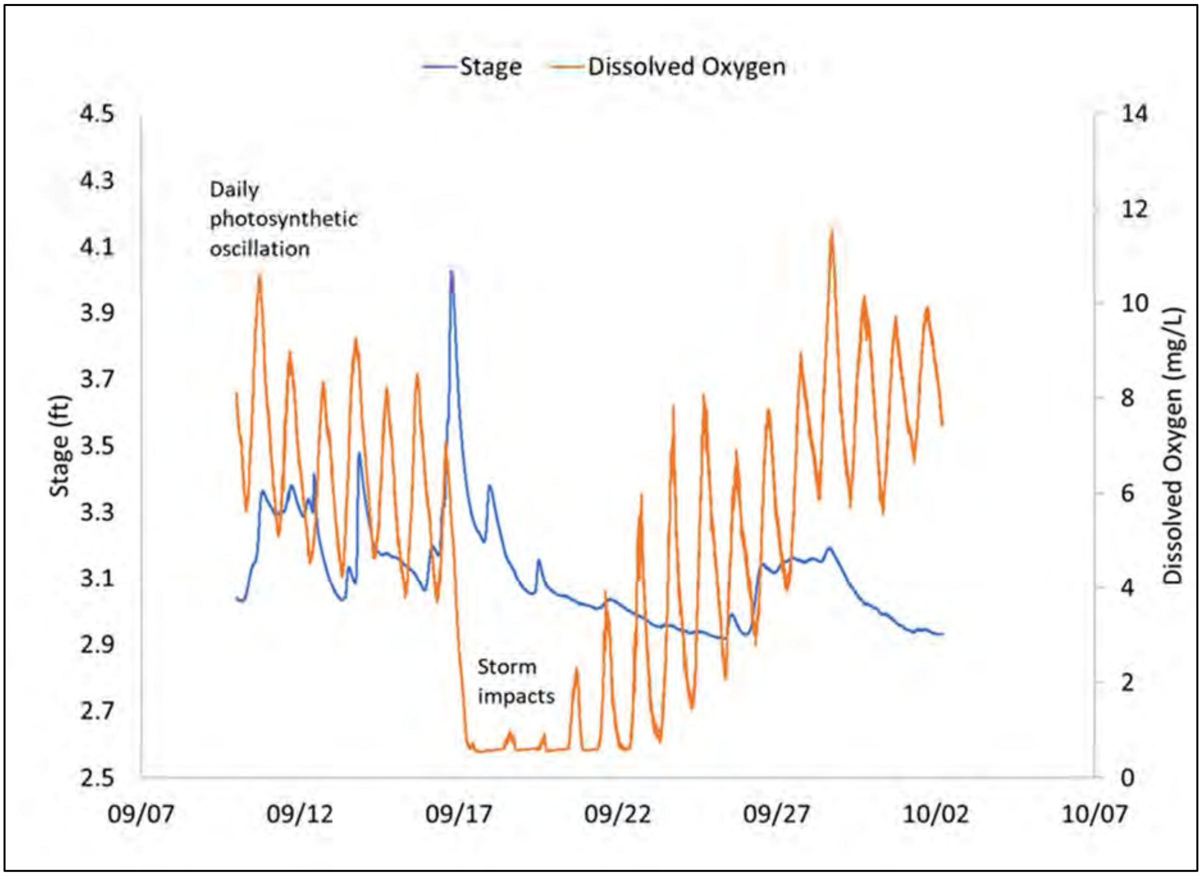
The follow-up grab sampling also provided the first insight into the benefits of WWTP flow toward ameliorating sudden DO sags. At Station M1, downstream of the WWTP, the level of DO on Sep. 18, 2019 was near or above the 5.0 mg/L objective for warm water habitat streams. Even though Marsh Creek was flowing at the time of sampling and lethally low DO was present upstream, flows from the WWTP apparently prevented lethally low DO levels downstream of the outfall.

Figure 6. Sampling Locations and DO Level Categories on Lower Marsh Creek – Sep. 18, 2019



The benefit of flow augmentation by the WWTP was confirmed by evaluating stage and DO data for a three-week period spanning the Sep. 17, 2019 fish kill event. In the preceding days, daily photosynthetic DO oscillation is evident upstream of the WWTP at M2 (Figure 7), at the WWTP outfall at M1 (Figure 8), and 2 miles downstream at East Cypress Road (Figure 9). The dramatic impact of the storm, bringing DO down to lethal levels, persisted for five days at M2 following the storm (Figure 7). M2 did not return to pre-storm conditions until about 10 days later.

Figure 7. Marsh Creek Station M2 Stage and DO – Sep. 10-Oct. 2, 2019



In contrast, at M1 (Figure 8) and further downstream at M0 (Figure 9), DO briefly dipped to near-lethal levels each night for two to three nights following the fish kill event, and quickly returned to above 5 mg/L in the morning. After 5 days, daily DO oscillations at M1 and M0 matched pre-storm conditions. This outcome is clearly tied to the flow augmentation provided by the WWTP. Without the flow augmentation, each night flows would approach zero downstream at M1 and M0. Ongoing flows of water from M2 having low DO and high BOD would likely have created a two-mile zone of depressed DO between M1 and M0, potentially leading to many more fish dying as observed in previous incidents.

Figure 8. Marsh Creek Station M1 Stage and DO – Sep. 10-Oct. 2, 2019

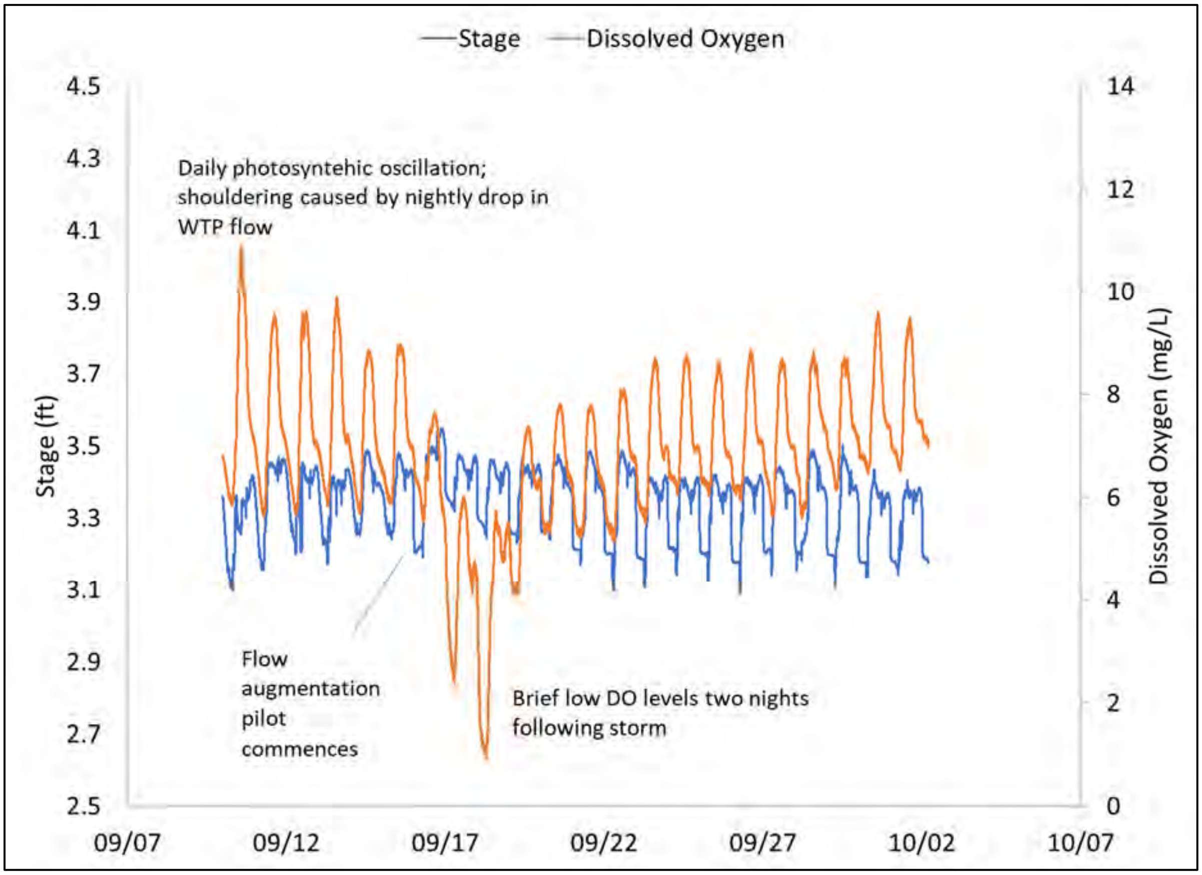
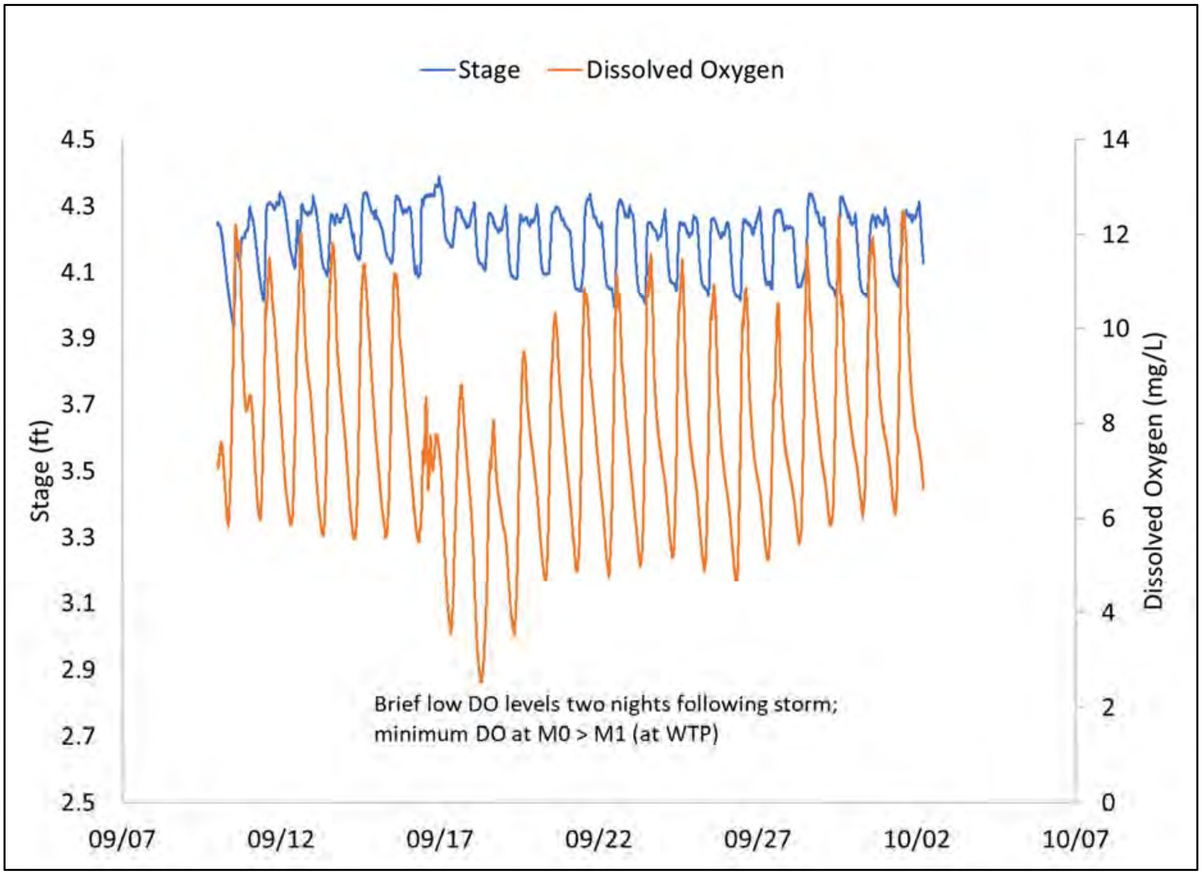


Figure 9. Marsh Creek Station M0 Stage and DO – Sep. 10-Oct. 2, 2019



3.3.2 THE NOVEMBER 26-27, 2019 STORM EVENT

Following the light rainfall of Sep. 16, only trace amounts occurred in the vicinity of Marsh Creek until Nov. 26, 2019. This storm produced 0.61 inches of rain in two periods from 16:24 Nov. 26 to 00:11, Nov. 27; and from 13:39 to 19:05 on Nov. 27. Similar to the stage after the rainfall of Sep. 16, a rise took place at M2 starting about 23:25 on Nov. 26. It was followed about 14 hours later by a deviation from the normal daily DO cycle at about 10:30 on Nov. 27. For about 36 hours, DO stayed very low at Station M2 in the range of 1.3 to 1.6 mg/L before beginning to rise again on Nov. 30 (Figure 10). The further downstream stations M1 and M0 experienced low DO levels during this period, but not as deep or for as long as M2. M1 had a low of 5.0 mg/L at 08:58 Nov. 29 (Figure 11), and M0 had a low of 4.2 mg/L at 01:00 Nov. 29 (Figure 12).

Figure 10. Marsh Creek Station M2 Stage and DO – Nov. 26-Dec. 1, 2019

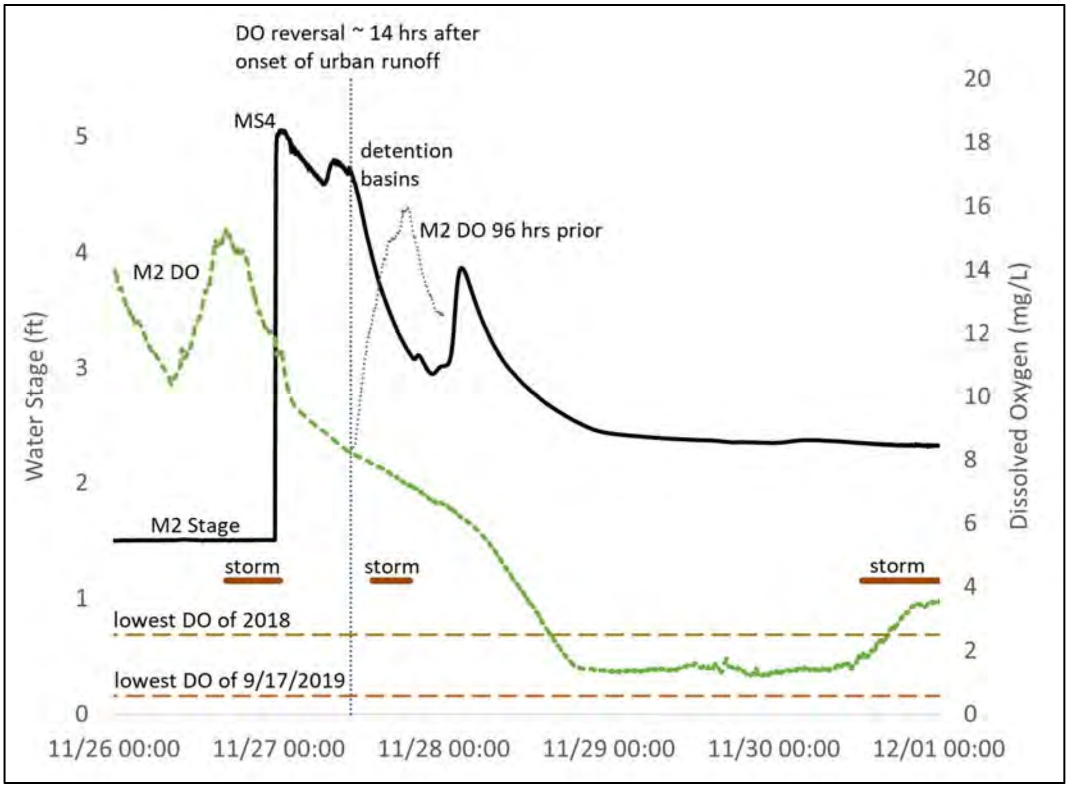


Figure 11. Marsh Creek Station M1 Stage and DO – Nov. 26-Dec. 1, 2019

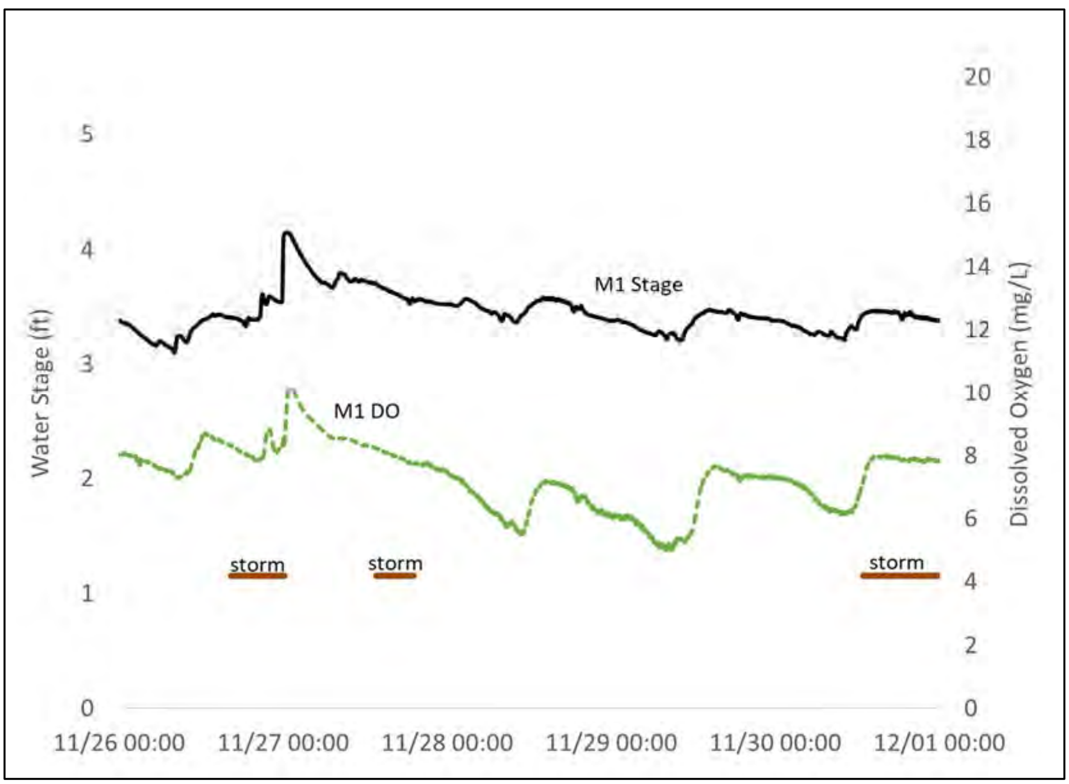
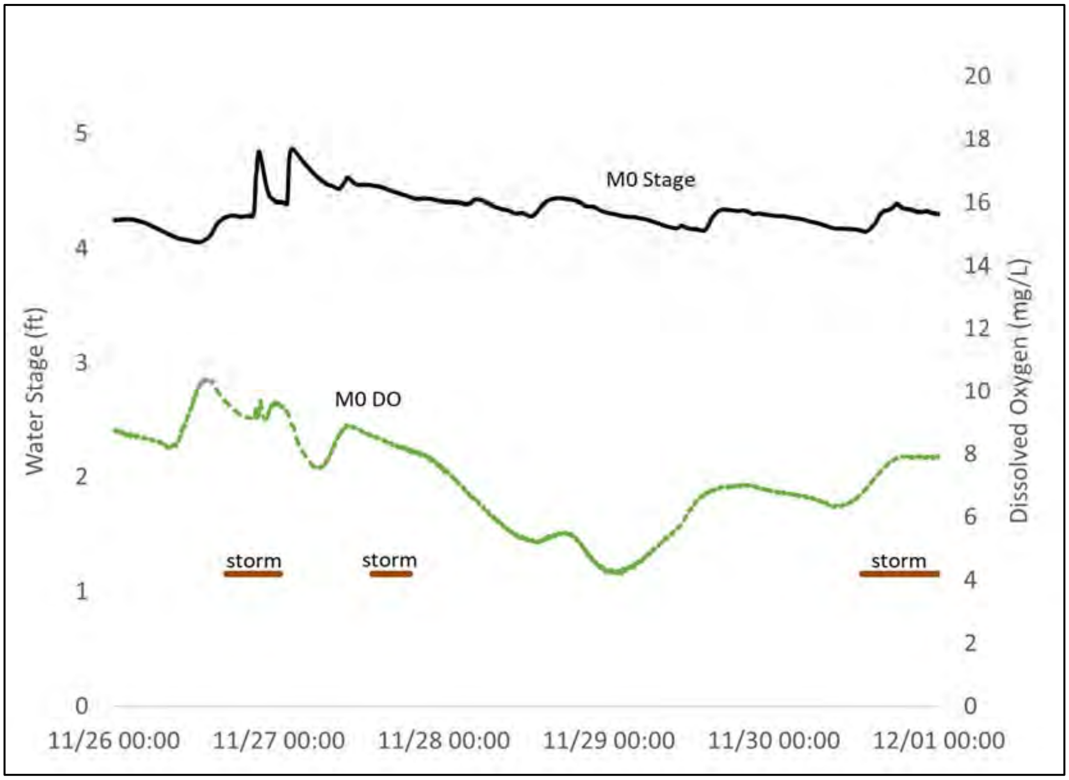


Figure 12. Marsh Creek Station M0 Stage and DO – Nov. 26-Dec. 1, 2019



There were several parallels between what occurred at Station M2 during these two storm events and the days after:

- Both storms were preceded by months of dry weather, though the durations were different. The September event was preceded by over four months of dry weather, while the November event was preceded by about two months of dry weather.
- Marsh Creek was not flowing at Station M2 prior to the onset of rainfall.
- Following the rises in stage at Station M2 from both storms, DO dropped to low levels and stayed low for several days. During the September event, the DO at Station M2 was lower (<1.0 mg/L) and stayed depressed longer than it did during the November event (>1.0 mg/L).

No fish kill was reported on Marsh Creek in the vicinity of Station M2 in November 2019. The flow augmentation pilot project had ceased by Nov. 14, 2019; however, summer irrigation had also ceased, and therefore nighttime flows from the WWTP were no longer reaching their more typical summertime minimum flow rates. However, the WWTP nighttime minimum flows were maintained without any other direct activity in late November 2019 (Table 3), during which the Nov. 26-27 storm event occurred.

Table 3. Minimum Wastewater Treatment Plant Flow (mgd) – Nov. 23-30, 2019

11/23	11/24	11/25	11/26	11/27	11/28	11/29	11/30
1.38	0.96	0.54	0.65	1.05	0.72	0.83	1.15

Source: Daily data reported by the City of Brentwood WWTP through personal communication.

While the Sep. 17 and the Nov. 26-27 periods had some phenomena in common (though not to the same degree), there were two important differences: the daily photosynthesis swings that occurred in September and the prior summer months had dampened substantially by November; and the nighttime minimum flows were lower during the latter period.

3.4 A TALE OF TWO DRY SEASONS: COMPARING DO/FLOW RESPONSES OF 2018 AND 2019

In 2018, and to a lesser extent in 2019, water quality conditions steadily deteriorated at Station M2 through the summer. In 2019, flows were greater than in 2018, but finally fell off to zero in early October. In 2018, water temperatures exceeded 90˚ F regularly at Station M2 in June and July. During those months in 2019, the peak water temperature did not exceed 88˚ F, largely due to greater flow rates in 2019.

DO and pH showed daily oscillations that are typical of streams with abundant algae. Photosynthesis during the day produces oxygen, leading to supersaturation at mid-day; at the same time, carbon dioxide is consumed, increasing the pH of water by day to nearly 9 pH units. The opposite occurs at night, when plant metabolism consumes DO and releases carbon dioxide, thereby concurrently lowering pH.

DO began dropping below the water quality objective of 5 mg/L at Station M2 on a nightly basis starting in late May of 2018, while it did not do so until late June 2019. At these points in the year, the behavior of DO at Station M2 diverged between the two years. By the end of July 2018, the nightly DO minimum at Station M2 was consistently below 3 mg/L, and at times was below 2 mg/L. DO at Station M2 picked up with the onset of dry weather flows from Sand Creek in September 2018, and then crashed abruptly to below 2 mg/L when those dry weather flows tailed off Oct. 2-6. In the summer of 2019, the nightly minimum of DO at Station M2 ranged between 3 to 5 mg/L before the huge crash down to 0.6 mg/L in September that lead to the fish kill. The higher nightly range of DO at Station M2 in 2019 compared to 2018 was very likely directly due to the continuous presence of flow at the station in the second year.

DO at Station M2 responds directly to flow, as seen by the sudden drop in DO in responses to the falling stage on Oct. 2, 2018, followed by a DO uptick concurrent with a stage rise on Oct. 4, 2018, followed by another sudden drop as flows tailed off Oct. 5-6 (Figure 13). Similar changes in DO appear in 2019, except the sudden drop was due to rainfall, rather than dry weather flow from an unknown source (Figure 14).

Figure 13. Comparison of Stage to DO at Station M2 – Aug. 15-Oct. 31, 2018

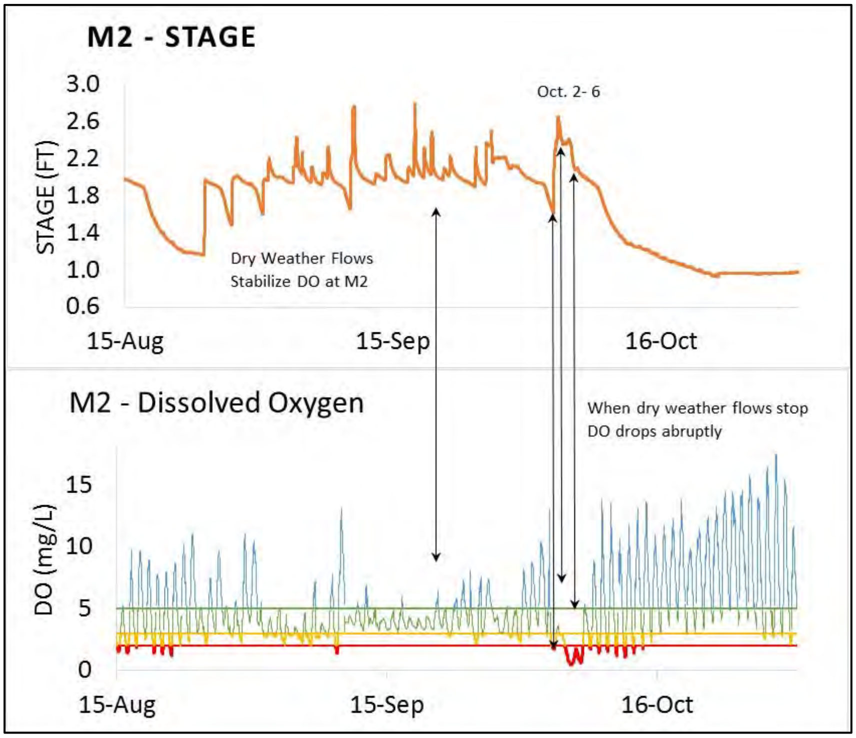
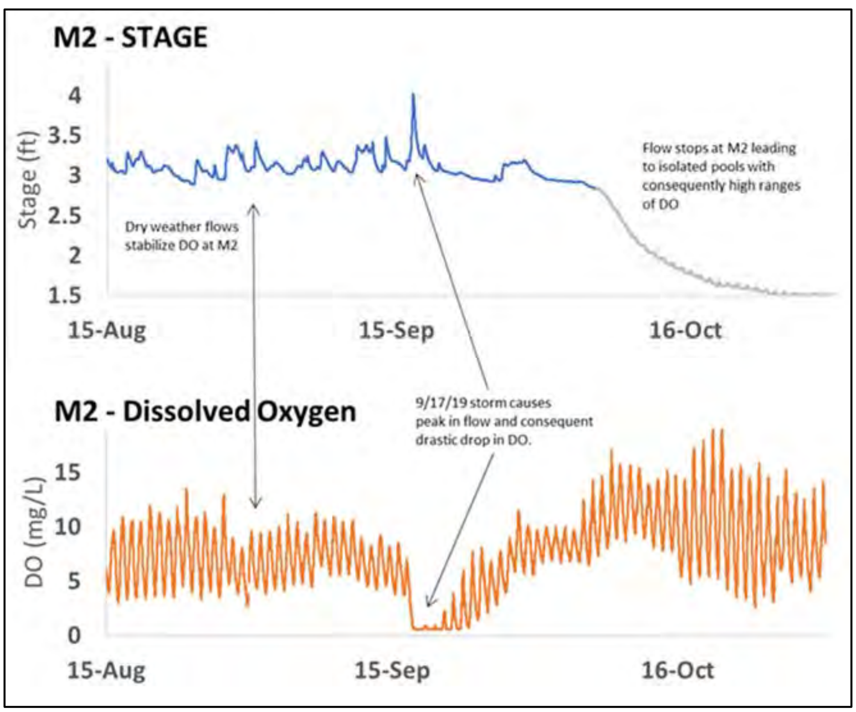


Figure 14. Comparison of Stage to DO at Station M2 – Aug. 15-Oct. 31, 2019[1]



[1] Stages are different at M2 between 2018 and 2019 because different datums were used.

Water quality was relatively stable at Station M1, immediately downstream of the WWTP outfall, during the periods monitored. DO and pH showed daily oscillations consistent with photosynthesis and respiration. In contrast with Station M2, pH at Station M1 remained within a much tighter range (7.2 to 8.2 in 2018; 7.4 to 8.2 in 2019) and DO went below 5 mg/L in 2018 only a few times and for a few days in 2019 during the fish kill. This stable behavior of water quality is attributable to daily flows from the WWTP. Without daily replenishment from WWTP discharges, water quality in the pool at Station M1 would likely resemble that of the pool at Station M2, upstream of the WWTP.

3.5 CAUSES OF LOW DO IN MARSH CREEK

Low DO in Marsh Creek is caused by the convergence of:

- Daily photosynthesis/respiration cycles that lead to pre-dawn minimum DO levels
- Dry season base flow that varies from year to year, depending on wet season rainfall
- Pre-dawn decreases in WWTP flows to Reach 1 of Marsh Creek
- Inputs of BOD during first flush storms, especially light storms following prolonged dry periods, like the 2019 event

Generally, in water bodies like Marsh Creek, DO tends to cycle daily, peaking in the late afternoon and reaching a minimum during pre-dawn hours due to the photosynthesis/respiration cycle. Flows also influence DO in streams: higher flows tend to re-aerate water, especially at riffles where velocity increases rapidly at the air-water interface. When flows near zero, nighttime respiration of aquatic plants and algae can steadily decrease DO in quiescent waters with no other natural aeration process.

Dry weather flows upstream of the WWTP appear to directly influence the minimum DO level reached at night during the summer dry season. This was evident during the summer of 2018 (CCCWP, 2019), when there were several discrete periods of low flow. Minimum DO levels at the most downstream monitoring location (M0) declined steadily each night without dry weather flow until the next dry flow weather event. This pattern was not observed in 2019, when some base flow was present throughout the summer, presumably resulting from the preceding above average rainfall year. Thus, the risk of low DO can vary from season, depending on base flow rates.

During typical summertime irrigation seasons, demands for recycled water can reduce flows from the WWTP into Marsh Creek to near zero. Thus, during dry years, when there is little to no base flow upstream of the WWTP, Lower Marsh Creek flow also diminishes to near zero. But the Creek does not dry up when flow stops, because along most of Lower Marsh Creek a series of erosion control check dams creates alternating pool and riffle habitat. In Reach 1, downstream of the WWTP, those pools are flushed daily by WWTP flows. Upstream of the WWTP, pools in Reach 2 are flushed only where there is dry weather flow from irrigation runoff and other sources, or natural flow following wet years.

During summer months, flow from the WWTP and/or dry weather runoff re-aerates the creek at riffles between pools. As the flow rate increases, so does the speed of the flow and aeration with a consequent increase in DO. This tends to counter some of the effects of respiration on DO at night, keeping DO above lethal levels. Conversely, when flow stops, DO begins to decline until flow resumes.

Those 2018 observations led CCCWP to request a flow augmentation pilot project at the Brentwood WWTP, which commenced in September 2019. The rationale was that deliberately maintaining base flow could support higher pre-dawn minimum DO levels compared to no flow. The results of the pilot project exceeded expectations.

The light storm of Sep. 16, 2019 appeared to bring BOD into Lower Marsh Creek, based on grab sampling performed after the event. When flow abated after the storm, DO consumption by aquatic plants and algae, combined with elevated BOD, overwhelmed re-aeration upstream of the WWTP in the pre-dawn hours of Sep. 17, 2019, creating near-zero DO concentrations. Downstream of the WWTP, DO levels sagged, but base flows from the augmentation pilot appeared to sustain DO to levels enough to avoid mass fish mortality.

3.6 POTENTIAL ROLE OF LOW DO IN PREVIOUS FISH MORTALITY EVENTS[2]

Ten documented fish kills have occurred in Marsh Creek since 2005. Table 4 presents relevant details about each of these events. Lessons learned from this study show that DO may have played a role in many of the prior fish kills, although the retrospective evidence is not as conclusive as the real time monitoring from this study.

Table 4. Dates of Marsh Creek Fish Kills, Antecedent DO Conditions, and Antecedent Dry Days and Rainfall

Fish Kill Date	Low DO Measured Upstream by Brentwood WWTP Prior to Fish Kill?	Days Between Previous Rain Event and Fish Kill	Previous Event Inches of Rain
09/15/05	No	117	0.1
09/05/07	Yes	123	0.1
05/02/08	No	36	0.05
09/27/14	Yes	2	0.3
03/19/15	No	8	0.2
10/04/15	Yes	1	0.5
07/06/16	No	61*	0.14
05/18/17	No	28	0.1
10/23/17	Yes	3	0.1
09/17/19	Yes	1	0.12

Source: CDEC, Brentwood Corp Yard (BTD); http://cdec.water.ca.gov/cdecstation2 (accessed 01/29/18). DO conditions as reported by the City of Brentwood WWTP through their weekly receiving water monitoring program.

Fully shaded rows highlight events where DO was low at the upstream receiving water monitoring location and a rainfall event occurred within three days of the event. The partly shaded row indicates low DO upstream but no recent rainfall.

*Note: The rain gauge at BTD recorded 0.5 inches on May 23, 2016; however, river stage was not affected by the recorded precipitation, none of the nearby rain gauges recorded bucket tips by rainfall, and weather report archives from Weather Underground do not indicate a precipitation event in Brentwood on May 23, 2016. The precipitation event recorded on May 23, 2016 at BTD is considered a data error.

[2] Detailed data and analysis supporting the descriptions of prior fish kill events provided in this section appear in CCCWP (2018).

The most recent fish kill of Sep. 17, 2019 is similar to four other prior fish kills:

- All occurred in late summer or early fall, preceded by months of hot and dry summer weather
- Low DO was measured in Marsh Creek just prior to each kill; these measurements were taken upstream of the Brentwood WWTP prior to 2019, and at Station M2 prior to the most recent event
- Four of the five occurred within a few days of a light storm event

The low DO measured upstream of the WWTP prior to the 2007, 2014, 2015 and 2017 events suggests a days-long DO depression. Those prior measurements are from a weekly receiving water monitoring program conducted by the WWTP that collects grab samples by day, when DO levels are naturally highest. When DO measured by day is low, it would indicate a severe and prolonged antecedent DO sag, such as the one shown in Figure 7 from Sep. 17, 2019. For that reason, the unshaded dates in Table 4 could also have involved pre-dawn lethally low DO that was not detected by daytime monitoring.

The event of Jul. 6, 2016 occurred under summer dry conditions like the summer of 2018. Prior to that event, there were two prolonged periods of no base flow, followed by a relatively small pulse of dry weather discharge two days prior to the fish kill. We know now from this study that when base flow upstream of the WWTP ceases, DO in isolated pools drops below 2 mg/L at night. The dry weather flow that preceded this July 2016 event would have likely translated those effects downstream.

This study confirms that during the night, when creek flows are generally lowest during the dry season and metabolic demand peaks, small pulses of BOD can cause sudden DO depressions. Applied to retrospective data gathered during work plan development, a coherent conceptual model emerges for what causes fish kills (low DO), and what historic conditions can explain the low DO events of September and November.

The events of May 2008, March 2015, and May 2017 are unique in Table 4. Generally, in springtime, the photosynthesis/respiration cycle may not be as pronounced because aquatic vegetation has not built up as much compared to summer. CCCWP does not usually commence continuous monitoring until after the end of the storm season, so the actual effect of photosynthesis/respiration for spring conditions is unknown for those spring mortality events.

In summary, low DO very likely played a role in up to seven prior fish mortality events, including 2019. The three prior spring events listed in Table 4 are less of a good fit for the conceptual model explaining the 2019 and similar events.

3.7 POTENTIAL BOD SOURCES

Sources of BOD during the Sep. 17, 2019 event are unknown. Potential sources include agricultural runoff, golf course runoff, residential runoff, decaying algae and plant matter within the stream bed, and flushing of ponds and water features in golf courses and residential areas during first-of-season storm events. Elevated BOD in first of season storm events is common in urban and non-urban watersheds.

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4. Conclusions and Next Steps

This SSID study successfully adressed the question of what caused the most recent fish kill in Marsh Creek. The understanding of stream processes in Marsh Creek derived from Year 1 monitoring pointed to flow augmentation as a pilot project that was implemented by the Brentwood Permitee in Year 2. Collection of continuous monitoring data was also funded by the Contra Costa County Flood Control and Water Conservation District (District) in Year 2. The flow augmentation pilot not only validated the role of DO, but likely contained the impact of the Sep. 17, 2019 event to hundreds rather than thousands of fish, as has occurred in the past.

This section briefly summarizes overall conclusions, which leads to next steps anticipated. This SSID study is concluded and the study is considered complete by CCCWP for the purpose of compliance with MRP Provision C.8.e. The next steps describe CCCWP recomendations to Brentwood Permitees and the District, as well as CCCWP's anticipated future activties in relation to the issue of low DO and fish mortality in Marsh Creek. The section concludes with an assessment of the uncertainties and remaining questions to be considered for inclusion in CCCWP's monitoring work plan for implementation during MRP 3.0.

4.1 CONCLUSIONS

Low DO undoubtedly caused the 2019 fish mortality event and, more likely than not, caused some of the prior nine events. Low DO results from a unique combination of circumstances (variable summertime dry weather flows, nighttime DO minima due to photosynthesis cycles, episodic BOD inputs) that occur within the configuration of Marsh Creek as a series of connected pools. An immediate intervention point is the flow, as demonstrated by this study. A flow augmentation pilot of a quarter million gallons per day made a big difference to minimum DO levels reach at night downstream of the WWTP.

CCCWP tested water collected from the Sep. 17, 2019 event for toxicity to fish and found no effects on fathead minnow survival. Six prior Marsh Creek samples collected from 2012-2019 also showed no significant toxicity to fathead minnows (Table 5). It's difficult to prove a negative, especially when seeking for causes of episodic events. In this study, continuous monitoring affirmatively identified low DO was the cause of fish mortality in that event, while concurrently bioassaying water collected from Marsh Creek water as dead fish were observed. In this instance, the negative result for toxicity provides strong evidence supporting low DO as the cause of mortality in the 2019 event.

The similarity of the 2019 event to prior events suggests low DO was the principal cause of fish mortality in many of them. The spring events are less clearly tied to low DO, simply based on the seasonal timing. Therefore, pesticides and other causes are not completely ruled out as potential causes of historic fish kills.

The cause of crayfish mortality observed in 2018 is unknown. As noted in the Work Plan for this study, crayfish have a greater tolerance for low DO compared to free swimming fish. Crayfish also have toxic responses to sediment-associated pyrethroid pesticides that are closer to benthic amphipods than fish. CCCWP has recorded numerous instances of sediment toxicity to amphipods in Marsh Creek, and so sediment toxicity to crayfish is not out of the question.

Table 5. Summary of Marsh Creek Watershed Toxicity Testing for Fathead Minnows

Sample Date	Station	Creek	Matrix	Sample Type	Percent Survival Fathead Minnow	Toxic Compared to Control Sample?
03/15/12	544R00025	Dry Creek*	Water	Wet Weather	100%	No
07/25/12	544R00025	Dry Creek*	Water	Dry Season	95%	No
04/04/13	544R00281	Marsh	Water	Wet Weather	95%	No
07/09/13	544R00281	Marsh	Water	Dry Season	98%	No
07/17/18	544R01737	Marsh	Water	Dry Season	95%	No
07/23/19	544MSH045	Marsh	Water	Dry Season	100%	No
09/17/19	M2	Marsh	Water	Dry Season	83%	No

*Tributary to Marsh Creek

4.2 CCCWP RECOMMENDATIONS TO PERMITTEES

Based on the findings and conclusions of this study, CCCWP recommends the following:

- **Brentwood considers the flow augmentation pilot for two more years for a limited duration each year.** The purpose of the next two years would be to evaluate whether the benefit of flow augmentation is reproducible, and to better assess how much flow is needed to be effective. Brentwood's recycled water is a valuable resource. More specific information on how much flow is needed, and when, will help guide wise use of water should flow augmentation be deemed a viable management approach by Brentwood. The limited duration needed is the two months of the critical period in the late summer to early fall when fish kills historically occur – September through October.

- **The District considers funding continuous monitoring for two more years.** Continuous water quality monitoring has proved essential to understanding root causes of low DO in this study. In conjunction with the flow augmentation pilot project by Brentwood, this will help further evaluate the effectiveness of this potential remedy. The purpose of the continued monitoring would be to provide early warning of potential lethally low DO conditions based on daytime reversals like those shown in Figure 5 and Figure 10. Early warning to Brentwood would allow the WWTP to temporarily increase augmented flow, within the constraints of their customer needs. This approach would be a test of both early warning and response and an evaluation of how different augmented flow rates affect the minimum DO levels attained after a DO depression event.

4.3 CCCWP NEXT STEPS AND UNCERTAINTIES TO ADDRESS IN MRP 2.0

Although this SSID study is complete, CCCWP anticipates performing some technical work during the next two years to document and track follow-up on this issue by Permittees. Within the constraints of available staff resources, CCCWP anticipates leading the following activities:

- Coordination and communication with Brentwood Permittees and the District regarding continuing the requested pilot augmentation project.
- Notify stakeholders in the event of a fish kill.
- Update the status of the flow augmentation effectiveness evaluation through the annual urban creeks monitoring report required by the MRP.
- Review and comment on the State Water Board's impairment assessment (the 303-d list). This activity is normal for program staff for all new or revised listings potentially affecting Permittees. The Water Board will likely want to make some findings of impairment based on the results of this study and other data from Marsh Creek. It will be helpful for CCCWP to guide the evaluation of Marsh Creek by providing information from this study along with specific listing recommendations, such as dividing Lower Marsh Creek into Reach 1 (downstream of the WWTP) and Reach 2 (upstream of the WWTP) for 303-d listing purposes.
- Present the findings and recommendations of this study to the Contra Costa Watershed Forum.
- Continue to monitor for pesticides and toxicity in Contra Costa County urban creeks, including Marsh Creek, in compliance with Provision C.9 of the current MRP and anticipated future iterations of the permit. CCCWP anticipates new and emerging pesticides (e.g. neonicotinoids) will be included in future pesticide monitoring work plans.

The remaining uncertainties will be considered by CCCWP for inclusion in the MRP 2.0 monitoring work plan:

What do crayfish indicate about creek health?

This question is framed more broadly than just "what causes crayfish mortality in Marsh Creek" to make the approach more relevant to countywide interests. The question would be narrowed down to an approachable scope by working with the Monitoring Committee and interested stakeholders.

Are dichlorination best practices consistently applied in Contra Costa County by water purveyors?

The one-time detection of chlorine (by smell only) in the summer of 2018 may warrant some follow up. The level of effort would be prioritized in consideration of other Program requirements and needs. The proposed follow-up may or may not include monitoring – a simple outreach and documentation task may suffice.

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Appendix: Event Log (September 17-October 2, 2019)

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Event Timeline

Following is a timeline of events, observations, and actions taken during Sep. 16-18, 2019.

September 16, 2019

00:00-6:00 The City of Brentwood Wastewater Treatment Plant (WWTP) initiated a requested flow augmentation pilot study. Approximately 250,000 gallons of recycled water was released from the main WWTP outfall located just upstream of Station M1 over a six-hour duration (i.e., approximately 700 gpm flow rate). The WWTP continued this pilot project flow augmentation nightly for two months beginning Sep. 16. From the documented history of fish mortality events, prior fish kills on Marsh Creek from 2005 to 2017 were generally observed at or downstream of the WWTP outfall.

08:00-10:00 A low intensity storm system produced between 0.08 and 0.17 inches of rain in the vicinity of the City of Brentwood and Lower Marsh Creek. Field crews had been observing this storm and planned sampling for the Pollutants of Concern (POC) project (copper and nutrients) on the morning of Sep. 17, 2019, with the hopes of capturing this as a suspected critical condition, high flow event following a long dry period. As these conditions were also a risk profile associated with prior fish kill events, opportunistic sampling for a new kill was also planned on a contingent basis.

13:28 The DO at Station M2 began to drastically deviate from its normal pattern, as shown in Figure 4.

18:20 Peak stage (4.02 feet) occurred at Station M2. This was one of the largest flow levels observed all summer. A preceding peak of higher magnitude (4.1 feet) occurred on Jun. 9, 2019. No rainfall occurred prior to or after the June peak.

23:20 A low DO alarm was received through email and text messaging from the datalogger at Station M2 indicating that DO had dipped below 2.5 mg/L.

September 17, 2019

05:30 DO levels at all stations (M0, M1 and M2) was checked remotely, and a phone call was placed to the field crew to notify them that DO levels were lethally low (<1.0 mg/L) at Station M2 and to be on the lookout for a fish kill. As noted earlier, the field crew had already planned to be onsite at Station M2 at 6:00 for a high flow sampling event for POC project sampling.

06:00 Field crew members observed dead fish (largemouth bass and blue gill) and numerous living catfish gulping air at surface (aquatic surface respiration) in and around the rip rap check dam at Station M2. Most dead bass were approximately 8 to 16 inches in length. A few dead specimens were collected and frozen for archival storage. The field crew commenced with scheduled sampling for the POC project.

06:50 Samples were collected for the fish kill suite including fathead minnow chronic toxicity; biochemical oxygen demand (BOD)-5 day; total sulfides; ammonia; total organic carbon; dissolved organic carbon; pyrethroid pesticides, chlorpyrifos, diazinon, fipronil and their degradants. Later bioassay results indicated there was no toxicity to survival or growth of fathead minnows. None of the chemistry results were outside of normal ranges.

07:10 At least 10 additional dead fish were noted between Station M2 and Sunset Road. An example is presented in Figure 1.

Dead Fish in Marsh Creek Above Station M2 – Sep. 17, 2019

07:15 The field crew inspected confluences of Sand and Deer Creeks with Marsh Creek upstream of Station M2. They discovered high volume flow coming from Sand Creek.

09:30 The field crew inspected Marsh Creek below the WWTP from Delta Road to Station M1 and from stations M1 to M2. No dead fish were observed downstream of Station M2.

10:00 The field crew completed POC project sampling.

15:30 The field crew returned to Marsh Creek and searched for dead fish below the WWTP from Station M0 to Delta Road. None were found.

16:00 Over 100 dead fish (many small fish from 3 to 8 inches in length) were discovered upstream of Station M2 up to Sunset Road and many catfish were performing aquatic surface respiration.

September 18, 2019

11:00 Field crew members observed water still flowing from Sand Creek but with significantly lower volume. Field measurements were taken using a handheld YSI 556 multi meter at site 544MSH045, between the Sand and Deer Creek confluences with Marsh Creek during a scheduled sediment toxicity sampling event. The results indicated non-lethal conditions: DO, 3.6 mg/L, 39.0%; pH, 7.56; water temperature, 18.94° C; specific conductivity, 1166 µS/cm.

12:50 The field crew spot-checked DO levels in Deer Creek (4.26 mg/L), Sand Creek (3.58 mg/L) and Marsh Creek below the Sand Creek confluence (4.63 mg/L). These results indicated non-lethal conditions.

13:40 DO measurements were recorded at Station M2 using a handheld YSI 556 meter as an independent check against the in situ sonde instrument at Station M2; the result (1.07 mg/L) was similar to the sonde reading and indicated lethal DO conditions. Some dead fish were seen at the site.

14:00 Over 100 dead fish of various sizes were seen between Station M2 and Sunset Road. DO was measured upstream of Station M2 and below Sunset Road. The DO result was 0.64 mg/L and indicates lethal conditions. Many living catfish were seen performing aquatic surface respiration. In the vicinity of these observations, the water was very turbid and dark in color.

17:00 Field measurements and BOD samples were collected from Sunset Road to upstream of Sand Creek Road. The results are presented in Table 1. BOD results greater than 5 mg/L indicate the water is elevated in organic matter and that bacteria are decomposing this organic matter (Polyseed, 2019).

Table A-1. Sondes, Field and Laboratory Results from Grab Samples Collected – Sep. 18, 2019

Station ID	Latitude	Longitude	Time	Temp (° C)	pH	DO[1] (mg/L)	Conductivity (µS/cm)	BOD[2] 5-day (mg/L)
M1[4]	37.96395	-121.6836	17:00-19:00	24.2-24.5	7.35-7.37	4.8-5.1	1368-1380	--
M2[4]	37.96261	-121.6875	17:00-19:00	23.0-23.4	7.05-7.06	*0.58-0.86*	664-665	--
544MSH029	37.95444	-121.6938	17:00	22.37	7.09	*0.82*	728	*31*
544MSH030	37.95280	-121.6959	17:10	22.69	7.20	*0.66*	705	*23*
544MSH031	37.95182	-121.6981	18:35	22.06	7.33	*0.70*	602	*12*
544MSH032	37.95079	-121.6993	18:50	21.29	7.40	1.15	555	--
544MSH033	37.95001	-121.6992	19:05	21.60	7.52	2.33	537	*6*
544MSH034	37.94973	-121.6990	18:55	21.66	7.51	2.89	536	--
544MSH035	37.94911	-121.6989	18:25	22.01	7.64	3.19	538	<5
544MSH036	37.94835	-121.6995	18:15	22.09	7.77	3.87	551	--
544MSH037	37.94717	-121.7015	17:50	21.44	7.68	3.03	605	<5
544MSH040	37.94470	-121.7052	17:30	21.54	7.69	3.99	707	<5
544MSH042	37.94263	-121.7063	17:35	21.63	7.88	4.36	611	--

1 dissolved oxygen
2 biochemical oxygen demand
3 Bold, italicized values indicate lethally low DO levels and elevated BOD results
4 Ranges of water quality parameters recorded by the YSI sonde devices at the sites for the time period shown
-- Sample was not collected

September 22, 2019

08:15 Field measurements and BOD samples were collected in Deer Creek (DO 5.41 mg/L), in Marsh Creek below Sand Creek confluence (DO 5.15 mg/L), and in Marsh Creek upstream of Sunset Road (DO 4.91 mg/L). Sand Creek was observed to have no flow. The results are presented in Table 2. Note that at these locations, DO is near or above the 5.0 mg/L objective for warm water habitat streams in the Basin Plan (SFBRWQCB, 2015) – Marsh Creek was recovering from the fish kill conditions. Dry weather flow coming in from Deer Creek had low but not lethal DO levels and undetected levels of BOD.

Table A-2. Field and Laboratory Results from Samples Collected in Deer and Marsh Creeks – Sep. 22, 2019

Station ID	Latitude	Longitude	Time	Temperature (°C)	pH	DO[1] (mg/L)	Conductivity (µS/cm)	BOD[2] 5-day (mg/L)
544DRC002	37.93633	-121.70924	08:15	15.98	7.90	5.41	1490	<5
544MSH044	37.93833	-121.70710	08:40	17.23	7.93	5.15	1050	<5
544MSH031	37.95182	-121.69810[3]	10:35	20.40	8.63	4.91	600	<5

1 dissolved oxygen
2 biochemical oxygen demand

09:30 Field measurements were taken in a vertical profile in the water column at Station M2 to test for stratification. A small degree of stratification in DO was present, with the lowest DO at the bottom of the water column. The results are presented in Table 3.

Table A-3. Field Data of Vertical Profile at Station M2 – Sep. 22, 2019

Water Column Location	Temperature (°C)	pH	DO[1] (mg/L)	Conductivity (µS/cm)
Surface	21.02	7.66	1.57	904
Middle	20.87	7.60	1.27	902
Bottom	20.71	7.56	1.07	896

1 dissolved oxygen

September 24, 2019

14:45 A field crew arrived on site at Station M2 to do follow-up observations on Marsh Creek after most of the conditions that lead to the fish kill had passed, and to determine the cause of a communication failure with the local datalogger telemetry unit. A reset of the modem fixed the problem.

15:00 The crew observed substantial change in water color from 37.957703, -121.68858 to 37.957933, -121.69039, just upstream of Station M2. The color was yellowish brown and the water was turbid. The source of the yellowish-brown water was from an outfall (approximately 18-inch corrugated metal pipe) at 37.957933, -121.69039. Samples for BOD and TSS were collected from the outfall. Field measurement and lab results from this sample are presented in Table 4. Other than elevated TSS, results were within normal ranges.

Table A-4. Field and Laboratory Results from Sample Collected Upstream of Station M2 – Sep. 24, 2019

Station ID	Latitude	Longitude	Time	Temperature (°C)	pH	DO[1] (mg/L)	Conductivity (µS/cm)	BOD[2] 5-day (mg/L)	TSS[3] (mg/L)
544MSH027	37.957933	-121.69039	15:00	21.12	8.23	6.04	1705	<5	76

1 dissolved oxygen
2 biochemical oxygen demand
3 total suspended solids

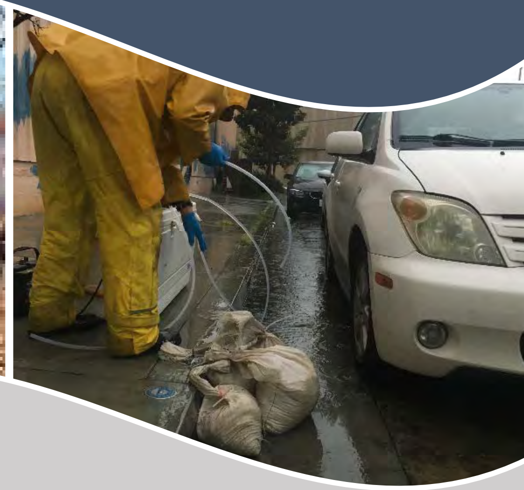
September 27, 2019 and After

The September 2019 Marsh Creek fish kill is over. Normal DO levels returned to Station M2 by Sep. 28. DO levels dipped at stations M1 and M0 on Sep. 17 and returned to normal levels by Sep. 23.

The six-day period from Sep. 17 to Sep. 22, during which DO at Station M2 remained at very low (lethal) levels was not anticipated. Note, however, that DO increased each day, small at first and then larger with each passing day due to daytime photosynthesis. The reason why this period of low to lethal levels of DO lasted six days is unknown. This phenomenon was not mentioned in any news or scientific source about prior fish kills on Marsh Creek.

Pollutant Removal from Stormwater with Biochar Amended Bioretention Soil Media (BSM)

Project Report



Prepared for:

Bay Area Stormwater Management Agencies Association

Prepared by:

OWP AT SACRAMENTO STATE

EOA inc.

SFEI

KINNETIC LABORATORIES INCORPORATED

Final

February 8, 2019

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BASMAA	Bay Area Stormwater Management Agencies Association
BMP	Best Management Practices
BSM	Bioretention Soil Media
CW4CB	Clean Watersheds for a Clean Bay
DQO	Data Quality Objective
EPA	Environmental Protection Agency
In/hr	Inches per hour
KLI	Kinnetic Laboratories, Inc.
K_{sat}	Saturated Hydraulic Conductivity
LCS	Laboratory Control Sample
MDD	Maximum Dry Density
MDL	Method Detection Limit
MQO	Measurement Quality Objectives
MRP	Municipal Regional Permit
MS/MSD	Matrix Spike/Matrix Spike Duplicate
MS4	Municipal Separate Storm Sewer System
ND	Non-detect
NPDES	National Pollutant Discharge Elimination System
OWP	Office of Water Programs
PCBs	Polychlorinated Biphenyls
PG&E	Pacific Gas and Electric Company
PMT	Project Management Team
POC	Pollutants of Concern
ppb	parts per billion
ppm	parts per million
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RL	Reporting Limit
RMP	Regional Monitoring Program
RPD	Relative Percent Difference
SAP	Sampling and Analysis Plan
SFEI	San Francisco Estuary Institute
SSC	Suspended Sediment Concentration

TMDL	Total Maximum Daily Loads
TOC	Total Organic Carbon

EXECUTIVE SUMMARY

The Bay Area Stormwater Management Agencies Association (BASMAA) implemented this regional study to evaluate the effectiveness of biochar-amended bioretention soil media (BSM) to remove polychlorinated biphenyls (PCBs) and mercury from stormwater collected from storm drains within the area covered by the Municipal Regional Permit (MRP; Order R2-2015-0049)[1] that are known to be impacted by diffuse PCB sources. The MRP requires that permittees[2] provide information to support the implementation of the wasteload allocations for mercury and PCB total maximum daily loads (TMDLs) as described in MRP Provisions C.11 and C.12. This study also contributes to implementation of MRP Provision C.8.f (Pollutant of Concern (POC) Monitoring) Priority #3, “Management Action Effectiveness,” which focuses on monitoring the effectiveness of specific management actions in reducing or avoiding loads of mercury and PCBs in municipal separate storm sewer system (MS4) discharges.

A prior BASMAA study, the Clean Watershed for a Clean Bay (CW4CB) project, found that BSM amended with biochar substantially improved PCBs removal compared to the standard BSM specified in MRP Provision C.3 at the same location (BASMAA 2017). The BSM contained 60 percent sand and 40 percent compost. The amended BSM contained 75 percent BSM and 25 percent biochar, which equates to 45 percent sand, 30 percent compost, and 25 percent biochar. Only one biochar source was tested, so it was unknown whether there would be substantial performance differences among differing biochar sources.

The goal of this study was to identify biochar media amendments that improve PCB and mercury load removal by bioretention BMPs. The primary management question supporting that goal was: “Are there readily available biochar-amended BSM that provide significantly better PCB and mercury load reductions than standard BSM and meet MRP infiltration rate requirements?” And the particular purpose of the laboratory testing in this study was: “screen alternative biochar-amended BSM and identify the most promising for further field testing.” (Monitoring Study Design, Appendix A)

The study was carried out by a project team comprised of the Office of Water Programs at Sacramento State (OWP), EOA Inc., Kinnetic Laboratories, Inc. (KLI), the San Francisco Estuary Institute (SFEI), and ALS Environmental (ALS). A BASMAA project management team (PMT) consisting of representatives from BASMAA stormwater programs and municipalities provided oversight and guidance to the project team throughout the monitoring study. Stormwater was collected in March and April of 2018, and the BSM testing was conducted in April and May of 2018.

METHODS

This study compared the removal of PCBs and mercury from stormwater in laboratory column tests of five locally-available biochars produced from a variety of feedstock and methods admixed at a 1-to-3 ratio by volume with BSM. The biochars used in this study were compared against each other and against a standard BSM. Due to availability, the BSM contained 65 percent sand and 35 percent

1 http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/Municipal/R2-2015-0049.pdf
2 A total of 76 cities, towns, unincorporated counties, and flood control and water conservation districts covered by the MRP.

compost, which is still within the acceptable range specific in the MRP Provision C.3 and the BASMAA specification (BASMAA 2016). The BSM-biochar blend ratio matched the CW4CB study (75% BSM and 25%). The resulting amended BSM contained 49 percent sand, 26 percent compost, and 25 percent biochar. Each of the test biochars was mixed with the standard BSM and placed in 7.5-inch-diameter glass columns to a depth of 18 inches, typical of standard field installations. One additional column was prepared as a control and filled with 18 inches of standard BSM. The stormwater used for all tests was collected during two storms from two sites that were located in the portion of the San Francisco Bay Area subject to the MRP and that had previously observed elevated levels of PCBs. Four sampling runs were performed on the columns, three runs using undiluted stormwater on all columns and the fourth run using stormwater diluted at a one-to-nine ratio to test removal effectiveness at lower influent concentrations on two[3] columns. Column influent and effluent samples were collected during each test run and analyzed for PCBs, total mercury, total organic carbon (TOC), suspended solids concentration (SSC), and turbidity.

Results

Influent concentrations of PCBs (9,860 to 19,600 picograms/liter or pg/L) were consistent with samples previously taken at the sampling sites during the CW4CB study (BASMAA 2017). The standard BSM control column had effluent concentrations of PCBs similar to the standard BSM tested alongside biochar in the CW4CB study. Two of the five biochar-amended BSM columns, Phoenix and Agrosorb, exhibited lower effluent concentrations of PCBs than the standard BSM column for all test runs. A third column, BioChar Solutions, produced three effluents with lower concentrations and a single effluent sample at a slightly higher concentration than that produced by the standard BSM. The remaining two biochar-amended BSM columns had one or two effluent samples that were much higher than those from the standard BSM, and one sample showed a substantial export of PCBs. However, these high PCB concentrations corresponded to unusually high infiltration rates compared to the testing conditions for all other data, suggesting channelizing or otherwise insufficient compaction of media within the column and so these data are not used in analysis and graphs. The remaining results collected for those two biochars under typical infiltration conditions exhibited PCB removal, and at least half of those results were superior to BSM.

Mercury influent concentrations (9.9-10.2 ng/L) were very similar across all samples. Mercury removal across all test runs occurred in two biochar-amended BSM columns, Phoenix and Agrosorb. The other columns showed variable treatment, including some export of mercury (the worst of which corresponds to a sample removed from the dataset due to abnormally high infiltration rates). The standard BSM column was the only column to export mercury for all test runs.

Conclusions

All five biochar-BSM blends showed evidence of overall improved PCB and mercury performance compared to the standard BSM. The results support these additional observations:

- Phoenix, Sunriver, BioChar Solutions, and Agrosorb appear to offer improved PCB removal compared to standard BSM and the other biochar-amended BSM.

3 The effluent of one column (CO6) in the dilution run could not be analyzed by the lab at the time of this study report so it is presumed lost.

- Phoenix and Agrosorb appear to offer improved mercury removal compared to standard BSM and the other biochar-amended BSM.
- Biochar may decrease performance variability from variable influent concentrations compared to standard BSM.
- Based on a single run on one column to explore removal at lower influent concentrations, biochar-amended BSM provided removal of PCBs at an influent concentration of 2,100 pg/L. BSM performance at this lower influent concentration could not be reported due to the sample being lost. Neither BSM nor biochar-amended BSM provided removal of mercury at an influent concentration of 3.00 ng/L.
- High initial infiltration rates correlated to poor performance (higher rates are associated with short-circuiting and higher pore velocities).
- Saturated hydraulic conductivity was poorly correlated to the falling head infiltration rates estimated during the water quality sampling runs, so biochars that were eliminated from column testing based on saturated hydraulic conductivity tests may be candidates for future testing.

Recommendations

Based on this study, biochar shows promise in marginally increasing performance; however, increased benefit relative to increased cost was not analyzed. With such limited data, benefit/cost analysis may be more appropriate after collection of substantial field data. Because of the marginal increase in performance, standard BSM should be a component of future side-by-side testing of biochar-amended BSM. If further biochar testing is pursued, the following recommendations should be considered.

If selecting biochar for PCB removal, the best-performing biochars were Phoenix, Sunriver, BioChar Solutions, and Agrosorb. If mercury removal is a design consideration, Phoenix and Agrosorb should be further studied. Because there was no correlation between performance and cost, less costly biochars that were not tested here (including those that were eliminated from this study based on possible inappropriate use of saturated hydraulic conductivity test procedures) might be considered for further field testing alongside one or more biochars from this study.

Site selection should consider the collective experience in this and other studies on irreducible minimum concentrations. This study suggests that value may be around 1,000 pg/L for PCBs. It is unclear for total mercury. Watersheds likely to have concentrations near or below irreducible concentrations should be avoided.

The most substantial enhancement to performance may be the use of outlet controls to increase contact time with biochar-amended BSM. Outlet controls should be considered for further study of both biochar-amended and standard BSM.

And finally, further development of procedures for laboratory tests of hydraulic conductivity or infiltration rate is recommended. Improving correlation between field-measured infiltration rates and laboratory test procedures for hydraulic conductivity may avoid screening out BSM blends and amendments based on tests that do not relate to field conditions.

1 INTRODUCTION

1.1 BACKGROUND

PCBs and mercury are pollutants of concern in the San Francisco Bay Area and removal of both from stormwater runoff using BSM amended with biochar has shown some promise in a previous investigation (BASMAA 2017).

Biochar is a highly porous, granular charcoal produced from a variety of organic materials and primarily marketed as a soil amendment. The majority of biochar research conducted to date has focused on agricultural applications, where biochar has been shown to improve plant growth, soil fertility, and soil water holding, especially in sandier soils. But investigation of stormwater treatment benefit is limited, especially for removal of mercury or PCBs.

A recent laboratory study on the effect of biochar addition to contaminated sediments showed that biochar is one to two orders of magnitude more effective at removing PCBs from soil pore water than natural organic matter, and may be effective at removing methylmercury but not total mercury (Gomez-Eyles et al. 2013). A laboratory column test study to determine treatment effectiveness of 10 media mixtures showed that a mixture of 70% sand/20% coconut coir/10% biochar was one of the top performers and less expensive than similarly effective mixtures using activated carbon (Kitsap County 2015). Liu et al. (2016) tested 36 different biochars for their potential to remove mercury from aqueous solution and found that concentrations of total mercury decreased by >90% for biochars produced at >600°C and by 40–90% for biochars produced at 300°C.

A prior BASMAA study, the CW4CB project (BASMAA 2017), examined whether BSM amended with biochar would substantially improve PCBs removal compared to the standard BSM specified in MRP Provision C.3. In the CW4CB study, the effect of adding a biochar to BSM was evaluated using data collected from two bioretention cells (LAU 3 and LAU 4) that treat roadway runoff just outside the Richmond Pacific Gas and Electric (PG&E) Substation at 1st Street and Cutting Boulevard. At this site, a standard bioretention cell (LAU 3) contains standard BSM (60 percent sand and 40 percent compost) while an enhanced bioretention cell (LAU 4) contains a mix of 75 percent standard BSM and 25 percent pine wood-based biochar (by volume), which equates to 45 percent sand, 30 percent compost, and 25 percent biochar. The results suggest that the addition of biochar to BSM is likely to increase removal of PCBs in bioretention best management practices (BMPs; BASMAA 2017).

Figure 1 shows a cumulative frequency plot of influent and effluent concentrations of PCBs for the two CW4CB bioretention cells. Although influent concentrations at the two cells were generally similar, effluent concentrations were much lower for the biochar enhanced bioretention cell (LAU 4) compared to those for the standard bioretention cell (LAU 3). The results for total mercury were different from those for PCBs, with both cells demonstrating little difference between influent and effluent concentrations. These CW4CB monitoring results suggest that the addition of biochar to BSM may increase removal of PCBs from stormwater. There was little effect on total mercury.

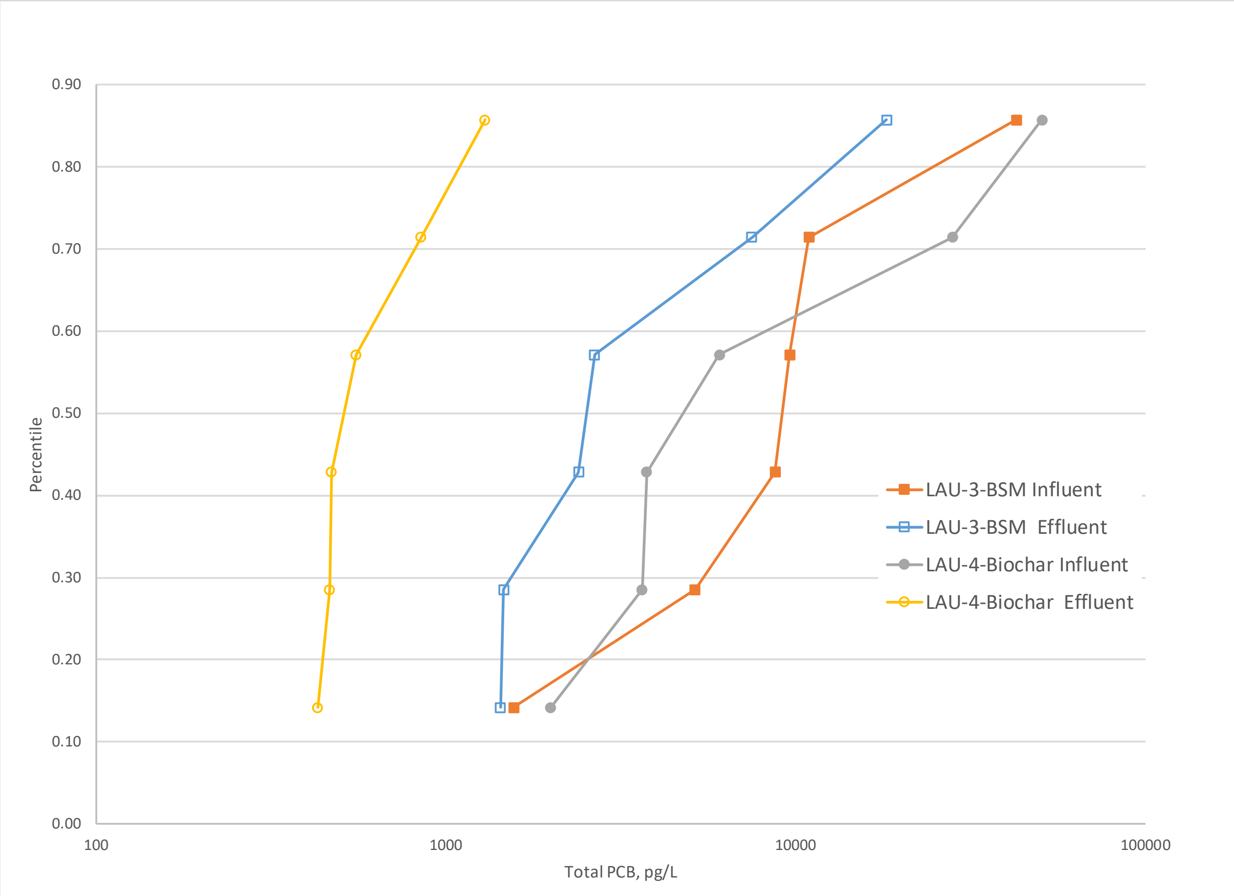

Figure 1. Cumulative Frequency Distribution of Total PCB Influent Concentrations for Bioretention Media with and without Biochar from CW4CB (BASMAA, 2017a)

Monitoring of the two bioretention cells at the CW4CB pilot site showed greater PCBs removal for a biochar-amended BSM than for standard BSM. However, to date, sampling has been limited to one test site and one biochar amendment. Besides the CW4CB study, there are no published literature studies on field PCBs and mercury removal from stormwater using biochars. Additional field testing can confirm the effectiveness of biochar in bioretention, but very little data is available on the selection of biochar for further field study. Laboratory testing of different biochars using actual stormwater from the Bay Area is a cost-effective tool to screen biochar media to identify good candidates for PCBs removal in future field testing.

1.2 Study Goals

The goal of this study, as identified in the Monitoring Study Design (Appendix A), was to identify biochar media amendments that improve PCB and mercury load removal by bioretention BMPs. The primary management question supporting that goal was: “Are there readily available biochar-amended BSM that provide significantly better PCB and mercury load reductions than standard BSM and meet MRP infiltration rate requirements?” And the particular purpose of the laboratory testing in this study was: “screen alternative biochar-amended BSM and identify the most promising for further field testing.”

The MRP requires that permittees provide information to support the implementation of the wasteload allocations for mercury and PCB total maximum daily loads (TMDLs) as described in MRP Provisions C.11 and C.12. This study also contributes to implementation of MRP Provision C.8.f (POC Monitoring) Priority #3, "Management Action Effectiveness," which focuses on monitoring the effectiveness of specific management actions in reducing or avoiding loads of mercury and PCBs in MS4 discharges.

The MRP infiltration rate requirements are described in Provision C.3.c of the MRP. This provision states: "Biotreatment (or bioretention) systems shall be designed to have a surface area no smaller than what is required to accommodate a 5 inches/hour stormwater runoff surface loading rate, infiltrate runoff through biotreatment soil media at a minimum of 5 inches per hour, and maximize infiltration to the native soil during the life of the Regulated Project." In addition to the 5 inches per hour MRP requirement, for any application that uses a non-standard BSM, the recently updated BASMAA specification requires "certification from an accredited geotechnical testing laboratory that the bioretention soil has an infiltration rate between 5 and 12 inches per hour" (BASMAA 2016).

To accomplish the purpose of this study, the following tasks were identified:

1. Collect all readily available west coast biochar;

2. Test each biochar-amended BSM and select those for water quality testing that meet infiltration requirements using saturated hydraulic conductivity tests;

2. Compare performance among select media mixes with biochar using influent-effluent column tests with Bay Area stormwater for PCBs and mercury removal;

3. Estimate whether PCBs and mercury reduction can occur at lower concentrations by using influent-effluent column tests for the best mix with diluted Bay Area stormwater

Because the purpose of the study design is to screen biochars for further field testing, the number of samples was spread out over as many biochars as possible while still producing enough data points for each biochar to distinguish large performance differences between biochars and BSM similar to what was observed in the CW4CB study.

This report presents the results of the BSM testing study conducted from March through May, 2018. The study was implemented by a project team comprised of the Office of Water Programs (OWP), EOA Inc., Kinnetic Laboratories, Inc. (KLI), the San Francisco Estuary Institute (SFEI), and ALS Environmental (ALS). A BASMAA project management team (PMT) consisting of representatives from BASMAA stormwater programs and municipalities provided oversight and guidance to the project team throughout the study.

The Methods section explains the study approach and methods used to complete this study. This is followed by the Results section that includes PCBs and mercury removal data. The Conclusions and Recommendations section summarizes the findings of this study and gives brief recommendations for media selection for future field sites. Appendices include the Monitoring Study Plan, Sampling and Analysis Plan and Quality Assurance Project Plan, Proposed Biochar Selection Factors, Hydraulic Test Results, Biochar Particle Size Distribution, and Water Quality Laboratory Reports.

2 METHODS

2.1 STUDY APPROACH

The study approach called for: 1. Gathering biochar products that are readily available locally (west coast) at the time of the study; 2. Collecting product information, including feedstock, pyrolysis temperature; 3. Testing saturated hydraulic conductivity of each biochar blended into standard BSM at a 1-to-3 ratio; 4. Selecting five biochars; and 5. Performing three runs through side-by-side column tests alongside a standard BSM serving as a control using Bay Area stormwater; and 5. Performing a single run on two columns[4] using diluted Bay Area stormwater. Details and adjustments to this approach are described below.

2.2 INITIAL MEDIA SELECTION AND BLENDS

A total of nine samples from all identified locally available biochar producers were gathered. The samples were mixed at a ratio of one-to-three by volume with standard BSM to match the CW4CB biochar-amended pilot project amendment ratio. All biochars used in this study were unmodified (i.e., the biochars were not sieved, rinsed, or chemically treated in any way; all were used as received from their manufacturers). When blending the biochar-amended BSM, care was taken to use a representative subsample of the biochar. The BSM vendor was L.H.Voss Materials, and the BSM consisted of 65% sand and 35% compost by volume. These percentages are slightly different from the CW4CB study (60% sand and 40% compost), but still within the requirements of the MRP Provision C.3 and BASMAA standard. A precise match could not be accommodated due to the project schedule and approaching stormwater sampling opportunities.

2.3 BIOCHAR SELECTION

Primary biochar selection factors included availability in the Western United States, to ensure any biochar tested would likely be available for use in the San Francisco Bay Area, and acceptable hydraulic conductivity. Initially, the goal of hydraulic testing was to identify biochar-BSM blends that had a hydraulic conductivity in an acceptable range of 5 to 12 in/hr (Appendix C). However, destruction of biochar during the Modified Proctor compaction procedure required adjustments in procedures that made the 5 to 12 in/hr an inappropriate comparison. Instead, biochar-BSM blends that provided the most consistent hydraulic conductivity relative to the standard BSM were selected for testing. Secondary biochar selection factors included a range of pyrolysis temperatures and costs. Up to five biochars could be tested under limitations of timing, resources, and desired minimum samples per column (Appendix A).

2.4 HYDRAULIC TESTING

The BASMAA specification for alternatives to BSM requires testing of saturated hydraulic conductivity (k_{sat}) at a compaction of 85% maximum dry density (MDD) using the Modified Proctor method (BASMAA 2016). Because of the observation that the standard level of compaction was crushing the biochar particles, and thus changing their characteristics, it was decided to compact to 85% MDD using the Standard Proctor method, which uses reduced energy. Before hydraulic testing, a compaction curve was developed by the Standard Proctor method to determine MDD for each biochar-amended BSM.

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4 One column was not analyzed due to a sample that is presumed lost after being shipped to the water chemistry laboratory.

Hydraulic testing was used as a screening tool to select the five media for the columns from the nine media tested. This testing, using deionized water that was de-gassed under vacuum and agitation overnight, was performed according to ASTM D2434 Standard Test Method for Permeability of Granular Soils (Constant Head) using a six-inch-diameter permeameter. All test equipment was purchased from the Humboldt Manufacturing Company.

2.5 Column Setup and Seasoning Runs

Six columns were constructed for this study, each column consisting of a 36-inch-long glass pipe with an internal diameter of 7.5 inches (Figure 2). Each column was capped with a Teflon plate that was milled to create a circular channel to nest the pipe in and make a water tight seal. Seven drainage holes were milled through each plate. To create flow paths for draining water to each of the seven drainage holes, each plate had additional drainage veins milled in the top side of each plate. To match each biochar-amended BSM column flow rate to the control BSM flow rate (i.e., outlet control), stainless steel screws were used to block the drainage holes (Figure 3). To create a water tight seal between Teflon cap and glass pipe without an adhesive or caulking (which could adsorb PCBs), ratcheting straps were used to apply force to the top of the glass columns to keep them firmly seated in their Teflon caps. Plugging the drainage holes and filling the empty column with water proved the seal was sufficient. Stainless steel mesh screen (number 40, opening size nominally 0.42 mm) was cut to shape and placed on top of the Teflon cap to keep media from filling the drainage channels and exiting the column. A two-inch layer of sand was placed on top of the stainless steel screen, followed by 18 inches of either the standard BSM control media or one of the five biochar-amended BSM.

Figure 2. Column test setup at Sacramento State showing five of six columns

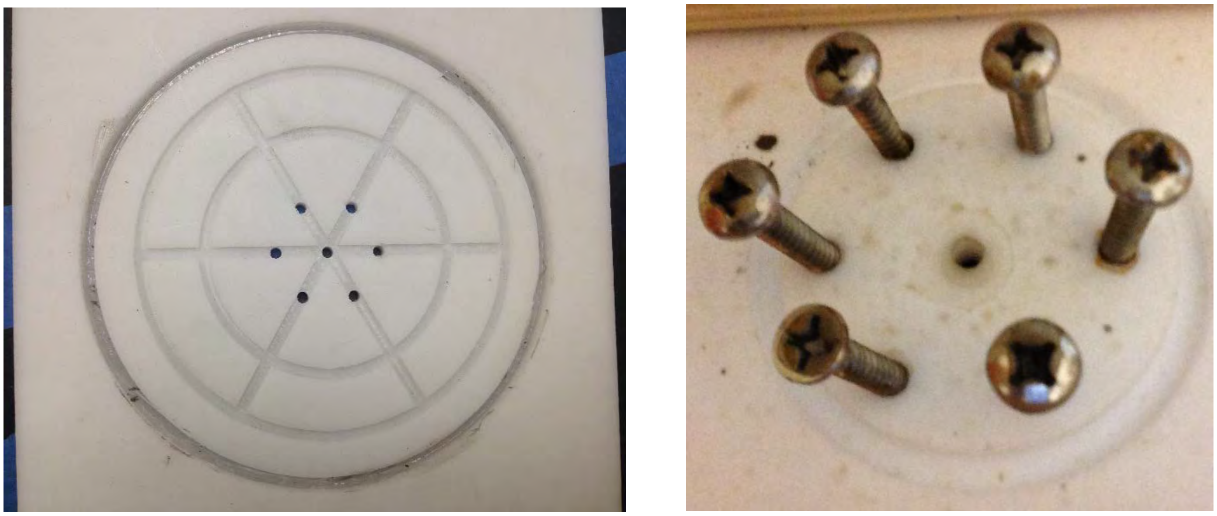

Figure 3. Teflon Column Cap with Drainage Veins and Holes (left) and Stainless Steel Throttling Screws (right)

Initial attempts at media placement and top-down hydro-compaction failed to achieve adequate infiltration rates so a wet placement technique was used to introduce water from the bottom of the column via a water supply cap fitted to the invert column cap. While placing the media in 1- to 2-inch lifts, water was slowly introduced and allowed to flow up through the media. As the previous lift was saturated and water reached the surface, an additional lift of media was placed. This technique allowed the air in the pore space of the media to be pushed out of a relatively thin overlying layer of media. Once all 18 inches of media were placed, the water was allowed to continue rising above the surface of the media until six inches of ponded water was achieved. Once this occurred, the water supply cap at the bottom of the column was removed and the water was allowed to drain. This draining of the six inches of ponded water served to hydraulically compact the media. An additional volume of water—equivalent to a depth of 18 inches of water—was added slowly to the top of the column to maintain the six inches of ponded water until the column was fully drained.

After the columns were filled with media and hydraulically compacted, the media was tested again to verify that infiltration rates were similar to field conditions. Columns were saturated and a falling head test was performed. The standard BSM had the slowest drain time and many of the biochar-amended columns had much faster drain times. Once the drain times had stabilized, a minimum level of outlet control was used on five columns so that the drain time in each column was more consistent with the slowest draining column.

During the first sampling run it was observed that all column effluents had high turbidity. To further stabilize the columns, two "seasoning" runs were performed. Turbidity was the only water quality measurement taken during these seasoning runs. Each run applied 18 inches of stormwater to the column. These seasoning runs were successful in decreasing turbidity in the effluent. Because stormwater was used, additional pollutant loading to the columns occurred during these two runs.

2.6 Stormwater Collection

Stormwater used during the seasoning and sampling runs was collected during storm events at two sites within the area covered by the MRP that were identified in previous studies as having consistently elevated concentrations of PCBs in the runoff (BASMAA 2017). Both sites were tree well locations that were installed in Oakland, CA, and tested during the CW4CB project. In addition to being previously monitored, tree well 2 (Ettie St and 28th NW) and tree well 6 (Poplar and 26th SW) were considered safe locations to conduct stormwater monitoring. To collect the necessary volume of stormwater for the study, OWP staff accompanied KLI staff to each site during two storm events and pumped stormwater directly from the street gutter into clean five-gallon glass carboys. These were then transported back to OWP in Sacramento, CA, by OWP staff and stored at room temperature until use. Stormwater had to be collected before the columns were ready for experimental runs. Complications in acquiring suitable BSM, hydraulic testing, and preparing columns delayed the experiment for three months, far enough into the wet season that the likelihood of ample rain events was quickly diminishing. To hedge against a lack of late-season rain events, sufficient stormwater was collected from two storm events to perform all sampling runs and seasoning runs. The weather was tracked in hopes of sampling a third storm event, but additional storm events failed to materialize. Nine carboys were filled from each sampling location during each monitored storm event. The preference was to use the stormwater within 72 hours of collection, but additional time was needed to finish the construction and initial seasoning of the columns. The stormwater was stored for four days before the first run. The stormwater for the dilution run was used two weeks after collection. The stormwater for a replacement run (required as a result of bottle breakage during shipping) was used four weeks after collection. This was not a concern for PCB analysis because of the stability of PCBs, though particle agglomeration likely occurred causing associated pollutants to be more easily removed. This was counteracted by using high-sheer mixing as described below.

2.7 Sampling Runs

Following the purpose to screen as many biochars as possible for further study (see Appendix A), only three sampling runs were performed for all six columns using undiluted stormwater. A fourth run was conducted on one biochar-amended BSM column (CO4; BioChar Solutions) and the standard BSM control column[5] (CO6; Control) using stormwater diluted at a one-to-nine ratio. A single replacement run was performed for the first undiluted run for one column (CO1; Sunriver) due to loss of a sample bottle that was damaged in transit between laboratories. A unique influent had to be generated for this replacement run. Each run applied 18 inches of water to each column to simulate the hydraulic loading from storm events near typical water quality design storms. For example, if bioretention is sized to 4 percent of a drainage area that has a volumetric runoff coefficient of 0.8, a 0.9-inch storm size would generate 18 inches of hydraulic loading to the bioretention surface.

A variety of influent concentrations was desired, however, all runs were performed within a period of 30 days so water quality analysis from the first run was not known when performing later runs. Consequently, the selection of which stormwater source (sampling location) and which storm event to use for each run was based on past data from the sampling locations (Table 3). Additionally, each run was sequentially dosed directly from a subset of carboys from each storm. Because all carboys were not used in a run, the visual quality of the stormwater in each carboy was used to select carboys with the most sediment for each run. The dosing sequence is described below.

At the start of each sample run, six cleaned and empty carboys were labeled for effluent collection for all columns and one clean and empty carboy was labeled for influent doses. All sample bottles were labeled to associate them with the collection carboys. Stormwater in the five-gallon storage carboys

5 As previously explained, this sample was not analyzed.

were vigorously agitated before each dose with a stainless steel paddle mixer until all sediment was suspended. A glass beaker marked for the level of a single dose was filled from the carboy and used to dose each column in turn. The dose was sized to be equivalent to one inch of water depth inside the 7.5-inch-diameter column. Each column and the carboy collecting influent received 18 total doses. If the stormwater storage carboy did not have sufficient volume for a complete round of dosing (six column doses and one influent dose), additional water was added to the carboy from the next carboy selected for dosing. This assured that the same batch of stormwater was used for a single dose to each column and influent carboy. Dosing the influent carboy for each round of column dosing allowed a single influent sample from the influent carboy at the end of all 18 doses to represent the composite influent of all columns for that run. If at any time during dosing a column had more than six inches of ponded water the dosing would stop until the water drained to a height of three inches. Figure 4 presents the column test setup.

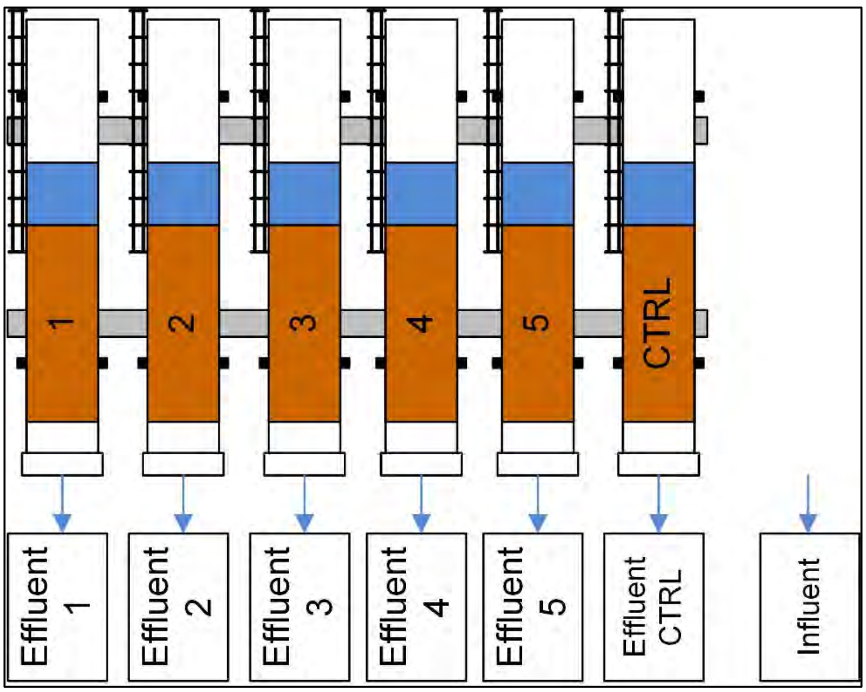

Figure 4. Column Test Setup

Column test observation forms were kept for each column and the time at which each dose was applied and the height of ponded water in the column was recorded. By recording the height of the water in the column at regular time intervals, it was possible to calculate an infiltration rate at each time step over the course of the sampling run. Three times during the dosing of the columns a grab sample was taken from the effluent of each column and tested using on-site meters to measure pH, temperature, and turbidity. At the midpoint of each sampling run, as specified in the sampling protocol to achieve ultra-low detection limits, mercury samples were collected directly from the effluent stream of the column into a preserved sample bottle. Direct collection eliminated losses that would occur if collecting from the effluent carboy. One person was able to handle bottle filling without the aid of a second pair of hands because the sampling person did not have to touch anything while handling the bottle because flow was collected at the air gap as water fell between the column and the effluent carboy.

After all influent water was applied, the columns were allowed to drain until no water was visible in the pore spaces of the soil and the effluent discharge had slowed to a drip. Once the columns drained, the carboy that received influent doses and the effluent carboys of each column were agitated with their own stainless steel paddle mixer before filling all required sample bottles. Sample bottles were refrigerated for up to two days then packed in blue ice and shipped overnight via FedEx to ALS for analysis.

Additional details are presented in Appendix B.

2.8 Constituents and Laboratory Methods

As specified in the study design (Appendix A) and Sampling and Analysis Plan (Appendix B), total PCBs[6] and total mercury were analyzed for all samples. Constituents for analysis of water samples must be consistent with Table 8.3 of the MRP. Table 1 lists the constituents and test methods for this study.

In addition to PCBs and total mercury, the other constituents selected for influent and effluent analysis were suspended solids concentration (SSC), turbidity, and total organic carbon (TOC). Suspended solids concentration was selected for measurement rather than total suspended solids (TSS) because the method more accurately characterizes larger-sized fractions within the sample by avoiding subsampling, while turbidity was selected because it is an inexpensive and quick test to describe treatment efficiency where a strong correlation to other pollutants has been established. As with the SSC analysis, TOC was included because it is a MRP Provision C.8.f POC monitoring parameter and is useful in cases where methylation is a concern.

Table 1. Selected Aqueous Constituents for Media Testing in Laboratory Columns

Constituent	Test Method	Reporting Limit
SSC	ASTM D3977-97	1 mg/L
Turbidity	Field meter	1 NTU
TOC	EPA 9060	2 mg/L
Total Mercury	EPA 1631E	0.5 ng/L
Total PCBs (Sum of RMP 40 congeners) in Water	EPA 1668C	190-220 pg/L

2.9 Analysis and Statistical Testing

Effluent and influent concentrations are presented independently and in chronological order to observe potential trends with loading. Additional analysis was performed for PCBs. Effluent concentration is also presented normalized by influent concentration for comparison to CW4CB study results. Normalization allows caparisons where influent concentrations vary between studies and where effluent concentration is dependent on influent concentration. In addition to traditional graphical or tabular comparisons, statistical testing was performed for PCBs using the Mann-Whitney U test (a rank sum test) on columns showing the greatest differentiation of performance. Correlations between PCB and SSC, and total mercury and TOC were also examined. Comparing total PCBs to suspended solids indicates whether suspended solids have a consistent quantity of associated PCBs.

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6 The 40 individual congeners routinely quantified by the Regional Monitoring Program (RMP) for Water Quality in San Francisco Bay include: PCBs 8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, 105, 110, 118, 128, 132, 138, 141, 149, 151, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203. The sum of these congeners are referred to as the PCBs or RMP 40 throughout this report.

3 RESULTS

3.1 BIOCHAR CHARACTERISTICS, HYDRAULIC CONDUCTIVITY, AND SELECTION

The study design called for water quality column testing of five biochars. Nine biochars produced in the Western United States were identified as potential candidates (Table 2). Hydraulic tests of the nine biochar-BSM blends produced a wide range of results. More details of the hydraulic conductivity calculations and particle size distributions are presented in Appendices D and E, respectively. Pulverization[7] of biochar during the compaction process could be a contributing factor to the range of the observed results, even when using the lower-energy Standard Proctor method. The five biochar-BSM blends that provided the most consistent hydraulic conductivity compared to the standard BSM were selected for further testing. The selected biochar are highlighted in Table 2, and include Sunriver, Rogue, Phoenix, BioChar Solutions (also used in CW4CB), and Agrosorb. Their associated conductivity measurements were within 4 in/hr of the standard BSM, except for Agrosorb, which was 4.3 in/hr above the value for standard BSM. The selected biochar cover a range of pyrolysis temperatures and costs, but all were manufactured at 500 ˚C or above. Contrary to expectations, cost did not correlate with pyrolysis temperature.

Table 2. Characteristics for Biochar Considered for Water Quality Testing

Biochar[a]	Ksat[b] (in/hr)	Texture[c]	Cost ($/yd^3)	Pyrolysis Temp (˚C)	Supplier Location
Blacksorb	2.56	Variable size, 3mm to fines	250	900	CA
Sonoma	5.11	Variable size, 1 cm chips to sand size particles, lots of fines	240	1315	CA
Pacific	5.41	Variable size, 1 cm chips to sand size particles, some fines	90	700	CA
Sunriver	7.67	Variable size, mostly pine needles with some small twigs and chips, 2 cm, little fines	500	500	OR
Rogue	7.85	Uniform size, 4mm, little to no fines	250	700	OR
Phoenix	10.4	chips, 1-.5 cm, little to no fines	254	700	CA
Control – Standard BSM from Voss	10.8	Organics and sand	40	N/A	CA
Biochar Solutions Large	11.0	Chips, 2.5 cm, lots of fines	225	700	CO
Agrosorb	15.1	Large chips, 2 cm, lots of fines	250	900	CA
Biochar Now Medium	17.2	Uniform size, 3mm to 26 mesh, little to no fines	350	600	CO

a. Biochars are sorted by Ksat and the five biochars closest to BSM were selected for column tests (shaded).
b. Ksat values are at 85% maximum dry density using standard Proctor. Computations are presented in Appendix D.
c. Particle Size Distribution of each biochar is presented in Appendix E.

7 Hydraulic compaction was used in the water quality testing columns to avoid pulverization.

3.2 QUALITY ASSURANCE AND QUALITY CONTROL

Data quality assurance (QA) and quality control (QC) was performed in accordance with the project's SAP/QAPP (Appendix B). The SAP/QAPP established data quality objectives (DQOs) to ensure that data collected are sufficient and of adequate quality for their intended use. These DQOs include both quantitative and qualitative assessments of the acceptability of data. The qualitative goals include representativeness and comparability, and the quantitative goals include completeness, sensitivity (detection and quantization limits), precision, accuracy, and contamination. Measurement quality objectives (MQOs) are the acceptance thresholds or goals for the data. The quality assurance summary is presented for PCBs followed by total mercury, TOC, and SSC.

3.2.1 PCBs

The column water dataset included 26 field samples (including 1 field replicate), with 3 blanks, 5 laboratory control samples (LCSs), and one matrix spike/matrix spike duplicate (MS/MSD) pair reported for the RMP 40 PCB analytes (with their coeluters, yielding 38 unique analytes). This met the minimum number of QC samples required. All samples were analyzed within 30 days, less than the recommended hold time of 1 year. Three of the analytes had poor recovery (>70% deviation from target values in MS samples) and were rejected as were 2 analytes that had individual field sample results <3x higher than blanks. Overall 91% of the field sample results were reportable. Two PCBs were non-detect (ND) in 100% of the samples, but all the rest had detects in more than half the samples. However, a large percentage of results were below the lab's reporting limit, and 17 analytes had relative percent differences (RPDs) in the field replicates below 100%, and thus 62% of all results were flagged as estimated. Additionally 25 of the 38 unique analytes had recoveries between 35–70% above target values, so they were flagged as qualified. Nearly half of the data is flagged as estimated (i.e., below the reporting limit (RL) but above the method detection limit (MDL)) or qualified (not compliant with project SAP/QAPP), and approximately 5% of the data were rejected for the reasons mentioned above. Thus individual results are not quantitative at the target levels of confidence (+/- 30%) and thus the data should not be used to draw conclusions regarding attainment of set performance or water quality thresholds. However, the primary management question in this study is answered using the relative comparison of results within this study. Consequently, the data quality is satisfactory for the purpose of this study and all data were used.

3.2.2 Total Mercury (Hg), TOC, and SSC

All field sample results in the Hg/TOC/SSC dataset for water were reportable. The column water dataset included 25 field samples for Hg and SSC, and 1 field replicate for SSC, with 23 samples reported for TOC. All TOC results were analyzed at least in duplicate (some 3 or 4 times). Blanks were reported for all analytes, MS/MSDs for Hg and TOC, and LCSs for SSC and TOC, meeting the minimum number of QC samples required (1 per 20 or per batch of blank, precision, and recovery sample types). Samples were all analyzed within their respective hold times (28 days for Hg and TOC, 7 days for SSC). No results were non-detect, although a few Hg and TOC were DNQ (detected not quantified). Mercury was detected in blanks averaging 2-3x MDL in the two batches, but field sample results were all over 3x higher than blanks, so all results were flagged for blank contamination, but no results were censored. Precision was acceptable, averaging <10% RPD for SSC, <5% for TOC, and <20% for Hg, so no precision qualifiers were added. Similarly, average recovery deviated <10% from target values for all analytes, so no recovery flags were added. Overall, data quality is satisfactory for the purpose of this study and all data were used.

3.3 Column Test Runs

Five sampling runs were performed and influent concentrations and stormwater collection characteristics for each run are presented in Table 3. Not all stormwater collected at one location during one storm was used in a single run, so extra water was available for later runs as described in Table 3. In each run, the storage carboys with more sediment (visual judgement) were preferred in early runs. Consequently, water remaining for later runs had less sediment. Infiltration rates and influent and effluent concentrations grouped by column and run are presented in Table 4. Graphical comparisons and discussion is presented in the following sections.

Table 3. Influent Descriptions, PCB and Mercury Concentrations, and Columns Dosed for each Sampling Run

Influent ID	Run Type	Storm ID: No. - Location[a] - Collection Date	Column Run Date	Influent Concentrations				Columns Loaded
				PCB (pg/L)	Total Hg (ng/L)	TOC (mg/L)	SSC (mg/L)	
Influent 1	no dilution	Storm 2 - TW2 - 4/6/18	4/10/2018	19600	9.99	5.39	19.4	all
Influent 2	no dilution	Storm 1 - TW2 - 3/1/18	4/13/2018	18600	10.2	1.71	40.2	all
Influent 3	no dilution	Storm 2 - TW6 - 4/6/18	4/17/2018	9860	9.86	1.64	16.3	all
Influent 4	9X dilution	Storm 1 - TW2 - 3/1/18[b]	4/19/2018	2100	3	NA	1.9	CO4, CO6
Influent 5	no dilution	Mix of Storm 1 and 2 - TW2 - 3/1/18 and 4/6/18[c]	5/9/2018	8160	NA	NA	NA	CO1

a. Stormwater collection locations were at two sites in West Oakland: TW2 is the influent to the Tree Well Site 2 (TW2) on Poplar at 26th and TW6 is the influent to Tree Well Site 6 (TW6) on Ettie St. near 28th

b.TW2 selected because CW4CB indicated it had lower concentrations and was selected to avoid dilution of a high-concentration sample (in this study TW2 had higher concentrations but those results were not available at the time)

c. The dirtiest (visually) of the remaining storage carboys from storms 1 and 2 that were not used in previous runs were selected to get a concentration near what was dosed in Run 1 because this was a makeup for Run 1.

Table 4. Infiltration Rates and PCB, Mercury, TOC, and SSC Results for each Sampling Run

Column ID	Biochar	Test Runs	Inf. Rate (in/hr)	PCBs Influent (pg/L)	PCBs Effluent (pg/L)	Total Mercury Influent (ng/L)	Total Mercury Effluent (ng/L)	TOC Influent (mg/L)	TOC Effluent (mg/L)	SSC Influent (mg/L)	SSC Effluent (mg/L)
CO6	Control (BSM only)	Run 1	6.7	19600	2920	9.99	14	5.39	32.9	19.4	118
		Run 2	6.0	18600	4680	10.2	13.1	1.71	15.9	40.2	35
		Run 3	3.7	9860	960	9.86	11.3	1.64	17.2	16.3	26.7
		Run 4	N/A	2100	NA[a]	3	7.41	NA	10.9	1.9	11.1
CO1	Sunriver	Run 1	>20	19600	NA[a]	9.99	24.4[b]	5.39	26.7[b]	19.4	116[b]
		Run 2	>12	18600	32000[b]	10.2	9.68[b]	1.71	12.3[b]	40.2	21.9[b]
		Run 3	5.7	9860	383	9.86	9.74	1.64	12.1	16.3	12.5
		Run 5	N/A	8160	662	NA	NA[c]	NA	NA	NA	NA
CO2	Rogue	Run 1	>20	19600	19400[b]	9.99	16.3[b]	5.39	11[b]	19.4	104[b]
		Run 2	3.2	18600	926	10.2	8.58	1.71	5.72	40.2	13.3
		Run 3	5	9860	4510	9.86	2.17	1.64	5.12	16.3	8.4
CO3	Phoenix	Run 1	8	19600	2000	9.99	6.77	5.39	42	19.4	50.3
		Run 2	7.3	18600	2270	10.2	5.69	1.71	19.1	40.2	14.5
		Run 3	3.8	9860	411	9.86	6.02	1.64	21.6	16.3	19.3
CO4	BioChar Solutions	Run 1	8.5	19600	3270	9.99	15.2	5.39	28.9	19.4	89.1
		Run 2	>12	18600	2310	10.2	11.2	1.71	13.8	40.2	17
		Run 3	3.7	9860	839	9.86	7.58	1.64	14.4	16.3	16.5
		Run 4	5.5	2100	782	3	5.26	NA	NA	1.9	9.7
CO5	Agrosorb	Run 1	8.4	19600	2160	9.99	7.57	5.39	27.7	19.4	78
		Run 2	4.9	18600	2920	10.2	4.53	1.71	12.5	40.2	17.3
		Run 3	5.2	9860	586	9.86	7.36	1.64	12	16.3	11.7

a. Lost sample

b. Values are not used in further analysis due to unusually high initial infiltration rates

c. No Hg for Run 5 because three samples were successfully analyzed and only PCB required a replacement run.

3.3.1 PCBs

Both qualified and estimated influent and effluent PCBs concentrations are presented chronologically in Figure 5. The first two runs had similar influent concentrations and effluent quality was generally similar, despite sediment and turbidity increases in the first run. Effluent concentrations were generally lower for the third run, but influent concentration for the third run was nearly half that of the previous runs. The fourth run is the dilution run for only two columns. The fifth run is the replacement run for the first Sunriver run, which could not be analyzed for PCBs due to a broken sample bottle. All columns reduced concentrations of PCBs. This is expected because PCBs are largely bound to particles and media filters work well to remove these particles. Biochar-amended BSM seems to have improved treatment when compared to the control BSM (CO6), but a more explicit comparison is presented later in this report.

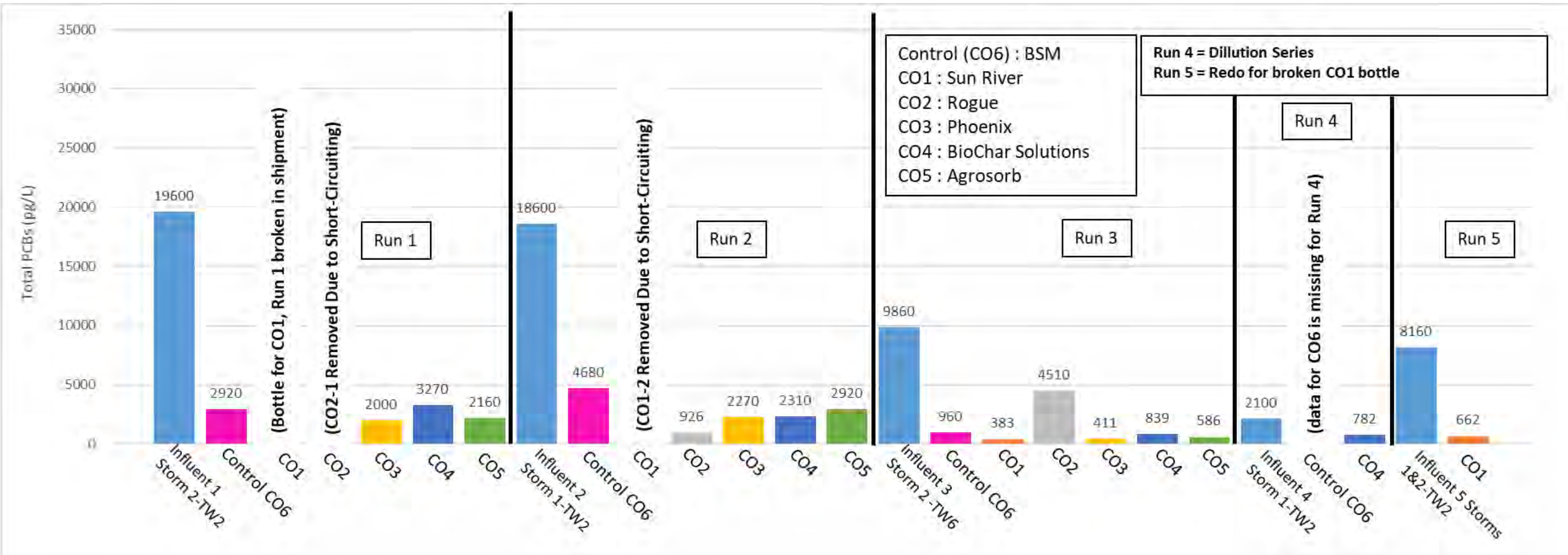

Figure 5. Total PCB Concentrations over Time

The data from Sunriver biochar-amended BSM (CO1) for test runs one and two, and the Rogue biochar-amended BSM (CO2) for test run one have been censored because both of these columns experienced unusually high initial infiltration rates that is indicative of short-circuiting of the media. The infiltration rates were so high that water did not remain in the column at the beginning of a subsequent dose when water level and time would be recorded. To drain this fast, the Sunriver column would have had an infiltration rate above 12 inches per hour and the Rogue column above 20 inches per hour. Because the occurrence of high infiltration rates are not successively repeated for later runs or in the initial runs of other columns, these two measurements have been deemed not representative of a properly compacted media and are not included in further analysis in this report. All other runs had had initial infiltration rates of 3 to 9 in/hr. Run 2 for BioChar Solutions (CO4) exceeded 12 in/hr, but that data was used because the first run was in an acceptable range, signifying that the variation in hydraulic performance could not be attributed to a lack of media seasoning or insufficient compaction. Consequently, later hydraulic variability could be an important longer-term characteristic of the media that would be important to consider in the study.

Despite initial seasoning that fully saturated the media, small air pockets were observed in some columns and it is probable that none of the columns were fully saturated during runs, so infiltration values are not representative of saturated hydraulic conductivity. Air pockets were not fully removed during the sampling runs because, unlike the initial seasoning and hydraulic compaction, water was introduced from the top of the columns.

Figure 6 displays the influent and effluent concentrations for PCBs grouped by column, along with means. There are four influent values because run 5 for Sunriver (CO1) required a unique influent (8,160 pg/L) which replaced the run 1 influent value (19,600 pg/L). Mean effluent concentrations for all biochar-amended BSM are lower than the mean effluent concentration of the control BSM (CO6), with the Rogue biochar-amended BSM (CO2) average just under the control BSM average.

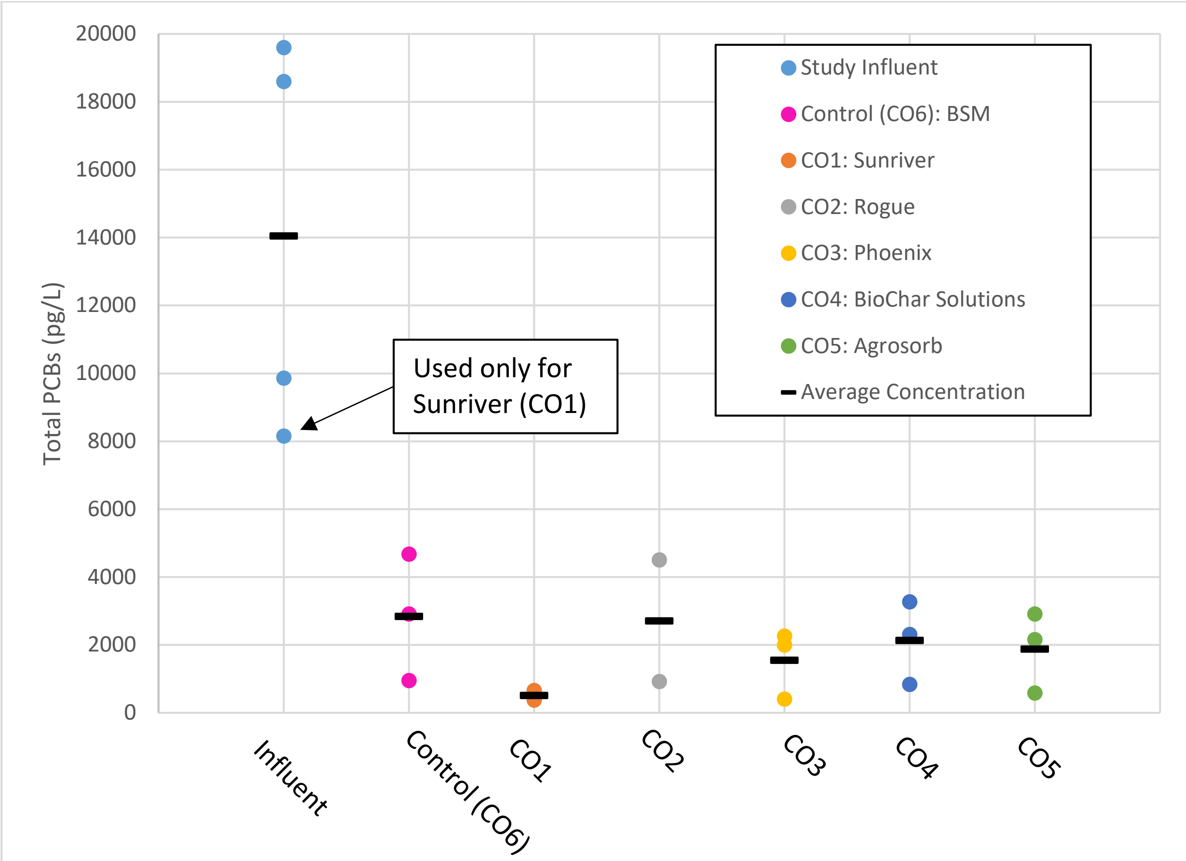

Figure 6. Observed Total PCB Concentrations for Undiluted Influent Runs and Column Test Media Effluent

Dividing each column effluent concentration by the paired influent concentration (Ce/Ci) normalizes the data to the influent and aids in comparison. In Figure 7, a red line has been placed at the mean value for the control BSM data. The noticeable difference between the Ce/Ci graph and the concentrations graph is that Rogue biochar-amended BSM (CO2) now has a higher mean than that of the control, while the average means for all other biochar-amended BSM are below the control. This is because each column had similar effluent values (4,680 and 4,510 pg/L, for the control and Rogue, respectively), but the influent concentration was substantially different (18,600 and 9,860 pg/L). This analysis indicates that all biochar may outperform the standard BSM mix with the possible exception of Rogue, but the data are limited. Further, the duplicate sample of run 3 for Rogue indicates it has better performance than the control but more data would be needed to show the primary sample was an outlier. The dilution run is not included in the analysis presented in Figure 6 because the lower influent concentration was not applied across all columns.

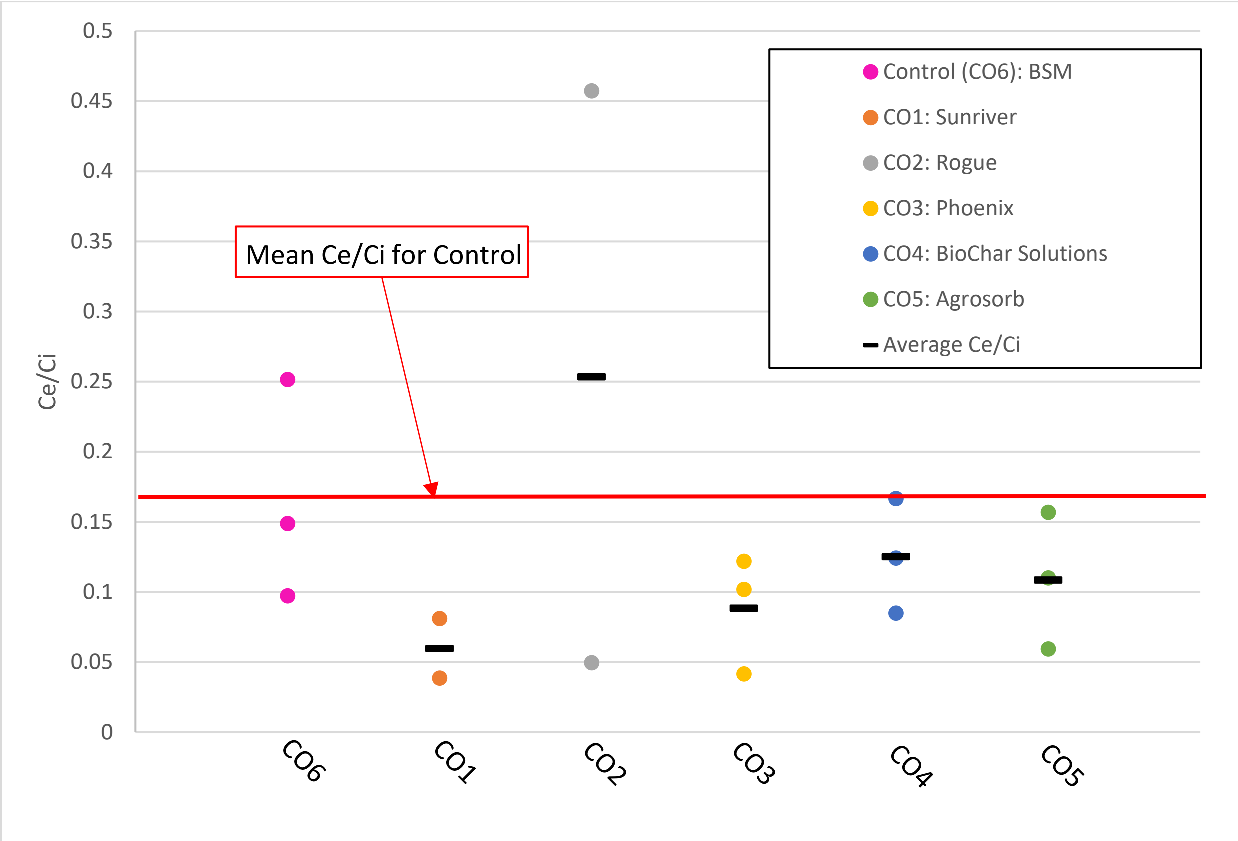

Figure 7. Ce/Ci Total PCB Concentrations for Column Test Media

Figure 8 compares the concentrations from this study to those from the CW4CB pilot site that tested BSM next to BSM with biochar. For ease of comparison, the influent concentrations from both field site influents are combined into one dataset under the label CW4CB Combined Influent. All five of the biochar-amended BSM columns are combined into one dataset under the label Study Biochar.

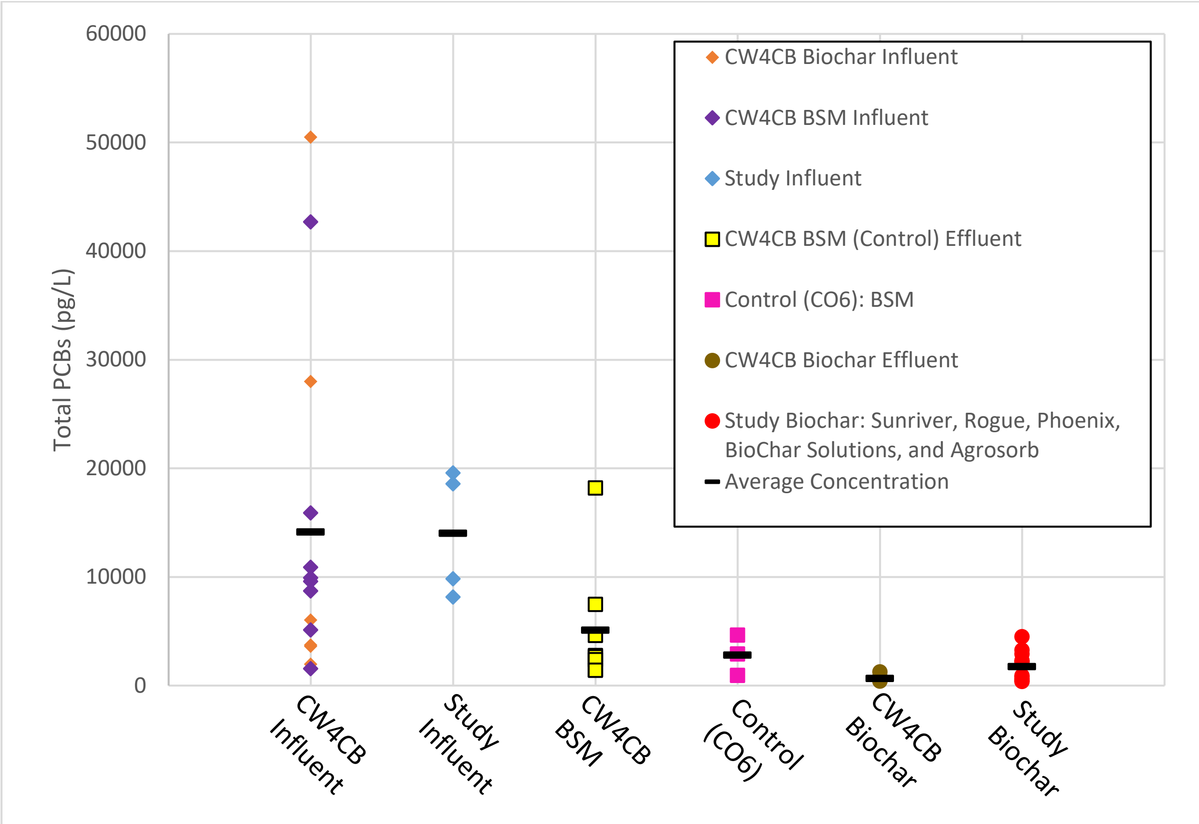

Figure 8. Total PCB Concentrations for CW4CB Pilot Sites Influent, Undiluted Influent Runs, CW4CB BSM Effluent, and Column Test BSM Effluent, CW4CB Biochar-amended Effluent, and Column Test Biochar-amended Effluent

The PCB concentrations in stormwater used in this study were within the range of PCB concentrations in influent at the CW4CB location that compared BSM and biochar-amended BSM. The range of influent concentrations for this study (9,860 pg/L to 19,600 pg/L) was narrower than the ranges of influent concentrations for both the CW4CB BSM site (1,560 pg/L to 42,700 pg/L) and the CW4CB biochar-amended site (1,990 pg/L to 50,500 pg/L). The range of influent concentrations from this study overlapped the middle range of the CW4CB grouped influent concentrations with the influent mean concentration from this study lower by 116 pg/L (less than 1% difference). The Control BSM effluent concentrations of this study were nearly half the concentrations of the CW4CB study BSM effluent concentrations. However, the biochar-amended BSM effluent concentrations from this study were higher than the biochar-amended CW4CB study. As before, normalized effluent is examined for the case that effluent has some dependence on influent.

Figure 9 compares effluent concentrations normalized by their paired influent concentrations for the CW4CB BSM, study BSM, the CW4CB biochar, and all study biochars combined.

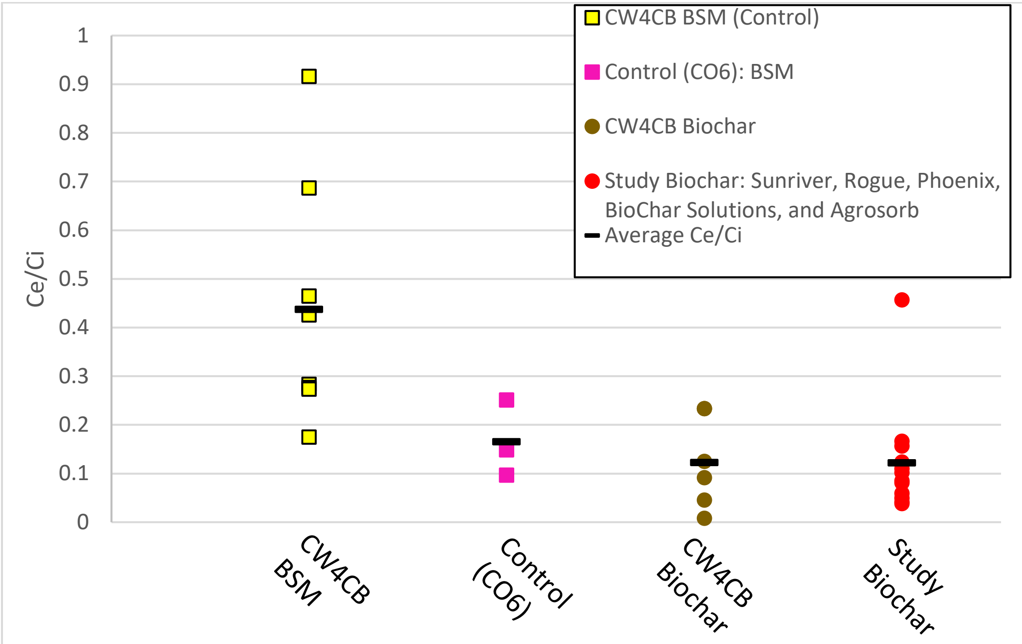

Figure 9. Ce/Ci Total PCB Concentrations for CW4CB Pilot Sites and All Biochar Test Media

Results from both CW4CB and this study indicate that PCB removal by biochar-amended BSM is less sensitive to influent concentrations than standard BSM. The influent-normalized performance (Ce/Ci) for the standard BSM (control) in this study appeared slightly improved compared to the CW4CB control BSM pilot site. In contrast, BioChar Solutions (CO4) influent-normalized performance (Ce/Ci) in this study was similar to the CW4CB biochar-amended pilot site (also using BioChar Solutions).

The improved performance suggests that conditions in the column tests were more ideal, or at least not worse, than field conditions. The normalized biochar data showed better agreement, but a secondary control to the field condition was planned to allow a more direct comparison between the same biochar. This was accomplished by using the same biochar (BioChar Solutions, CO4) as was used at the CW4CB site. The CW4CB biochar site and the column constructed with the same biochar (CO4) are compared in Figure 10, including the dilution run. Though data are limited, it appears that the CW4CB performance is slightly superior, which is in contrast to the comparison of standard BSM. This suggests that there are performance factors influencing the CW4CB site that were not replicated in this study, and there may be differences, besides biochar, contributing to the improvement of performance of the CW4CB biochar over the standard BSM. The CW4CB biochar site also tested a wider range of influent concentrations (Figure 8), which may be another cause for differing results.

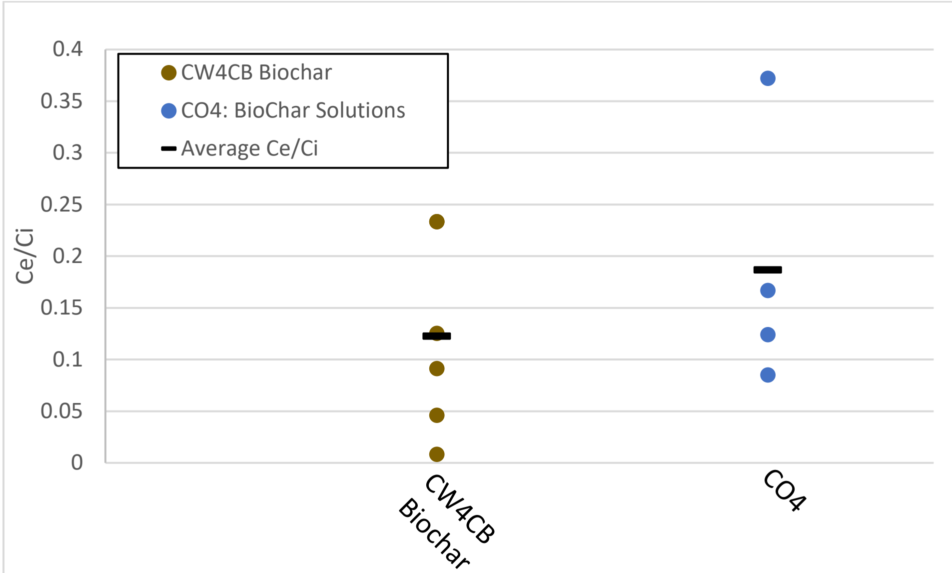

Figure 10. Ce/Ci Total PCB Concentrations for CW4CB Biochar Pilot Site and BioChar Solutions Test Media

All effluent concentrations are plotted against influent concentrations in Figure 11, and all media show removal of PCBs as evidenced by all points appearing under the 1:1 line representing no treatment. The effluent data appears stacked due to the common influent for three of the five runs. Overall, the data may be indicating an irreducible concentration somewhere around 300 pg/L (select Run 3 effluent concentrations) to 800 pg/L (Run 4 dilution effluent concentration), but only a single data point represents the lower end of the influent range.

The dilution run gives a rough estimation of whether biochar-amended BSM would be effective in treatment of concentrations that are lower than the sampled watershed. The single run was performed with stormwater diluted at a one-to-nine ratio to assess one biochar-amended BSM (BioChar Solutions) and the control BSM (The control BSM analysis is not available). The biochar-amended BSM continued to show reduction potential, but the removal relative to influent was not as great, indicating that the influent value may be approaching an irreducible concentration. Even though this analysis is on the most limited basis, the data indicate that biochar may also show benefits at lower concentrations. However, the variation in water column concentration is much larger than that tested in this study. The range of the total PCBs concentration of influent samples was compared to the range found in a summary of water column PCBs concentration data in the Bay Area (McKee et al. 2015). Of 31 locations sampled over several years, seven had concentrations lower than the range of the media study, 16 were within the range, and eight were above. Most of these monitoring locations were in-channel rather than higher upstream in the drainage system where BSM is more traditionally used. Consequently, actual concentrations at upstream BSM locations could vary even more since discrete PCB source areas should get diluted as other cleaner water and sediment combine downstream. Gilbreath et al. (2018) reported a maximum of 160,000 pg/L, a minimum of 533 pg/L, and a median stormwater concentration of 8,923 pg/L, but that is also based on many of the same in-channel monitoring locations. As a result, the biochars that show some promise for further field testing were exposed to a fairly small range of concentrations that would likely be found at random green infrastructure locations.

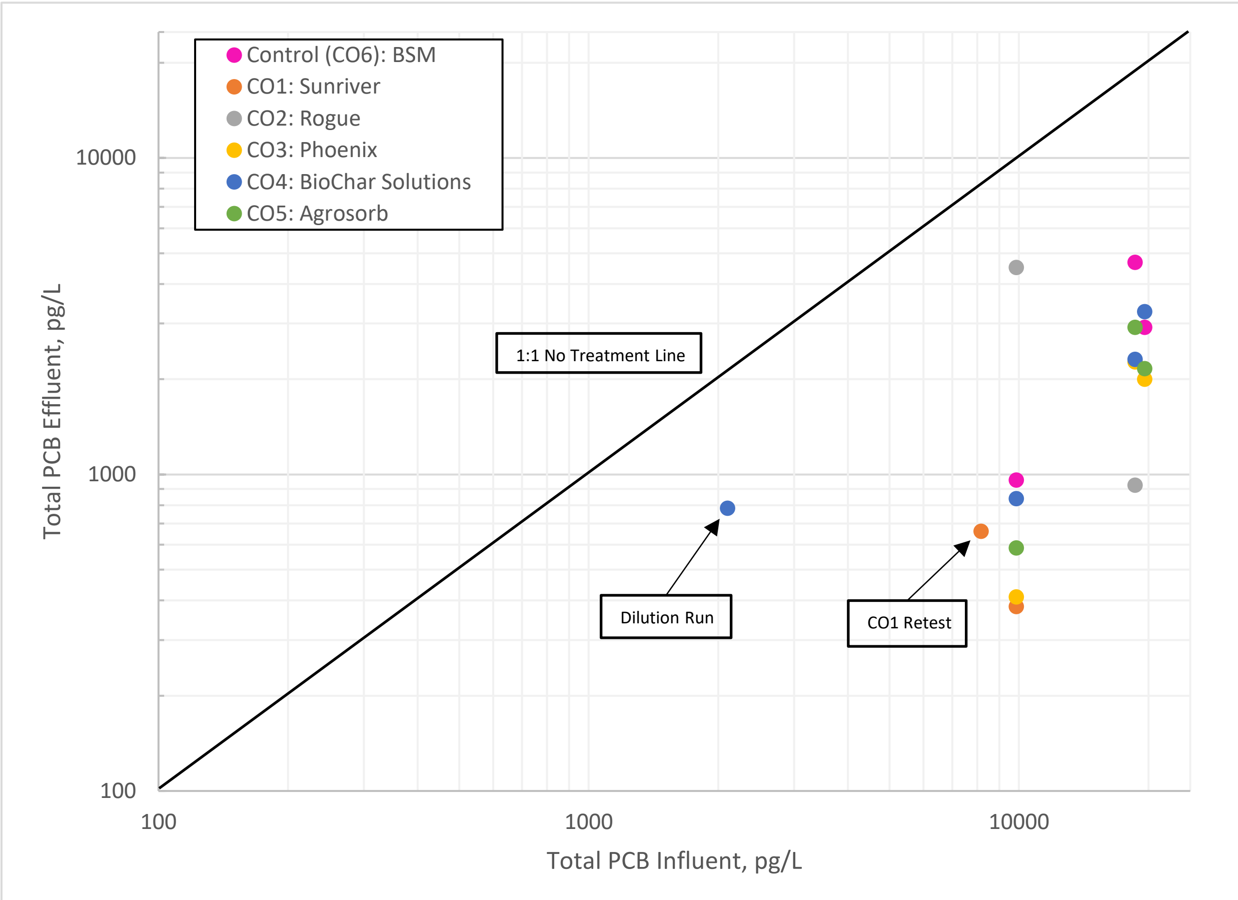

Figure 11. Total PCB Concentrations for all Study Effluent versus Influent

3.3.2 Mercury

Figure 12 shows mercury concentrations for all four test runs in chronological order. Phoenix (CO3) and Agrosorb (CO5) biochar-amended BSM show mercury removal across all three test runs. All biochar-amended BSM shows improved treatment over the standard BSM, except for BioChar Solutions (CO4) in the first and second run.

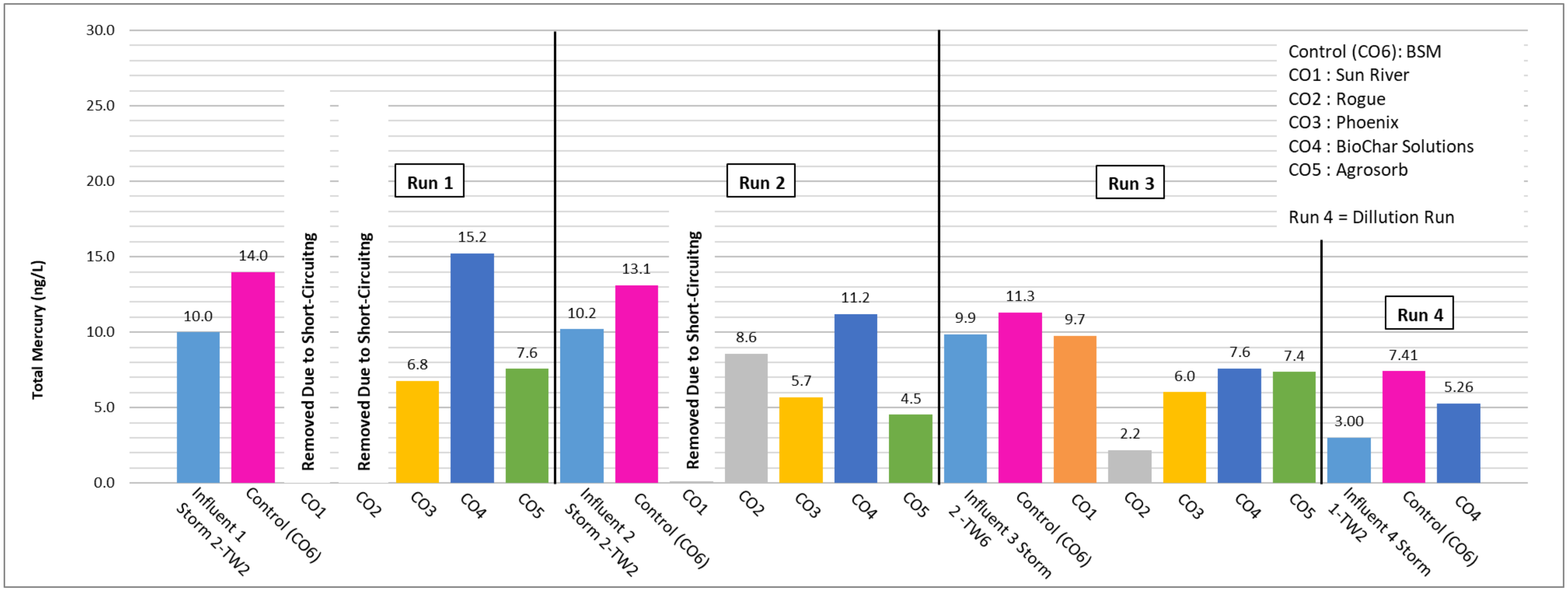

Figure 12. Mercury Concentrations over Time

As stated in the PCB results section, Sunriver biochar-amended BSM (CO1) had unusually high infiltration rates for the first and second test runs and Rogue biochar-amended BSM (CO2) had high rates for the first test run. These data points were removed from the total PCBs dataset for all analyses and were also removed from the mercury dataset.

The mercury export by the control BSM (CO6) for all test runs could indicate that the media itself is releasing mercury. Biochar-amended BSM contain less BSM by volume, which may partially explain the lower mercury concentrations for those columns. Mercury export will likely decrease at locations with higher influent concentrations, and mercury removal is possible if the influent concentration is substantially higher than the export concentration. Gilbreath et al. (2018) reported a median stormwater concentration of 29.2 ng/L, which is almost three times the influent concentration in the three primary test runs.

3.3.3 Other Constituents

Total PCB and mercury concentrations were compared to SSC and TOC respectively. Turbidity was collected during sampling and seasoning runs to provide immediate insight into the performance of the filters throughout the experiment.

Figure 13 shows the relationship between total PCBs and SSC divided into two groups, Influent and Effluent samples.

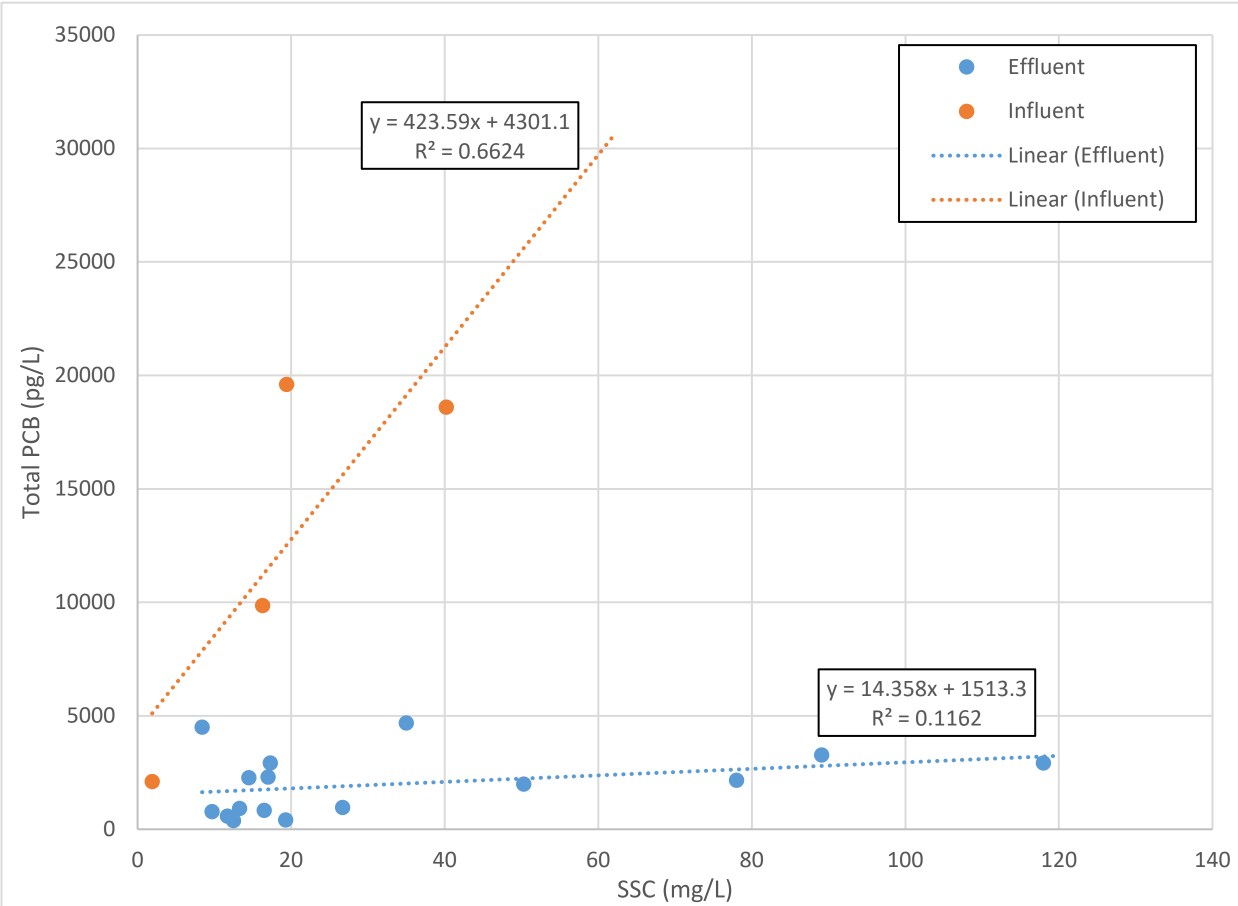

Figure 13. Comparison of Total PCB to SSC Concentrations

Figure 13 confirms the relationship between PCBs and SSC in influent samples (R^2 value of 0.66). The effluent samples have a much shallower regression line with a very low R^2 value of 0.116. This poor correlation is also evidence of contribution of solids from the media rather than the passing of influent solids through the media to the effluent sample, assuming low PCB concentration in the media.

There is no expected correlation between TOC and mercury. It is presented for consideration in cases where methylation is a concern. Figure 14 presents total mercury versus TOC. Normalizing the TOC effluent concentrations by dividing them by influent concentrations shows that TOC at least doubles from influent to effluent, with more typical increases around eight times (Figure 15). This increase is likely from both loss of BSM and leaching of dissolved organic content. Figure 16 shows normalized SSC effluent, which demonstrates substantial export of media, but not as much as TOC. The higher export of TOC is likely due to TOC analysis accounting for particulate and dissolved organic content, while SSC only measures particulates. SSC and TOC increases in these column tests should not be construed as representing field performance. To minimize the concentration reduction in the underdrain, a thin (2-inch) layer of washed coarse sand was used. This underlying coarse sand layer may have exacerbated loss of media solids and consequential increase in TOC and SSC compared to a traditional underdrain with more depth, more fines, and more restriction to infiltration rate.

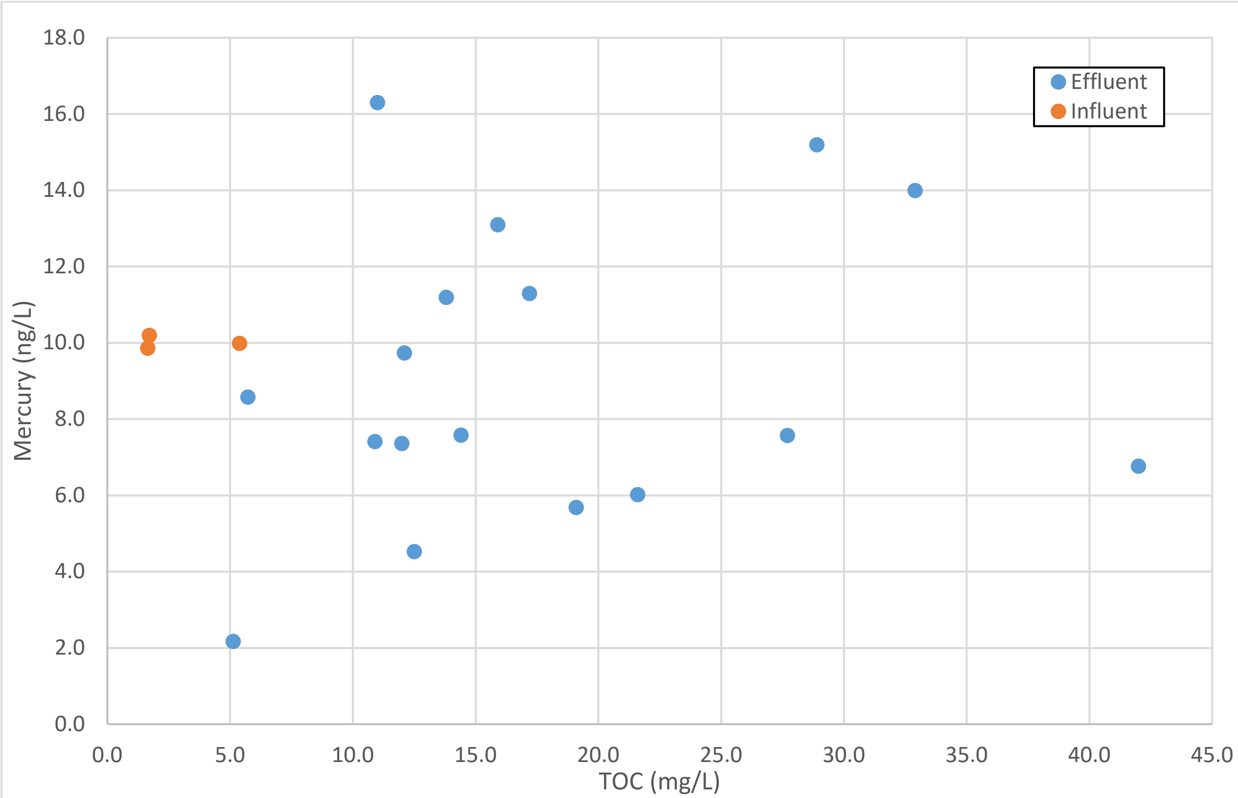

Figure 14. Comparison of Mercury to TOC Concentrations

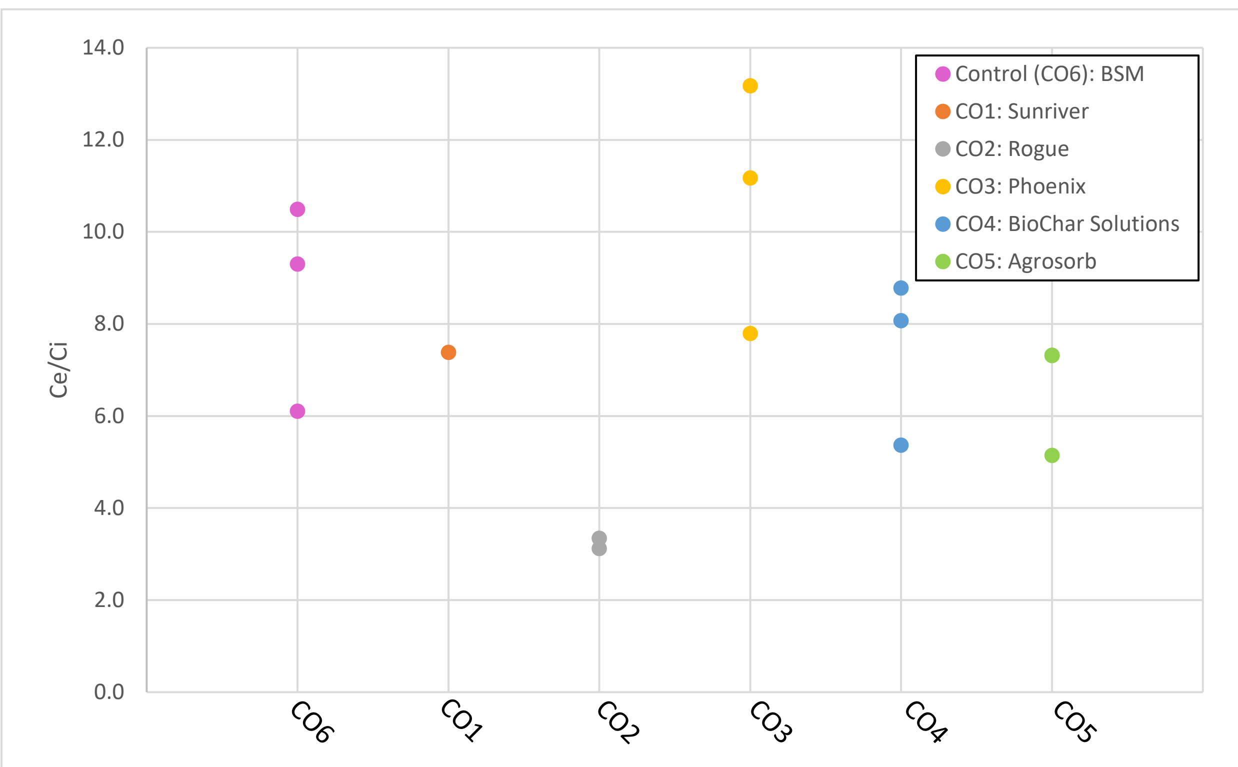

Figure 15. Ce/Ci TOC Concentrations for Column Test Media

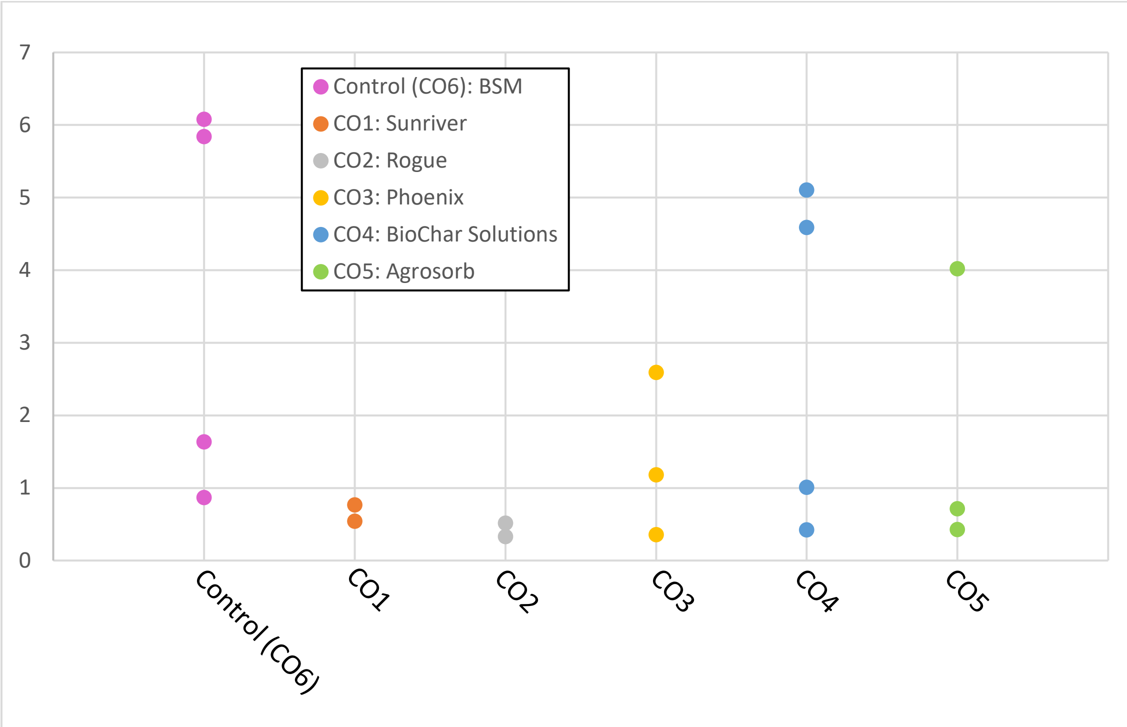

Figure 16. Ce/Ci SSC Concentrations for Column Test Media

Figure 17 shows turbidity measurements for all columns in chronological order over all runs (sampling and seasoning). During the first sampling test run, it was observed that the effluents of all columns had high turbidity and were not representative of a well-established media (see Table 4 for all concentrations). Two seasoning runs were performed next, and the effluent turbidity of all columns stabilized by the end of the second run. Turbidity data is in Appendix F.

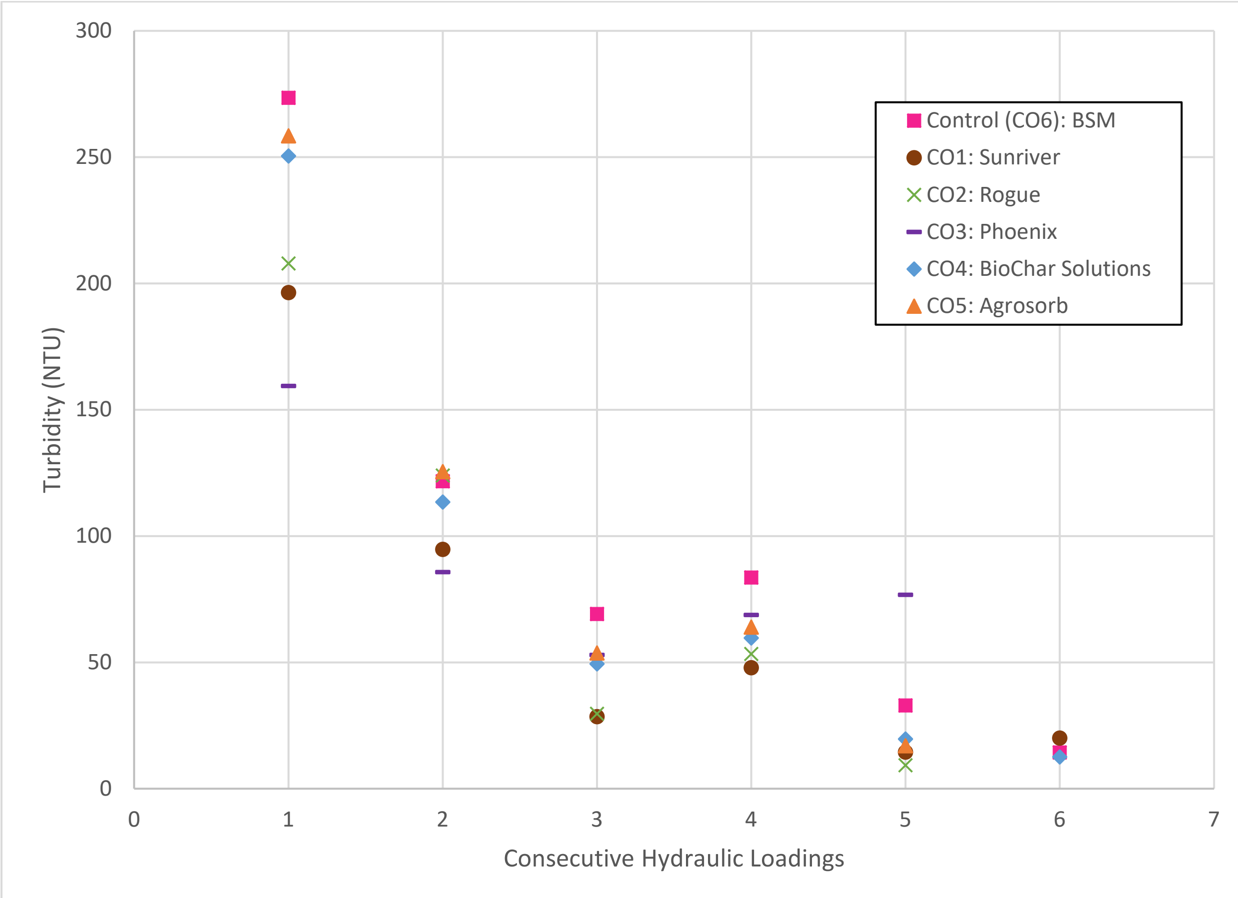

Figure 17. Average Turbidity versus Consecutive Hydraulic Loading (Sampling Runs are labeled 1, 3, 4, 5, and 6 and Seasoning Loading are labeled 2 and 3)

3.4 Statistical Tests

The statistical analysis (Mann-Whitney U test) on normalized effluent PCB concentrations was unable to establish statistical significance at 90% confidence among media type due to the small sample size, even when grouped by class (e.g., with biochar and without). This also held for mercury. Consequently, further statistical tests were not pursued.

4 CONCLUSIONS AND RECOMMENDATIONS

The goal of this study, as identified in the Monitoring Study Design (Appendix A), was to identify biochar media amendments that improve PCB and mercury load removal by bioretention BMPs. The primary management question supporting that goal was: "Are there readily available biochar-amended BSM that provide significantly better PCB and mercury load reductions than standard BSM and meet MRP infiltration rate requirements?" And the particular purpose of the laboratory testing in this study was: "screen alternative biochar-amended BSM and identify the most promising for further field testing." This study's use of bench scale column testing suggests that there may be some utility in pre-testing materials before use in field applications to ensure that they are likely to meet infiltration requirements at the project site, as well as provide some preliminary evidence of improved or at least equivalent pollutant removal as standard BSM.

4.1 Conclusions

Nine biochar were readily available from suppliers in the Western United States, and five were tested in this study to compare their impacts on PCBs and mercury concentrations in effluent. All five biochar-BSM blends showed evidence of overall improved PCB and mercury performance compared to the standard BSM for influent concentrations ranging from 9,860 pg/L to 19,600 pg/L[8]. Though performance varied, no biochars could be conclusively eliminated from consideration in future field study. The results support the following observations:

- Phoenix, Sunriver, BioChar Solutions, and Agrosorb appear to offer improved PCB removal compared to standard BSM and the other biochar-amended BSM.
- Phoenix and Agrosorb appear to offer improved mercury removal compared to standard BSM and the other biochar-amended BSM.
- Based on a single run on one column to explore removal at lower influent concentrations, biochar-amended BSM provided removal of PCBs at an influent concentration of 2,100 pg/L. BSM performance at this lower influent concentration could not be reported due to the sample being lost. Neither BSM nor biochar-amended BSM provided removal of mercury at an influent concentration of 3.00 ng/L.
- High initial infiltration rates (associated with short-circuiting and higher pore velocities) correlated to poor performance. Three of four runs with high infiltration rates correlated with poor reduction of PCBs and mercury. All three runs with poor performance (two of which were on one column) occurred prior to a run with a moderate infiltration rate (< 12 in/hr).
- Saturated hydraulic conductivity had poor correlation to the falling head infiltration rates estimated during the water quality sampling runs so biochar that were eliminated from column testing based on saturated hydraulic conductivity tests may be candidates for future testing.

Because the study was a screening level analysis of biochars for potential further study, the limited data for each biochar did not allow for exploration of several factors that are presented in the following section for consideration in development of future study designs.

4.2 Recommendations

Based on this study, biochar shows promise in marginally increasing performance for PCB and mercury removal, however, increased benefit relative to increased cost was not analyzed. With such limited data, meaningful benefit-cost analysis may require collection of substantial field data. Because of the marginal increase in performance, standard BSM should be a component of future side-by-side testing of biochar-amended BSM. Sample size should be selected to provide suitable statistical power to better understand and qualify the performance differences. Other study considerations include long-term performance, media life expectancy, performance for other pollutants, impacts to plant health and water use, and maintenance ramifications. The study team developed the following recommendations for potential biochar testing.

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8 The lowest influent concentration for Sunriver (CO1) was 8,160 pg/L.

4.2.1 Biochar Selection

For enhanced PCB removal, biochar candidates for further field testing are Phoenix, Sunriver, BioChar Solutions, or Agrosorb. If mercury removal is a design consideration, Phoenix and Agrosorb should be selected over Sunriver and BioChar Solutions. All biochar-amended BSM have falling head drain times in the column tests that were faster than the control BSM, so hydraulic performance should not influence selection. Other factors, such as cost and local sourcing should be considered in final biochar selection. Due to a lack of differentiation of performance and a lack of correlation between performance and cost, less expensive biochar that were not tested here may offer higher benefit/cost. Column tests could provide data for an indication of benefit/cost prior to field testing, but more data is recommended to quantify performance than what was specified in this study for screening-level analysis.

4.2.2 Site Selection

The results of this study could also have implications on site selection for future study. As a general principal, study locations should represent concentrations typical of watersheds that will be receiving green infrastructure, unless those concentrations are below the irreducible concentration. The data indicate that irreducible PCBs concentrations may be occurring around 1,000 pg/L. It is unclear for total mercury. Data from other studies in the San Francisco Bay Area should be consulted to develop a better estimate of irreducible concentrations so future study can avoid areas that are too clean for the technology to be effective for these pollutants.

4.2.3 Outlet Control

Outlet control may be the most important factor in performance. Outlet controls minimize short-circuiting (preferential flow paths) and they increase contact time. Elevated outlets can also increase contact time in between storm events, but this may also affect mercury speciation by providing an anoxic environment where methylation may occur. Further study should control for both contact time and presence of biochar to determine which has the greatest effect in field conditions. Further investigation into contact time (i.e., infiltration rates) and underdrain behavior at the CW4CB biochar location may also be helpful in development of future study plans.

4.2.4 Saturated Hydraulic Conductivity Testing Requirements

The representativeness and utility of the saturated hydraulic conductivity test under typical compaction conditions for highly organic and friable material may be a matter worth discussion within the appropriate BASMAA bioretention working groups. Use of outlet control could obviate the verification of the upper-end conductivity. A lower-end conductivity may still be recommended to assure that the outlet control governs flow rather than the media.

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APPENDIX A: MONITORING STUDY DESIGN

POC Monitoring for Management Action Effectiveness

Monitoring Study Design

Final, September 2017

Prepared for:

Bay Area Stormwater Management Agencies Association

Prepared by:

EOA inc.
1410 Jackson Street
Oakland, California
94612

Water Programs, Sacramento State
6000 J Street
Sacramento, California
95819

SFEI
4911 Central Avenue
Richmond, California
94804

Kinnetic Laboratories Incorporated
307 Washington Street
Santa Cruz, California
95060

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1. Introduction

Discharges of PCBs and mercury in stormwater have caused impairment to the San Francisco Bay estuary. In response, the Regional Water Board adopted total maximum daily loads (TMDLs) to address these pollutants of concern (POC) (SFBRWQCB, 2012). Provisions C.11 and C.12 the Municipal Regional Stormwater NPDES Permit, MRP (SFBRWQCB, 2015) implement the Mercury and PCB Total Maximum Daily Loads (TMDLs) for the San Francisco Bay Area. These provisions require mercury and PCB load reductions and the development of a Reasonable Assurance Analysis (RAA) demonstrating that control measures will be sufficient to attain the TMDL waste load allocations within specified timeframes. Provision C.8.f of the MRP supports implementation of the mercury and PCB TMDLs provisions by requiring that Permittees conduct pollutants of concern (POC) monitoring to address the five priority information needs listed below.

1. *Source Identification* – identifying which sources or watershed source areas provide the greatest opportunities for reductions of POCs in urban stormwater runoff;
2. *Contributions to Bay Impairment* – identifying which watershed source areas contribute most to the impairment of San Francisco Bay beneficial uses (due to source intensity and sensitivity of discharge location);
3. *Management Action Effectiveness* – providing support for planning future management actions or evaluating the effectiveness or impacts of existing management actions;
4. *Loads and Status* – providing information on POC loads, concentrations, and presence in local tributaries or urban stormwater discharges; and
5. *Trends* – evaluating trends in POC loading to the Bay and POC concentrations in urban stormwater discharges or local tributaries over time.

Table 8.2 of Provision C.8.f identifies the minimum number of samples that each MRP Countywide Program (i.e., Santa Clara, San Mateo, Alameda, and Contra Costa) must collect and analyze to address each monitoring priority. Although individual Countywide monitoring programs can meet these monitoring requirements, some requirements can be conducted more efficiently and will likely yield more valuable information if coordinated and implemented on a regional basis. The minimum of eight (8) PCB and mercury samples required by each Program to address information priority #3 is one such example. Findings from a regionally-coordinated monitoring effort would better support development of the RAA.

This Study Design describes monitoring and sample collection activities designed to meet the requirements of information priority #3 of Provision C.8.f of the MRP. The activities planned include field sampling of hydrodynamic separators and laboratory experiments with amended bioretention soils. Study planning is important to ensure that the right type of data are collected and there is a sufficient sample size and power to help address the management questions within the available time and budget constraints. Essential components of the study plan include describing problems, defining study goals, identifying important study parameters, specifying methodologies, and validating and optimizing the study design.

2. Problem Definition

Studies conducted to date have identified PCB source areas in the Bay Area where pollutant management options may be feasible and beneficial. Enhanced municipal operational PCB management options (e.g., street sweeping, storm drain line cleanout) have the advantage of being familiar and well-practiced, address multiple benefits, and the cost-benefit may exceed that for stormwater treatment (BASMAA, 2017a). Site-specific stormwater treatment via bioretention, however, is now commonly implemented to meet new and redevelopment (MRP Provision C.3) requirements. An added benefit of redevelopment is that PCB-laden sediment sources can be immobilized. However, many areas where certain land uses or activities generate higher PCB concentrations in runoff are unlikely to undergo near-term redevelopment, and instead may only be subject to maintenance operations or stormwater BMP retrofit projects implemented by the municipality. Consequently it is valuable to maximize cost effective PCB removal benefit of both operations and maintenance, and stormwater treatment.

Two treatment options that have the potential to reduce PCB discharges include hydrodynamic separators (HDS units) and enhanced bioretention filters. These options were pilot-tested in the Clean Watersheds for a Clean Bay (CW4CB) Project (BASMAA, 2017a). HDS units are being implemented for trash control throughout the Bay Area and collect sediment to some extent along with trash and other debris. Quantifying PCB mass removed by these units will help MRP Permittees account for the associated load reductions. For these and other control measures, an Interim Accounting Methodology has been developed based on relative mercury and PCBs yields from different land use categories (BASMAA, 2017c). Bioretention is a common treatment practice for new development and redevelopment in the San Francisco Bay Area, so enhancing the performance of bioretention is also attractive.

At this time reducing mercury loads in stormwater runoff is a lower priority than PCBs load reduction. The assumption during the MRP 2.0 permit term is that actions taken to reduce PCBs loads in stormwater runoff are generally sufficient to address mercury. Therefore, optimizing stormwater controls for PCBs is the primary focus in this study.

2.1 HDS Units

Limited CW4CB monitoring conducted at two HDS sites was used to calculate the mass of PCBs in trapped sediment (BASMAA, 2017a). The two sites sampled were Leo Avenue in San Jose and City of Oakland Alameda and High Street. The Leo Avenue HDS unit treats runoff from approximately 178 acres of watershed with a long history of industrial land uses, including auto repair and salvage yards, metal recyclers, and historic rail lines. The City of Oakland Alameda and High Street HDS has a tributary drainage area of approximately 35 acres with a high concentration of old industrial and commercial land uses, including historic rail lines.

Sampling of the two CW4CB HDS units was opportunistic and associated with scheduled cleanouts. Two sump cleanout events took place in August 2013, one at the Leo Avenue HDS unit and one at the Alameda and High Street HDS unit. However, due to a lack of captured sediment the samples collected were aqueous phase samples instead of sediment samples. An additional cleanout took place at Leo Avenue in October 2014. A sump sediment sample collected and analyzed during this cleanout contained total PCB concentrations of 1.5 mg/kg and mercury concentrations of 0.33 mg/kg for sediment less than 2 mm in size, and estimated annual total PCB and mercury removals were 375 mg and 82.4 mg, respectively (Table 2.1). The HDS sediment concentrations are comparable to previous Leo Avenue watershed measurements in sediments from piping assessed via manholes, drop inlets/catch basins, streets/gutters, and private properties (ND to 27 mg/kg for PCBs and 0.089 to 6.2 mg/kg for mercury) (BASMAA, 2014). At the Alameda and High Street HDS unit, tidal influences of Bay water prevented additional monitoring.

Table 2.1 Summary of Data Collected from Leo Avenue HDS during October, 2014 Annual Cleanout Event

Parameter	Result	Units
Volume of Sediment Removed	4	Cubic yards
Total PCBs Concentration	1.5	mg/Kg
Mercury Concentration	0.33	mg/Kg
Bulk density	0.67	g/cm^3
Percent solids	39	%
Particle Size (< 2 mm)	31	%

There are no known published studies characterizing HDS sediment for PCBs or mercury, so the Leo Avenue results are compared to relevant drain inlet/catch basin sediment studies. In the Bay Area, different municipalities have collected and analyzed drain inlet cleaning sediment samples. The analytical results for these drain inlet sediment samples are summarized in Table 2.2 (BASMAA, 2014). As can be seen from Table 2.2, the Leo Avenue sediment PCB concentrations are higher than those measured in Bay Area drain inlet sediment by up to an order-of-magnitude, but mercury concentrations are comparable.

Table 2.2 Summary of Bay Area Drain Inlet Sediment Concentration Data

(Based on readily available data; see BASMAA (2016b) for additional summaries for street and storm drain sediment)

	PCBs			Mercury		
Municipality	No. Drain Inlet Sediment Samples	Mean PCB DI Sediment Concentration (mg/Kg)	Median PCB DI Sediment Concentration (mg/Kg)	No. Drain Inlet Sediment Samples	Mean Mercury DI Sediment Concentration (mg/Kg)	Median Mercury DI Sediment Concentration (mg/Kg)
Fairfield & Suisun	8	0.244	0.055	16	0.510	0.228
San Mateo County Municipalities	29	0.318	0.123	28	0.160	0.147
San Carlos	22	0.267	0.129	25	0.167	0.147
Alameda County Municipalities	47	0.294	0.122	75	0.384	0.204
Berkeley	8	0.147	0.122	11	0.343	0.241
Oakland	24	0.402	0.155	28	0.539	0.297
San Leandro	11	0.219	0.106	21	0.230	0.151
Contra Costa County Municipalities	46	0.515	0.168	48	0.413	0.308
Richmond	31	0.736	0.482	28	0.460	0.349

Notes:
Mean and median drain inlet sediment concentrations were calculated from the SFEI database (SFEI 2010, KLI and EOA 2002; City of San Jose and EOA 2003).

Monitoring by the City of Spokane, Washington, showed total PCBs in catch basin sediment ranged between 0.025 mg/kg and 1.7 mg/kg for an industrial area with known PCB contamination (City of Spokane, 2015). A City of San Diego study characterized sediments in eight catch basins in a 9.5 acre area of downtown San Diego classified as high density mixed use with roads, sidewalks, and parking lots (City of San Diego, 2012). Concentrations of common aroclors in the catch basin sediments varied from about 0.040 to over 0.9 mg/kg. Monitoring by the City of Tacoma showed PCB concentrations in stormwater sediment traps varied from nondetect to a maximum near 2 mg/kg (City of Tacoma, 2015). The highest PCB concentrations in catch basin sediments ranged from 16 mg/kg in downtown Tacoma to 18 mg/kg in East Tacoma. These published drain inlet/catch basin studies show that PCB and mercury concentrations can vary substantially in storm drain sediments depending on the characteristics of the watershed.

Sampling of captured sediment at the Leo Avenue HDS in San Jose highlighted the potential of HDS maintenance as a management practice for controlling PCB and mercury loads. The BASMAA Interim Accounting Methodology that is currently being used to calculate load reductions assumes a default 20% reduction of the area-weighted land-used based pollutant yields for a given catchment. This default value was based on average percent removal of TSS from HDS units based on analysis of paired influent/effluent data. However, significant data gaps remain in determining the effectiveness of this practice and expected load reductions. HDS sediment sampling has been limited to a few samples. PCB concentrations in the Leo Avenue HDS sample were much higher than average concentrations in Bay Area drain inlet sediment. Drain inlet/catch basin sediment sampling by others suggests that sediment PCB and mercury concentrations can vary substantially from watershed to watershed. **The monitoring performed to date is not sufficient to characterize pollutant concentrations of sediment captured in HDS units that drain catchments with different loading scenarios (e.g., land-uses, stormwater volumes, etc.), nor to estimate the percent removal based on the pollutant load captured by the HDS unit. Additional sampling is needed to better quantify the PCB and mercury loads capture by these devices, and calculate the percent removal achieved**. Consequently, quantification of PCBs removed at other HDS locations and evaluation of the percent load reduction achieved is needed to provide better estimates of PCB load reductions from existing HDS unit maintenance practices.

2.2 Bioretention

The results of monitoring the performance of bioretention soil media (BSM) amended with biochar at one CW4CB pilot site suggest that the addition of biochar to BSM is likely to increase removal of PCBs in bioretention BMPs. Biochar is a highly porous, granular material similar to charcoal. In the CW4CB study, the effect of adding biochar to BSM was evaluated using data collected from two bioretention cells (LAU 3 and LAU 4) at the Richmond PG&E Substation 1st and Cutting site. At this site, cell LAU 3 contains standard engineered soil mix (60% sand and 40% compost) while cell LAU 4 contains a mix of 75% standard engineered soil and 25% pine wood-based biochar (by volume).

Figure 2.1 shows a cumulative frequency plot of influent and effluent PCB concentrations for the two bioretention cells. Although influent PCB concentrations at the two cells were generally similar, effluent PCB concentrations were much lower for the enhanced bioretention cell (LAU 4) compared to those for the standard bioretention cell (LAU 3). The results for total mercury were different from those for PCBs, with both cells demonstrating little difference between influent and effluent concentrations. These CW4CB monitoring results suggest that the addition of biochar to BSM may increase removal of PCBs but not mercury from stormwater. However, analysis of methylmercury indicated that BSM may encourage methylation while biochar may mitigate the effect such that there is no substantial transformation of mercury to methylmercury. Tidal influences at 1st and Cutting also may be a contributing factor that should be controlled in future study.

The majority of biochar research conducted to date has focused on agricultural applications, where biochar has been shown to improve plant growth, soil fertility, and soil water holding, especially in sandier soils. Only a handful of field-scale projects have investigated the effects of biochar in stormwater treatment and no known field studies have investigated removal of mercury or PCBs from stormwater by biochar-amended media.

A recent laboratory study on the effect of biochar addition to contaminated sediments showed that biochar is one to two orders of magnitude more effective at removing PCBs from soil pore water than natural organic matter, and may be effective at removing methylmercury but not total mercury (Gomez-Eyles et al., 2013). A laboratory column testing study to determine treatment effectiveness of 10 media mixtures showed that a mixture of 70% sand/20% coconut coir/10% biochar was one of the top performers and cheaper than similarly effective mixtures using activated carbon (Kitsap County, 2015). Liu et al (2016) tested 36 different biochars for their potential to remove mercury from aqueous solution and found that concentrations of total mercury decreased by >90% for biochars produced at >600◦C but about 40–90% for biochars produced at 300◦C.

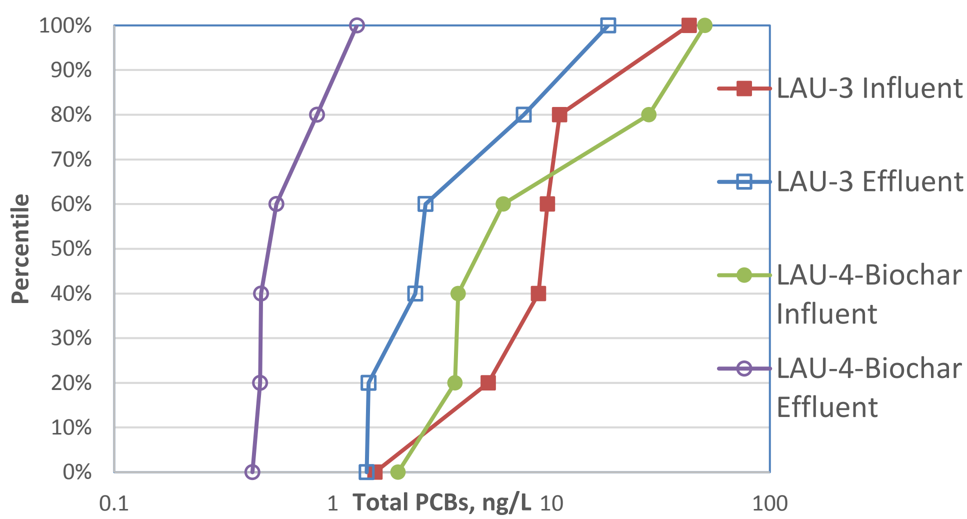

Figure 2.1 Cumulative Frequency Distribution of Total PBCs Influent Concentrations for Bioretention Media with and without Biochar

Monitoring of two bioretention cells at the Richmond PG&E Substation 1st and Cutting pilot site showed greater PCB removal for a biochar-amended BSM than that for standard BSM.

However, to date sampling has been limited to one test site and one biochar amendment, and the operational life of the amended media is unknown. **Besides the CW4CB study, there are no published literature studies on field PCB and mercury removal for biochars. Additional field testing can confirm the effectiveness of bioretention implementation in more typical conditions, and laboratory testing is recommended as an initial screening to help identify potential biochars for field testing**. Laboratory testing using actual stormwater from the Bay Area can be a cost-effective screening tool to identify biochar media that are effective for PCB removal, do not exacerbate mercury problems or even improve mercury removal, and meet operational requirements, including an initial maximum infiltration rate of 12 in/h and a minimum long-term infiltration capacity of 5 in/h.

3. Study Goals

The goals of this study identified from the problem statements are as follows:

1. Quantify annual PCB and mercury load removals during maintenance (cleanout) of HDS units
2. Identify biochar media amendments that improve PCB and mercury load removal by bioretention BMPs

To reach these goals, the following management questions are prioritized as primary or secondary management questions.

3.1 Primary Management Questions

A properly conceived study will address the study goals in a manner that supports planning for future management actions or evaluating the effectiveness or impacts of existing management actions. The resulting primary management questions focus on performance and are:

1. What are the average annual PCB and mercury loads captured by existing HDS units in Bay Area urban watersheds?
2. Are there readily available biochar-amended BSM that provide significantly better PCB and mercury load reductions than standard BSM and meet MRP infiltration rate requirements?

The MRP infiltration rate requirements are described in Provision C.3.c of the MRP (SFBRWQCB, 2015). This provision states the following: "Biotreatment (or bioretention) systems shall be designed to have a surface area no smaller than what is required to accommodate a 5 inches/hour stormwater runoff surface loading rate, infiltrate runoff through biotreatment soil media at a minimum of 5 inches per hour, and maximize infiltration to the native soil during the life of the Regulated Project. In addition to the 5 inches/hour MRP requirement, for non-standard BSM the recently updated BASMAA specification requires "certification from an accredited geotechnical testing laboratory that the bioretention soil has an infiltration rate between 5 and 12 inches per hour" (BASMAA, 2016a).

3.2 Secondary Management Questions

Secondary management questions are helpful, but they are not critical to the usefulness of the study. Study scope, budget, and schedule constraints limit the extent to which they can be addressed. Possible secondary management questions include the following:

HDS

1. How does sizing of HDS units affect annual PCB and mercury loads captured in HDS sediment?
2. Do design differences between HDS units (e.g., single vs multiple chambers) result in significant differences in pollutant capture?
3. How does the frequency of cleanout of HDS units affect load capture?

4. If present, does washout of HDS sediment depend on remaining sediment volume capacity?
5. Are there significant concentrations of PCBs in the pore (interstitial) water of HDS sediment?
6. Are PCBs and mercury removal correlated to removal of better-studied surrogate constituents, such as TSS?
7. Is there evidence of increased methylation within HDS sediment chambers?

Enhanced Bioretention

1. How does biochar performance vary with feedstock?
2. How does biochar performance vary with manufacturing method?
3. Should the biochar be mixed with the BSM or provided as a separate layer below the standard BSM?
4. Does biochar have leaching issues or require conditioning before use?
5. How long does the improved performance of biochar-amended BSM last?
6. Does the promising media increase methylation of mercury?
7. What is the expected increase in BSM costs due to inclusion of media amendment?
8. Does knowledge of the association of PCBs and mercury to specific particle sizes improve understanding of performance?
9. Is mass removal comparable to that expected from a conceptual understanding of removal mechanisms?

The above secondary management questions are provided as examples, and the questions answered will depend on budget, schedule, and actual data collected.

3.3 Level of Confidence

The level of confidence in the answers to the above management questions depends on sample representativeness and size. Samples are considered representative if they are derived from sites or test conditions that are representative of the watershed or treatment being considered. A power analysis can be used after monitoring commences or at the end of a study to determine if sample size is sufficient to draw statistically valid conclusions at a pre-selected level of confidence. Power analysis can also be used prior to study commencement, but its usefulness in estimating sample size requirements may be limited by lack of knowledge of variability in the biochar-amended BSM data to be collected.

Level of confidence can also be assessed in terms of consistency of treatment (e.g., a particular biochar consistently shows better removals than other biochars for a variety of stormwaters), which can be assessed with non-parametric approaches such as a sign-rank test.

Data analysis approaches are discussed in Section 8.5.

4. Study Design Options

An overview of the available study designs is presented here to understand the methods, value, and constraints of each design. This information is helpful in identifying which study designs are appropriate for the various management questions. To answer the primary management questions, the mass of pollutants captured must be quantified. This is accomplished by monitoring pollutant input and export for each HDS unit or media option, or directly quantifying captured pollutant. For example, the typical input and output pathways for a stormwater treatment measure (i.e., BMP) are illustrated in **Error! Reference source not found.**4.1. This overview describes how data are collected and how they are used to answer the primary study questions.

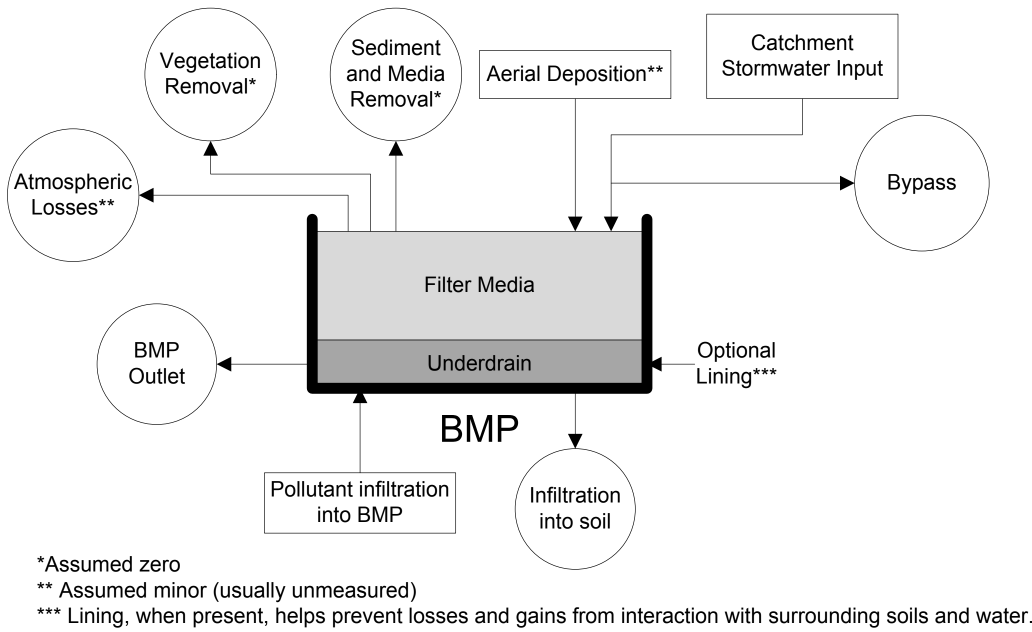

Figure 4.1 Typical BMP system and pollutant pathways

The study designs discussed here address major inputs and losses, but not all. Selection of study design is based on the management questions, the type of BMP(s), the study constraints, and the current and historic conditions of the study area. Each type of study has associated strengths and weaknesses as described below:

- Influent-effluent monitoring
  Influent and effluent monitoring tests water going into and discharging from a selected BMP or treatment option for a particular storm event. This approach is typically used to assess BMP effectiveness. An advantage of this approach is its ability to discern differences in limited data sets. A weakness of this approach is that measured load reductions may not be representative of true load reductions if there is infiltration to the native soil, baseflow entering the BMP, or bypass flows that are not monitored

- Sediment sampling
  Sediment sampling occurs within the BMP or treatment option and is used to estimate cumulative load removed over several storms. Sediment sampling can occur in dry periods.

- Before-after monitoring
  Before-after monitoring occurs at the same location. In the before-after approach, data are collected at some location, a change is made (i.e., a BMP is implemented or modified), and additional data are then collected at the same location. This introduces variability because in field monitoring the storms monitored before BMP implementation may not have the same characteristics as those after implementation.

- Paired watershed monitoring
  Paired watershed attempts to characterize two watersheds that are as similar as possible, except one has BMP treatment (e.g., an HDS unit). The paired watershed approach is typically used when monitoring the influent of the BMP is infeasible. While the storms monitored are the same, inevitable differences in the watersheds often lead to unexplainable variability.

  Paired watershed monitoring is not discussed further because it is not applicable to this study. The scope of work does not require influent monitoring at field sites or monitoring of paired sites without BMPs.

Volume measurement is critical to estimating load removal efficiency for BMPs that have volume losses. Volumes can be measured at influent, effluent, and bypass locations and within the BMP for individual storms or over a longer period.

The following subsections provide more detail on each monitoring approach.

4.1 Influent-Effluent Monitoring

Comparison of influent and effluent water quality and load is the method most often used in studies of treatment BMPs. This method is used to estimate the pollutant removal capability of field devices such as individual BMPs or a series of in-line BMPs (i.e., a treatment train) or laboratory treatment systems such as filter media columns. This type of study results in paired samples. Paired samples are beneficial because fewer samples are needed to show statistically significant levels of pollutant reduction compared to unpaired samples. This can result in substantial cost savings for sample collection and sample analysis.

Comparison of performance among BMPs may not be possible if there are only a limited number of locations because of different influent qualities. This is illustrated in **Error! Reference source not found.** for two non-overlapping BMP data sets, which show confidence intervals for effluent estimates (vertical dashed and dotted lines with arrows) expand as the distance between the hypothetical influent *x*-value and the mean *x*-value of the data increases. Although the effluent estimates at a common influent concentration (solid black square and diamond) may reflect true effluent qualities, confidence in these predictions is low because of this extrapolation and the performance of the two BMPs may not be statistically distinguishable. A better study design is one that selects sites with similar influent characteristics or ensures collection of a sufficient number of samples at or close to the common influent level.

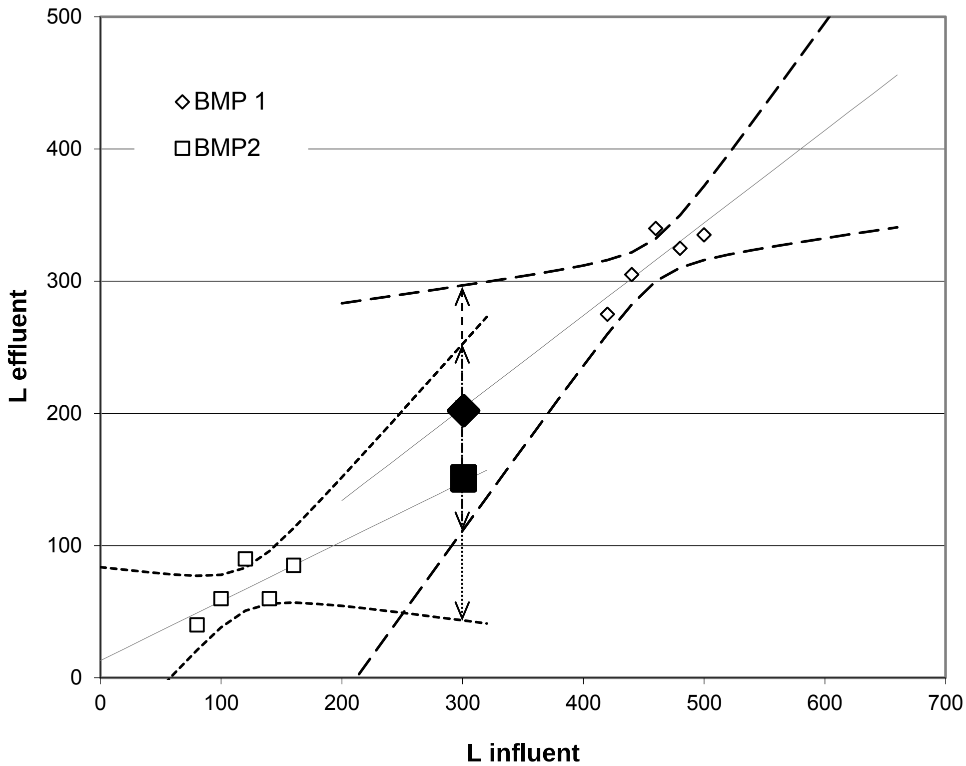

Figure 4.2 Comparison of two hypothetical non-overlapping BMP regressions

4.2 Sediment Sampling

Sediment sampling involves taking samples of actual sediment captured in a BMP in lieu of influent and effluent monitoring. Analysis of the accumulated sediment can provide estimates of the total mass of conservative pollutants removed[1]. An advantage of sediment sampling is reduced cost because expensive storm event sampling is not required. Another advantage is that the measure of pollutants is direct and it is not possible to obtain negative results as in the case of sampling highly variable influent/effluent.

There are a number of limitations to sediment sampling. Annual sediment sampling during a maintenance interval generates fewer data points than influent-effluent sampling throughout a storm season, so comparisons among BMP factors (design, loading, etc.) may require a greater number of monitoring sites. Another limitation is that influent monitoring data are not available to describe how the mass removal estimates may be sensitive to influent loading, and influent monitoring may be required in addition to sediment sampling to

[1] In the context of sediment sampling, "conservative pollutants" are those that are not substantially lost to volatilization or plant uptake in between periods of sediment analysis. Sediment analysis underestimates performance where volatilization or plant uptake is substantial.

characterize pollutant loading. This limitation is addressed in this study during the data analysis by using model estimates of stormwater flows and pollutant loads from each HDS unit catchment to provide estimates of the influent and associated percent removals achieved.

Another limitation of sediment sampling is the potential error resulting in non-homogeneous pollutant distribution within the sediment. Compositing multiple samples will better characterize the sediment, much as the collection of several aliquots throughout a stormwater runoff event can better represent the total volume of water. Mixing the removed sediment before compositing can provide samples that are more homogeneous.

Consequently, the effectiveness of sediment sampling depends on the type of BMP. HDS are the best candidates for sediment sampling. The sumps are cleaned and empty at the start of the study, and the entire mass of retained sediment is removed at each maintenance event (sump cleanout). Conversely, bioretention has background sediment (planting media) that obscure pollutant accumulation. Since pollutants tend to accumulate on the surface of media (typically within the first few inches), surface sediments should be targeted when sampling these systems. Coring these systems and compositing the core sediments will most likely result in further dilution of the PCBs retained in the media, making quantification more difficult. For all systems, larger pieces of litter and vegetation may be difficult to include in the analysis. A conservative approach is to exclude larger material and assume these have little association with PCBs.

4.3 Before-After Monitoring

Pollutant removal can also be estimated by monitoring discharge quality for treatment devices before and after installation. This may be attractive for green street projects that have multiple BMPs with multiple influent and effluent locations. Monitoring all of these individual systems is almost impossible because of space constraints. Note that since the data from before/after implementation are unpaired, variability is expected to be larger and the number of samples required to show significant removal much higher than for paired samples.

Before-after monitoring is also applicable to laboratory test systems in which water quality is measured before and after a change is made. For example, the rate of adsorption or the adsorptive capacity of media can be determined by measuring the water quality before and after addition of a known quantity of media.

5. Primary Data Objectives

The study design options discussed previously are matched to the primary management questions. The primary management questions require two data objectives: determine annual mass captured by HDS units and load removal by biochar-amended BSM. The primary management questions are:

1. What are the **annual PCB and mercury loads captured** by existing HDS units in Bay Area urban watersheds?
2. Are there readily available biochar-amended BSM that provide significantly better **PCB and mercury load reductions** than standard BSM and meet MRP infiltration rate requirements?

Monitoring to address the first management question should at minimum provide the average annual PCB and mercury loads captured by HDS units.

5.1 Data Objective 1: Annual Loads Captured by HDS Units

Determined by influent-effluent monitoring for individual storm events over one or more seasons or filter media/sediment sampling at end of each season.

Options:

- ❖ Influent-effluent monitoring. Requires monitoring of as many storms as possible over a season and flow measurement in addition to water quality sampling. Flow measurement is a critical component for estimating stormwater volumes treated, retained, and bypassed, and is often associated with additional measurements such as water depth within a BMP to estimate bypass and retention.
- ❖ Filter media/sediment sampling. Requires sampling at end of season but does not require influent/effluent water quality or flow measurement. Sediment sampling has a high value for estimating annual mass removal because a single composite sample of retained sediment over a season can yield an estimate of load removal for the constituents analyzed. However, influent characterization would also help explain mass removal performance. This method is most appropriate when applied to HDS systems because they can isolate retained sediment.

5.2 Data Objective 2: Loads Reduced by Biochar-Amended BSM

Determined by influent-effluent monitoring or filter media/sediment sampling for individual events until sufficient data are available for statistical analysis.

Options:

- ❖ Influent-effluent monitoring. Requires monitoring of multiple individual events and flow measurement in addition to water quality sampling. Accurate flow measurement in BMPs is difficult because flows can vary an order of magnitude during individual events and measurements may be required at multiple locations within a device because of bypass, infiltration etc. (see Figure 4.2). This complexity introduces a great degree of variability in the monitored data that can substantially increase the number of data points required to show statistically significant load removals, particularly for BMPs such as HDS units that show relatively small differences between influent and effluent load reductions. This option is most appropriate for testing filter media, for example in laboratory experiments, in which accurate flow measurements are possible and sampling of accumulated sediment is infeasible.

- Filter media/sediment sampling. Requires sampling after individual events but does not require influent/effluent water quality or flow measurement. This method is not feasible for filter media because the retained sediment cannot be isolated from the filter media.

6. BMP Processes and Key Study Variables

The treatment mechanisms that occur in a BMP help inform selection and control of the study variables. These treatment mechanisms, also called *unit processes*, may include physical, chemical, or biological processes. The primary physical, chemical, and biological processes that are responsible for removing contaminants include the following:

- Sedimentation – The physical process by which suspended solids and other particulate matter are removed by gravity settling. Sedimentation is highly sensitive to many factors, including size of BMP, flow rate/regime, particle size, and particle concentration, and it does not remove dissolved contaminants. Treated water quality is less consistent compared to other mechanisms due to high dependence on flow regime, particle characteristics, and scour potential.
- Flocculation – Flocculation is a process by which colloidal size particles come out of suspension in the form of larger flocs either spontaneously or due to the addition of a flocculating agent. The process of sedimentation can physically remove flocculated particles.
- Filtration – The physical process by which suspended solids and other particulate matter are removed from water by passage through layers of porous media. Filtration provides physical screening of particles and trapping of particles within the porous media. Filtration depends on a number of factors, including hydraulic loading and head, media type and physical properties (composition, media depth, grain size, permeability), and water quality (proportion of dissolved contaminants, particle size, particle size distribution). Compared to sedimentation, filtration provides a more consistent treated quality over a wider range of contaminant concentrations.
- Infiltration – The physical process by which water percolates into underlying soils. Infiltration is similar to filtration except it results in overall volume reduction.
- Screening – The physical process by which suspended solids and other particulate matter are removed by means of a screen. Unlike filtration, screening is used to occlude and remove relatively larger particles and provide little or no removal for particles smaller than the screen opening size and for dissolved contaminants.
- Sorption – The processes of absorption and adsorption occur when water enters a permeable material and contaminants are brought into contact with the surfaces of substrate media, plant roots, and sediments, resulting in short-term retention or long-term immobilization of contaminants. The effectiveness of sorptive processes depends on many factors, including the properties of the water (contaminant concentration, particle concentration, organic matter, proportion of dissolved contaminants, particle size, pH, particle size and charge), media type (surface charge, absorptive capacity), and contact time.

- Chemical Precipitation – The conversion of contaminants in the influent stream, through contact with the substrate or root zone, to an insoluble solid form that settles out. Consistent performance often depends on controlling other parameters such as pH.
- Aerobic/Anaerobic Biodegradation – The metabolic processes of microorganisms, which play a significant role in removing organic compounds and nitrogen in filters.
- Phytoremediation – The uptake, accumulation, and transpiration of organic and inorganic contaminants, especially nutrients, by plants.

The relative importance of individual treatment mechanisms depend to a large extent on the chemical and physical properties of the contaminant(s) to be removed i.e. the influent quality. The two contaminants of interest in this study are PCBs and mercury. PCBs are relatively inert hydrophobic compounds that have very limited solubility and a strong affinity for organic matter. They are often associated with fine and medium-grained particles in stormwater runoff, making them subject to removal through gravitational settling or filtering through sand, soils, media or vegetation. Most of the mercury in water, soil, and sediments is in the form of inorganic mercury salts and organic forms of mercury such as methylmercury that are strongly adsorbed to organic matter (e.g., humic materials). In general, mercury is most strongly associated with fine particles while PCBs are generally associated with relatively larger and/or heavier particles. It is therefore expected that sedimentation, flocculation, and related processes will be less effective for mercury removal than for removal of PCBs (Yee and McKee, 2010).

The following subsections provide a brief description of the BMP types being evaluated in this study, the unit processes involved in each, and key variables that indicate possible data collection approaches. The final selection of the quantity and type of data to collect is presented in the "Optimized Study Design" section.

6.1 HDS Units

Hydrodynamic separators rely on sedimentation and screening as the primary removal mechanism for sediment and particulate pollutants. Treatment performance is highly dependent on the following:

- Influent quality (contaminant concentration, proportion of dissolved contaminants, particle size, particle size distribution, and particle density)
- BMP design and hydraulic loading/flow regime (size of unit versus catchment area)
- Operational factors (remaining sediment capacity)

HDS effluent quality is highly variable, particularly for contaminants such as mercury that are associated with fine particles that are not as effectively removed in HDS. These devices are expected to require a relatively large number of influent-effluent samples to demonstrate statistically significant reductions in pollutant concentrations. Therefore, analysis of retained sediment is an appropriate alternative to influent-effluent sampling for determining pollutant mass captured. Sediment can be analyzed when the device is cleaned.

6.2 Bioretention

Bioretention is a slow-rate filter bed system. It is planted with macrophytes (typically shrubs and smaller non-woody vegetation). The major sediment removal mechanism is physical filtration through the planting media. When retention time is sufficient, dissolved constituents can be removed by sorption to plant roots in the planting media, which typically contains clays and organics to enhance sorption. Treatment performance is highly dependent on the following variables:

- Influent quality (contaminant concentration, particle concentration, organic matter, proportion of dissolved contaminants, particle size, particle size distribution)
- BMP design and hydraulic loading rate/head (size of the unit in relation to catchment area and storm character)
- Media type and properties (composition, grain size, grain size distribution, adsorptive properties, and hydraulic conductivity)
- Volume reduction by infiltration
- Operational factors (surface clogging, short-circuiting)

The effluent quality from bioretention and enhanced bioretention is expected to be consistently higher than for sedimentation-type BMPs. These devices are expected to require a relatively fewer number of samples than HDS units to demonstrate statistically significant reduction because of better treatment of fine particles and dissolved contaminants.

It is important to note that laboratory and not field bioretention systems are of interest in this study. These laboratory systems, essentially cylindrical columns filled with the media being tested, attempt to simulate most, but not all, of the chemical, biological, and physical processes that occur in field devices. For example, volume reductions due to infiltration are not simulated in laboratory column experiments. The advantages of using media columns as proxies for field devices include improved control over operation, monitoring, and sample collection in ways that would be impractical in the field. This improved control makes it possible to test a large number of potential media and identify the most promising for future field testing.

7. Monitoring and Sampling Options

Key variables that affect water quality and sediment quality data are identified from knowledge of treatment processes. The following lists the process variables identified through knowledge of the treatment processes:

- Influent quality (contaminant concentration, particle concentration, organic matter, proportion of dissolved contaminants, particle size, particle size distribution, particle density)
- BMP design and hydraulic loading (flow rate, hydraulic head, flow regime)
- Media type and properties (composition, grain size, grain size distribution, adsorptive properties, and hydraulic conductivity)
- Operational factors (surface clogging, short-circuiting, remaining sediment capacity)

Some of the above variables can be controlled and others are measured to determine their effect on water quality and sediment quality. Inevitably, some variables will be beyond the control of the study but their expected impact should be considered based on theory, past experience, models, or observations from other studies.

7.1 HDS Units

7.1.1 Influent Quality

The location of the BMP can greatly affect influent water quality such as pollutant concentrations and particle characteristics because land use and land cover affect sediment mobilization and pollutant concentrations within the sediments. Land use is often used as an indicator of pollutant loading. The land uses of the areas of interest include industrial, commercial/mixed use, roads/rail, institutional, and residential. Because of past use of PCB and past PCB and mercury handling practices, age of the land use is also important, with generally higher concentrations from older industrial, commercial, and transportation areas, and lower concentrations from newer residential areas. However, PCB analysis by the San Francisco Estuary Institute (SFEI) showed that PCB concentration patterns were patchy within larger urban watersheds with higher concentrations. This finding indicates that mass reductions of PCBs may require site-specific sampling of influent loads or site-specific quantification of mass removed. Mercury data suggest areas with higher mercury concentrations are not as pronounced although generally where there is PCB contamination there is also high to moderate Hg contamination (Yee and McKee, 2010).

Since HDSs are primarily installed for trash capture, their distribution within the study area is assumed to be random. However, the primary interest is in watersheds with relatively high pollutant loads that are most likely to result in significant removal in HDSs (e.g., the Leo Avenue watershed). Land use or land use based pollutant yields can be used to represent average influent water quality when influent monitoring is not conducted.

Figure 7.1 shows the land use based PCB and mercury loadings for key designated land use types. It can be seen that unit PCB loading from watersheds with higher PCB concentrations and mercury loading from old industrial watersheds are substantially higher than the other land uses. Assuming particle size, particle size distribution, and other stormwater characteristics are similar for the different land uses, HDSs in higher concentration watersheds or old industrial watersheds are expected to capture much higher pollutant loads than those in other watersheds.

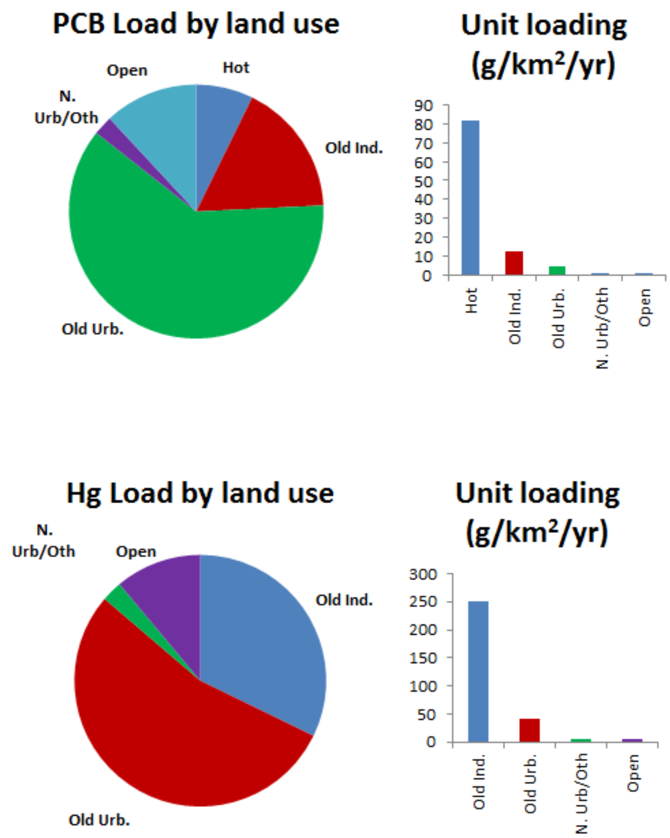

Figure 7.1 Land Use based PCB and Mercury Loading based on BASMAA Integrated Monitoring Reports (SFEI, 2015)

A preliminary land use based study design could categorize HDS sites as show in Table 7.1.

Table 7.1 HDS Sampling Design based on Watershed Land Use

Land Use	HDS Samples
Higher Concentration	X, X, X[1]
Old Industrial	X, X, X[1]
Old Urban	X, X, X[1]

1 – "X" represents a sample from a selected HDS unit in the specified land use category.

The above design is appropriate if HDS units can be categorized easily into one of the three land use categories. A review of the land uses within HDS watersheds indicates that most HDS units are in predominantly old urban watersheds, and it is unclear how many HDSs are within areas with higher PCB concentrations (Table 7.2).

Table 7.2 Percent of Land Use in HDS Watershed Areas

(Based on FY 2015-16 Co-permittee Annual Reports, Section 10 - Trash Load Reduction. Source: Chris Sommers Personal Communication)

HDS Catchment ID	New Urban	Old Industrial	Old Urban	Open Space	Other
287; Sonora Ave		16	84	1	
27A	15	50	34	2	
996; Parkmoor Ave		1	98	1	
1084; Oswego		0	89	0	10
600; Edwards Ave		33	39	28	
611; Balfour		14	55	30	
1082; Melody/33rd		0	97	3	
612; Lewis			93	7	
604; Sunset			96		4
1012; Blossom Hill/Shadowcrest			100	0	
1083; Lucretia		0	98	1	1
1002; Selma Olinder		10	86	5	
995; Dupont St.		9	91	0	
9-A; 73rd Ave and International Blvd		0	94	6	
475; 7th		68	29	3	
509; Coyote	22		77	1	
47			99	1	
8-A; Alameda Ave near Fruitvale		40	57	4	
575; Bulldog		6	93	1	
601; W. Virginia		7	90	3	
1504; Phelps			100	0	
390; Remillard		4	87	10	
Tennyson at Ward Creek		1	97	2	
W Meadow Dr		2	97	1	
Leland and Fair Oaks		1	99		
Ward and Edith			100	0	
5-D; 22nd and Valley		1	99	0	
8-C; High St @ Alameda Bridge		67	32	0	
5-G; Perkins & Bellvue (Nature Center)			100		
999; William		0	95	5	
Main St and Hwy 1			85	15	
Central Expy at Fair Oaks		11	89	0	
393; Wool Creek		18	78	4	
5-C; 27 St & Valdez Ave		2	98		
998; Pierce		1	96	3	
Maple and Ebensburg			98	2	
Ventura Ave			99	1	
Golden Gate and St Patrick			100	0	
5-A; Euclid Ave @ Grand Ave			100		
5-H; Lake Merritt (SD Outfall 11)			100		
5-B; Staten Ave & Bellvue			100		
Central Expy at De la Cruz		33	67		
5-I; Lake Merritt (SD Outfall 26)			100		
Mathilda overpass project CDS2		0	100		
Mathilda overpass project CDS1		10	84	7	

Given the few sites in categories other than old urban, an alternative study design based on mixed land uses may be more appropriate (Table 7.3).

Table 7.3 HDS Sampling Design based on Predominant Land Use

Predominant Land Use	HDS Samples
Higher Concentration/Old Industrial	X, X, X[1]
Old Urban/Old Industrial	X, X, X[1]
New Urban/Old Urban	X, X, X[1]

1 – "X" represents a sample from a selected HDS unit in the specified land use category.

The sampling design in Table 7.3 assumes that at least three HDS units are available for sampling in each PCB land use category. The sampling design may need to be modified further if there are an insufficient number of units available for sampling. For example, any site with more than 30% old industrial may be considered especially if it is a mixed zoned watershed (with industrial, commercial, residential and transportation land uses). The range of values in each land use category can be determined upon review of the most recent information. The design in Table 7.3 assumes that the characteristics of the runoff (e.g., particle sizes) are similar for the different land uses and only the yield is different.

Only sediment sampling is proposed for HDS. Since HDS influent-effluent monitoring is not required, variables such as proportion of dissolved contaminants, particle size, particle size distribution, and particle density are not measured or controlled, but their effect on influent quality and treatment is accounted for by randomly selecting HDSs within each land use category.

7.1.2 BMP Design and Hydraulic Loading

BMP design and hydraulic loading, which depends on the size of the BMP, can have a substantial impact on effluent water quality and the quantity of sediment retained in a BMP. Consequently, a full range of BMP designs and sizes are of interest. Properly sized, BMPs infrequently exceed their design capacity. However, BMPs are not always sized to standard specification, especially in retrofit environments in which typical hydraulic loading is much higher due to space constraints.

HDS units are typically proprietary and designs and sizing vary widely. Sediment capture may vary because of design differences such as number of chambers and design of overflow weirs and baffles, as well as different sizing criteria that can greatly affect both hydraulic loading and flow regime. The purpose of the study is to characterize sediment in HDS units in the study area. Since BMP design and sizing are important factors affecting HDS performance, it is necessary to include a range of HDS units in the study design and not just randomly select HDS units. A randomized blocked study design is therefore considered more appropriate than a completely random one that may result in an insufficient number of HDS units of a certain size.

In a randomized design, one factor or variable is of primary interest (e.g., land use), but there are one or more other confounding variables that may affect the measured result but are not of primary interest (e.g., HDS design, HDS size). Blocking is used to remove the effects of one or more of the most important confounding variables and randomization within blocks is then used to reduce the effects of the remaining confounding variables. An appropriate sampling design could therefore be land use as the primary factor and HDS size as the blocking factor. Since the population of HDS units in the land use categories of interest is limited, only two size blocks are used (≤ 50^{th} percentile, > 50^{th} percentile), and other variables such as design differences are accounted for by random selection within each block (Table 7.4).

Table 7.4 HDS Sampling Design based on Predominant Land Use and HDS Size

Predominant Land Use	HDS Size	
	≤50th percentile	>50th percentile
Higher Concentration/Old Industrial	X, X, X[1]	X, X, X[1]
Old Urban/Old Industrial	X, X, X[1]	X, X, X[1]
New Urban/Old Urban	X, X, X[1]	X, X, X[1]

1 – "X" represents a sample from a selected HDS unit in the specified land use category.

For the sampling design in Table 7.4, an HDS size factor is required to differentiate the two types of sizes that are of interest. In controlled field study of 4 different proprietary HDS units and laboratory testing of 2 other units, Wilson et al. (2009) developed a *performance function* (treatment factor) that reasonably predicted the removal efficiency of a given hydrodynamic separator. The performance function explained particle removal efficiency in terms of a Péclet number, P_e, which accounts for particle settling and turbulent diffusion. In the following equation, V_s is the particle settling velocity, h is the settling depth in the device, d is the device diameter, and Q is the flow through the device:

$$P_e = \frac{V_s hd}{Q}$$

The above Péclet number (Wilson et al's performance function) can be used in the sampling design as the HDS size factor. For grouping the available HDS units into the two blocks, information is required on the particle diameter and design parameters for each device (settling depth, diameter, and design flow). Particle diameter can be assumed to be 75 µm, which is the critical size used for partitioning PCB fractions in Yee and McKee (2010), and is also approximately the size separating silt and fine sand size particles. The design flow can be calculated from knowledge of the drainage area to the device and a standard design storm. Note that the design flow should not be based on manufacturer guidance because different manufacturers use different sizing criteria and device sizing may not always follow manufacturer guidance.

The final sampling design may need revision depending on the monitoring approach, availability of HDSs, information on watershed land use and sizing, and the level of participation from municipalities.

7.1.3 Operation and Maintenance

Maintenance frequency can greatly impact BMP performance. For sedimentation BMPs such as HDS, sediment levels may exceed the sediment capacity of the BMP, decreasing the volume for sedimentation and increasing scour.

Operation and maintenance (e.g., cleanout frequency) are not of direct interest in this study and their effect on treatment is not being tested. However, these are confounding variables that need to be excluded. In the HDS sediment sampling design, HDS units that are considered at capacity or will reach capacity during the study should be excluded from the population of interest. Field observations are required to make this determination (e.g., whether the screen is blocked). These units can be cleaned out and sampled in a subsequent year. For each selected HDS unit, maintenance schedules (past and current) will need to be reviewed to determine the time period over which sediment accumulated.

7.2 Enhanced Bioretention

7.2.1 Influent Quality

The purpose of the laboratory testing is to screen alternative biochar-amended BSM and identify the most promising for further field testing. The laboratory testing requires influent-effluent monitoring. Influent water characteristics can vary depending on the source of the test water. PCB and mercury loading is largely a result of historic activities that result in accumulation in sediments of pervious areas. Mobilization of these sediments may require exceeding site-specific intensity and volume thresholds. Storm intensity is critical to detach and mobilize particles and storm volume must exceed any depression storage within the pervious areas. However, the precise effect of storm intensity and volume on the mobilization of PCB-contaminated and mercury-contaminated sediments has not been established. Influent water characteristics also depend greatly on drainage area characteristics including traffic and industrial and commercial activity.

Since the purpose of the laboratory study is to screen alternative biochar-amended BSM that can be used throughout the Bay Area, collection and use of stormwater from one or more representative watersheds is preferred. A preliminary review of available Bay Area stormwater runoff monitoring data from 27 sites (Table 7 of SFEI 2015) suggests median PCB concentration is about 9 ng/L. Therefore, one or more previously monitored watersheds with mean PCB concentrations well above 10 ng/L may be appropriate for collection of stormwater for the laboratory testing. Since the relative treatment performance of the various media at even lower concentrations may be different, additional tests with diluted stormwater may be required to confirm study results.

Storms from the representative watershed should be targeted randomly without bias, thereby accounting for the effects of storm intensity and ensuring variability in contaminant concentration, proportion of dissolved contaminants, particle size, particle size distribution, and particle density. To achieve this, minimal mobilization criteria should be used to ensure predicted storm intensity and runoff volume are likely to yield the desired volume.

7.2.2 BMP Design and Hydraulic Loading

The design variables in the enhanced bioretention testing laboratory study include media type, media depth, and media configuration. Media type is a key variable that is discussed further below. Testing the effect of different media depths or media configurations is not a research objective of the laboratory study, so these can be fixed for all experiments. Typical bioretention media depth in the Bay Area is 18 inches, so all column experiments should use 18 inches of BSM. In the Richmond PG&E Substation 1st and Cutting enhanced BSM testing, the biochar was not installed as a separate layer but was instead mixed with the standard BSM. It is unclear how treatment is affected by these two media configurations, but for consistency with previous field work the biochar and standard BSM should be mixed.

Hydraulic loading is a controlled variable that can be kept constant for all columns. Since the laboratory study is attempting to replicate field bioretention, the hydraulic loading can be the design loading for bioretention. Bioretention designs in the Bay Area typically have a maximum ponding depth of 6 inches, so a loading of 6 inches could be used for the column tests. There are two options for loading the columns: pump and manual. Peristaltic pumps are ideal for controlled loading, but in this study manual loading (batch loading) is more appropriate because of the potential for PCBs and mercury to stick to tubing, pump parts, etc. For manual loading, up to 10 inches of stormwater may be needed each time to ensure sufficient sample volume.

7.2.3 Media Type and Properties

Media type and properties have a substantial effect on the treatment performance of filtration devices. This group of variables include composition, grain size, grain size distribution, adsorptive properties such as surface area, and hydraulic conductivity. Media composition is a primary variable that accounts for differences in the biochars used and the proportion of each biochar in the amended BSM mix. The other variables (grain size, grain size distribution, adsorptive properties, and hydraulic conductivity) are not of direct interest in this study and are assumed to vary randomly or are controlled through screening experiments that limit their variability.

Biochar is produced from nearly any biomass feedstock, such as crop residues (both field residues and processing residues such as nut shells, fruit pits, and bagasse); yard, food, and forestry wastes; animal manures, and solid waste. Biochar feedstock and production conditions can vary widely and significantly affect biochar properties and performance in different applications, making it difficult to compare performance results from one study to another (BASMAA, 2017a). A laboratory study that characterized the physical properties of six different waste wood derived biochars found particle sizes ranging from over 20mm to fine powder and surface areas ranging from 0.095 to 155.1 m^2/g (Yargicoglu et al., 2015). The variability in biochar types and properties is expected to result in large variation in treatment efficiency and infiltration rates. Given the large number of potential biochars that could be tested and the need to meet an initial maximum 12 in/h infiltration rate and a minimum long-term infiltration rate of 5 in/h, a phased study design is appropriate. In such a phased study, promising readily available biochars are first identified through a review of the literature, and hydraulic screening experiments are performed on biochar-BSM media mixes to ensure infiltration rates are met prior to performance testing. This approach is expected to be the most cost-effective because it reduces analytical costs.

There is little information on hydraulic properties of bioretention media amended with biochar, and it is not clear what percentage of the amended BSM should be biochar to maximize treatment benefit. Given the variable physical size of the biochar media, relatively fine biochars could result in a mix that does not meet the initial 12 in/h maximum infiltration rate or minimum 5 in/h long-term infiltration rate. Kitsap County (2015) tested a BSM mix containing 60% sand, 15% Compost, 15% Biochar, and 10% shredded bark, and found that the biochar mix had an infiltration rate of only 6.0 in/h. One conclusion of the study was that the reduction in infiltration rate with the biochar additive was most likely because of fines in the biochar. To overcome this, hydraulic screening experiments are required in which the infiltration rate for each media mix is measured prior to water quality testing to ensure that both the maximum and minimum rates are met. Initially, each biochar can be mixed with standard BSM at a rate of 25% biochar by volume (the same as that at the CW4CB Richmond PG&E Substation 1st and Cutting site). Hydraulic conductivity can be determined using the method stated in the BASMAA soil specification, method ASTM D2434, which requires measurement of water levels and drain times. If a mix does not meet the infiltration requirements, the percentage of biochar is adjusted and the new mix tested. Amended mixes that do not meet the infiltration rate requirements are removed from further consideration (i.e. the effect of hydraulic conductivity is controlled by screening).

The final phase of the laboratory study can be column testing to identify the most effective amended BSM mixes for field testing. An influent-effluent monitoring design is typically used in column testing and media effectiveness is assessed on a storm-to-storm basis with real stormwater collected in the Bay Area. Only media mixes that have passed the hydraulic screening should be tested. All media columns should be sufficiently large or replicated to account for or minimize the impact of variability in media installation and experimental technique. Standard BSM should be used as a control since the primary interest is to identify media mixes that perform significantly better than standard BSM. An example of the column sampling design for 5 new media mixes and one standard BSM control is shown in Table 7.5. The key variable of interest in the sampling design in Table 7.5 is the media mix (composition).

Table 7.5 Example Sampling Design for Laboratory Column Experiments

Biochar/BSM Mix	Column Samples
A Mix	X, X, X[1]
B Mix	X, X, X[1]
C Mix	X, X, X[1]
D Mix	X, X, X[1]
E Mix	X, X, X[1]
Control Mix	X, X, X[1]

1 – "X" represents an influent or effluent sample.

7.2.4 Operation and Maintenance Parameters

Operational life depends on the capacity to pass the minimum required stormwater flows. Like media life, operational life is important because it determines the frequency and cost of maintenance requirements. Maintenance frequency can greatly impact BMP performance, and lack of maintenance can lead to surface clogging and sediment clogging in the inlets which reduces treatment capacity and increases bypass and overflow. Operation and maintenance are not of direct interest in this study and their effect on treatment is not being tested. However, these are confounding variables that need to be excluded.

Media mixes that do not meet the maximum 12 in/h and minimum 5 in/h infiltration rates can be excluded by hydraulic screening experiments (discussed above). As well as meeting the maximum 12 in/h initial infiltration rate requirement, these screening experiments help ensure that the BSM mixes do not fail during the laboratory testing. However, operational performance in laboratory experiments is not expected to be representative of that in the field because of differences in influent quality, variability in loading, effects of vegetation, etc. Therefore, laboratory estimates of long term infiltration rate are of little use and field testing is required to confirm that selected media mixes meet the long-term minimum infiltration rate of 5 in/h. The laboratory testing, however, can provide relative comparisons of hydraulic performance that can be used to decide and screen out media mixes that are likely to hydraulically fail in the field.

7.3 Uncontrolled Variables and Study Assumptions

The following assumptions were adapted from the Caltrans PSGM (Caltrans, 2009):

- Site Assumptions
  - HDS sediment concentrations are representative of the land use within the watershed, i.e. there are no sources of sediment from adjoining watersheds, from illicit discharges, or from construction activities
  - HDS sediment or influent is not affected by base flow, groundwater, or saltwater intrusion
  - Differences in storm patterns throughout the Bay Area are not sufficient to change the HDS performance measurements
  - Water quality of stormwater collected for laboratory testing is representative of that observed in Bay Area urban watersheds
- BMP Operation Assumptions
  - Sampled HDS units operated as designed (e.g., no significant scouring)
  - Volatilization of pollutants is negligible
  - There is no short-circuiting of flows in laboratory column studies
- Media Selection Assumptions
  - The readily available biochars selected are representative of all biochars
  - Selected media do not leach contaminates and media conditioning (e.g., washing) is not required
- Monitoring Assumptions

- Data collected from a few sites over a relatively short time span will accurately represent sediment at all HDS sites over longer time frames
- There are minimal contaminant losses in collecting and transporting water for laboratory experiments
- Water quality of stormwater for laboratory tests does not change significantly during each test
- Stormwater loading of laboratory columns is representative of loading in the field
- Long-term infiltration performance of biochar mixes is to be tested in the field

8. Final Study Design

The study design is optimized to answer the primary management questions within the available budget. The design used prioritizes sampling of HDS units, but allocates sufficient funding for minimum sampling requirements for the laboratory media testing study. Monitoring that does not relate directly to the primary management questions is considered lower priority.

8.1 Statistical Testing & Sample Size

In a traditional test of a treatment, the null hypothesis is that there is no difference between the influent and effluent of a treatment (i.e., the treatment does not work). In the case of HDS sampling, influent-effluent sampling is not required, and interest is only in determining if HDS units remove PCBs and mercury and how the sediment concentrations and load removals vary for different land uses, and for different rainfall and stormwater flow characteristics. Statistical testing in the HDS study is therefore limited to testing if there is a difference in the concentrations and loads captured by HDS units in different watersheds. This testing will require sampling of a sufficient number of HDS units in each land use category associated with differing pollutant load yields.

In the laboratory study, influent-effluent sampling is required and traditional statistical tests can be used depending on sample size.

As well as traditional statistical testing, confidence in the conclusions can be established by comparing total PCB and mercury performance to that for other constituents that directly affect it (e.g., suspended solids, total organic carbon) or have similar chemistry (e.g., other organics). As stated previously, total PCB and mercury concentrations are expected to correlate to some extent with particulates and organics. Comparisons to other constituents are particularly useful for studies in which treatment is expected to be low and the corresponding sample size requirements very high.

Sample size requirements are smaller for paired sampling designs (i.e., influent and effluent sampling for the same storm event) than for independent sampling designs. Paired sampling is not possible for the HDS sampling study that has no influent-effluent monitoring, but is possible in the laboratory media testing study. Additionally, the number of samples required to show significant treatment are generally fewer for filtration-type BMPs than sedimentation-type BMPs because of their better and more consistent treatment.

8.2 Constituents for Sediment Analysis

Constituents selected for HDS sediment analysis must meet the data objectives discussed previously in “Primary Data Objectives”, and be consistent with Table 8.3 of the MRP (SFRWQCB, 2015). Sediment samples will be screened using a 2 mm screen prior to analysis. Table 8.1 lists the constituents for sediment quality analysis. Total organic carbon (TOC) is included because it is a MRP requirement and can be useful for normalizing PCBs data collected for the sediment.

The primary objective of sediment analysis is quantification of the mass of PCBs and mercury accumulating within HDS units. Consequently, PCBs and total mercury are analyzed for all screened sediment samples. The secondary objective is to establish a relationship between total PCBs, mercury, and particle size. Correlating total PCBs and mercury to particle sizes will complement past studies and provide insight into the type of BMPs that are appropriate to achieve the most cost-effective mass removal.

Analysis of PCBs at the CW4CB Leo Avenue HDS showed that PCBs in the water above the sediment may be minor when compared to sediment-associated PCBs (BASMAA, 2017b). PCB concentrations in overlying water are expected to be low and sampling of this water is not included in this study design.

Table 8.1 Selected Constituents for HDS Sediment Monitoring

Constituent
TOC
Total Mercury[1]
PCBs (40 congeners) in Sediment
Particle Size Distribution
Bulk Density

1 – Only total mercury analyzed. Methyl mercury is not relevant for SF Bay TMDL.

8.3 Constituents for Water Quality Analysis

Constituents for analysis of water samples must meet the data objectives discussed previously in “Primary Data Objectives”, and be consistent with Table 8.3 of the MRP (SFRWQCB, 2015). Table 8.2 lists the constituents for the laboratory media testing studies. The list of water quality constituents must provide data to address the primary management question to quantify total PCB and mercury reduction, so PCBs and total mercury are analyzed for all samples. Secondary management questions relate to understanding removal performance for total PCB and mercury.

In addition to PCBs and total mercury, the other constituents selected for influent and effluent analysis are SSC, turbidity, and TOC. SSC was selected because it more accurately characterizes larger size fractions within the water column, while turbidity was selected because it is an inexpensive and quick test to describe treatment efficiency where strong correlation to other pollutants has been established. As with the sediment analysis, TOC is included because it is a MRP requirement and can be useful for normalizing PCBs data collected for water samples.

Table 8.2 Selected Aqueous Constituents for Media Testing in Laboratory Columns

Constituent
SSC
Turbidity
TOC
Total Mercury[1]
PCBs (40 congeners) in Water

1 – Only total mercury analyzed. Methyl mercury is not relevant for SF Bay TMDL.

8.4 Budget and Schedule

The monitoring budget for the study is approximately $200,000. A contingency of 10 percent of the water quality monitoring budget is recommended to account for unforeseen costs such as equipment failure. Another constraint is that all sampling will occur in one wet season.

8.5 Optimized Study Design

The optimized study designs are presented in Tables 8.3 and 8.4 for the HDS Monitoring and Enhanced Bioretention studies, respectively. Several iterations were analyzed and the study designs shown are based on best professional judgment to allocate the budget to the various data collection options.

The final design for the HDS monitoring study is based on selection and sampling of 9 HDS units in key land use areas. The number of units that can be sampled is limited because sampling is expected to be opportunistic as part of regular maintenance programs. Therefore, a simple design with 9 units is appropriate. The data analysis will evaluate the percent removal achieved for each HDS unit during the time period of interest (i.e., the time period between the date of the previous cleanout, and the current cleanout date for each HDS unit sampled) by incorporating modeled estimates of stormwater volumes and associated pollutant loads for each HDS unit catchment. Because HDS units are sized to treat stormwater runoff from storms of a given size and intensity, excess flows for storms exceeding the design capacity will bypass the unit and are not treated. Storm by storm analysis of rainfall data during the time period of interest will allow estimation of the total stormwater volume and pollutant load to the catchment during each storm, as well as the volume and pollutant load that bypassed the HDS unit and was not treated. This information will then be combined with the measured pollutant mass captured by each HDS unit to quantify the percent removal of PCBs and mercury from the total catchment flow, and the percent removal of PCBs and mercury from the treated flow. For each HDS unit sampled in the study, the total and treated pollutant mass removed will be calculated using the following equations.

(1) Total Pollutant Mass Removed (%) = $[M_{HDS\text{-}i}/M_{Catchment\text{-}i}] \times 100\%$

(2) Treated Pollutant Mass Removed (%) = $[M_{HDS\text{-}i}/(M_{Catchment\text{-}i} - M_B)] \times 100\%$

Where:

M_{HDS-i} the total POC mass captured in the sump of HDS Unit i over the time period of interest

$M_{Catchment-i}$ the total POC mass discharged from Catchment-A (the catchment draining to HDS unit A) over the time period of interest

M_B the total POC mass that bypassed HDS unit A over the time period of interest

The following inputs will be measured or modeled for the time period of interest for use in the equations above:

- Total PCBs and mercury mass captured by a given HDS unit. This is the mass measured in each HDS unit during this project.
- The total stormwater volume and associated PCBs and mercury load from the HDS unit catchment. This will be modeled on a storm by storm basis using available rainfall data, catchment runoff coefficients, and assumed pollutant stormwater concentrations.
- The stormwater volume and associated PCBs and mercury load that bypassed the HDS unit. The bypass volume (and associated pollutant load) during each storm (if any) will be calculated based on the design criteria for a given HDS unit.
- The total PCBs and mercury load treated by a given HDS unit. This will be determined by subtracting the bypass load (if any) from the total pollutant load for the catchment.

The corresponding design for the enhanced BSM study is based on testing of readily available biochars in hydraulic screening experiments followed by column testing of up to five promising BSM mixes as well as a standard BSM control mix. The final number of BSM mixes will depend on availability and media properties (e.g., expected hydraulic conductivity). The optimized designs will yield 33 data points for the key data objectives, 9 from the HDS monitoring study and 24 from the enhanced BSM media testing column study.

Table 8.3 HDS Monitoring Study Design

<table>
<tr><td>Primary Management Question(s)</td><td>What are the annual PCB and mercury loads captured by existing HDS units in Bay Area urban watersheds and the associated percent removal?</td></tr>
<tr><td>Type of Study</td><td>Sediment monitoring; modeling stormwater volume and pollutant load</td></tr>
<tr><td>Data Objective(s)</td><td>Annual PCB and mercury mass captured in HDS units and percent removal</td></tr>
<tr><td>Description of Key Treatment Processes</td><td>Sedimentation, Flocculation & Screening
• Removal by gravity settling and physical screening of particulates
• Effectiveness depends on water quality, BMP design and hydraulic loading/flow regime, and operational factors</td></tr>
<tr><td>Key Variables</td><td>• Sediment quality and quantity
• Influent quantity and quality (contaminant concentration,)
• BMP design and hydraulic loading/flow regime
• BMP maintenance (remaining sediment capacity)</td></tr>
<tr><td>Monitoring Needs</td><td>Monitored variables: sediment quality, sediment mass
Controlled variables: influent quality, BMP maintenance (remaining sediment capacity)
Uncontrolled variables: HDS design, hydraulic loading, flow regime</td></tr>
<tr><td>Monitoring Approach</td><td>Influent quantity and quality: based on rainfall/runoff characteristics and on land use pollutant yield (old urban, new urban, etc.)
Hydraulic loading: base on HDS size (diameter and settling depth) and flow (design flow for known watershed size)
BMP maintenance: base on remaining sump capacity</td></tr>
<tr><td>Sampling Design</td><td>Sampling expected to be opportunistic as part of regular maintenance programs. Targeted predominant land uses for HDS selection and corresponding data generation:
<table>
<tr><th>Predominant Land Use</th><th>HDS Samples</th><th>No. Samples (Total 9)</th></tr>
<tr><td>Higher Concentration/Old Industrial</td><td>X, X, X[1]</td><td>3</td></tr>
<tr><td>Old Urban/Old Industrial</td><td>X, X, X[1]</td><td>3</td></tr>
<tr><td>New Urban/Old Urban</td><td>X, X, X[1]</td><td>3</td></tr>
</table>
1 – “X” represents a sample from a selected HDS unit. Yield categories will be determined during site selection.
• Exclude units at full sump capacity (cleanout and monitor subsequent year if possible)</td></tr>
<tr><td>Constituent List</td><td>TOC, total mercury, PCBs (40 congeners) in sediment, particle size distribution, and bulk density</td></tr>
<tr><td>Data Analysis</td><td>Independent (unpaired) samples. Present range of total PCB and mercury concentrations measured and mass removed/area treated. Analyze using ANOVA. Model estimates of catchment stormwater volumes and PCB and mercury stormwater loads combined with the measured mass captured in the unit to calculate the percent removal.</td></tr>
</table>

Table 8.4 Enhanced BSM Testing Study Design

<table>
<tr><td>Primary Management Question(s)</td><td>Are there readily available biochar-amended BSM that provide significantly better PCB and mercury load reductions than standard BSM and meet MRP infiltration rate requirements?</td></tr>
<tr><td>Type of Study</td><td>Influent-effluent monitoring</td></tr>
<tr><td>Data Objective(s)</td><td>PCB and mercury load removal</td></tr>
<tr><td>Description of Key Treatment Processes</td><td>Filtration and Adsorption
Removal by physical screening, trapping in media, and retention on media surface
Effectiveness depends on influent water quality, BMP design and hydraulic loading/flow regime, media type and properties, and operational factors</td></tr>
<tr><td>Key Variables</td><td>Influent and effluent quality (PCB concentration, particle concentration, organic matter, proportion of dissolved contaminants, particle size, particle size distribution)
BMP design (media depth) and hydraulic loading/head
Media type and properties (composition, grain size/size distribution, adsorptive properties, hydraulic conductivity)
BMP maintenance (surface clogging, short-circuiting)</td></tr>
<tr><td>Monitoring Needs</td><td>Monitored variables: Influent and effluent quality contaminant concentration, particle concentration, organic matter, surface clogging
Controlled variables: media depth, hydraulic loading/head, media composition and adsorptive properties, hydraulic conductivity
Uncontrolled variables: Influent and effluent proportion of dissolved contaminants, particle size, particle size distribution, short-circuiting</td></tr>
<tr><td>Monitoring Approach</td><td>Phased approach because of number of media/need to ensure MRP infiltration rates
Hydraulic tests to ensure amended media meet infiltration requirements
Influent-effluent column tests for select mixes with Bay Area stormwater
Influent-effluent column tests for best mix with Bay Area stormwater at lower concentrations</td></tr>
<tr><td>Sampling Design</td><td>Phase I Hydraulic Tests:
- Determine infiltration rates for media mixes with 25% biochar by volume
- If MRP infiltration rates not met, adjust biochar proportion and retest
- Target infiltration rate of 5 - 12 in/h for all mixes, attempt to control rate to +/- 1 in/hr.

Phase II Influent-Effluent Column Tests with Bay Area Stormwater (up to 5 mixes)
<table><tr><th>Biochar/BSM Mix</th><th>Column Samples</th><th>No. Samples (Total 21)</th></tr><tr><td>A Mix</td><td>X, X, X</td><td>3</td></tr><tr><td>B Mix</td><td>X, X, X</td><td>3</td></tr><tr><td>C Mix</td><td>X, X, X</td><td>3</td></tr><tr><td>D Mix</td><td>X, X, X</td><td>3</td></tr><tr><td>E Mix</td><td>X, X, X</td><td>3</td></tr><tr><td>Control Mix</td><td>X, X, X</td><td>3</td></tr><tr><td>Influent</td><td>X, X, X</td><td>3</td></tr></table>
Phase III Influent-Effluent Column Tests for Select Mix with Diluted Bay Area Stormwater
- Perform tests with diluted stormwater, if necessary, to confirm effectiveness at concentrations representative of New Urban and New Industrial land
- Test at one dilution (1 influent and 1 mix and 1 control effluent) (3 samples)</td></tr>
<tr><td>Constituent List</td><td>SSC, turbidity, TOC, total mercury, PCBs (40 congeners) in water</td></tr>
<tr><td>Data Analysis</td><td>Dependent (paired) samples. Present range of total PCB and mercury concentrations measured and mass removal efficiencies. Analyze using ANOVA and regressions of influent/effluent quality. Perform sign-rank test to compare consistency in relative performance among the columns.</td></tr>
</table>

8.6 Adequacy of Study Design

The primary management questions are reviewed in this section in light of the budgeted data collection efforts. The primary management questions are restated and followed by an analysis of the adequacy of the data collection effort.

1. *What are the annual PCB and mercury loads captured by existing HDS units in Bay Area urban watersheds?*

Table 8.3 lists the number of data points that are anticipated for the HDS monitoring study.

This selected design will provide 9 data points for each of the following: PCB sediment concentration, mercury sediment concentration, and sediment mass. This design will not be able to assess the effect of HDS size and hydraulic loading on pollutant removal, and may not be able to statistically differentiate load capture between different land uses because of the small sample count for each land use (3). However, this design is selected because of the lack of information available on HDS sizing and the opportunistic nature of the sampling which limits the number of HDS units that can be sampled. The effect of maintenance is eliminated by ensuring that samples are not collected from units that have no remaining sump capacity.

The HDS study design collects independent (unpaired) samples since each HDS unit is sampled independently and there is no relationship between the various HDS units. This limits ability to discern differences due to land use or HDS size, especially when sample size is relatively low and there is considerable variability in the data collected. Although the study design yields 9 data points for each data objective, it may not be sufficient to draw statistically-based conclusions. However, the study will provide point estimates of loads removed during cleanouts and how they vary for different land uses (e.g., X g of PCBs are removed per unit area of Y land use). This is the metric used for effectiveness of HDS cleanouts, so the study will provide a practical improvement in knowledge that can be applied to future HDS effectiveness estimates.

In addition, modeled stormwater flows and associated POC loads to each HDS unit catchment during the time period between cleanouts will be developed. These modeled estimates will be used along with the measured mass captured in the HDS unit between cleanouts to quantify the percent removal for each unit during the study.

2. *Are there readily available biochar-amended BSM that provide significantly better PCB and mercury load reductions than standard BSM and meet MRP infiltration rate requirements?*

Table 8.4 lists the number of data points that are anticipated for the enhanced BSM testing study. The sampling design will yield 19 data points for each of the following: effluent PCB concentration, effluent mercury concentration. Including influent analysis, a total of 24 samples will be analyzed. The purpose of this study is to identify the best biochar amended BSM mixes for field testing and not test the effect of confounding variables such as influent quality and hydraulic loading on load removals. The study design accounts for these confounding variables by either ensuring their effect is randomized (e.g., influent water quality) or keeps them fixed (e.g., hydraulic loading). To ensure influent stormwater concentrations are representative of typical Bay Area concentrations, an additional column test with diluted stormwater is performed on an effective media mix. Standard BSM controls are used for each column run so that removal by biochar amended mixes can be compared directly to removal by standard BSM. Infiltration experiments are performed prior to the column testing to ensure media selected for final column testing will meet the MRP infiltration rate requirements.

The enhanced BSM column study design collects dependent (paired) samples since each effluent sample is related to a corresponding influent sample. Additionally, standard BSM controls are used for each run which makes it possible to directly compare effluent quality for each amended BSM to standard BSM. The paired sampling design, use of standard BSM controls, and ability to control or fix many of the variables that effect load removal increase the ability to discern differences in treatment. Therefore, only 3 column runs are proposed, and available budget is instead used in initial hydraulic screening experiments to ensure selected media mixes meet MRP infiltration rate requirements. The study design may not be sufficient to draw statistically-based conclusions because it yields only 3 data points for each biochar mix tested. However, the study will enable direct comparisons of effluent quality and treatment between mixes for individual events and consistency of treatment between events. The information provided by the study is expected to be sufficient to identify the most promising biochar mixes for field testing.

The study designs for the HDS monitoring and enhanced bioretention studies meet MRP sample collection requirements. The sampling design for the HDS monitoring study will yield a minimum of 9 PCB and mercury data points, while the sampling design for the enhanced bioretention laboratory study will yield 24 PCB and mercury data points (including influent analysis). The minimum number of PCB samples for this study plan is 33 (9+24). Because 3 of the 32 BMP effectiveness samples required by the current MRP have already been collected, the minimum number required for this project is 29. This study must yield 29 of the 32 permit-required samples, per Provision C.8.f of the MRP. To ensure that at least 29 samples are collected to meet the MRP requirement, additional samples will be collected during the laboratory media testing runs if fewer than 5 HDS units are available for sampling.

9. Recommendations for Sampling and Analysis Plans

This section presents specific recommendations for the development of SAPs. More detailed information is available in Section 6 of the Caltrans Monitoring Guidance Manual (Caltrans, 2015) and in the Urban Stormwater BMP Performance Monitoring (WERF 2009). Analysis of constituents should follow the CW4CB Quality Assurance Project Plan (BASMAA 2013).

9.1 HDS Monitoring

The following SAP recommendations are based on the lessons learned from sampling the Leo Avenue HDS site (BASMAA, 2017b):

- Include equipment to determine sump capacity before sampling. The study design does not require sampling of units that are full (i.e., have no remaining sump capacity). The depth of the unit can make it difficult to inspect for sump basin contents, and use of a “sludge judge” or other similar equipment may not be possible because of difficulty penetrating through compacted organic materials.
- The sampling is expected to be opportunistic sampling during regular cleanouts. Since it coincides with regular maintenance patterns, the occurrence of a clean and empty vactor truck from which samples of the sediment can be taken is unlikely. To obtain representative samples, multiple grab samples that extend from the top of the sediment layer to the bottom of the sump will need to be collected and composited prior to analyses.
- Sediment samples will require screening to remove coarse particles, trash, etc. In the CW4CB study (BASMAA, 2007b), only sediment less than 2 mm in size was analyzed.

It is unclear how samples of the HDS sediment were taken in the Leo Avenue HDS sampling. Appropriate sampling methods should be developed to ensure the samples collected are representative of the sediment in the HDS units.

HDS sediment sampling is not expected to require additional handling/safety precautions beyond normal drain cleaning safety procedures. Human health criteria for PCBs are for exposure via ingestion or vapor intake and not for contact. OSHA directive STD 01-04-002 state that “repeated skin contact hazards with all PCB's could be addressed by the standards 1910.132 and 1910.133”. Both 1910.132 and 1910.133 OSHA standards require use of personal protective equipment, including eye and face protection.

9.2 Enhanced Bioretention Media Testing

The following SAP recommendations are based on past experience and specific guidance provided in DEMEAU (2014):

- The enhanced BSM testing will use real stormwater for the column experiments to account for the effect of influent water quality on load removal. A stormwater collection site will need to be identified in a watershed with typical PCB concentrations to ensure PCB concentrations are representative of those expected in Bay Area urban watersheds. Also, guidance will need to be developed on mobilization to ensure storms are targeted randomly.

- Stormwater properties are known to change significantly with time due to natural flocculation and settling of particles. Appropriate procedures should be developed to ensure collected stormwater is well mixed at all times, and experiments are performed in a timely manner to insure the stormwater used is representative.
- PCBs can readily attach to test equipment, including the inside of tubing that may be used for pumps and the inside of PVC columns. Alternatives should be considered that eliminate the need for pumping equipment and reduce attachment within columns (e.g., by use of glass columns).
- The results of column experiments can be affected by channeling and wall effects. Use a column diameter to particle diameter ratio greater than about 40 to minimize these.
- How media is packed in columns will affect infiltration rates and treatment performance. Therefore, detailed procedures should be developed for the packing of media in columns to ensure consistency between columns and between experiments.

9.3 Data Quality Objectives

Data quality objectives (DQOs) should follow standard stormwater monitoring protocols and be described in detail in individual SAPs. Both sampling and laboratory data quality objectives should be included. For sampling, the SAP should specify sediment and water collection procedures and equipment as well as sample volume and handling requirements. For laboratories, numeric DQOs are appropriate for sample blanks, duplicates (or field splits), and matrix spike recovery.

10. References

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APPENDIX B: SAMPLING AND ANALYSIS PLAN AND QUALITY ASSURANCE PROJECT PLAN

BASMAA
Regional Monitoring Coalition

Pollutants of Concern Monitoring for Source Identification and Management Action Effectiveness, 2017-2018

Sampling and Analysis Plan and Quality Assurance Project Plan

Prepared for:

The Bay Area Stormwater Management Agencies Association (BASMAA)

Prepared by:

EOA inc.
1410 Jackson Street
Oakland, CA
94612

Water Programs, Sacramento State
6000 J Street
Sacramento, CA
95819

SFEI
4911 Central Avenue
Richmond, CA
94804

Kinnetic Laboratories Incorporated
307 Washington Street
Santa Cruz, CA
95060

Version 2
September 29, 2017

Title and Approval Sheet

Program Title	Pollutants of Concern (POC) Monitoring for Source Identification and Management Action Effectiveness
Lead Organization	Bay Area Stormwater Management Agencies Association (BASMAA) P.O. Box 2385, Menlo Park, CA 94026, 510-622-2326 info@basmaa.org
Primary Contact	Geoff Brosseau
Effective Date	September 29, 2017
Revision Number	Version 2

Approval Signatures:

A signature from the BASMAA Executive Director approving the BASMAA POC Monitoring for Source Identification and Management Action Effectiveness is considered approval on behalf of all Program Managers.

Geoff Brosseau	Date

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List of Acronyms

ACCWP	Alameda Countywide Clean Water Program
ALS	ALS Environmental Laboratory
BASMAA	Bay Area Stormwater Management Agencies Association
BSM	Bioretention Soil Media
CCCWP	Contra Costa Clean Water Program
CCV	continuing calibration verification
CEDEN	California Environmental Data Exchange Network
CEH	Center for Environmental Health
COC	Chain of Custody
Consultant-PM	Consultant Team Project Manager
CRM	Certified Reference Material
CSE	Confined Space Entry
ECD	Electron capture detection
EDD	Electronic Data Deliverable
EOA	Eisenberg, Olivieri & Associates, Inc.
EPA	Environmental Protection Agency (U.S.)
FD	Field duplicate
Field PM	Field Contractor Project Manager
FSURMP	Fairfield-Suisun Urban Runoff Management Program
GC-MS	Gas Chromatography-Mass Spectroscopy
IDL	Instrument Detection Limits
ICV	initial calibration verification
KLI	Kinnetic Laboratories Inc.
LCS	Laboratory Control Samples
Lab-PM	Laboratory Project Manager
MS/MSD	Matrix Spike/Matrix Spike Duplicate
MDL	Method Detection Limit
MQO	Measurement Quality Objective
MRL	Method Reporting Limit
MRP	Municipal Regional Permit
NPDES	National Pollutant Discharge Elimination System
OWP-CSUS	Office of Water Programs at California State University Sacramento
PCB	Polychlorinated Biphenyl
PM	Project Manager
PMT	Project Management Team
POC	Pollutants of Concern
QA	Quality Assurance
QA Officer	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QC	Quality Control
ROW	Right-of-way
RPD	Relative Percent Difference
RMC	Regional Monitoring Coalition
RMP	Regional Monitoring Program for Water Quality in the San Francisco Estuary
SFRWQCB	San Francisco Regional Water Quality Control Board (Regional Water Board)
SAP	Sampling and Analysis Plan
SCCVURPP	Santa Clara Valley Urban Runoff Pollution Prevention Program
SCVWD	Santa Clara Valley Water Department
SFEI	San Francisco Estuary Institute

SMCWPPP	San Mateo County Water Pollution Prevention Program
SOP	Standard Operating Procedure
SWAMP	California Surface Water Ambient Monitoring Program
TOC	Total Organic Carbon
TMDL	Total Maximum Daily Load
VSFCD	Vallejo Sanitation and Flood Control District

1. Problem Definition/Background

The Bay Area Stormwater Management Agencies Association (BASMAA) member agencies will implement a regional monitoring program for Pollutants of Concern (POC) Monitoring for Source Identification and Management Action Effectiveness (Monitoring Program). The Monitoring Program is intended to fulfill components of the Municipal Regional Stormwater NPDES Permit (MRP; Order No. R2-2015-0049), which implements the polychlorinated biphenyls (PCBs) and Mercury Total Maximum Daily Loads (TMDLs) for the San Francisco Bay Area. Monitoring for Source Identification and Management Action Effectiveness are two of five monitoring priorities for POCs identified in the MRP. Source identification monitoring is conducted to identify the sources or watershed source areas that provide the greatest opportunities for reductions of POCs in urban stormwater runoff. Management action effectiveness monitoring is conducted to provide support for planning future management actions or to evaluate the effectiveness or impacts of existing management actions.

BASMAA developed two study designs to implement each component of the Monitoring Program. The ***Evaluation of PCBs Presence in Public Roadway and Storm Drain Infrastructure Caulk and Sealants Study Design*** (BASMAA 2017a) addresses the source identification monitoring requirements of Provision C.8.f, as well as requirements of Provision C.12.e to investigate PCBs in infrastructure caulk and sealants. The ***POC Monitoring for Management Action Effectiveness Study Design*** (BASMAA 2017b) addresses the management action effectiveness monitoring requirements of Provision C.8.f. The results of the Monitoring Program will contribute to ongoing efforts by MRP Permittees to identify PCB sources and improve the PCBs and mercury treatment effectiveness of stormwater control measures in the Phase I permittee area of the Bay Area. This Sampling and Analysis Plan and Quality Assurance Project Plan (SAP/QAPP) was developed to guide implementation of both components of the Monitoring Program.

1.1. Problem Statement

Fish tissue monitoring in San Francisco Bay (Bay) has revealed bioaccumulation of PCBs and mercury. The measured fish tissue concentrations are thought to pose a health risk to people consuming fish caught in the Bay. As a result of these findings, California has issued an interim advisory on the consumption of fish from the Bay. The advisory led to the Bay being designated as an impaired water body on the Clean Water Act "Section 303(d) list" due to PCBs and mercury. In response, the California Regional Water Quality Control Board, San Francisco Bay Region (Regional Water Board) has developed TMDL water quality restoration programs targeting PCBs and mercury in the Bay. The general goals of the TMDLs are to identify sources of PCBs and mercury to the Bay and implement actions to control the sources and restore water quality.

Since the TMDLs were adopted, Permittees have conducted a number of projects to provide information that supports implementation of management actions designed to achieve the wasteload allocations described in the Mercury and PCBs TMDL, as required by Provisions of the MRP. The Clean Watersheds for a Clean Bay project (CW4CB) was a collaboration among BASMAA member agencies that pilot tested various stormwater control measures and provided estimates of the PCBs and mercury load reduction effectiveness of these controls (BASMAA, 2017c). However, the results of the CW4CB project identified a number of remaining data gaps on the load reduction effectiveness of the control measures that were tested. In addition, MRP Provisions C.8.f. and C.12.e require Permittees to conduct further source identification and management action effectiveness monitoring during the current permit term.

1.2. Outcomes

The Monitoring Program will allow Permittees to satisfy MRP monitoring requirements for source identification and management action effectiveness, while also addressing some of the data gaps identified by the CW4CB project (BASMAA, 2017c). Specifically, the Monitoring Program is intended to provide the following outcomes:

1. Satisfy MRP Provision C.8.f. requirements for POC monitoring for source identification; and Satisfy MRP Provision C.12.e.ii requirements to evaluate PCBs presence in caulks/sealants used in storm drain or roadway infrastructure in public ROWs;
    a. Report the range of PCB concentrations observed in 20 composite samples of caulk/sealant collected from structures installed or rehabilitated during the 1970's;
2. Satisfy MRP Provision C.8.f. requirements for POC monitoring for management action effectiveness;
    a. Quantify the annual mass of mercury and PCBs captured in HDS Unit sumps during maintenance; and
    b. Identify bioretention soil media (BSM) mixtures for future field testing that provide the most effective mercury and PCBs treatment in laboratory column tests.

The information generated from the Monitoring Program will be used by MRP Permittees and the Regional Water Board to better understand potential PCB sources and better estimate the load reduction effectiveness of current and future stormwater control measures.

2. Distribution List and Contact Information

The distribution list for this BASMAA SAP/QAPP is provided in Table 2-1.

Table 2-1. BASMAA SAP/QAPP Distribution List.

Project Group	Title	Name and Affiliation	Telephone No.
BASMAA Project Management Team	BASMAA Project Manager, Stormwater Program Specialist	Reid Bogert, SMCWPPP	650-599-1433
	Program Manager	Jim Scanlin, ACCWP	510-670-6548
	Watershed Management Planning Specialist	Lucile Paquette, CCCWP	925-313-2373
	Program Manager	Rachel Kraai, CCCWP	925-313-2042
	Technical Consultant to ACCWP and CCCWP	Lisa Austin, Geosyntec Inc. CCCWP	510-285-2757
	Supervising Environmental Services Specialist	James Downing, City of San Jose	408-535-3500
	Senior Environmental Engineer	Kevin Cullen, FSURMP	707-428-9129
	Pollution Control Supervisor	Doug Scott, VSFCD	707-644-8949 x269
Consultant Team	Project Manager	Bonnie de Berry, EOA Inc.	510-832-2852 x123
	Assistant Project Manager SAP/QAPP Author and Report Preparer	Lisa Sabin, EOA Inc.	510-832-2852 x108
	Technical Advisor	Chris Sommers, EOA Inc.	510-832-2852 x109
	Study Design Lead and Report Preparer	Brian Currier, OWP-CSUS	916-278-8109
	Study Design Lead and Report Preparer	Dipen Patel, OWP-CSUS	
	Technical Advisor	Lester McKee, SFEI	415-847-5095
	Quality Assurance Officer	Don Yee, SFEI	510-746-7369
	Data Manager	Amy Franz, SFEI	510-746-7394
	Field Contractor Project Manager	Jonathan Toal, KLI	831-457-3950
Project Laboratories	Laboratory Project Manager	Howard Borse, ALS	360-430-7733
	XRF Laboratory Project Manager	Matt Nevins, CEH	510-655-3900 x318

3. Program Organization

3.1. Involved Parties and Roles

BASMAA is a 501(c)(3) non-profit organization that coordinates and facilitates regional activities of municipal stormwater programs in the San Francisco Bay Area. BASMAA programs support implementation of the MRP (Order No. R2-2015-0049), which implements the PCBs and Mercury TMDLs for the San Francisco Bay Area. BASMAA is comprised of all 76 identified MRP municipalities and special districts, the Alameda Countywide Clean Water Program (ACCWP), Contra Costa Clean

Water Program (CCCWP), the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), the San Mateo Countywide Water Pollution Prevention Program (SMCWPPP), the Fairfield-Suisun Urban Runoff Management Program (FSURMP), the City of Vallejo and the Vallejo Sanitation and Flood Control District (VSFCD) (Table 3-1).

MRP Permittees have agreed to collectively implement this Monitoring Program via BASMAA. The Program will be facilitated through the BASMAA Monitoring and Pollutants of Concern Committee (MPC). BASMAA selected a consultant team to develop and implement the Monitoring Program with oversight and guidance from a BASMAA Project Management Team (PMT), consisting of representatives from BASMAA stormwater programs and municipalities (Table 3-1).

Table 3-1. San Francisco Bay Area Stormwater Programs and Associated MRP Permittees Participating in the BASMAA Monitoring Program.

Stormwater Programs	MRP Permittees
Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)	Cities of Campbell, Cupertino, Los Altos, Milpitas, Monte Sereno, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, Sunnyvale, Los Altos Hills, and Los Gatos; Santa Clara Valley Water District; and, Santa Clara County
Alameda Countywide Clean Water Program (ACCWP)	Cities of Alameda, Albany, Berkeley, Dublin, Emeryville, Fremont, Hayward, Livermore, Newark, Oakland, Piedmont, Pleasanton, San Leandro, and Union City; Alameda County; Alameda County Flood Control and Water Conservation District; and, Zone 7 Water District
Contra Costa Clean Water Program (CCCWP)	Cities of, Clayton, Concord, El Cerrito, Hercules, Lafayette, Martinez, , Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon, Walnut Creek, Danville, and Moraga; Contra Costa County; and, Contra Costa County Flood Control and Water Conservation District
San Mateo County Wide Water Pollution Prevention Program (SMCWPPP)	Cities of Belmont, Brisbane, Burlingame, Daly City, East Palo Alto, Foster City, Half Moon Bay, Menlo Park, Millbrae, Pacifica, Redwood City, San Bruno, San Carlos, San Mateo, South San Francisco, Atherton, Colma, Hillsborough, Portola Valley, and Woodside; San Mateo County Flood Control District; and, San Mateo County
Fairfield-Suisun Urban Runoff Management Program (FSURMP)	Cities of Fairfield and Suisun City
Vallejo Permittees (VSFCD)	City of Vallejo and Vallejo Sanitation and Flood Control District

3.2. BASMAA Project Manager (BASMAA-PM)

The BASMAA Project Manager (BASMAA-PM) will be responsible for directing the activities of the below-described PMT, and will provide oversight and managerial level activities, including reporting status updates to the PMT and BASMAA, and acting as the liaison between the PMT and the Consultant Team. The BASMAA PM will oversee preparation, review, and approval of project deliverables, including the required reports to the Regional Water Board.

3.3. BASMAA Project Management Team (PMT)

The BASMAA PMT will assist the BASMAA-PM and the below described Consultant Team with the design and implementation of all project activities. PMT members will assist the BASMAA-PM and Consultant Team to complete project activities within scope, on-time, and within budget by having specific responsibility for planning and oversight of project activities within the jurisdiction of the BASMAA agency that they represent. In addition, the PMT will coordinate with the municipal project partners and key regional agencies, including the Regional Water Board. The PMT is also responsible for reviewing and approving project deliverables (e.g., draft and final project reports).

3.4. Consultant Team Project Manager (Consultant-PM)

The Consultant Team Project Manager (Consultant-PM) will be responsible for ensuring all work performed during the Monitoring Program is consistent with project goals, and provide oversight of all day-to-day operations associated with implementing all components of the Monitoring Program, including scheduling, budgeting, reporting, and oversight of subcontractors. The Consultant-PM will ensure that data generated and reported through implementation of the Monitoring Program meet measurement quality objectives (MQOs) described in this SAP/QAPP. The Consultant -PM will work with the Quality Assurance Officer as required to resolve any uncertainties or discrepancies. The Consultant -PM will also be responsible for overseeing development of draft and final reports for the Monitoring Program, as described in this SAP/QAPP.

3.5. Quality Assurance Officer (QA Officer)

The role of the Quality Assurance Officer (QA Officer) is to provide independent oversight and review of the quality of the data being generated. In this role, the QA Officer has the responsibility to require data that is of insufficient quality to be flagged, or not used, or for work to be redone as necessary so that the data meets specified quality measurements. The QA Officer will oversee the technical conduct of the field related components of the Monitoring Program, including ensuring field program compliance with the SAP/QAPP for tasks overseen at the programmatic level.

3.6. Data Manager (DM)

The Data Manager will be responsible for receipt and review of all project related documentation and reporting associated with both field efforts and laboratory analysis. The Data Manager will also be responsible for storage and safekeeping of these records for the duration of the project.

3.7. Field Contractor Project Manager (Field-PM)

The Field Contractor Project Manager (Field-PM) will be responsible for conduct and oversight of all field monitoring- and reporting-related activities, including completion of field datasheets, chain of custodies, and collection of field measurements and field samples, consistent with the monitoring methods and procedures in the SAP/QAPP. The Field-PM will also be responsible for ensuring that personnel conducting monitoring are qualified to perform their responsibilities and have received appropriate training. The Field-PM will be responsible for initial receipt and review of all project related documentation and reporting associated with both field efforts and laboratory analysis.

The Field-PM will also be responsible for receiving all samples collected opportunistically by participating municipalities, including all caulk/sealant samples, initial review of sample IDs to ensure there are no duplicate sample IDs, and shipping the samples under COC to the appropriate laboratory (CEH for the caulk/sealant samples; ALS for all other samples). Participating municipalities should ship all samples they collect to the Field PM at the following address:

Jon Toal
Kinnetic Laboratories, Inc.
307 Washington Street
Santa Cruz, CA 95060
Reference: BASMAA POC Monitoring Project
(831)457-3950

3.8. Laboratory Project Manager (Lab-PM)

The Laboratory Project Manager (Lab-PM) and chemists at each analytical laboratory will be responsible for ensuring that the laboratory's quality assurance program and standard operating procedures (SOPs) are consistent with this SAP/QAPP, and that laboratory analyses meet all applicable requirements or explain any deviations. Each Lab-PM will also be responsible for coordinating with the Field-PM and other staff (e.g., Consultant -PM, Data Manager, QA Officer) and facilitating communication between the Field-PM, the Consultant -PM, and analytical laboratory personnel, as required for the project.

The Center for Environmental Health (CEH) will provide chlorine content screening of all caulk/sealant samples collected using X-Ray Fluorescence (XRF) technology to assist in selection of samples for further laboratory analysis of PCBs. This XRF-screening will also provide additional information on the utility of XRF in prioritizing samples for chemical PCBs analyses.

All other laboratory analyses will be provided by ALS Environmental.

3.1. Report Preparer

The Report Preparer (RP) will be responsible for developing draft and final reports for each of the following components of the Monitoring Program: (1) Source identification; and (2) Management action effectiveness. All draft reports will be submitted to the PMT for review and input prior to submission for approval by the BASMAA Board of Directors (BOD).

4. Monitoring Program Description

4.1. Work Statement and Program Overview

The Monitoring Program consists of the following three major tasks, each of which has a field sampling component:

- **Task 1. Evaluate presence and possible concentrations of PCBs in roadway and storm drain infrastructure caulk and sealants**. This task involves analysis of 20 composite samples of caulk/sealant collected from public roadway and storm drain infrastructure throughout the permit area to investigate PCB concentrations. The goal of this task is to evaluate, at a limited screening level, whether and in what concentrations PCBs are present in public roadway and storm drain infrastructure caulk and sealants in the portions of the Bay Area under the jurisdiction of the Phase I Permittees identified in Table 3-1 (Bay Area).

- **Task 2. Evaluate Annual mass of PCBs and mercury captured in Hydrodynamic Separator (HDS) Unit sumps during maintenance.** This task involves collecting sediment samples from the sumps of public HDS unit during maintenance cleanouts to evaluate the mass of PCBs and mercury captured by these devices. The goal of this task is to provide data to better characterize the concentrations of POCs in HDS Unit sump sediment and improve estimates of the mass captured and removed from these units during current maintenance practices for appropriate TMDL load reduction crediting purposes.

- **Task 3. Bench-scale testing of the mercury and PCBs removal effectiveness of selected BSM mixtures enhanced with biochar.** This task involves collecting stormwater from the Bay Area that will then be used to conduct laboratory column tests designed to evaluate the mercury and PCBs treatment effectiveness of various biochar-amended BSM mixtures. Real stormwater will be used for the column tests to account for the effect of influent water quality on load removal. The goal of this task is to identify BSM mixtures amended with biochar that meet operational infiltration requirements and are effective for PCBs and mercury removal for future field testing.

All monitoring results and interpretations will be documented in BASMAA reports for submission to the Regional Water Board according to the schedule in the MRP.

4.2. Sampling Detail

The Monitoring Program includes three separate sampling tasks that involve collection and analysis of the following types of samples: caulk/sealants (Task 1); sediment from HDS units (Task 2); and stormwater collected and used for column tests in the lab (Task 3). Additional details specific to the sampling design for each task are provided below.

4.2.1. Task 1 - Caulk/Sealant samples

The PMT will recruit municipal partners from within each stormwater program to participate in this task. All caulk/sealant samples will be collected from locations within public roadway or storm drain infrastructure in the participating municipalities. Exact sample sites will be identified based on available information for each municipal partner, including: age of public infrastructure; records of infrastructure repair or rehabilitation (aiming for the late 1960s through the 1970s); and current municipal staff knowledge about locations that meet the site selection criteria identified in the study design (BASMAA, 2017a). Field crews led by the Field-PM and/or municipal staff will conduct field reconnaissance to further identify specific sampling locations and if feasible, will collect caulk/sealant samples during these initial field visits. Follow-up sampling events will be conducted for any sites that require additional planning or equipment for sample collection (e.g., confined space entry, parking controls, etc.). Sample locations will include any of the following public infrastructure where caulk/sealant are present: roadway or sidewalk surfaces, between expansion joints for roadways, parking garages, bridges, dams, or storm drain pipes, and/or in pavement joints (e.g., curb and gutter). Sampling will only occur during periods of dry weather when urban runoff flows through any structures that will be sampled are minimal, and do not present any safety hazards or other logistical issues during sample collection. Sample collection methods are described further in Section 9.

As opportunities arise, municipal staff will also collect samples following the methods and procedures described in this SAP/QAPP during ongoing capital projects that provide access to public infrastructure locations with caulk/sealant that meet the sample site criteria. All samples collected by participating municipal staff will be delivered to the Field PM under COC. The Field-PM will be responsible for storing all caulk/sealant samples and shipping the samples under COC to CEH for XRF screening analysis.

All caulk/sealant samples collected will be screened for chlorine content using XRF technology described in Section 9. Samples will be grouped for compositing purposes as described in the study design (BASMAA, 2017a). Up to three samples will be included per composite and a total of 20 composite caulk/sealant samples will be analyzed for the RMP 40 PCB congeners[1]. All compositing and PCBs analysis will be conducted blind to the location where each sample was collected. Laboratory analysis methods must be able to detect a minimum PCBs concentration of 200 parts per billion (ppb, or µg/Kg). Laboratory analytical methods are described further in Section 12. The range of PCB concentrations found in caulk based on this documented sampling design will be reported to the Regional Water Board within the Permittees' 2018 Annual Reports.

4.2.2. Task 2 - Sediment samples from HDS Units

The PMT will recruit municipal partners that maintain public HDS units to participate in this task. All sediment samples will be collected from the sump of selected HDS units during scheduled cleaning and maintenance. Selection of the HDS units for sampling will be opportunistic, based on the units that are scheduled for maintenance by participating municipalities during the project period. Field crews led by the Field-PM and municipal maintenance staff will coordinate sampling with scheduled maintenance events. As needed, municipal staff will dewater the HDS unit sumps prior to sample collection, and provide assistance to field crews with access to the sump sediment as needed (e.g., confined space entry, parking controls, etc.). All sump sediment samples will be collected following the methods and procedures described in this SAP/QAPP. Sampling will only occur during periods of dry weather when urban runoff flows into the HDS unit sumps are minimal, and do not present any safety hazards or other logistical issues during sample collection. Sample collection methods are described further in Section 9.

All sediment samples collected will be analyzed for the RMP 40 PCB congeners, total mercury, total organic carbon (TOC), particle size distribution (PSD), and bulk density. Laboratory analytical methods are described further in Section 12. The range of PCB and mercury concentrations observed in HDS Unit sump sediments and the annual pollutant masses removed during cleanouts will be reported to the Regional Water Board in March 2019.

4.2.3. Task 3 - Storm Water and Column Test Samples

This task will collect stormwater from Bay Area locations that will then be used as the influent for column tests of biochar-amended BSM. Bay Area stormwater samples will be collected from locations

[1] The 40 individual congeners routinely quantified by the Regional Monitoring Program (RMP) for Water Quality in the San Francisco Estuary include: PCBs 8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, l05, 110, 118, 128, 132, 138, 141, 149, l51, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203

within public roadway or storm drain infrastructure in participating municipalities. Field personnel lead by the Field PM will collect stormwater samples during three qualifying storm events and ensure all samples are delivered to the lab of OWP at CSUS within 24-hours of collection. Stormwater will be collected from one watershed that has a range of PCB concentrations and is considered representative of Bay Area watersheds (e.g. the West Oakland Ettie Street Pump Station watershed). Storms from the representative watershed should be targeted randomly without bias, thereby accounting for the effects of storm intensity and ensuring variability in contaminant concentration, proportion of dissolved contaminants, particle size, particle size distribution, and particle density. To achieve this, minimal mobilization criteria should be used to ensure predicted storm intensity and runoff volume are likely to yield the desired volume. Sample collection methods are described further in Section 9.

The stormwater collected will be used as the influent for column tests of various BSM mixtures amended with biochar. These tests will be implemented in three phases. First, hydraulic screening tests will be performed to ensure all amended BSM mixtures meet the MRP infiltration rate requirements of 12 in/h initial maximum infiltration or minimum 5 in/h long-term infiltration rate. Second, column tests will be performed using Bay Area stormwater to evaluate pollutant removal. Third, additional column tests will be performed using lower concentration (e.g., diluted) Bay Area stormwater to evaluate relative pollutant removal performance at lower concentrations. Further details about the column testing are provided in Section 9.3.

All influent and effluent water samples collected will be analyzed for the RMP 40 PCB congeners, total mercury, suspended sediment concentrations (SSC), TOC, and turbidity. Laboratory analytical methods are described further in Section 12. The range of PCB and mercury concentrations observed in influent and effluent water samples and the associated pollutant mass removal efficiencies for each BSM mixture tested will be reported to the Regional Water Board in March 2019.

4.3. Schedule

Caulk/sealant sampling (Task 1) will be conducted between July 2017 and December 2017. HDS Unit sampling (Task 2) will be conducted between July 2017 and May 2018. Stormwater sample collection and BSM column tests (Task 3) will occur between October 2017 – April 2018.

4.4. Geographical Setting

Field operations will be conducted across multiple Phase I cities in the San Francisco Bay region within the counties of San Mateo, Santa Clara, Alameda, and Contra Costa, and the City of Vallejo.

4.5. Constraints

Caulk/sealant sampling and HDS unit sampling will only be conducted during dry weather, when urban runoff flows through the sampled structures are minimal and do not present safety hazards or other logistical concerns. Caulk/sealant sampling will be limited to the caulk/sealant available and accessible at sites that meet the project site criteria (described in the Study Design, BASMAA 2017a). HDS unit sampling will be limited by the number of public HDS units that are available for maintenance during the project period. Extreme wet weather may pose a safety hazard to sampling personnel and may therefore impact wet season sampling.

5. Measurement Quality Objectives (MQO)

The quantitative measurements that estimate the true value or concentration of a physical or chemical property always involve some level of uncertainty. The uncertainty associated with a measurement generally results from one or more of several areas: (1) natural variability of a sample; (2) sample handling conditions and operations; (3) spatial and temporal variation; and (4) variations in collection or analytical procedures. Stringent Quality Assurance (QA) and Quality Control (QC) procedures are essential for obtaining unbiased, precise, and representative measurements and for maintaining the integrity of the sample during collection, handling, and analysis, as well and for measuring elements of variability that cannot be controlled. Stringent procedures also must be applied to data management to assure that accuracy of the data is maintained.

MQOs are established to ensure that data collected are sufficient and of adequate quality for the intended use. MQOs include both quantitative and qualitative assessment of the acceptability of data. The qualitative goals include representativeness and comparability, and the quantitative goals include completeness, sensitivity (detection and quantization limits), precision, accuracy, and contamination.

MQOs associated with representativeness, comparability, completeness, sensitivity, precision, accuracy, and contamination are presented below in narrative form.

5.1. Representativeness and Comparability

The representativeness of data is the ability of the sampling locations and the sampling procedures to adequately represent the true condition of the sample sites. The comparability of data is the degree to which the data can be compared directly between all samples collected under this SAP/QAPP. Field personnel, including municipal personnel that collect samples, will strictly adhere to the field sampling protocols identified in this SAP/QAPP to ensure the collection of representative, uncontaminated, comparable samples. The most important aspects of quality control associated with chemistry sample collection are as follows:

- Field personnel will be thoroughly trained in the proper use of sample collection equipment and will be able to distinguish acceptable versus unacceptable samples in accordance with pre-established criteria.
- Field personnel are trained to recognize and avoid potential sources of sample contamination (e.g., dirty hands, insufficient field cleaning).
- Samplers and utensils that come in direct contact with the sample will be made of non-contaminating materials, and will be thoroughly cleaned between sampling stations.
- Sample containers will be pre-cleaned and of the recommended type.
- All sampling sites will be selected according to the criteria identified in the project study design (BASMAA, 2017a)

Further, the methods for collecting and analyzing PCBs in infrastructure caulk and sealants will be comparable to other studies of PCBs in building material and infrastructure caulk (e.g., Klosterhaus et al., 2014). This SAP/QAPP was also developed to be comparable with the California Surface Water Ambient Monitoring Program (SWAMP) Quality Assurance Program Plan (QAPrP, SWAMP 2013). All sediment and water quality data collected during the Monitoring Program will be performed in a manner so that data are SWAMP comparable [2].

5.2. Completeness

Completeness is defined as the percentage of valid data collected and analyzed compared to the total expected to being obtained under normal operating conditions. Overall completeness accounts for both sampling (in the field) and analysis (in the laboratory). Valid samples include those for analytes in which the concentration is determined to be below detection limits.

Under ideal circumstances, the objective is to collect 100 percent of all field samples desired, with successful laboratory analyses on 100% of measurements (including QC samples). However, circumstances surrounding sample collections and subsequent laboratory analysis are influenced by numerous factors, including availability of infrastructure meeting the required sampling criteria (applies to both infrastructure caulk sampling and HDS Unit sampling), flow conditions, weather, shipping damage or delays, sampling crew or lab analyst error, and QC samples failing MQOs. An overall completeness of greater than 90% is considered acceptable for the Monitoring Program.

5.3. Sensitivity

Different indicators of the sensitivity of an analytical method to measure a target parameter are often used including instrument detection limits (IDLs), method detection limits (MDLs), and method reporting limits (MRLs). For the Monitoring Program, MRL is the measurement of primary interest, consistent with SWAMP Quality Assurance Project Plan (SWAMP 2013). Target MRLs for all analytes by analytical method provided in Section 13.

5.4. Precision

Precision is used to measure the degree of mutual agreement among individual measurements of the same property under prescribed similar conditions. Overall precision usually refers to the degree of agreement for the entire sampling, operational, and analysis system. It is derived from reanalysis of individual samples (laboratory replicates) or multiple collocated samples (field replicates) analyzed on equivalent instruments and expressed as the relative percent difference (RPD) or relative standard deviation (RSD). Analytical precision can be determined from duplicate analyses of field samples, laboratory matrix spikes/matrix spike duplicates (MS/MSD), laboratory control samples (LCS) and/or reference material samples. Analytical precision is expressed as the RPD for duplicate measurements:

$$RPD = ABS\left([X1 - X2] / [(X1 + X2) / 2]\right)$$

Where: X1 = the first sample result
X2 = the duplicate sample result.

[2] SWAMP data templates and documentation are available online at http://waterboards.ca.gov/water_issues/programs/swamp/data_management_resources/templates_docs.shtml

Precision will be assessed during the Monitoring Program by calculating the RPD of laboratory replicate samples and/or MS/MSD samples, which will be run at a frequency of 1 per analytical batch for each analyte. Target RPDs for the Monitoring Program are identified in Section 13.

5.5. Accuracy

Accuracy describes the degree of agreement between a measurement (or the average of measurements of the same quantity) and its true environmental value, or an acceptable reference value. The “true” values of the POCs in the Monitoring Program are unknown and therefore “absolute” accuracy (and representativeness) cannot be assessed. However, the analytical accuracy can be assessed through the use of laboratory MS samples, and/or LCS. For MS samples, recovery is calculated from the original sample result, the expected value (EV = native + spike concentration), and the measured value with the spike (MV):

$$\% \text{ Recovery} = (MV-N) \times 100\% / (EV-N)$$

Where: MV = the measured value
EV = the true expected (reference) value
N = the native, unspiked result

For LCS, recovery is calculated from the concentration of the analyte recovered and the true value of the amount spiked:

$$\% \text{ Recovery} = (X/TV) \times 100\%$$

Where: X = concentration of the analyte recovered
TV = concentration of the true value of the amount spiked

Surrogate standards are also spiked into samples for some analytical methods (i.e., PCBs) and used to evaluate method and instrument performance. Although recoveries on surrogates are to be reported, control limits for surrogates are method and laboratory specific, and no project specific recovery targets for surrogates are specified, so long as overall recovery targets for accuracy (with matrix spikes) are achieved. Where surrogate recoveries are applicable, data will not be reported as surrogate-corrected values.

Analytical accuracy will be assessed during the Monitoring Program based on recovery of the compound of interest in matrix spike and matrix spike duplicates compared with the laboratory’s expected value, at a frequency of 1 per analytical batch for each analyte. Recovery targets for the Monitoring Program are identified in Section 13.

5.6. Contamination

Collected samples may inadvertently be contaminated with target analytes at many points in the sampling and analytical process, from the materials shipped for field sampling, to the air supply in the analytical laboratory. When appropriate, blank samples evaluated at multiple points in the process chain help assure that compound of interest measured in samples actually originated from the target matrix in the sampled environment and are not artifacts of the collection or analytical process.

Method blanks (also called laboratory reagent blanks, extraction blanks, procedural blanks, or preparation blanks) are used by laboratory personnel to assess laboratory contamination during all stages of sample preparation and analysis. The method blank is processed through the entire analytical procedure in a manner identical to the samples. A method blank concentration should be less than the RL or should not exceed a concentration of 10% of the lowest reported sample concentration. A method blank concentration greater than 10% of the lowest reported sample concentration will require corrective action to identify and eliminate the source(s) of contamination before proceeding with sample analysis. If eliminating the blank contamination is not possible, all impacted analytes in the analytical batch shall be flagged. In addition, a detailed description of the likely contamination source(s) and the steps taken to eliminate/minimize the contaminants shall be included in narrative of the data report. If supporting data is presented demonstrating sufficient precision in blank measurement that the 99% confidence interval around the average blank value is less than the MDL or 10% of the lowest measured sample concentration, then the average blank value may be subtracted.

A field blank is collected to assess potential sample contamination levels that occur during field sampling activities. Field blanks are taken to the field, transferred to the appropriate container, preserved (if required by the method), and treated the same as the corresponding sample type during the course of a sampling event. The inclusion of field blanks is dependent on the requirements specified in the relevant MQO tables or in the sampling method.

6. Special Training Needs / Certification

All fieldwork will be performed by contractor staff that has appropriate levels of experience and expertise to conduct the work, and/or by municipal staff that have received the appropriate instruction on sample collection, as determined by the Field PM and/or the PMT. The Field-PM will ensure that all members of the field crew (including participating municipal staff) have received appropriate instructions based on methods described in this document (Section 9) for collecting and transporting samples. As appropriate, sampling personnel may be required to undergo or have undergone OSHA training / certification for confined space entry in order to undertake particular aspects of sampling within areas deemed as such.

Analytical laboratories are to be certified for the analyses conducted at each laboratory by ELAP, NELAP, or an equivalent accreditation program as approved by the PMT. All laboratory personal will follow methods described in Section 13 for analyzing samples.

7. Program Documentation and Reporting

The Consultant Team in consultation with the PMT will prepare draft and final reports of all monitoring data, including statistical analysis and interpretation of the data, as appropriate, which will be submitted to the BASMAA BOD for approval. Following approval by the BASMAA BOD, Final project reports will be available for submission with each stormwater program's Annual Report in 2018 (Task 1) or in the March 31, 2019 report to the Regional Water Board (Tasks 2 and 3). Procedures for overall management of project documents and records and report preparation are summarized below.

7.1. Field Documentation

All field data gathered for the project are to be recorded in field datasheets, and scanned or transcribed to electronic documents as needed to permit easy access by the PMT, the consultant team, and other appropriate parties.

7.1.1. Sampling Plans, COCs, and Sampling Reports

The Field-PM will be responsible for development and submission of field sampling reports to the Data Manager and Consultant-PM. Field crews will collect records for sample collection, and will be responsible for maintaining these records in an accessible manner. Samples sent to analytical laboratories will include standard Chain of Custody (COC) procedures and forms; field crews will maintain a copy of originating COCs at their individual headquarters. Analytical laboratories will collect records for sample receipt and storage, analyses, and reporting. All records, except lab records, generated by the Monitoring Program will be stored at the office of the Data Manager for the duration of the project, and provided to BASMAA at the end of the project.

7.1.2. Data Sheets

All field data gathered by the Monitoring Program will be recorded on standardized field data entry forms. The field data sheets that will be used for each sampling task are provided in Appendix A.

7.1.3. Photographic Documentation

Photographic documentation is an important part of sampling procedures. An associated photo log will be maintained documenting sites and subjects associated with photos. If an option, the date function on the camera shall be turned on. Field Personnel will be instructed to take care to avoid any land marks when taking photographs, such as street signs, names of buildings, road mile markers, etc. that could be used later to identify a specific location. A copy of all photographs should be provided at the conclusion of sampling efforts and maintained for project duration.

7.2. Laboratory Documentation

The Monitoring Program requires specific actions to be taken by contract laboratories, including requirements for data deliverables, quality control, and on-site archival of project-specific information. Each of these aspects is described below.

7.2.1. Data Reporting Format

Each laboratory will deliver data in electronic formats to the Field-PM, who will transfer the records to the Data Manager, who is responsible for storage and safekeeping of these records for the duration of the project. In addition, each laboratory will deliver narrative information to the QA Officer for use in data QA and for long-term storage.

The analytical laboratory will report the analytical data to the Field-PM via an analytical report consisting of, at a minimum:

1. Letter of transmittal
2. Chain of custody information
3. Analytical results for field and quality control samples (Electronic Data Deliverable, EDD)
4. Case narrative

5. Copies of all raw data.

The Field-PM will review the data deliverables provided by the laboratory for completeness and errors. The QA Officer will review the data deliverables provided by the laboratory for review of QA/QC. In addition to the laboratory's standard reporting format, all results meeting MQOs and results having satisfactory explanations for deviations from objectives shall be reported in tabular format on electronic media. SWAMP-formatted electronic data deliverable (EDD) templates are to be agreed upon by the Data Manager, QA Officer, and the Lab-PM prior to onset of any sampling activities related to that laboratory.

Documentation for analytical data is kept on file at the laboratories, or may be submitted with analytical results. These may be reviewed during external audits of the Monitoring Program, as needed. These records include the analyst's comments on the condition of the sample and progress of the analysis, raw data, and QC checks. Paper or electronic copies of all analytical data, field data forms and field notebooks, raw and condensed data for analysis performed on-site, and field instrument calibration notebooks are kept as part of the Monitoring Program archives for a minimum period of eight years.

7.2.2. Other Laboratory QA/QC Documentation

All laboratories will have the latest version of this Monitoring Program SAP/QAPP in electronic format. In addition, the following documents and information from the laboratories will be current, and they will be available to all laboratory personnel participating in the processing of samples:

1. Laboratory QA plan: Clearly defines policies and protocols specific to a particular laboratory, including personnel responsibilities, laboratory acceptance criteria, and corrective actions to be applied to the affected analytical batches, qualification of data, and procedures for determining the acceptability of results.

2. Laboratory Standard Operation Procedures (SOPs): Contain instructions for performing routine laboratory procedures, describing exactly how a method is implemented in the laboratory for a particular analytical procedure. Where published standard methods allow alternatives at various steps in the process, those approaches chosen by the laboratory in their implementation (either in general or in specific analytical batches) are to be noted in the data report, and any deviations from the standard method are to be noted and described.

3. Instrument performance information: Contains information on instrument baseline noise, calibration standard response, analytical precision and bias data, detection limits, scheduled maintenance, etc.

4. Control charts: Control charts are developed and maintained throughout the Program for all appropriate analyses and measurements for purposes of determining sources of an analytical problem or in monitoring an unstable process subject to drift. Control charts serve as internal evaluations of laboratory procedures and methodology and are helpful in identifying and correcting systematic error sources. Control limits for the laboratory quality control samples are ±3 standard deviations from the certified or theoretical concentration for any given analyte.

Records of all quality control data, maintained in a bound notebook at each workstation, are signed and dated by the analyst. Quality control data include documentation of standard calibrations, instrument maintenance and tests. Control charts of the data are generated by the analysts monthly or for analyses done infrequently, with each analysis batch. The laboratory quality assurance specialist will review all QA/QC records with each data submission, and will provide QA/QC reports to the Field-PM with each batch of submitted field sample data.

7.3. Program Management Documentation

The BASMAA-PM and Consultant-PM are responsible for managing key parts of the Monitoring Program's information management systems. These efforts are described below.

7.3.1. SAP/QAPP

All original SAP/QAPPs will be held by the Consultant-PM. This SAP/QAPP and its revisions will be distributed to all parties involved with the Monitoring Program. Copies will also be sent to the each participating analytical laboratory's contact for internal distribution, preferably via electronic distribution from a secure location.

Associated with each update to the SAP/QAPP, the Consultant-PM will notify the BASMAA-PM and the PMT of the updated SAP/QAPP, with a cover memo compiling changes made. After appropriate distributions are made to affected parties, these approved updates will be filed and maintained by the SAP/QAPP Preparers for the Monitoring Program. Upon revision, the replaced SAP/QAPPs will be discarded/deleted.

7.3.2. Program Information Archival

The Data Manager and Consultant-PM will oversee the actions of all personnel with records retention responsibilities, and will arbitrate any issues relative to records retention and any decisions to discard records. Each analytical laboratory will archive all analytical records generated for this Program. The Consultant-PM will be responsible for archiving all management-level records.

Persons responsible for maintaining records for this Program are shown in Table 7-1.

Table 7-1. Document and Record Retention, Archival, and Disposition

Type	Retention (years)	Archival	Disposition
Field Datasheets	8	Data Manager	Maintain indefinitely
Chain of Custody Forms	8	Data Manager	Maintain indefinitely
Raw Analytical Data	8	Laboratory	Recycling
Lab QC Records	8	Laboratory	Recycling
Electronic data deliverables	8	Data Manager	Maintain indefinitely
Reports	8	Consultant-PM	Maintain indefinitely

As discussed previously, the analytical laboratory will archive all analytical records generated for this Program. The Consultant-PM will be responsible for archiving all other records associated with implementation of the Monitoring Program.

All field operation records will be entered into electronic formats and maintained in a dedicated directory managed by the BASMAA-PM.

7.4. Reporting

The Consultant team will prepare draft and final reports for each component of the Monitoring Program. The PMT will provide review and input on draft reports and submit to the BASMAA BOD for approval. Once approved by the BASMAA BOD, the Monitoring Program reports will be available to each individual stormwater program for submission to the Regional Water Board according to the schedule outlined in the MRP and summarized in Table 7.2.

Table 7-2. Monitoring Program Final Reporting Due Dates.

Monitoring Program Component	Task	MRP Reporting Due Date
Source Identification	Task 1 - Evaluation of PCB concentrations in roadway and storm drain infrastructure caulk and sealants	September 30, 2018
Management Action Effectiveness	Task 2 - Evaluation of the annual mass of PCBs and mercury captured in HDS Unit sump sediment	March 31, 2019
	Task 3 - Bench-scale testing of the mercury and PCBs removal effectiveness of selected BSM mixtures.	

8. Sampling Process Design

All information generated through conduct of the Monitoring Program will be used to inform TMDL implementation efforts for mercury and PCBs in the San Francisco Bay region. The Monitoring Program will implement the following tasks: (1) evaluate the presence and concentrations of PCB in caulk and sealants from public roadway and stormdrain infrastructure; (2) evaluate mass of PCBs and mercury removed during HDS Unit maintenance; and (3) evaluate the mercury and PCBs treatment effectiveness of various BSM mixtures in laboratory column tests using stormwater collected from Bay Area locations. Sample locations and the timing of sample collection will be selected using the directed sampling design principle. This is a deterministic approach in which points are selected deliberately based on knowledge of their attributes of interest as related to the environmental site being monitored. This principle is also known as "judgmental," "authoritative," "targeted," or "knowledge-based." Individual monitoring aspects are summarized further under Field Methods (Section 9) and in the task-specific study designs (BASMAA 2017a,b).

8.1. Caulk/Sealant Sampling

Caulk/sealant sampling will support the Monitoring Program's Task 1 to evaluate PCBs in roadway and stormdrain infrastructure caulk/sealant, as described previously (see Section 4). Further detail on caulk/sealant sampling methods and procedures are provided under Field Methods (Section 9).

8.2. Sediment Quality Sampling

Sediment sampling will support the Monitoring Program's Task 2 to evaluate the mass of mercury and PCBs removed during HDS unit maintenance, as described previously (see Section 4). Further detail on sediment sampling methods and procedures are provided under Field Methods (Section 9).

8.3. Water Quality Sampling

Water sampling will support the Monitoring Program's Task 3 to evaluate the mercury and PCBs treatment effectiveness of various BSM mixtures, as described previously (see Section 4). Further detail on water sampling methods and procedures are provided under Field Methods (Section 9).

8.4. Sampling Uncertainty

There are multiple sources of potential sampling uncertainty associated with the Monitoring Program, including: (1) measurement error; (2) natural (inherent) variability; (3) undersampling (or poor representativeness); and (4) sampling bias (statistical meaning). Measures incorporated to address these areas of uncertainty are discussed below:

(1) Measurement error combines all sources of error related to the entire sampling and analysis process (i.e., to the measurement system). All aspects of dealing with uncertainty due to measurement error have been described elsewhere within this document.

(2) Natural (inherent) variability occurs in any environment monitored, and is often much wider than the measurement error. Prior work conducted by others in the field of stormwater management have demonstrated the high degree of variability in environmental media, which will be taken into consideration when interpreting results of the various lines of inquiry.

(3) Under- or unrepresentative sampling happens at the level of an individual sample or field measurement where an individual sample collected is a poor representative for overall conditions encountered given typical sources of variation. To address this situation, the Monitoring Program will be implementing a number of QA-related measures described elsewhere within this document, including methods refined through implementation of prior, related investigations.

(4) Sampling bias relates to the sampling design employed and whether the appropriate statistical design is employed to allow for appropriate understanding of environmental conditions. To a large degree, the sampling design required by the Monitoring Program is judgmental, which will therefore incorporate an unknown degree of sampling bias into the Project. There are small measures that have been built into the sampling design to combat this effect (e.g., homogenization of sediments for chemistry analyses), but overall this bias is a desired outcome designed to meet the goals of this Monitoring Program, and will be taken into consideration when interpreting results of the various investigations.

Further detail on measures implemented to reduce uncertainty through mobilization, sampling, sample handling, analysis, and reporting phases are provided throughout this document.

9. Sampling Methods

The Monitoring Program involves the collection of three types of samples: Caulk/sealants; sediment from HDS unit sumps; and water quality samples. Field collection will be conducted by field contractors or municipal staff using a variety of sampling protocols, depending on the media and parameter monitored. These methods are presented below. In addition, the Monitoring Program will utilize several field sampling SOPs previously developed by the BASMAA Regional Monitoring Coalition identified in Table 9-3 (RMC, BASMAA, 2016).

9.1. Caulk/Sealant Sampling (Task 1)

Procedures for collecting caulk and sealant samples are not well established. Minimal details on caulk or sealant sample collection methodologies are available in peer-reviewed publications. The caulk/sealant sampling procedures described here were adapted from a previous study examining PCBs in building materials conducted in the Bay Area (Klosterhaus et al., 2014). The methods described by Klosterhaus et al. (2014) were developed through consultation with many of the previous authors of caulk literature references therein, in addition to field experience gained during the Bay Area study. It is anticipated that lessons will also be learned during the current study.

9.1.1. Sample Site Selection

Once a structure has been identified as meeting the selection criteria and permission is granted to perform the testing or collection of sealant samples, an on-site survey of the structure will be used to identify sealant types and locations on the structure to be sampled. It is expected that sealants from a number of different locations on each structure may sampled; however, inconspicuous locations on the structure will be targeted.

9.1.2. Initial Equipment Cleaning

The sampling equipment that is pre-cleaned includes:

- Glass sample jars
- Utility knife, extra blades
- Stainless-steel forceps

Prior to sampling, all equipment will be thoroughly cleaned. Glass sample containers will be factory pre-cleaned (Quality Certified™, ESS Vial, Oakland, CA) and delivered to field team at least one week prior to the start of sample collection. Sample containers will be pre-labeled and kept in their original boxes, which will be transported in coolers. Utility knife blades, forceps, stainless steel spoons, and chisels will be pre-cleaned with Alconox, Liquinox, or similar detergent, and then rinsed with deionized water and methanol. The cleaned equipment will then be wrapped in methanol-rinsed aluminum foil and stored in clean Ziploc bags until used in the field.

9.1.3. Field Cleaning Protocol

Between each use the tool used (utility knife blade, spoon or chisel) and forceps will be rinsed with methanol and then deionized water, and inspected to ensure all visible sign of the previous sample have been removed. The clean tools, extra blades, and forceps will be kept in methanol-rinsed aluminum foil and stored in clean Ziploc bags when not in use.

9.1.4. Blind Sampling Procedures

The intention of this sampling is to better determine whether sealants in road and storm drain infrastructure contain PCBs at concentrations of concern, and to understand the relative importance of PCBs in this infrastructure among the other known sources of PCBs that can affect San Francisco Bay. At this phase of the project, we are not seeking to identify specific facilities requiring mitigation (if PCBs are identified, this could be a future phase). Therefore, in this initial round of sampling, we are not identifying sample locations, but instead implementing a blind sampling protocol, as follows:

- All samples will be collected without retaining any information that would identify structure locations. The information provided to the contractor on sampling locations will not be retained. Structure location information will not be recorded on any data sheets or in any data spreadsheets or other electronic computer files created for the Project. Physical sealant samples collected will be identified only by a sample identification (ID) designation (Section 4). Physical sealant sample labels will contain only the sample ID (see Section 4 and example label in Appendix A). Samples will be identified only by their sample ID on the COC forms.
- As an added precaution and if resources allow, oversampling will occur such that more samples will be collected than will be sent to the laboratory for compositing and analysis. In this case, the Project team would select a subset of samples for PCB analysis based on factors such as application type and/or chlorine content, but blind to the specific location where each sample was collected.
- Up to three individual sealant samples will be composited by the laboratory prior to analysis for PCBs, following instructions from the Consultant PM. This further ensures a blind sampling approach because samples collected at different locations will be analyzed together.

9.1.5.Caulk/Sealant Collection Procedures

At each sample location, the Field-PM, and/or municipal staff, will make a final selection of the most accessible sampling points at the time of sampling. From each point sampled, a one inch strip (aiming for about 10 g of material) of caulk or sealant will be removed from the structure using one of the following solvent-rinsed tools: a utility knife with a stainless-steel blade, stainless steel spoon to scrape off the material, or a stainless steel chisel. The Field-PM or municipal staff at the site will select the appropriate tool based on the conditions of the caulk/sealant at each sample point. Field personnel will wear nitrile gloves during sample collection to reduce potential sample contamination. The sample will then be placed in a labeled, factory-cleaned glass jar. For each caulk sample collected, field personnel will fill out a field data sheet at the time of sample collection, which includes the following information:

- Date and time of sample collection,
- sample identification designation,
- qualitative descriptions of relevant structure or caulk/sealant features, including use profile, color and consistency of material collected, surface coating (paint, oily film, masonry residues etc.)
- crack dimensions, the length and/or width of the caulk bead sampled, spacing of expansion joints in a particular type of application, and
- a description of any unusual occurrences associated with the sampling event (especially those that could affect sample or data quality).

Appendix A contains an example field data sheet. All samples will be kept in a chilled cooler in the field (i.e., at 4 ºC ± 2 ºC), and kept refrigerated pending delivery under COC to the Field PM at KLI. Further, the field data sheets will remain with the samples when they are shipped to KLI, and will then be maintained by the Field PM at KLI.

As needed, the procedure for replacement of the caulk/sealant will be coordinated with the appropriate municipal staff to help ensure that the sampling does not result in damage to the structure.

9.1.6. Sample ID Designation

Every sample must have a unique sample ID to ensure analytical results from each sample can be differentiated from every other sample. This information should follow the sample through the COC, analytical, and interpretation and reporting processes. For the infrastructure caulk/sealant samples, the sample ID must not contain information that can be used to identify where the sample was collected. The following 2-step process will be followed to assign sample IDs to the caulk/sealant samples.

1. Upon collection, the sample will be labeled according to the following naming convention:

   MMDDYYYY-TTTT-##

   Where:

MM	2 digit month of collection
DD	2 digit date of collection
YYYY	4 digit year of collection
TTTT	4 digit time of collection (military time)
##	Sequential 2-digit sample number (i.e., 01, 02, 03…etc.)

   For example, a sample collected on September 20, 2017 at 9 AM could be assigned the following sample ID: 09202017-0900-01.

2. This second step was added to avoid issues that could arise due to duplicate sample IDs, while maintaining the blind sampling approach. While the sample naming system identified above is unlikely to produce duplicate sample IDs, there is a chance that different groups may collect samples simultaneously. This second step will be implemented by the Field PM at KLI upon receipt of caulk/sealant samples from participating municipalities. The Field PM at KLI will review the sample IDs on the COC forms for all samples and compare the sample IDs to all caulk samples for this project already in storage at KLI. If any two samples have the same sample IDs, the Field PM will add a one-digit number to the end of one of the sample IDs, selected at random. This extra number will be added to the sample container label, the field data sheet, and the COC form for that sample.

9.2. HDS Unit Sampling Procedures (Task 2)

9.2.1. Sample Site Selection

Sample site selection will be opportunistic, based on the public HDS units that participating municipalities schedule for cleaning during the project. The project team will coordinate with participating municipalities to schedule sampling during HDS unit cleanouts.

9.2.2. Field Equipment and Cleaning

A list of potential sampling equipment for soil/sediment is presented in Table 5. The equipment list should be reviewed and tailored by field contractors to meet the needs of each individual sampling site. Appropriate sampling equipment is prepared in the laboratory a minimum of four days prior to sampling. Prior to sampling, all equipment will be thoroughly cleaned. Equipment is soaked (fully immersed) for three days in a solution of Alconox, Liquinox, or similar phosphate-free detergent and deionized water. Equipment is then rinsed three times with deionized water. Equipment is next rinsed with a dilute solution

(1-2%) of hydrochloric acid, followed by a rinse with reagent grade methanol, followed by another set of three rinses with deionized water. All equipment is then allowed to dry in a clean place. The cleaned equipment is then wrapped in aluminum foil or stored in clean Ziploc bags until used in the field.

Table 9-1 Field Equipment for HDS Unit Sampling.

Description of Equipment	Material (if applicable)
Sample scoops	Stainless steel or Kynar coated
Sample trowels	Stainless steel or Kynar coated
Compositing bucket	Stainless steel or Kynar coated
Ekman Dredge (as needed)	Stainless steel
Sample containers (with labels)	As coordinated with lab(s)
Methanol, Reagent grade (Teflon squeeze bottle with refill)	
Hydrochloric acid, 1-2%, Reagent grade (Teflon squeeze bottle)	
Liquinox detergent (diluted in DI within Teflon squeeze bottle)	
Deionized / reverse osmosis water	
Plastic scrub brushes	
Container for storage of sampling derived waste, dry	
Container for storage of sampling derived waste, wet	
Wet ice	
Coolers, as required	
Aluminum foil (heavy duty recommended)	
Protective packaging materials	Bubble / foam bags
Splash proof eye protection	
PPE for sampling personnel, including traffic mgmt as required	
Gloves for dry ice handling	Cotton, leather, etc.
Gloves for sample collection, reagent handling	Nitrile
Field datasheets	
COC forms	
Custody tape (as required)	
Shipping materials (as required)	
GPS	

9.2.3. Soil / Sediment Sample Collection

Field sampling personnel will collect sediment samples from HDS unit sumps using methods that minimize contamination, losses, and changes to the chemical form of the analytes of interest. The samples will be collected in the field into pre-cleaned sample containers of a material appropriate to the analysis to be conducted. Pre-cleaned sampling equipment is used for each site, whenever possible and/or when necessary. Appropriate sampling technique and measuring equipment may vary depending on the location, sample type, sampling objective, and weather. Additional safety measures may be necessary in some cases; for example, if traffic control or confined space entry is required to conduct the sampling.

Ideally and where a sufficient volume of soil/sediment allows, samples are collected into a composite container, where they are thoroughly homogenized, and then aliquoted into separate jars for chemical analysis. Sediment samples for metals and organics are submitted to the analytical laboratories in separate jars, which have been pre-cleaned according to laboratory protocol. It is anticipated that soil / solid media will be collected for laboratory analysis using one of two techniques: (1) Remote grab of submerged sediments within HDS unit sumps using Ekman dredge or similar; or (2) direct grab sampling of sediments after dewatering HDS unit sumps using individual scoops, push core sampling, or similar. Each of these techniques is described briefly below.

- Soil and Sediment Samples, Submerged. Wet soil and sediment samples may be collected from within HDS unit sumps. Sample crews must exercise judgment on whether submerged samples can be collected in a manner that does not substantially change the character of the soil/sediment collected for analysis (e.g., loss of fine materials). It is anticipated that presence of trash within the sumps may interfere with sample collection by preventing complete grab closure and loss of significant portion of the sample. Field crews will have the responsibility to determine the best method for collection of samples within each HDS Unit sump. If sampling personnel determine that sample integrity cannot be maintained throughout collection process, it is preferable to cancel sampling operations rather than collect samples with questionable integrity. This decision making process is more fully described in Section 11, Field Variances.

- Soil and Sediment Samples, Dry. Soils / sediments may be collected from within the HDS unit sump after dewatering. Field crews will have the responsibility to identify areas of sediment accumulation within areas targeted for sampling and analysis, and determine the best method for collection of samples with minimal disturbance to the sampling media.

After collection, all soil/sediment samples for PCBs and mercury analyses will be homogenized and transferred from the sample-dedicated homogenization pail into factory-supplied wide-mouth glass jars using a clean trowel or scoop. The samples will be transferred to coolers containing double-bagged wet ice and chilled to 6°C immediately upon collection.

For each sample collected, field personnel will fill out a field data sheet at the time of sample collection. Appendix A contains an example field data sheet. All samples will be kept in a chilled cooler in the field, and kept refrigerated pending delivery under COC to the field-PM. The Field PM will be responsible for sending the samples in a single batch to CEH for XRF analysis under COC. Following XRF analysis, CEH will deliver the samples under COC to the Consultant-PM. The Consultant-PM will be responsible for working with the project team to group samples for compositing, and sending those samples to the analytical laboratory under COC.

9.2.4. Sample ID Designation

Every sample must have a unique sample ID so that the analytical results from each sample can be differentiated from every other sample. This information should follow the sample through the COC, analytical, and interpretation and reporting processes. Each sediment/soil sample collected from HDS units will be labeled according to the following naming convention:

MMM-UUU-##

where:

MMM	Municipal Abbreviation (i.e., SJC=San Jose; OAK=Oakland; SUN=Sunnyvale).
UUU	HDS Unit Catchment ID; this is the number provided by the municipality for a specific HDS unit.
##	Sequential Sample Number (i.e., 01, 02, 03…etc.)

9.3. Water Quality Sampling and Column Testing Procedures (Task 3)

For this task, monitoring will be conducted during three storm events. The stormwater collected during these events will then be used as the influent for the laboratory column tests of amended BSM mixtures. Four influent samples (i.e., one sample of Bay Area stormwater from each of the three monitored storm events plus one diluted stormwater sample) and 20 effluent samples from the column tests that includes 3 tests for each of the six columns, plus one test with the diluted stormwater in two columns (one test column and one control column) will be collected and analyzed for pollutant concentrations.

9.3.1. Sample Site Selection

Two stormwater collection sites have been selected based on influent PCB concentrations measured during CW4CB (BASMAA, 2017c). Both sites are near tree wells located on Ettie Street in West Oakland. The first site is the influent to tree well #6 (station code = TW6). During CW4CB, influent stormwater concentrations at this location were average to high, ranging from 30 ng/L to 286 ng/L. Stormwater collected from this site will be used as the influent for one of the main column tests and some water will be reserved for the dilution series column tests. The amount of dilution will be determined after results are received from the lab from the first run. The second site is the influent to tree well #2 (station code=TW2). During CW4CB, influent stormwater concentrations at this location were low to average, ranging from 6 ng/L to 39 ng/L. Stormwater collected from this site will be used for the remaining two main column tests..

9.3.2. Field Equipment and Cleaning

Field sampling equipment includes:

1. Borosilicate glass carboys
2. Glass sample jars
3. Peristaltic pump tubing

Prior to sampling, all equipment will be thoroughly cleaned. Glass sample containers and peristaltic pump tubing will be factory pre-cleaned. Prior to first use and after each use, glass carboys (field carboys and effluent collection carboys) will be washed using phosphate-free laboratory detergent and scrubbed with a plastic brush. After washing the carboy will be rinsed with methylene chloride, then de-ionized water, then 2N nitric acid, then again with de-ionized water. Glass carboys will be cleaned after each sample run before they are returned to the Field PM for reuse in the field.

9.3.3. Water Sampling Procedures

During each storm event, stormwater will be collected in six, five-gallon glass carboys. To fill the carboys, the Field PM will create a backwater condition in the gutter before the drain inlet at each site and use a peristaltic pump to pump the water into glass carboys. Field personnel will wear nitrile gloves during sample collection to prevent contamination. Carboys will be stored and transported in coolers with either wet ice or blue ice, and will be delivered to OWP within 24 hours of collection.

9.3.4. Hydraulic Testing

Based on the literature review and availability, the best five biochars will be mixed with the standard BSM to create biochar amended BSMs. Initially, each biochar will be mixed with standard BSM at a rate of 25% biochar by volume (the same as that at the CW4CB Richmond PG&E Substation 1st and Cutting site). Hydraulic conductivity can be determined using the method stated in the BASMAA soil specification, method ASTM D2434.

1. Follow the directions for permeability testing in ASTM D2434 for the BSM.
2. Sieve enough of the sample biochar to collect at least 15 in^3 on a no. 200 sieve.
3. Mix the sieved biochar with standard BSM at a 1 to 4 ratio.
4. Thoroughly mix the soil.
5. Follow the directions for permeability testing in ASTM D2434.
6. If the soil mix is more than 1 in/hr different from the BSM, repeat steps 1-4 but on step 3, adjust the ratio as estimated to achieve the same permeability as the BSM.
7. Repeat steps 2-6 for each biochar.

9.3.5. Column Testing Procedures

Column Setup: Up to five biochar amended BSMs and one standard BSM will be tested (based on performance and availability of biochars). Six glass columns with a diameter of eight inches and a height of three feet will be mounted to the wall with sufficient height between the bottom of the columns and the floor to allow for effluent sample collection. Each column will be capped at the bottom and fitted with a spigot to facilitate sampling. Soil depth for all columns will be 18" after compaction, which is a standard depth used in bay area bioretention installations (see Figure 9-1 below). To retain soil the bottom of the soil layer will be contained by a layer of filter fabric on top of structural backing. Behind each column, a yardstick will be mounted to the wall so that the depth of water in the column can be monitored.

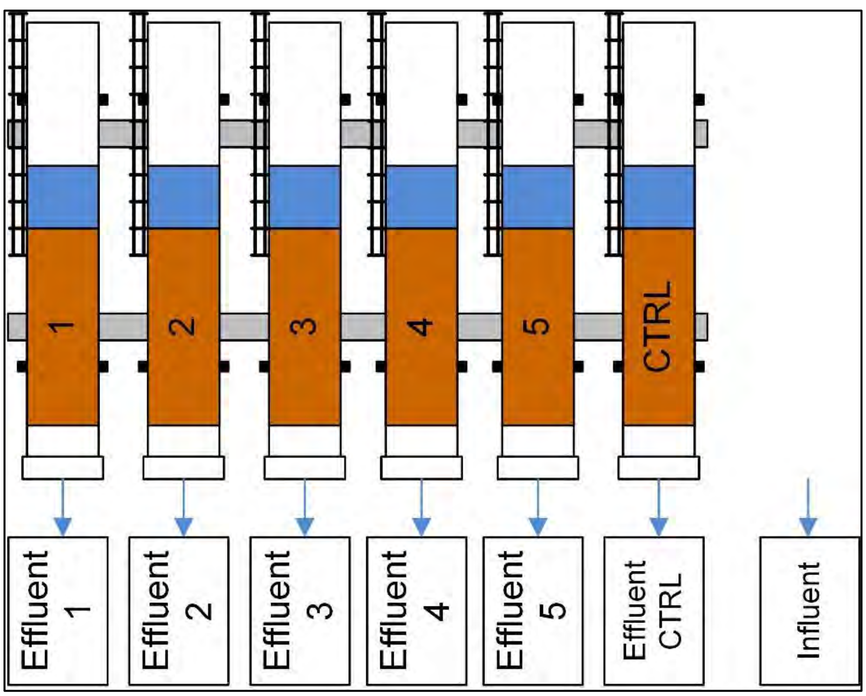

Figure 9-1. Column Test Setup

Dilution Run Column Setup: One of the existing biochar-amended BSM column and the standard BSM will be tested using diluted stormwater.

Testing procedure pre run setup: Before a sampling run begins a clean glass carboy will be placed under each soil column and labeled to match, this carboy will be sized to collect the full effluent volume of the sample run. A glass beaker will also be assigned and labeled for each column of sufficient volume to accurately measure a single influent dose equivalent to 1 inch of depth in the column. An additional beaker will be prepared and labeled influent.

Media conditioning: Within 24 to 72 hours prior to the first column test run, pre-wet each column with a stormwater matrix collected from the CSUS campus by filling each column from the invert until water ponds above the media. Drain the water after 3 hours.

Sampling run: When the six glass carboys are delivered:

1. Inspect each carboy and fill out the Sample Receiving worksheet.
2. The runs will begin within 72 hours of delivery.
3. Select one carboy at random and fully mix it using a portable lab mixer for five minutes.
4. Turn off and remove the mixer, allow the sample to rest for one minute to allow the largest particles to settle to the bottom.
5. Fill each of the six dosing beakers and the one influent sample jar.
6. Pour each aliquot beaker into its respective column; record the time and height of water in each column.
7. Repeat steps 3-6 for each of the remaining carboys until a total of 18 inches of water is applied to each column. Before pouring an aliquot record the height of water in each column and the time. Pour each successive aliquot from the carboy when all columns have less than three inches of water above the soil surface. The water level should never be above 6 inches in any column at any time (6 inches is a standard ponding depth used in the bay area). Pour all aliquots from a single carboy into the columns at the same time.
8. Collect turbidity samples from the effluent of each column at the beginning, middle, and end of the sampling run. Fill the cuvettes for turbidity measurement directly from the effluent stream of each column and dispose of them after testing.
9. Collect mercury samples from the effluent of each column at the middle of the sample run using pre-labeled sample containers provided by the lab for that purpose.
10. Fill a pre-labeled sample jar from each columns effluent. The jar will be obtained from the laboratory performing the PCB analysis.
11. Pack each jar in ice and complete the lab COCs.
12. Ship the samples to the lab for analysis.

9.3.6. Sample ID Designations

Every sample must have a unique sample identification to ensure analytical results from each sample can be differentiated from every other sample. This information should follow the sample through the COC, analytical, and interpretation and reporting processes. Each influent and effluent water quality sample will be labeled according to the following naming convention:

SSS-TT-MMDDYYYY-##

<u>Where:</u>

SSS	Station code (see Table 9-2 for station codes)
TT	Sample Type (IN=influent; EF=Effluent)
MM	2 digit month of collection
DD	2 digit date of collection
YYYY	4 digit year of collection
##	Sequential 2-digit sample number (i.e., 01, 02, 03…etc.)

For example, a sample collected at the West Oakland Tree Well #2 site on October 20, 2017 and used for the influent sample for run #3 could be assigned the following sample ID: TW2-IN-09202017-03.

Table 9-2 Station Codes for Stormwater Influent Samples and Column Tests.

Station Code	Station Description
TW2	Stormwater sample collected from the West Oakland Tree Well #2
TW6	Stormwater sample collected from the West Oakland Tree Well #6
CO1	Effluent sample collected from column number 1
CO2	Effluent sample collected from column number 2
CO3	Effluent sample collected from column number 3
CO4	Effluent sample collected from column number 4
CO5	Effluent sample collected from column number 5
CO6	Effluent sample collected from column number 6

9.4. Collection of Samples for Archiving

Archive samples will not be collected for this Monitoring Program. The sample size collected will be enough to support additional analyses if QA/QC issues arise. Once quality assurance is certified by the QA Officer, the laboratory will be instructed to dispose of any leftover sample materials.

9.5. Waste Disposal

Proper disposal of all waste is an important component of field activities. At no time will any waste be disposed of improperly. The proper methods of waste disposal are outlined below:

9.5.1. Routine Garbage

Regular garbage (paper towels, paper cups, etc.) is collected by sampling personnel in garbage bags or similar. It can then be disposed of properly at appropriate intervals.

9.5.2. Detergent Washes

Any detergents used or detergent wash water should be collected in the field in a water-tight container and disposed of appropriately.

9.5.3. Chemicals

Methanol, if used, should be disposed of by following all appropriate regulations. It should always be collected when sampling and never be disposed in the field.

9.1. Responsibility and Corrective Actions

If monitoring equipment fails, sampling personnel will report the problem in the comments section of their field notes and will not record data values for the variables in question. Actions will be taken to replace or repair broken equipment prior to the next field use.

9.2. Standard Operating Procedures

SOPs associated with sampling and sample handling expected to be used as part of implementation of The Monitoring Program are identified in Table 9-3. Additional details on sample container information, required preservation, holding times, and sample volumes for all Monitoring Program analytes are listed in Table 10-1 of Section 10.

Table 9-3. List of BASMAA RMC SOPs Utilized by the Monitoring Program.

RMC SOP #	RMC SOP	Source
FS-2	Water Quality Sampling for Chemical Analysis, Pathogen Indicators, and Toxicity	BASMAA 2016
FS-3	Field Measurements, Manual	BASMAA 2016
FS-4	Field Measurements, Continuous General Water Quality	BASMAA 2016
FS-5	Temperature, Automated, Digital Logger	BASMAA 2016
FS-6	Collection of Bedded Sediment Samples for Chemical Analysis and Toxicity	BASMAA 2016
FS-7	Field Equipment Cleaning Procedures	BASMAA 2016
FS-8	Field Equipment Decontamination Procedures	BASMAA 2016
FS-9	Sample Container, Handling, and Chain of Custody Procedures	BASMAA 2016
FS-10	Completion and Processing of Field Datasheets	BASMAA 2016
FS-11	Site and Sample Naming Convention	BASMAA 2016

In addition, contractor-specific plans and procedures may be required for specific aspects of the Monitoring Program implementation (e.g., health and safety plans, dry ice shipping procedures).

10. Sample Handling and Custody

Sample handling and chain of custody procedures are described in detail in RMC SOP FS-9 (Table 9-3) (BASMAA 2016). The Field-PM or designated municipal staff on site during sample collection will be responsible for overall collection and custody of samples during field sampling. Field crews will keep a field log, which will consist of sampling forms for each sampling event. Sample collection methods described in this document and the study designs (BASMAA 2017a, b) will be followed for each sampling task. Field data sheets will be filled out for each sample collected during the project. Example field data sheets are provided in Appendix A, and described further in Section 9.

The field crews will have custody of samples during field sampling, and COC forms will accompany all samples from field collection until delivery to the analyzing laboratory. COC procedures require that possession of samples be traceable from the time the samples are collected until completion and submittal of analytical results. Each laboratory will follow sample custody procedures as outlined in its QA plans.

Information on sampling containers, preservation techniques, packaging and shipping, and hold times is described below and summarized in Table 10.1.

10.1. Sampling Containers

Collection of all sample types require the use of clean containers. Factory pre-cleaned sample containers of the appropriate type will be provided by the contracted laboratory and delivered to field team at least one week prior to the start of sample collection. Individual laboratories will be responsible for the integrity of containers provided. The number and type of sample containers required for all analytes by media type for each sampling task are provided in Table 10.1.

10.2. Sample Preservation

Field Crews will collect samples in the field in a way that neither contaminates, loses, or changes the chemical form of the analytes of interest. The samples will be collected in the field into pre-cleaned sample containers of a material appropriate to the analysis to be conducted. Pre-cleaned sampling equipment is used for each site, whenever possible and/or when necessary. Appropriate sampling technique and measurement equipment may vary depending on the location, sample type, sampling objective, and weather.

In general, all samples will be packed in sufficient wet ice or frozen ice packs during shipment, so that they will be kept between 2 and 4º C (Table 10.1). When used, wet ice will be double bagged in Zip-top bags to prevent contamination via melt water. Where appropriate, samples may be frozen to prevent degradation. If samples are to be shipped frozen on dry ice, then appropriate handling procedures will be followed, including ensuring use of appropriate packaging materials and appropriate training for shipping personnel.

10.3. Packaging and Shipping

All samples will be handled, prepared, transported, and stored in a manner so as to minimize bulk loss, analyte loss, contamination, or biological degradation. Sample containers will be clearly labeled with an indelible marker. All caps and lids will be checked for tightness prior to shipping. Ice chests will be sealed with packing tape before shipping. Samples will be placed in the ice chest with enough ice or frozen ice packs to maintain between 2 and 4º C. Additional packing material will be added as needed. COC forms will be placed in a zip-top bag and placed inside of the ice chest.

10.4. Commercial Vehicle Transport

If transport of samples to the contracted laboratories is to be by commercial carriers, pickup will be pre-arranged with the carrier and all required shipping forms will be completed prior to sample pickup by the commercial carrier.

10.5. Sample Hold Times

Sample hold times for each analyte by media type are presented in Table 10-1.

Table 10-1 Sample Handling for the Monitoring Program Analytes by media type.

Analyte	Sample Media	Sample Container	Minimum Sample / Container Size[a]	Preservative	Hold Time (at 6º C)
PCBs (40-RMP Congeners)	Caulk or sealant	Pre-cleaned 250-mL glass sample container (e.g., Quality Certified™, ESS Vial, Oakland, CA)	10 g	Cool to 6° C within 24 hours, then freeze to ≤-20° C	1 year at -20º C; Samples must be analyzed within 14 days of collection or thawing.
	Sediment	Pre-cleaned 250-mL I-Chem 200 Series amber glass jar with Teflon lid liner	500 mL (two jars)	Cool to 6° C within 24 hours, then freeze to ≤-20° C	1 year at -20º C; Samples must be analyzed within 14 days of collection or thawing.
	Water	1000-mL I-Chem 200-Series amber glass bottle, with Teflon lid-liner	1000 mL/per individual analyses	Cool to 6º C in the dark.	1 year until extraction, 1 year after extraction
Total Mercury	Sediment	Pre-cleaned 250-mL I-Chem 200 Series amber glass jar with Teflon lid liner	100 g	Cool to 6º C and in the dark	1 year at -20º C; Samples must be analyzed within 14 days of collection or thawing.
	Water	250-mL glass or acid-cleaned Teflon bottle	250 mL	Cool to 6º C in the dark and acidify to 0.5% with pre-tested HCl within 48 hours	6 months at room temperature following acidification
Bulk Density	Sediment	250-mL clear glass jar; pre-cleaned	250 mL	Cool to 6º C	7 days
Grain Size and TOC	Sediment	250-mL clear glass jar; pre-cleaned	250 mL	Cool to 6º C, in the dark up to 28 days[2]	28 days at ≤6 ◦C; 1 year at ≤-20 ◦C
SSC	Water	125-mL amber glass jar or Polyethylene Bottles	125 mL	Cool to 6º C and store in the dark	7 days
Turbidity	Water				
Total Solids	Water	1 L HDPE	1 L	Cool to ≤6 ◦C	7 days
TOC	Water	40-mL glass vial	40 mL	Cool to 6º C and store in the dark. If analysis is to occur more than two hours after sampling, acidify (pH < 2) with HCl or H_2SO_4.	28 days
Particle Size Distribution	Water	1 L HDPE	2 L	Cool to 6º C and store in the dark	7 days

[a]QC samples or other analytes require additional sample bottles.

11. Field Health and Safety Procedures

All field crews will be expected to abide by their employer's (i.e., the field contractor's) health and safety programs. Additionally, prior to the fieldwork, field contractors are required to develop site-specific Health and Safety plans that include the locations of the nearest emergency medical services.

Implementation of the Monitoring Program activities may require confined space entry (CSE) to accomplish sampling goals. Sampling personnel conducting any confined space entry activities will be expected to be certified for CSE and to abide by relevant regulations.

12. Laboratory Analytical Methods

12.1. Caulk/Sealant Samples (Task 1)

12.1.1. XRF Chlorine analysis

XRF technology will be used in a laboratory setting to rank samples for chlorine content before sending the samples to the project laboratory for chemical analysis. Procedures for testing caulk or sealants using X-Ray fluorescence (XRF) and collecting caulk and sealant samples are not well described, and minimal detail on caulk or sealant sample collection is available in peer-reviewed publications. Sealant sampling procedures were adapted from the previous study examining PCBs in building materials (Klosterhaus et al., 2014).

An XRF analyzer will be used at the Center for Environmental Health (CEH) as a screening tool to estimate the concentration of chlorine (Cl) in collected caulk and sealant samples from various structures. Settings for the analyzer will be 'standardized' using procedures developed/ recommended by CEH each time the instrument is turned on and prior to any measurement. European plastic pellet reference materials (EC680 and EC681) will be used as 'check' standards upon first use to verify analyzer performance. A 30 second measurement in 'soil' mode will be used. CEH personnel will inspect the caulk/sealant surfaces and use a stainless steel blade to scrape off any paint, concrete chips, or other visible surface residue. The caulk/sealant surface to be sampled will then be wiped with a laboratory tissue to remove any remaining debris that may potentially interfere with the XRF analysis. At least two XRF readings will be collected from each sample switching the orientation or position of the sample between readings. If Cl is detected, a minimum of four additional readings will be collected on the same material to determine analytical variability. Each individual Cl reading and its detection limit will be recorded on the data sheet. After XRF analysis, all samples will be returned to their original sample container. Results of the XRF analysis will be provided to the project team as a table of ranked Cl screening results for possible selection for chemical (PCBs) analysis.

12.1.2. Selection of Samples for PCB analysis and Compositing

Once samples have been ranked for their chlorine content, primarily samples with the highest Cl will preferentially be selected for chemical analysis. About 75% of samples to be analyzed should be selected from samples with the top quartile Cl content. The remaining 25% should be selected from samples with medium (25 to 75th percentile) Cl, as the previous study using XRF screening showed inconsistent correlation between total Cl and PCB. Although samples with very low Cl seldom had much PCBs, samples with medium Cl on occasion had higher PCBs than samples with high Cl, and within the high Cl group, Cl content was not a good predictor of their ranks of PCB concentration.

In addition to Cl content, other factors about each sample that were recorded on the field data sheets at the time of sample collection, including the color or consistency of the sample, the type and/or age of the structure that was sampled, or the type of caulk or sealant application will be considered in selecting the samples that will be sent to the laboratory for PCBs analysis, as well as how the samples will be grouped for compositing purposes. Those factors are described in more detail in the study design (BASMAA, 2017a).

The Consultant PM will work with the project team to identify up to three samples for inclusion in each composite. A common composite ID will then be assigned to each sample that will be composited together (i.e., all samples the lab should composite together will be identified by the common composite ID). The composite ID will consist of a single letter designation and will be identical for all samples (up to 3 total) that will be composited together. The Consultant PM will add the composite ID to each sample container label, to each sample ID on all COC forms, and to each field data sheet for all samples prior to sending the samples to the laboratory for PCBs analysis.

12.1.3. Sample Preparation

The project laboratory will composite the samples prior to extraction and PCBs analysis according to the groupings identified by the common composite ID. Sample preparation will include removal of any paint, concrete chips, or other surface debris, followed by homogenization of the caulk/sealant material and compositing up to three samples per composite. Each sample will have a composite ID that will be used to identify which samples should be composited together. Samples with the same composite ID will be combined into a single composite sample. For example, all samples with composite ID = “A” will be composited together; all samples with composite ID = “B” will be composited together, etc. Sample preparation and compositing will follow the procedures outlined in the laboratory SOPs (Appendix B). After compositing, each composite sample will be assigned a new sample ID using the following naming convention:

X-MMDDYYYY

Where:

X	the single letter Composite ID that is common to all samples included in a given composite.
MM	2 digit month of composite preparation
DD	2 digit date of composite preparation
YYYY	4 digit year of composite preparation

For example, if three samples with the composite ID= “A” are combined into a single composite sample on December 12, 2017, the new (composite) sample ID would be the following: A-12122017.

12.1.4. PCBs Analysis

All composite caulk/sealant samples will be extracted by Method 3540C, and analyzed for the RMP-40 PCB congeners[3] using a modified EPA Method 8270C (GC/MS-SIM), in order to obtain positive

[3] The 40 individual congeners routinely quantified by the Regional Monitoring Program (RMP) for Water Quality in the San Francisco Estuary include: PCBs 8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, l05, 110, 118, 128, 132, 138, 141, 149, l51, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203

identification and quantitation of PCBs. PCB content of these material covers an extremely wide range, so the subsampling of material should include sufficient material for quantification assuming that the concentration is likely to be around the median of previous results. There may be samples with much higher concentrations, which can be reanalyzed on dilution as needed. Method Reporting Limits (MRLs) for each of the RMP-40 PCB Congeners are 0.5 µg/Kg.

12.2. Sediment Samples Collected from HDS Units (Task 2)

All sediment samples collected from HDS units under Task 2 will be analyzed for TOC, grain size, bulk density, total mercury, and PCBs (RMP 40 Congeners1) by the methods identified in Table 12-1. All sediment samples (with the exception of grain size) will be sieved by the laboratory at 2 mm prior to analysis.

Table 12-1. Laboratory Analytical Methods for Analytes in Sediment

Analyte	Sampling Method	Recommended Analytical Method	Reporting Units
Total Organic Carbon (TOC)	Grab	EPA 415.1, 440.0, 9060, or ASTM D4129M	%
Grain Size	Grab	ASTM D422M/PSEP	%
Bulk Density	Grab	ASTM E1109-86	g/cm3
Mercury	Grab	EPA 7471A, 7473, or 1631	µg/kg
PCBs (RMP 40 Congeners)	Grab	EPA 1668	µg/kg

12.3. Water Samples – Stormwater and Column Tests (Task 3)

All water samples submitted to the laboratory will be analyzed for SSC, TOC, total mercury and PCBs (RMP-40 congeners) according to the methods identified in Table 12-2.

Table 12-2. Laboratory Analytical Methods for Analytes in Water

Analyte	Sampling Method	Recommended Analytical Method	Reporting Units
Suspended Sediment Concentration (SSC)	Grab	ASTM D3977-97 (Method C)	mg/L
Total Organic Carbon (TOC)	Grab	EPA 415.1 or SM 5310B	%
Mercury (Total)	Grab	EPA 1631	µg/L
PCBs (RMP 40 Congeners)	Grab	EPA 1668	ng/L

12.4. Method Failures

The QA Officer will be responsible for overseeing the laboratory implementing any corrective actions that may be needed in the event that methods fail to produce acceptable data. If a method fails to provide acceptable data for any reason, including analyte or matrix interferences, instrument failures, etc., then the involved samples will be analyzed again if possible. The laboratory in question's SOP for handling these types of problems will be followed. When a method fails to provide acceptable data, then the laboratory's

SOP for documenting method failures will be used to document the problem and what was done to rectify it.

Corrective actions for chemical data are taken when an analysis is deemed suspect for some reason. These reasons include exceeding accuracy or precision ranges and/or problems with sorting and identification. The corrective action will vary on a case-by-case basis, but at a minimum involves the following:

- A check of procedures.
- A review of documents and calculations to identify possible errors.
- Correction of errors based on discussions among analysts.
- A complete re-identification of the sample.

The field and laboratory coordinators shall have systems in place to document problems and make corrective actions. All corrective actions will be documented to the FTL and the QA Officer.

12.5. Sample Disposal

After analysis of the Monitoring Program samples has been completed by the laboratory and results have been accepted by QA Officer and the Field-PM, they will be disposed by laboratory staff in compliance with all federal, state, and local regulations. The laboratory has standard procedures for disposing of its waste, including left over sample materials

12.6. Laboratory Sample Processing

Field samples sent to the laboratories will be processed within their recommended hold time using methods agreed upon method between the Lab-PM and Field-PM. Each sample may be assigned unique laboratory sample ID numbers for tracking processing and analyses of samples within the laboratory. This laboratory sample ID (if differing from the field team sample ID) must be included in the data submission, within a lookup table linking the field sample ID to that assigned by the lab.

Samples arriving at the laboratory are to be stored under conditions appropriate for the planned analytical procedure(s), unless they are processed for analysis immediately upon receipt. Samples to be analyzed should only be removed from storage when laboratory staff are ready to proceed.

13. Quality Control

Each step in the field collection and analytical process is a potential source of contamination and must be consistently monitored to ensure that the final measurement is not adversely affected by any processing steps. Various aspects of the quality control procedures required by the Monitoring Program are summarized below.

13.1. Field Quality Control

Field QC results must meet the MQOs and frequency requirements specified in Tables 13-1 – 13-4 below.

13.1.1. Field Blanks

A field blank is collected to assess potential sample contamination levels that occur during field sampling activities. Field blanks are taken to the field, transferred to the appropriate container, preserved (if required by the method), and treated the same as the corresponding sample type during the course of a sampling event. The inclusion of field blanks is dependent on the requirements specified in the relevant MQO tables or in the sampling method or SOP.

Collection of caulk or sealant field blank samples has been deemed unnecessary due to the difficulty in collection and interpretation of representative blank samples and the use of precautions that minimize contamination of the samples. Additionally, PCBs have been reported to be present in percent concentrations when used in sealants; therefore any low level contamination (at ppb or even ppm level) due to sampling equipment and procedures is not expected to affect data quality because it would be many orders of magnitude lower than the concentrations deemed to be a positive PCB signal.

For stormwater samples, field blanks will be generated using lab supplied containers and clean matrices. Sampling containers will be opened as though actual samples were to be collected, and clean lab-supplied matrix (if any) will be transferred to sample containers for analysis.

13.1.2. Field Duplicates

Field samples collected in duplicate provide precision information as it pertains to the sampling process. The duplicate sample must be collected in the same manner and as close in time as possible to the original sample. This effort is to attempt to examine field homogeneity as well as sample handling, within the limits and constraints of the situation. These data are evaluated in the data analysis/assessment process for small-scale spatial variability.

Field duplicates will not be collected for caulk/sealant samples (Task 1), as assessment of within-structure variability of PCB concentrations in sealants is not a primary objective of the Project. Due to budget limitations, PCBs analysis of only one caulk/sealant sample per application will be targeted to maximize the number of Bay Area structures and structure types that may be analyzed in the Project. The selected laboratory will conduct a number of quality assurance analyses (see Section 13), including a limited number of sample duplicates, to evaluate laboratory and method performance as well as variability of PCB content within a sample.

For all sediment and water samples, 5% of field duplicates and/or column influent/effluent duplicates will be collected along with primary samples in order to evaluate small scale spatial or temporal variability in sample collection without specifically targeting any apparent or likely bias (e.g. different sides of a seemingly symmetrical unit, or offset locations in making a composite, or immediately following collection of a primary water sample would be acceptable, whereas collecting one composite near an inlet and another near the outlet, or intentionally collecting times with vastly different flow rates, would not be desirable).

13.1.3. Field Corrective Action

The Field PM is responsible for responding to failures in their sampling and field measurement systems. If monitoring equipment fails, personnel are to record the problem according to their documentation protocols. Failing equipment must be replaced or repaired prior to subsequent sampling events. It is the combined responsibility of all members of the field organization to determine if the performance requirements of the specific sampling method have been met, and to collect additional samples if necessary. Associated data is to be flagged accordingly. Specific field corrective actions are detailed in Table 13-8.

13.2. Laboratory Quality Control

Laboratories providing analytical support to the Monitoring Program will have the appropriate facilities to store, prepare, and process samples in an ultra-clean environment, and will have appropriate instrumentation and staff to perform analyses and provide data of the required quality within the time period dictated by the Monitoring Program. The laboratories are expected to satisfy the following:

1. Demonstrate capability through pertinent certification and satisfactory performance in inter-laboratory comparison exercises.
2. Provide qualification statements regarding their facility and personnel.
3. Maintain a program of scheduled maintenance of analytical balances, laboratory equipment and instrumentation.
4. Conduct routine checking of analytical balances using a set of standard reference weights (American Society of Testing and Materials Class 3, NIST Class S-1, or equivalents). Analytical balances are serviced at six-month intervals or when test weight values are not within the manufacturer's instrument specifications, whichever occurs first.
5. Conduct routine checking and recording the composition of fresh calibration standards against the previous lot. Acceptable comparisons are within 2% of the precious value.
6. Record all analytical data in bound (where possible) logbooks, with all entries in ink, or electronically.
7. Monitor and document the temperatures of cold storage areas and freezer units on a continuous basis.
8. Verify the efficiency of fume/exhaust hoods.
9. Have a source of reagent water meeting specifications described in Section 8.0 available in sufficient quantity to support analytical operations.
10. Label all containers used in the laboratory with date prepared, contents, initials of the individual who prepared the contents, and other information as appropriate.
11. Date and safely store all chemicals upon receipt. Proper disposal of chemicals when the expiration date has passed.
12. Have QAPP, SOPs, analytical methods manuals, and safety plans readily available to staff.
13. Have raw analytical data readily accessible so that they are available upon request.

In addition, laboratories involved in the Monitoring Program are required to demonstrate capability continuously through the following protocols:

1. Strict adherence to routine QA/QC procedures.
2. Regular participation in annual certification programs.
3. Satisfactory performance at least annually in the analysis of blind Performance Evaluation Samples and/or participation in inter-laboratory comparison exercises.

Laboratory QC samples must satisfy MQOs and frequency requirements. MQOs and frequency requirements are listed in Tables 13-1 – 13-3. Frequency requirements are provided on an analytical batch level. The Monitoring Program defines an analytical batch as 20 or fewer samples and associated quality control that are processed by the same instrument within a 24-hour period (unless otherwise specified by method). Target Method Reporting Limits are provided in Tables 13.4 – 13.8. Details regarding sample preparation are method- or laboratory SOP-specific, and may consist of extraction, digestion, or other techniques.

13.2.1. Calibration and Working Standards

All calibration standards must be traceable to a certified standard obtained from a recognized organization. If traceable standards are not available, procedures must be implemented to standardize the utilized calibration solutions (*e.g.*, comparison to a CRM – see below). Standardization of calibration solutions must be thoroughly documented, and is only acceptable when pre-certified standard solutions are not available. Working standards are dilutions of stock standards prepared for daily use in the laboratory. Working standards are used to calibrate instruments or prepare matrix spikes, and may be prepared at several different dilutions from a common stock standard. Working standards are diluted with solutions that ensure the stability of the target analyte. Preparation of the working standard must be thoroughly documented such that each working standard is traceable back to its original stock standard. Finally, the concentration of all working standards must be verified by analysis prior to use in the laboratory.

13.2.2. Instrument Calibration

Prior to sample analysis, utilized instruments must be calibrated following the procedures outlined in the relevant analytical method or laboratory SOP. Each method or SOP must specify acceptance criteria that demonstrate instrument stability and an acceptable calibration. If instrument calibration does not meet the specified acceptance criteria, the analytical process is not in control and must be halted. The instrument must be successfully recalibrated before samples may be analyzed.

Calibration curves will be established for each analyte covering the range of expected sample concentrations. Only data that result from quantification within the demonstrated working calibration range may be reported unflagged by the laboratory. Quantification based upon extrapolation is not acceptable; sample extracts above the calibration range should be diluted and rerun if possible. Data reported below the calibration range must be flagged as estimated values that are Detected not Quantified.

13.2.3. Initial Calibration Verification

The initial calibration verification (ICV) is a mid-level standard analyzed immediately following the calibration curve. The source of the standards used to calibrate the instrument and the source of the standard used to perform the ICV must be independent of one another. This is usually achieved by the purchase of standards from separate vendors. Since the standards are obtained from independent sources and both are traceable, analyses of the ICV functions as a check on the accuracy of the standards used to calibrate the instrument. The ICV is not a requirement of all SOPs or methods, particularly if other checks on analytical accuracy are present in the sample batch.

13.2.4. Continuing Calibration Verification

Continuing calibration verification (CCV) standards are mid-level standards analyzed at specified intervals during the course of the analytical run. CCVs are used to monitor sensitivity changes in the instrument during analysis. In order to properly assess these sensitivity changes, the standards used to perform CCVs must be from the same set of working standards used to calibrate the instrument. Use of a second source standard is not necessary for CCV standards, since other QC samples are designed to assess the accuracy of the calibration standards. Analysis of CCVs using the calibration standards limits this QC sample to assessing only instrument sensitivity changes. The acceptance criteria and required frequency for CCVs are detailed in Tables 13-1 through 13-3. If a CCV falls outside the acceptance limits, the analytical system is not in control, and immediate corrective action must be taken.

Data obtained while the instrument is out of control is not reportable, and all samples analyzed during this period must be reanalyzed. If reanalysis is not an option, the original data must be flagged with the appropriate qualifier and reported. A narrative must be submitted listing the results that were generated while the instrument was out of control, in addition to corrective actions that were applied.

13.2.5. Laboratory Blanks

Laboratory blanks (also called extraction blanks, procedural blanks, or method blanks) are used to assess the background level of a target analyte resulting from sample preparation and analysis. Laboratory blanks are carried through precisely the same procedures as the field samples. For both organic and inorganic analyses, a minimum of at least one laboratory blank must be prepared and analyzed in every analytical batch or per 20 samples, whichever is more frequent. Some methods may require more than one laboratory blank with each analytical run. Acceptance criteria for laboratory blanks are detailed in Tables 13-1 through 13-3. Blanks that are too high require corrective action to bring the concentrations down to acceptable levels. This may involve changing reagents, cleaning equipment, or even modifying the utilized methods or SOPs. Although acceptable laboratory blanks are important for obtaining results for low-level samples, improvements in analytical sensitivity have pushed detection limits down to the point where some amount of analyte will be detected in even the cleanest laboratory blanks. The magnitude of the blanks must be evaluated against the concentrations of the samples being analyzed and against project objectives.

13.2.6. Reference Materials and Demonstration of Laboratory Accuracy

Evaluation of the accuracy of laboratory procedures is achieved through the preparation and analysis of reference materials with each analytical batch. Ideally, the reference materials selected are similar in matrix and concentration range to the samples being prepared and analyzed. The acceptance criteria for reference materials are listed in Tables 13-1 – 13-3. The accuracy of an analytical method can be assessed using CRMs only when certified values are provided for the target analytes. When possible, reference materials that have certified values for the target analytes should be used. This is not always possible, and often times certified reference values are not available for all target analytes. Many reference materials have both certified and non-certified (or reference) values listed on the certificate of analysis. Certified reference values are clearly distinguished from the non-certified reference values on the certificate of analysis.

13.2.7. Reference Materials vs. Certified Reference Materials

The distinction between a reference material and a certified reference material does not involve how the two are prepared, rather with the way that the reference values were established. Certified values are determined through replicate analyses using two independent measurement techniques for verification. The certifying agency may also provide “non-certified or “reference” values for other target analytes. Such values are determined using a single measurement technique that may introduce bias. When available, it is preferable to use reference materials that have certified values for all target analytes. This is not always an option, and therefore it is acceptable to use materials that have reference values for these analytes. Note: Standard Reference Materials (SRMs) are essentially the same as CRMs. The term "Standard Reference Material" has been trademarked by the National Institute of Standards and Technology (NIST), and is therefore used only for reference materials distributed by NIST.

13.2.8. Laboratory Control Samples

While reference materials are not available for all analytes, a way of assessing the accuracy of an analytical method is still required. LCSs provide an alternate method of assessing accuracy. An LCS is a specimen of known composition prepared using contaminant-free reagent water or an inert solid spiked with the target analyte at the midpoint of the calibration curve or at the level of concern. The LCS must be analyzed using the same preparation, reagents, and analytical methods employed for regular samples. If an LCS needs to be substituted for a reference material, the acceptance criteria are the same as those for the analysis of reference materials..

13.2.9. Prioritizing Certified Reference Materials, Reference Materials, and Laboratory Control Samples

Certified reference materials, reference materials, and laboratory control samples all provide a method to assess the accuracy at the mid-range of the analytical process. However, this does not mean that they can be used interchangeably in all situations. When available, analysis of one certified reference material per analytical batch should be conducted. Certified values are not always available for all target analytes. If no certified reference material exists, reference values may be used. If no reference material exists for the target analyte, an LCS must be prepared and analyzed with the sample batch as a means of assessing accuracy. The hierarchy is as follows: analysis of a CRM is favored over the analysis of a reference material, and analysis of a reference material is preferable to the analysis of an LCS. Substitution of an LCS is not acceptable if a certified reference material or reference material is available, contact the Project Manager and QAO for approval before relying exclusively on an LCS as a measure of accuracy.

13.2.10.Matrix Spikes

A MS is prepared by adding a known concentration of the target analyte to a field sample, which is then subjected to the entire analytical procedure. The MS is analyzed in order to assess the magnitude of matrix interference and bias present. Because these spikes are often analyzed in pairs, the second spike is called the MSD. The MSD provides information regarding the precision of measurement and consistency of the matrix effects. Both the MS and MSD are split from the same original field sample. In order to properly assess the degree of matrix interference and potential bias, the spiking level should be approximately 2-5x the ambient concentration of the spiked sample. To establish spiking levels prior to sample analysis, if possible, laboratories should review any relevant historical data. In many instances, the laboratory will be spiking samples blind and will not meet a spiking level of 2-5x the ambient concentration. In addition to the recoveries, the relative percent difference (RPD) between the MS and MSD is calculated to evaluate how matrix affects precision. The MQO for the RPD between the MS and MSD is the same regardless of the method of calculation. These are detailed in Tables 13-1 – 13-3. Recovery data for matrix spikes provides a basis for determining the prevalence of matrix effects in the samples collected and analyzed. If the percent recovery for any analyte in the MS or MSD is outside of the limits specified in Tables 13-1 – 13-3, the chromatograms (in the case of trace organic analyses) and raw data quantitation reports should be reviewed. Data should be scrutinized for evidence of sensitivity shifts (indicated by the results of the CCVs) or other potential problems with the analytical process. If associated QC samples (reference materials or LCSs) are in control, matrix effects may be the source of the problem. If the standard used to spike the samples is different from the standard used to calibrate the instrument, it must be checked for accuracy prior to attributing poor recoveries to matrix effects.

13.2.11.Laboratory Duplicates

In order to evaluate the precision of an analytical process, a field sample is selected and prepared in duplicate. Specific requirements pertaining to the analysis of laboratory duplicates vary depending on the type of analysis. The acceptance criteria for laboratory duplicates are specified in Tables 13-1 – 13-3.

13.2.12.Laboratory Duplicates vs. Matrix Spike Duplicates

Although the laboratory duplicate and matrix spike duplicate both provide information regarding precision, they are unique measurements. Laboratory duplicates provide information regarding the precision of laboratory procedures at actual ambient concentrations. The matrix spike duplicate provides information regarding how the matrix of the sample affects both the precision and bias associated with the results. It also determines whether or not the matrix affects the results in a reproducible manner. MS/MSDs are often spiked at levels well above ambient concentrations, so thus are not representative of typical sample precision. Because the two concepts cannot be used interchangeably, it is unacceptable to analyze only an MS/MSD when a laboratory duplicate is required.

13.2.13.Replicate Analyses

The Monitoring Program will adopt the same terminology as SWAMP in defining replicate samples, wherein replicate analyses are distinguished from duplicate analyses based simply on the number of involved analyses. Duplicate analyses refer to two sample preparations, while replicate analyses refer to three or more. Analysis of replicate samples is not explicitly required.

13.2.14.Surrogates

Surrogate compounds accompany organic measurements in order to estimate target analyte losses or matrix effects during sample extraction and analysis. The selected surrogate compounds behave similarly to the target analytes, and therefore any loss of the surrogate compound during preparation and analysis is presumed to coincide with a similar loss of the target analyte. Surrogate compounds must be added to field and QC samples prior to extraction, or according to the utilized method or SOP. Surrogate recovery data are to be carefully monitored. If possible, isotopically labeled analogs of the analytes are to be used as surrogates.

13.2.15.Internal Standards

To optimize gas chromatography mass spectrometry (GC-MS) analysis, internal standards (also referred to as “injection internal standards”) may be added to field and QC sample extracts prior to injection. Use of internal standards is particularly important for analysis of complex extracts subject to retention time shifts relative to the analysis of standards. The internal standards can also be used to detect and correct for problems in the GC injection port or other parts of the instrument. The analyst must monitor internal standard retention times and recoveries to determine if instrument maintenance or repair or changes in analytical procedures are indicated. Corrective action is initiated based on the judgment of the analyst. Instrument problems that affect the data or result in reanalysis must be documented properly in logbooks and internal data reports, and used by the laboratory personnel to take appropriate corrective action. Performance criteria for internal standards are established by the method or laboratory SOP.

13.2.16.Dual-Column Confirmation

Due to the high probability of false positives from single-column analyses, dual column confirmation should be applied to all gas chromatography and liquid chromatography methods that do not provide definitive identifications. It should not be restricted to instruments with electron capture detection (ECD).

13.2.17.Dilution of Samples

Final reported results must be corrected for dilution carried out during the process of analysis. In order to evaluate the QC analyses associated with an analytical batch, corresponding batch QC samples must be analyzed at the same dilution factor. For example, the results used to calculate the results of matrix spikes must be derived from results for the native sample, matrix spike, and matrix spike duplicate analyzed at the same dilution. Results derived from samples analyzed at different dilution factors must not be used to calculate QC results.

13.2.18.Laboratory Corrective Action

Failures in laboratory measurement systems include, but are not limited to: instrument malfunction, calibration failure, sample container breakage, contamination, and QC sample failure. If the failure can be corrected, the analyst must document it and its associated corrective actions in the laboratory record and complete the analysis. If the failure is not resolved, it is conveyed to the respective supervisor who should determine if the analytical failure compromised associated results. The nature and disposition of the problem must be documented in the data report that is sent to the Consultant-PM. Suggested ccorrective actions are detailed in Table 13-9.

Table 13-1. Measurement Quality Objectives - PCBs.

Laboratory Quality Control	Frequency of Analysis	Measurement Quality Objective
Tuning[2]	Per analytical method	Per analytical method
Calibration	Initial method setup or when the calibration verification fails	• Correlation coefficient (r^2 >0.990) for linear and non-linear curves • If RSD<15%, average RF may be used to quantitate; otherwise use equation of the curve • First- or second-order curves only (not forced through the origin) • Refer to SW-846 methods for SPCC and CCC criteria[2] • Minimum of 5 points per curve (one of them at or below the RL)
Calibration Verification	Per 12 hours	• Expected response or expected concentration ±20% • RF for SPCCs=initial calibration[4]
Laboratory Blank	Per 20 samples or per analytical batch, whichever is more frequent	<RL for target analytes
Reference Material	Per 20 samples or per analytical batch	70-130% recovery if certified; otherwise, 50-150% recovery
Matrix Spike	Per 20 samples or per analytical batch, whichever is more frequent	50-150% or based on historical laboratory control limits (average±3SD)
Matrix Spike Duplicate	Per 20 samples or per analytical batch, whichever is more frequent	50-150% or based on historical laboratory control limits (average±3SD); RPD<25%
Surrogate	Included in all samples and all QC samples	Based on historical laboratory control limits (50-150% or better)
Internal Standard	Included in all samples and all QC samples (as available)	Per laboratory procedure
Field Quality Control	**Frequency of Analysis**	**Measurement Quality Objective**
Field Duplicate	5% of total Project sample count (sediment and water samples only)	RPD<25% (n/a if concentration of either sample<RL)
Field Blank	Not required for the Monitoring Program	<RL for target analytes

Table 13-2. Measurement Quality Objectives – Inorganic Analytes.

Laboratory Quality Control	Frequency of Analysis	Measurement Quality Objective
Calibration Standard	Per analytical method or manufacturer's specifications	Per analytical method or manufacturer's specifications
Continuing Calibration Verification	Per 10 analytical runs	80-120% recovery
Laboratory Blank	Per 20 samples or per analytical batch, whichever is more frequent	<RL for target analyte
Reference Material	Per 20 samples or per analytical batch, whichever is more frequent	75-125% recovery
Matrix Spike	Per 20 samples or per analytical batch, whichever is more frequent	75-125% recovery
Matrix Spike Duplicate	Per 20 samples or per analytical batch, whichever is more frequent	75-125% recovery ; RPD<25%
Laboratory Duplicate	Per 20 samples or per analytical batch, whichever is more frequent	RPD<25% (n/a if concentration of either sample<RL)
Internal Standard	Accompanying every analytical run when method appropriate	60-125% recovery
Field Quality Control	**Frequency of Analysis**	**Measurement Quality Objective**
Field Duplicate	5% of total Project sample count	RPD<25% (n/a if concentration of either sample<RL), unless otherwise specified by method
Field Blank, Equipment Field, Eqpt Blanks	Not required for the Monitoring Program	Blanks<RL for target analyte

Table 13-3. Measurement Quality Objectives – Conventional Analytes.

Laboratory Quality Control	Frequency of Analysis	Measurement Quality Objective
Calibration Standard	Per analytical method or manufacturer's specifications	Per analytical method or manufacturer's specifications
Laboratory Blank	Total organic carbon only: one per 20 samples or per analytical batch, whichever is more frequent (n/a for other parameters)	80-120% recovery
Reference Material	One per analytical batch	RPD<25% (n/a if native concentration of either sample<RL)
Laboratory Duplicate	(TOC only) one per 20 samples or per analytical batch, whichever is more frequent (n/a for other parameters)	80-120% recovery
Field Quality Control	**Frequency of Analysis**	**Measurement Quality Objective**
Field Duplicate	5% of total Project sample count	RPD<25% (n/a if concentration of either sample<RL)
Field Blank, Travel Blank, Field Blanks	Not required for the Monitoring Program analytes	NA

Consistent with SWAMP QAPP and as applicable, percent moisture should be reported with each batch of sediment samples. Sediment data must be reported on a dry weight basis.

Table 13-4. Target MRLs for Sediment Quality Parameters.

Analyte	MRL
Sediment Total Organic Carbon	0.01% OC
Bulk Density	n/a
%Moisture	n/a
%Lipids	n/a
Mercury	30 µg/kg

Table 13-5. Target MRLs for PCBs in Water, Sediment and Caulk

Congener	Water MRL (µg/L)	Sediment MRL (µg/kg)	Caulk/Sealant MRL (µg/kg)
PCB 8	0.002	0.2	0.5
PCB 18	0.002	0.2	0.5
PCB 28	0.002	0.2	0.5
PCB 31	0.002	0.2	0.5
PCB 33	0.002	0.2	0.5
PCB 44	0.002	0.2	0.5
PCB 49	0.002	0.2	0.5
PCB 52	0.002	0.2	0.5
PCB 56	0.002	0.2	0.5
PCB 60	0.002	0.2	0.5
PCB 66	0.002	0.2	0.5
PCB 70	0.002	0.2	0.5
PCB 74	0.002	0.2	0.5
PCB 87	0.002	0.2	0.5
PCB 95	0.002	0.2	0.5
PCB 97	0.002	0.2	0.5
PCB 99	0.002	0.2	0.5
PCB 101	0.002	0.2	0.5
PCB 105	0.002	0.2	0.5
PCB 110	0.002	0.2	0.5
PCB 118	0.002	0.2	0.5
PCB 128	0.002	0.2	0.5
PCB 132	0.002	0.2	0.5
PCB 138	0.002	0.2	0.5
PCB 141	0.002	0.2	0.5
PCB 149	0.002	0.2	0.5
PCB 151	0.002	0.2	0.5
PCB 153	0.002	0.2	0.5
PCB 156	0.002	0.2	0.5
PCB 158	0.002	0.2	0.5
PCB 170	0.002	0.2	0.5
PCB 174	0.002	0.2	0.5
PCB 177	0.002	0.2	0.5
PCB 180	0.002	0.2	0.5
PCB 183	0.002	0.2	0.5
PCB 187	0.002	0.2	0.5
PCB 194	0.002	0.2	0.5
PCB 195	0.002	0.2	0.5
PCB 201	0.002	0.2	0.5
PCB 203	0.002	0.2	0.5

Table 13-6. Size Distribution Categories for Grain Size in Sediment

Wentworth Size Category	Size	MRL
Clay	<0.0039 mm	1%
Silt	0.0039 mm to <0.0625 mm	1%
Sand, very fine	0.0625 mm to <0.125 mm	1%
Sand, fine	0.125 mm to <0.250 mm	1%
Sand, medium	0.250 mm to <0.5 mm	1%
Sand, coarse	0.5 mm to < 1.0 mm	1%
Sand, very coarse	1.0 mm to < 2 mm	1%
Gravel	2 mm and larger	1%

Table 13-7. Target MRLs for TOC, SSC, and Mercury in Water

Analyte	MRL
Total Organic Carbon	0.6 mg/L
Suspended Sediment Concentration	0.5 mg/L
Mercury	0.0002 µg/L

Table 13-8. Corrective Action – Laboratory and Field Quality Control

Laboratory Quality Control	Recommended Corrective Action
Calibration	Recalibrate the instrument. Affected samples and associated quality control must be reanalyzed following successful instrument recalibration.
Calibration Verification	Reanalyze the calibration verification to confirm the result. If the problem continues, halt analysis and investigate the source of the instrument drift. The analyst should determine if the instrument must be recalibrated before the analysis can continue. All of the samples not bracketed by acceptable calibration verification must be reanalyzed.
Laboratory Blank	Reanalyze the blank to confirm the result. Investigate the source of contamination. If the source of the contamination is isolated to the sample preparation, the entire batch of samples, along with the new laboratory blanks and associated QC samples, should be prepared and/or re-extracted and analyzed. If the source of contamination is isolated to the analysis procedures, reanalyze the entire batch of samples. If reanalysis is not possible, the associated sample results must be flagged to indicate the potential presence of the contamination.
Reference Material	Reanalyze the reference material to confirm the result. Compare this to the matrix spike/matrix spike duplicate recovery data. If adverse trends are noted, reprocess all of the samples associated with the batch.
Matrix Spike	The spiking level should be near the midrange of the calibration curve or at a level that does not require sample dilution. Reanalyze the matrix spike to confirm the result. Review the recovery obtained for the matrix spike duplicate. Review the results of the other QC samples (such as reference materials) to determine if other analytical problems are a potential source of the poor spike recovery.
Matrix Spike Duplicate	The spiking level should be near the midrange of the calibration curve or at a level that does not require sample dilution. Reanalyze the matrix spike duplicate to confirm the result. Review the recovery obtained for the matrix spike. Review the results of the other QC samples (such as reference materials) to determine if other analytical problems are a potential source of the poor spike recovery.
Internal Standard	Check the response of the internal standards. If the instrument continues to generate poor results, terminate the analytical run and investigate the cause of the instrument drift.
Surrogate	Analyze as appropriate for the utilized method. Troubleshoot as needed. If no instrument problem is found, samples should be re-extracted and reanalyzed if possible.
Field Quality Control	**Recommended Corrective Action**
Field Duplicate	Visually inspect the samples to determine if a high RPD between results could be attributed to sample heterogeneity. For duplicate results due to matrix heterogeneity, or where ambient concentrations are below the reporting limit, qualify the results and document the heterogeneity. All failures should be communicated to the project coordinator, who in turn will follow the process detailed in the method.
Field Blank	Investigate the source of contamination. Potential sources of contamination include sampling equipment, protocols, and handling. The laboratory should report evidence of field contamination as soon as possible so corrective actions can be implemented. Samples collected in the presence of field contamination should be flagged.

14. Inspection/Acceptance for Supplies and Consumables

Each sampling event conducted for the Monitoring Program will require use of appropriate consumables to reduce likelihood of sample contamination. The Field-PM will be responsible for ensuring that all supplies are appropriate prior to their use. Inspection requirements for sampling consumables and supplies are summarized in Table 14-1.

Table 14-1. Inspection / Acceptance Testing Requirements for Consumables and Supplies

Project-related Supplies	Inspection / Testing Specifications	Acceptance Criteria	Frequency	Responsible Person Sampling Containers
Sampling supplies	Visual	Appropriateness; no evident contamination or damage; within expiration date	Each purchase	Field Crew Leader

15. Non Direct Measurements, Existing Data

No data from external sources are planned to be used with this project.

16. Data Management

As previously discussed, the Monitoring Program data management will conform to protocols dictated by the study designs (BASMAA 2017a, b). A summary of specific data management aspects is provided below.

16.1. Field Data Management

All field data will be reviewed for legibility and errors as soon as possible after the conclusion of sampling. All field data that is entered electronically will be hand-checked at a rate of 10% of entries as a check on data entry. Any corrective actions required will be documented in correspondence to the QA Officer.

16.2. Laboratory Data Management

Record keeping of laboratory analytical data for the proposed project will employ standard record-keeping and tracking practices. All laboratory analytical data will be entered into electronic files by the instrumentation being used or, if data is manually recorded, then it will be entered by the analyst in charge of the analyses, per laboratory standard procedures.

Following the completion of internal laboratory quality control checks, analytical results will be forwarded electronically to the Field-PM. The analytical laboratories will provide data in electronic format, encompassing both a narrative and electronic data deliverable (EDD).

17. Assessments and Response Actions

17.1. Readiness Reviews

The Field-PM will review all field equipment, instruments, containers, and paperwork to ensure that everything is ready prior to each sampling event. All sampling personnel will be given a brief review of the goals and objectives of the sampling event and the sampling procedures and equipment that will be used to achieve them. It is important that all field equipment be clean and ready to use when it is needed. Therefore, prior to using all sampling and/or field measurement equipment, each piece of equipment will be checked to make sure that it is in proper working order. Equipment maintenance records will be checked to ensure that all field instruments have been properly maintained and that they are ready for use. Adequate supplies of all preservatives, bottles, labels, waterproof pens, etc. will be checked before each field event to make sure that there are sufficient supplies to successfully support each sampling event, and, as applicable, are within their expiration dates. It is important to make sure that all field activities and measurements are properly recorded in the field. Therefore, prior to starting each field event, necessary paperwork such as logbooks, chain of custody record forms, etc. will be checked to ensure that sufficient amounts are available during the field event. In the event that a problem is discovered during a readiness review it will be noted in the field log book and corrected before the field crew is deployed. The actions taken to correct the problem will also be documented with the problem in the field log book. This information will be communicated by the Field-PM prior to conducting relevant sampling. The Field-PM will track corrective actions taken.

17.2. Post Sampling Event Reviews

The Field-PM will be responsible for post sampling event reviews. Any problems that are noted will be documented along with recommendations for correcting the problem. Post sampling event reviews will be conducted following each sampling event in order to ensure that all information is complete and any deviations from planned methodologies are documented. Post sampling event reviews will include field sampling activities and field measurement documentation in order to help ensure that all information is complete. The reports for each post sampling event will be used to identify areas that may be improved prior to the next sampling event.

17.3. Laboratory Data Reviews

The Field-PM will be responsible for reviewing the laboratory's data for completeness and accuracy. The data will also be checked to make sure that the appropriate methods were used and that all required QC data was provided with the sample analytical results. Any laboratory data that is discovered to be incorrect or missing will immediately be reported to the both the laboratory and Consultant-PM. The laboratory's QA manual details the procedures that will be followed by laboratory personnel to correct any invalid or missing data. The Consultant-PM has the authority to request re-testing if a review of any of the laboratory data is found to be invalid or if it would compromise the quality of the data and resulting conclusions from the proposed project.

18. Instrument/Equipment Testing, Inspection and Maintenance

18.1. Field Equipment

Field measurement equipment will be checked for operation in accordance with manufacturer's specifications. All equipment will be inspected for damage when first employed and again when returned from use. Maintenance logs will be kept and each applicable piece of equipment will have its own log that documents the dates and description of any problems, the action(s) taken to correct problem(s), maintenance procedures, system checks, follow-up maintenance dates, and the person responsible for maintaining the equipment.

18.2. Laboratory Equipment

All laboratories providing analytical support for chemical or biological analyses will have the appropriate facilities to store, prepare, and process samples. Moreover, appropriate instrumentation and staff to provide data of the required quality within the schedule required by the program are also required. Laboratory operations must include the following procedures:

- A program of scheduled maintenance of analytical balances, microscopes, laboratory equipment, and instrumentation.
- Routine checking of analytical balances using a set of standard reference weights (American Society of Testing and Materials (ASTM) Class 3, NIST Class S-1, or equivalents).
- Checking and recording the composition of fresh calibration standards against the previous lot, wherever possible. Acceptable comparisons are < 2% of the previous value.
- Recording all analytical data in bound (where possible) logbooks, with all entries in ink, or electronic format.
- Monitoring and documenting the temperatures of cold storage areas and freezer units once per week.
- Verifying the efficiency of fume hoods.
- Having a source of reagent water meeting ASTM Type I specifications (ASTM, 1984) available in sufficient quantity to support analytical operations. The conductivity of the reagent water will not exceed 18 megaohms at 25°C. Alternately, the resistivity of the reagent water will exceed 10 mmhos/cm.
- Labeling all containers used in the laboratory with date prepared, contents, initials of the individual who prepared the contents, and other information, as appropriate.
- Dating and safely storing all chemicals upon receipt. Proper disposal of chemicals when the expiration date has passed.
- Having QAPP, SOPs, analytical methods manuals, and safety plans readily available to staff.
- Having raw analytical data, such as chromatograms, accessible so that they are available upon request.

Laboratories will maintain appropriate equipment per the requirements of individual laboratory SOPs and will be able to provide information documenting their ability to conduct the analyses with the required level of data quality. Such information might include results from interlaboratory comparison studies, control charts and summary data of internal QA/QC checks, and results from certified reference material analyses.

19. Instrument/Equipment Calibration and Frequency

19.1. Field Measurements

Any equipment used should be visually inspected during mobilization to identify problems that would result in loss of data. As appropriate, equipment-specific SOPs should be consulted for equipment calibration.

19.2. Laboratory Analyses

19.2.1. In-house Analysis – XRF Screening

A portable XRF analyzer will be used as a screening tool to estimate the chlorine concentration in each caulk sample. Since caulk often contains in excess of 1% PCBs and detection limits of portable XRF may be in the ppm range, the portable XRF may be able to detect chlorine within caulk containing PCBs down to about 0.1%. The analysis will be performed on the field samples using a test stand. The analyzer will be calibrated for chlorine using plastic pellet European reference materials (EC680 and EC681) upon first use, and standardized each time the instrument is turned on and prior to any caulk Cl analysis. The standardization procedure will entail a calibration analysis of the materials provided/recommended with the XRF analyzer. Analyses will be conducted in duplicate on each sample and notes kept. The mean will be used for comparison to GC–MS results.

19.2.2. Contract Laboratory Analyses

The procedures for and frequency of calibration will vary depending on the chemical parameters being determined. Equipment is maintained and checked according to the standard procedures specified in each laboratory's instrument operation instruction manual.

Upon initiation of an analytical run, after each major equipment disruption, and whenever on-going calibration checks do not meet recommended DQOs (see Section 13), analytical systems will be calibrated with a full range of analytical standards. Immediately after this procedure, the initial calibration must be verified through the analysis of a standard obtained from a different source than the standards used to calibrate the instrumentation and prepared in an independent manner and ideally having certified concentrations of target analytes of a CRM or certified solution. Frequently, calibration standards are included as part of an analytical run, interspersed with actual samples.

Calibration curves will be established for each analyte and batch analysis from a calibration blank and a minimum of three analytical standards of increasing concentration, covering the range of expected sample concentrations. Only those data resulting from quantification within the demonstrated working calibration range may be reported by the laboratory.

The calibration standards will be prepared from reference materials available from the EPA repository, or from available commercial sources. The source, lot number, identification, and purity of each reference material will be recorded. Neat compounds will be prepared weight/volume using a calibrated analytical balance and Class A volumetric flasks. Reference solutions will be diluted using Class A volumetric glassware. Individual stock standards for each analyte will be prepared. Combination working standards will be prepared by volumetric dilution of the stock standards. The calibration standards will be stored at -20º C. Newly prepared standards will be compared with existing standards prior to their use. All solvents used will be commercially available, distilled in glass, and judged suitable for analysis of selected chemicals. Stock standards and intermediate standards are prepared on an annual basis and working standards are prepared every three months.

Sampling and analytical logbooks will be kept to record inspections, calibrations, standard identification numbers, the results of calibrations, and corrective action taken. Equipment logs will document instrument usage, maintenance, repair and performance checks. Daily calibration data will be stored with the raw sample data

20. Data Review, Verification, and Validation

Defining data review, verification, and validation procedures helps to ensure that Monitoring Plan data will be reviewed in an objective and consistent manner. Data review is the in-house examination to ensure that the data have been recorded, transmitted, and processed correctly. The Field-PM will be responsible for initial data review for field forms and field measurements; QA Officer will be responsible for doing so for data reported by analytical laboratories. This includes checking that all technical criteria have been met, documenting any problems that are observed and, if possible, ensuring that deficiencies noted in the data are corrected.

In-house examination of the data produced from the proposed Monitoring Program will be conducted to check for typical types of errors. This includes checking to make sure that the data have been recorded, transmitted, and processed correctly. The kinds of checks that will be made will include checking for data entry errors, transcription errors, transformation errors, calculation errors, and errors of data omission.

Data generated by Program activities will be reviewed against MQOs that were developed and documented in Section 13. This will ensure that the data will be of acceptable quality and that it will be SWAMP-comparable with respect to minimum expected MQOs.

QA/QC requirements were developed and documented in Sections 13.1 and 13.2, and the data will be checked against this information. Checks will include evaluation of field and laboratory duplicate results, field and laboratory blank data, matrix spike recovery data, and laboratory control sample data pertinent to each method and analytical data set. This will ensure that the data will be SWAMP-comparable with respect to quality assurance and quality control procedures.

Field data consists of all information obtained during sample collection and field measurements, including that documented in field log books and/or recording equipment, photographs, and chain of custody forms. Checks of field data will be made to ensure that it is complete, consistent, and meets the data management requirements that were developed and documented in Section 13.1.

Lab data consists of all information obtained during sample analysis. Initial review of laboratory data will be performed by the laboratory QA/QC Officer in accordance with the lab's internal data review procedures. However, upon receipt of laboratory data, the Lab-PM will perform independent checks to ensure that it is complete, consistent, and meets the data management requirements that were developed and documented in Section 13.2. This review will include evaluation of field and laboratory QC data and also making sure that the data are reported in compliance with procedures developed and documented in Section 7.

Data verification is the process of evaluating the completeness, correctness, and conformance / compliance of a specific data set against the method, procedural, or contractual specifications. The Lab-PM and Data Manager will conduct data verification, as described in Section 13 on Quality Control, in order to ensure that it is SWAMP-comparable with respect to completeness, correctness, and conformance with minimum requirements.

Data will be separated into three categories for use with making decisions based upon it. These categories are: (1) data that meets all acceptance requirements, (2) data that has been determined to be unacceptable for use, and (3) data that may be conditionally used and that is flagged as per US EPA specifications.

21. Verification and Validation Methods

Defining the methods for data verification and validation helps to ensure that Program data are evaluated objectively and consistently. For the proposed Program many of these methods have been described in Section 20. Additional information is provided below.

All data records for the Monitoring Program will be checked visually and will be recorded as checked by the checker's initials as well as with the dates on which the records were checked. Consultant Team staff will perform an independent re-check of at least 10% of these records as the validation methodology.

All of the laboratory's data will be checked as part of the verification methodology process. Each contract laboratory's Project Analyst will conduct reviews of all laboratory data for verification of their accuracy.

Any data that is discovered to be incorrect or missing during the verification or validation process will immediately be reported to the Consultant-PM. If errors involve laboratory data then this information will also be reported to the laboratory's QA Officer. Each laboratory's QA manual details the procedures that will be followed by laboratory personnel to correct any invalid or missing data. The laboratory’s QA Officer will be responsible for reporting and correcting any errors that are found in the data during the verification and validation process.

If there are any data quality problems identified, the QA Officer will try to identify whether the problem is a result of project design issues, sampling issues, analytical methodology issues, or QA/QC issues (from laboratory or non-laboratory sources). If the source of the problems can be traced to one or more of these basic activities then the person or people in charge of the areas where the issues lie will be contacted and efforts will be made to immediately resolve the problem. If the issues are too broad or severe to be easily corrected then the appropriate people involved will be assembled to discuss and try to resolve the issue(s) as a group. The QA Officer has the final authority to resolve any issues that may be identified during the verification and validation process.

22. Reconciliation with User Requirements

The purpose of the Monitoring Program is to comply with Provisions of the MRP and provide data that can be used to identify sources of PCBs to urban runoff, and to evaluate management action effectiveness in removing POCs from urban runoff in the Bay Area. The objectives of the Monitoring Program are to provide the following outcomes:

1. Satisfy MRP Provision C.8.f. requirements for POC monitoring for source identification;

2. Satisfy MRP Provision C.12.e.ii requirements to evaluate PCBs presence in caulks/sealants used in storm drain or roadway infrastructure in public ROWs;
3. Report the range of PCB concentrations observed in 20 composite samples of caulk/sealant collected from structures installed or rehabilitated during the 1970's;
4. Satisfy MRP Provision C.8.f. requirements for POC monitoring for management action effectiveness;
5. Quantify the annual mass of mercury and PCBs captured in HDS Unit sumps during maintenance; and
6. Identify BSM mixtures for future field testing that provide the most effective mercury and PCBs treatment in laboratory column tests.

Information from field data reports (including field activities, post sampling events, and corrective actions), laboratory data reviews (including errors involving data entry, transcriptions, omissions, and calculations and laboratory audit reports), reviews of data versus MQOs, reviews against QA/QC requirements, data verification reports, data validation reports, independent data checking reports, and error handling reports will be used to determine whether or not the Monitoring Program's objectives have been met. Descriptions of the data will be made with no extrapolation to more general cases.

Data from all monitoring measurements will be summarized in tables. Additional data may also be represented graphically when it is deemed helpful for interpretation purposes.

The above evaluations will provide a comprehensive assessment of how well the Program meets its objectives. The final project reports will reconcile results with project MQOs.

23. References

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BASMAA 2017a. The Evaluation of PCBs Presence in Public Roadway and Storm Drain Infrastructure Caulk and Sealants Study Design. Prepared by EOA Inc. and the San Francisco Estuary Institute (SFEI). June 2017.

BASMAA 2017b. POC Monitoring for Management Action Effectiveness Study Design. Prepared by the Office of Water Programs, Sacramento State, CA, EOA Inc., and the San Francisco Estuary Institute (SFEI). July 2017.

BASMAA, 2017c. Clean Watershed for a Clean Bay (CW4CB) Final Report. Prepared for Bay Area Stormwater Management Agencies Association. Prepared by Geosyntec and EOA, Inc., May 2017.

Klosterhaus, S. McKee, L.J. Yee, D., Kass, J.M., and Wong, A. 2014. Polychlorinated Biphenyls in the Exterior Caulk of San Francisco Bay Area Buildings, California, USA. Environment International 66, 38-43.

Surface Water Ambient Monitoring Program Quality Assurance Team, 2013. *SWAMP Quality Assurance Project Plan.* Prepared for the California State Water Quality Control Board. 2013.

24. Appendix A: Field Documentation

Caulk/Sealant Sampling Field Data Sheet	Composite ID:		Contractor:	Pg of Pgs
Sample ID:	Date (mm/dd/yyyy):		Personnel:	Failure Reason
Photos (Y / N)	ArrivalTime:	DepartureTime:		
Photo Log Identifier	**Land-Use at the Sample Location:**		Commercial (pre-1980; post 1980)	Open Space
	Industrial (pre-1980; post-1980)		Residential (pre 1980; post 1980)	Other:

Description of Structure: (Do not include any information on the location of the structure)						**Diagram of Structure (if needed) to identify where caulk/sealants were located in/on structure**
Structure Type:	Storm Drain Catch Basin	Roadway Surface	Sidewalk	Curb/Gutter	Bridge	
	Other:					
Structure Material:	Concrete	Asphalt	Other:			
Condition of Structure:	Good	Fair	Poor	Other:		
Year of Strucutre Construction						
Year of Repair						

Description of Caulk or Sealant Sample Collected:							
Application or Usage	Caulk	caulk between adjoining surfaces of same material (e.g., concrete-concrete); Describe:					
		caulk between adjoining surfaces of different types of material (e.g., concrete-asphalt); Describe:					
		Other:					
	Sealant	Crack Repair (describe):					
		Other:					
Color							
Texture	Hard/brittle	Soft/pliable	Other:				
Condition	Good (intact/whole)		Poor (crumbling/disintegrating)	Other:			
Location	Surface	Between Joints	Submerged	Exposed	At street level	Below street level	Other:
Amount of Caulk/Sealant observed on structure	Crack dimensions:			Spacing of expansion joints			
	Length&width of caulk bead sampled:				Other:		

Samples Taken	
COLLECTION DEVICE:	Equiptment type used:
SITE/SAMPLING DESCRIPTION AND COMMENTS:	

HDS Unit Sampling Field Data Sheet (Sediment Chemistry)			Contractor:	Pg of Pgs
City:	Date (mm/dd/yyyy):	/ /	*Contractor:	
HDS Catchment ID:	ArrivalTime:	DepartureTime:	*SampleTime (1st sample):	Failure Reason
	Personnel:			

Photos (Y / N)	*GPS/DGPS	**Lat (dd.ddddd)**	**Long (ddd.ddddd)**	Address, Location, and Sketches (if needed)
Photo Log Identifier	**Target (if known):**			
	***Actual:**			
	GPS Device:			

Estimate of Volume of Sediment in the HDS unit sump prior to cleanout:	
Estimate of Volume of Sediment REMOVED from the HDS unit sump during the cleanout:	

Env. Conditions		WIND DIRECTION (from):	N W E S	
SITE ODOR:	None,Sulfides,Sew age,Petroleum,Smoke,Other_______			
SKY CODE:	Clear, Partly Cloudy, Overcast, Fog, Smoky, Hazy			
PRECIP:	None, Fog, Drizzle, Rain			
PRECIP (last 24 hrs):	Unknow n, <1", >1", None			
SOILODOR:	None, Sulfides, Sew age, Petroleum, Mixed, Other_______________			
SOILCOLOR:	Colorless, Green, Yellow , Brow n			
SOILCOMPOSITION:	Silt/Clay, Sand, Gravel, Cobble, Mixed, Debris			
SOILPOSITION	Submerged, Exposed			

Samples Taken (3 digit ID nos. of containers filled)	**Field Dup at Site? YES / NO:** (create separate datasheet for FDs, with unique IDs (i.e., blind samples)
COLLECTION DEVICE:	Equiptment type used: Scoop (SS / PC / PE), Core (SS / PC / PE), Grab (Van Veen / Eckman / Petite Ponar), Broom (nylon, natural fiber)

Sample ID (City-Catchment ID-Sample	DepthCollec (cm)	Composite / Grab (C / G)	Grain Size	PCBs	Hg	Bulk Density	TOC	OTHER		

SITE/SAMPLING DESCRIPTION AND COMMENTS:

Stormwater Field Data Sheet (Water Chemistry)

Entered in d-base (initial/date)		Pg of Pgs	
*Station Code:	*Date (mm/dd/yyyy): / /	*PurposeFailure:	*Agency:
Personnel:	ArrivalTime:	DepartureTime:	*Protocol:

	*GPS/DGPS	**Lat (dd.ddddd)**	**Long (ddd.ddddd)**
GPS Device:	**Target:**		-
Datum: NAD83 / Accuracy (ft / m):	***Actual:**		-

OCCUPATION METHOD: Walk-in Bridge R/V __________ Other

Sampling Location (e.g., gutter at SW corner of 10th Street)

Habitat Observations (CollectionMethod = Habitat_generic)

SITE ODOR:	None,Sulfides,Sewage,Petroleum,Smoke,Other____	WADEABILITY: Y / N / Unk	BEAUFORT SCALE (see attachment)
SKY CODE:	Clear, Partly Cloudy, Overcast, Fog, Smoky, Hazy	WIND DIRECTION (from):	N W E S
OTHER PRESENCE:	Vascular,Nonvascular,OilySheen,Foam,Trash,Other_		
DOMINANT SUBSTRATE:	Bedrock, Concrete, Cobble, Boulder, Gravel, Sand, Mud, Unk, Other_________		
WATERCLARITY:	Clear (see bottom), Cloudy (>4" vis), Murky (<4" vis)	PRECIPITATION:	None, Fog, Drizzle, Rain, Snow
WATERODOR:	None, Sulfides, Sewage, Petroleum, Mixed, Other___	PRECIPITATION (last 24 hrs):	Unknown, <1", >1", None
WATERCOLOR:	Colorless, Green, Yellow, Brown		
OVERLAND RUNOFF (Last 24 hrs):	none, light, moderate / heavy, unknown		
OBSERVED FLOW:	NA, Dry Waterbody Bed, No Obs Flow, Isolated Pool, Trickle (<0.1cfs), 0.1-1cfs, 1-5cfs, 5-20cfs, 20-50cfs, 50-200cfs, >200cfs		

PHOTOS (RB & LB assigned when facing downstream; RENAME to StationCode_yyyy_mm_dd_uniquecode):

1: (RB / LB / BB / US / DS / ##)

2: (RB / LB / BB / US / DS / ##)

3: (RB / LB / BB / US / DS / ##)

Field Samples (Record Time Sample Collected)

Carboy ID #	Start Sample Time	End Sample Time	Sample Type (Grab=G; Integrated = I)	Collection Depth (m)	Field Dup (Yes/No)	Indiv bottle (by hand, by pole, by bucket); Teflon tubing; Kemmer; Pole & Beaker; Other

COMMENTS:

Stormwater Influent Samples – Office of Water Programs

Sample Receiving			
Date (mm/dd/yy):		Time (24 hr) :	Team Member's Initial:
Carboy	Temperature	pH	Observations
1			
2			
3			
4			
5			
6			
7			

Stormwater Column Tests – Office of Water Programs

Sampling Run			
Date (mm/dd/yy):	Time (24 hr) :	Team Member's Initials:	Column ID:

During Test - Timed Measurements

Time	Water Depth	Media Condition	Other Observations

Grab Sample - Beginning of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Middle of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - End of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Mercury

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

25. Appendix B: Laboratory Standard Operating Procedures (SOPs)

APPENDIX C: PROPOSED BIOCHAR SELECTION FACTORS

The primary goal of this study is to select a biochar and bioretention soil mix (BSM) for field testing which will be conducted to assess improved removal of PCBs and mercury. The selection for field tests will be informed by column tests performed by this study. This memorandum contains a review of known biochar available in the Western United States. Five biochars are needed for column tests; nine biochars will be obtained and mixed with BSM at a ratio of 75 percent BSM and 25 percent biochar. These mixes will be tested hydraulically according to the alternative BSM specification to see which mixes pass the hydraulic requirement of an infiltration rate of 5-12 inches per hour. If more than five biochar mixes pass the hydraulic test then five will be chosen based on probable treatment efficiency and cost. Factors that will be used to determine probable treatment efficiency are pH, surface area, source material, pyrolysis method, and hydrophobicity.

Feasibility Criteria

Three criteria were chosen to screen potential biochars for sample gathering. All nine of the biochars selected for initial hydraulic testing have met reasonable expectations of cost, availability, and consistency.

Cost

Generally, biochar is a byproduct of the lumber industry or more recently household yard waste and tree trimmings. This byproduct is cheap and plentiful in certain regions especially when compared to more costly adsorbents commonly used to treat stormwater such as zeolite, activated alumina, activated carbon, or proprietary engineered media. Because even a relatively expensive biochar can be considered inexpensive when compared to other soil additives, biochars will not be excluded based solely on cost.

Availability

The selection process for the different biochars ensures that local soil suppliers have consistent access to the tested biochar in commercial quantities. To ensure availability, producers that are well established and offer biochar in commercial quantities in stock year round were prioritized.

Consistency

Biochar can be made from a variety of feedstocks and processed at various temperatures, which will produce biochars with varying properties and treatment capacities. To ensure that the biochars tested in this study will be available with the same properties, only suppliers who use a consistent feedstock and process will be considered.

Performance Criteria

Hydraulic Conductivity

A current requirement of alternative BSM is to have an infiltration rate between 5 and 12 inches per hour with a long-term infiltration rate of at least 5 inches per hour. In a previous study, the hydraulic conductivity of a biochar was studied before and after having the fines removed by sieving. The sample with fines removed had a hydraulic conductivity nearly four times higher than the one with fines (Yargicoglu et al., 2015). Any biochar amended BSM that does not achieve 5 to 12 inches per hour infiltration rate will be removed from the study.

Soil pH

There is a correlation between increased pyrolysis temperatures and increased pH, though there is a large variation between feedstocks (Cantrell et al., 2012). If the pH is raised enough it could affect plant health as several key nutrients required by plants can be immobilized in high pH soils. Ideally the biochars chosen should have a pH as close to seven as possible.

Surface Area

Surface area is arguably the most important characteristic for treatment performance. Adsorption capacity is directly related to available surface area of the adsorbent. Some biochars have been lab tested to measure surface area via N_2 adsorption but not many. From literature, a correlation between pyrolysis temperature and surface area is established, pyrolysis temperatures of 600-700 C show much higher surface areas than those produced at 500 C or less (Ahmad et al., 2014).

Hydrophobicity

Hydrophobicity is important to our study because hydrophobic substances, like PCBs, in a water solution are attracted to hydrophobic surfaces like biochar where they are adsorbed and removed from the water. Hydrophobicity is a difficult characteristic to measure, requiring either specialized equipment or lengthy experimentation. However, it has been well documented that hydrophobicity in biochar decreases as pyrolysis temperature increases (Zimmerman, 2010). The hydrophobicity in biochar is likely due to hydrophobic substances that are not completely volatilized at lower temperatures (Gray et al., 2014). Hydrophobicity in biochar will decline over time as these hydrophobic substances are consumed by microbes or oxidized, eventually making the biochar hydrophilic (Zimmerman, 2010). This is a concern for long-term treatment effectiveness if treatment depends on hydrophobicity.

Source Material and Pyrolysis Method

Many studies have compared the physical and chemical properties of biochar produced using different feedstocks and different methods of pyrolysis. However, because we have chosen to only study biochars that meet our availability requirements we do not have the option to make source material a primary selection criteria. Most of the biochars that meet our selection requirements are produced from woodchips and other industrial forestry residues. Consequently, biochars will be ordered by pyrolysis temperature. A range of pyrolysis temperatures are recommended since low temperatures tend to produce more hydrophobic biochars and higher temperatures produce biochars with more surface area (Zimmerman, 2010).

Probable Treatment Efficiency

From literature there are many factors that will affect overall treatment efficiency in a biochar. To simplify the selection process, pyrolysis temperature was chosen as the factor to represent treatment efficiency. Because pyrolysis temperature affects both surface area and hydrophobicity directly, biochars will be chosen that are produced at a wide range of temperatures. This will ensure biochars with the greatest surface area, the greatest hydrophobicity, and combinations of the two will be tested.

Table 1. Biochar Selection Table

Biochar Name	Cost ($/yd³)	Pyrolysis Temp (Degrees C)
1. Pacific	$ 90.00	700
2. Sonoma Biochar	$ 240.00	1315
3. Rogue Biochar	$ 249.50	700
4. BioChar Now - Medium	$ 350.00	600
5. Sunriver High Porosity Biochar	$ 500.00	500
6. Biochar Solutions (CW4CB)	$ 225.00	700
7. Agrosorb	$ 250.00	900
8. BlackSorb	$ 250.00	900
9. Cool Terra CF-11	$ 700.00	600
10. Phoenix	$ 254.00	700

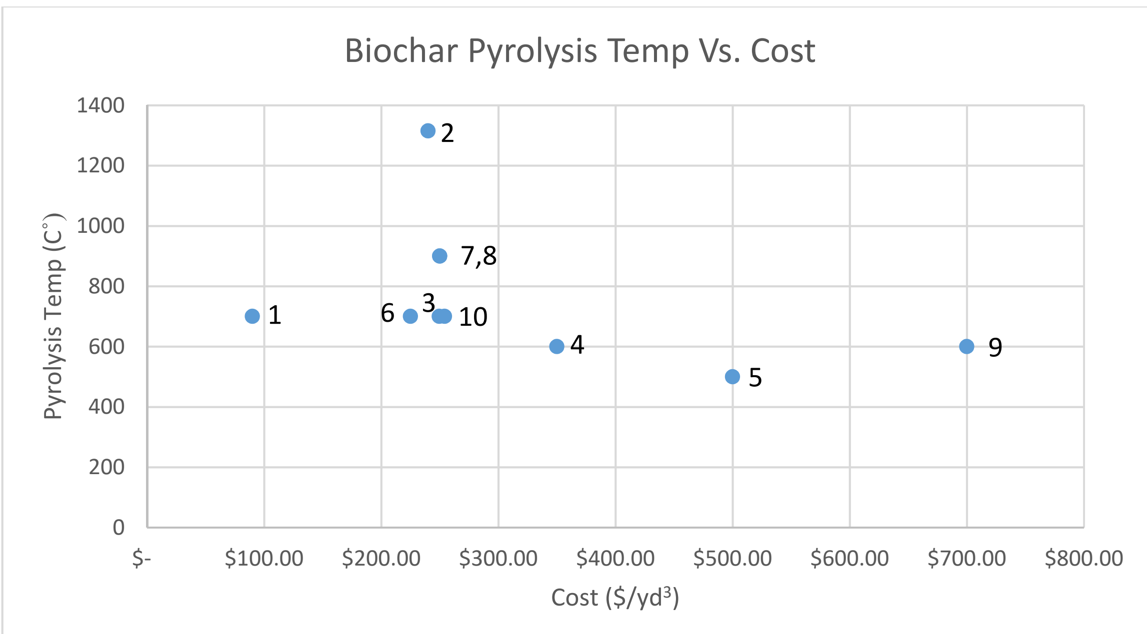

Figure 1. Biochar Pyrolysis Temperature Vs. Cost

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APPENDIX D: HYDRAULIC TEST RESULTS

Blacksorb biochar-amended BSM Compacted to 85% MDD of Standard Proctor

Length	15.2	cm
Area	182.3222	cm2

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
43.7	35.1	8.6	46	240	0.001051	0.565789	19.9	0.001858	0.00186303	2.640514
42.75	27.6	15.15	49.5	150	0.00181	0.996711	19.9	0.001816	0.00182084	2.580724
42.3	24.7	17.6	49.5	135	0.002011	1.157895	19.9	0.001737	0.00174153	2.468306
									Average K	2.563181

Sonoma biochar-amended BSM Compacted to 85% MDD of Standard Proctor

Length	15.2	cm
Area	182.3222	cm2

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
43.98	37.1	6.88	48.8	165	0.001622	0.452632	20	0.003584	0.00358473	5.080723
43.25	32.3	10.95	48	100	0.002633	0.720395	20	0.003655	0.00365541	5.1809
42.65	28.05	14.6	47	75	0.003437	0.960526	20	0.003578	0.00357926	5.072965
									Average K	5.111529

Pacific biochar-amended BSM Compacted to 85% MDD of Standard Proctor

Length	15.2	cm
Area	182.3222	cm2

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
42.2	38.1	4.1	43.5	225	0.00106	0.269737	20.5	0.003931	0.0038846	5.505762
42.1	38	4.1	43	225	0.001048	0.269737	20.5	0.003886	0.00384	5.442478
40.4	34.2	6.2	43	150	0.001572	0.407895	20.5	0.003855	0.003809	5.398587
35.2	24.15	11.05	45	90	0.002742	0.726974	20.5	0.003772	0.0037276	5.283264
									Average K	5.407523

Sunriver biochar-amended BSM Compacted to 85% MDD of Standard Proctor

Length	15.2	cm
Area	182.3222	cm2

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
43.2	40.7	2.5	47	280	0.000921	0.164474	21.5	0.005598	0.005399934	7.65345
42.8	39.6	3.2	47.5	210	0.001241	0.210526	21.5	0.005893	0.005684771	8.057156
41.7	36.6	5.1	46	128	0.001971	0.335526	21.5	0.005875	0.005667171	8.032211
39.85	32.2	7.65	48	90	0.002925	0.503289	21.5	0.005812	0.00560694	7.946844
39.4	31.8	7.6	46.5	90	0.002834	0.5	21.5	0.005668	0.005467458	7.749154
34.5	22.5	12	200	255	0.004302	0.789474	21.5	0.005449	0.005256507	7.450167
33.4	22.3	11.1	200	255	0.004302	0.730263	21.5	0.005891	0.00568271	8.054234
33.1	22.2	10.9	200	305	0.003597	0.717105	21.5	0.005015	0.004838294	6.857425
32.5	22.15	10.35	200	305	0.003597	0.680921	21.5	0.005282	0.005095402	7.221829
									Average K	7.669163

Rogue biochar-amended BSM Compacted to 85% MDD of Standard Proctor

Length	15.2	cm		viscosity at 20		1.0034
Area	182.3222	cm2		viscosity at 22		0.955
				Ratio		0.951764

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
44.65	42.5	2.15	40	270	0.000813	0.141447	22	0.005745	0.005476319	7.761713
43.5	35.75	7.75	48.5	90	0.002956	0.509868	22	0.005797	0.005526225	7.832444
43.3	34.75	8.55	45	75	0.003291	0.5625	22	0.00585	0.005577199	7.904691
42.6	31.5	11.1	46.5	60	0.004251	0.730263	22	0.005821	0.005548936	7.864634
42	28.75	13.25	41.7	45	0.005083	0.871711	22	0.005831	0.005558258	7.877845
43	34.95	8.05	50.5	90	0.003078	0.529605	22	0.005811	0.005539671	7.851503
									Average K	7.848805

Phoenix biochar-amended BSM Compacted to 85% MDD of Standard Proctor

Length	15.2	cm
Area	182.3222	cm2

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
42.58	39.9	2.68	49	210	0.00128	0.176316	19.5	0.007258	0.007349893	10.41717
40.3	34.9	5.4	47.5	100	0.002605	0.355263	19.5	0.007333	0.007425726	10.52465
38.9	31.65	7.25	49.2	80	0.003373	0.476974	19.5	0.007072	0.007161041	10.14951
									Average K	10.36378

Voss Compacted to 85% MDD of Standard Proctor

Length	15.2	cm		viscosity at 20		1.0034
Area	182.3222	cm2		viscosity at 21		0.979
				Ratio		0.975683

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
40.2	37.35	2.85	44.5	165	0.001479	0.1875	21	0.007889	0.007702247	10.91657
39.81	33.45	6.36	43	75	0.003145	0.418421	21	0.007515	0.007337301	10.39932
39.55	30.8	8.75	46	58	0.00435	0.575658	21	0.007557	0.00737748	10.45627
39	27.5	11.5	203	176	0.006326	0.756579	21	0.008362	0.008163413	11.57019
									Average K	10.83559

BioChar Solutions biochar-amended BSM Compacted to 85% MDD of Standard Proctor

Length	15.2	cm
Area	182.3222	cm2

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
44.2	41.7	2.5	49.5	220	0.001234	0.164474	20	0.007503	0.00750502	10.63704
43.5	39.05	4.45	49.5	120	0.002262	0.292763	20	0.007728	0.00772989	10.95575
42.7	36.48	6.22	49.5	85	0.003194	0.409211	20	0.007805	0.00780738	11.06558
42.3	35.4	6.9	46.5	70	0.003643	0.453947	20	0.008026	0.00802814	11.37847
41.45	32.7	8.75	47.8	58	0.00452	0.575658	20	0.007852	0.00785419	11.13192
									Average K	11.03375

Agrosorb biochar-amended BSM Compacted to 85% MDD of Standard Proctor

Length	15.2	cm		viscosity at 20		1.0034
Area	182.3222	cm2		viscosity at 22		0.955
				Ratio		0.951764

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
44.23	40.58	3.65	47	100	0.002578	0.240132	20.4	0.010735	0.0106337	15.07137
43.09	36.4	6.69	45.2	50	0.004958	0.440132	20.4	0.011265	0.0111589	15.81576
43.05	36.3	6.75	45.4	50	0.00498	0.444079	20.4	0.011215	0.0111086	15.74453
41.82	32.2	9.62	51.2	40	0.007021	0.632895	20.4	0.011093	0.0109879	15.57337
41.82	32.09	9.73	38	30	0.006947	0.640132	20.4	0.010853	0.0107505	15.23692
40.85	28.58	12.27	39.1	25	0.008578	0.807237	20.4	0.010627	0.0105262	14.91901
40.85	28.5	12.35	39	25	0.008556	0.8125	20.4	0.010531	0.0104313	14.78446
44	39.9	4.1	41.8	85	0.002697	0.269737	20.4	0.009999	0.009905	14.03852
									Average K	15.14799

Biochar Now biochar-amended BSM Compacted to 85% MDD of Standard Proctor

Length	15.2	cm
Area	182.3222	cm2

Manometers										
H1	H2	head	Q	t	Q/At	h/L	Temp	k cm/s	k corrected	k in/hr
44.3	40.8	3.5	48	90	0.002925	0.230263	21	0.012704	0.01240272	17.57866
44	39.3	4.7	49	70	0.003839	0.309211	21	0.012417	0.01212234	17.18127
43.5	36.85	6.65	49.5	50	0.00543	0.4375	21	0.012411	0.01211713	17.17389
42.85	34.25	8.6	45.1	35	0.007068	0.565789	21	0.012491	0.01219541	17.28483
42.15	31.35	10.8	200	128	0.00857	0.710526	21	0.012061	0.01177559	16.68981
									Average K	17.18169

Appendix E: Biochar Particle Size Distribution

Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name: ____ **Tested By:** RH & JB **Date:** 7/10/2018

Location: ____ **Checked By:** ____ **Date:** ____

Boring No: ____ **Test Number:** ____

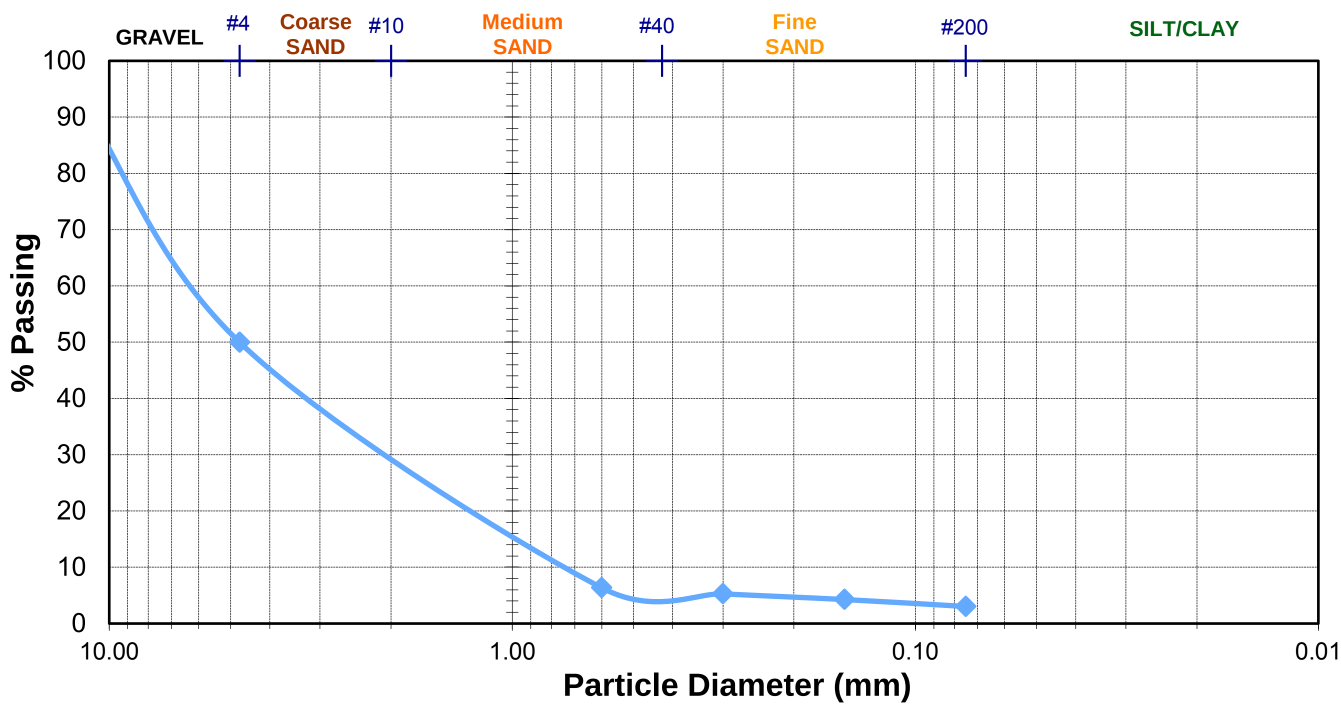
Sample Depth: ____ **Gnd Elev.:** ____

Biochar Type: BioChar Solutions

Weight of Container (g): 52.4 **Weight of Container & Soil (g):** 97.0

Weight of Dry Sample (g): 44.6

Sieve Number	Diameter (mm)	Mass of Container (g)	Mass of Container & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
0.5	12.70	13.9837	15.1551	1.2	2.6	97.4
4	4.75	13.9837	35.5409	21.6	47.4	50.0
30	0.60	13.9837	33.8176	19.8	43.6	6.4
50	0.30	13.9837	14.4764	0.5	1.1	5.3
100	0.15	13.9837	14.4401	0.5	1.0	4.3
200	0.075	0.7018	1.2622	0.6	1.2	3.0
Pan		0.7018	2.0797	1.4	3.0	0.0
			TOTAL:	**45.4**	**100.0**	



Grain Size Distribution Curve Results:

% Gravel:	2.6	D_{10}:	0.72	C_u:	8.61
% Sand:	94.4	D_{30}:	2.05	C_c:	0.94
% Fines:	3	D_{60}:	6.2		

Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name: ______ **Tested By:** RH & JB **Date:** 7/10/2018

Location: ______ **Checked By:** ______ **Date:** ______

Boring No: ______ **Test Number:** ______

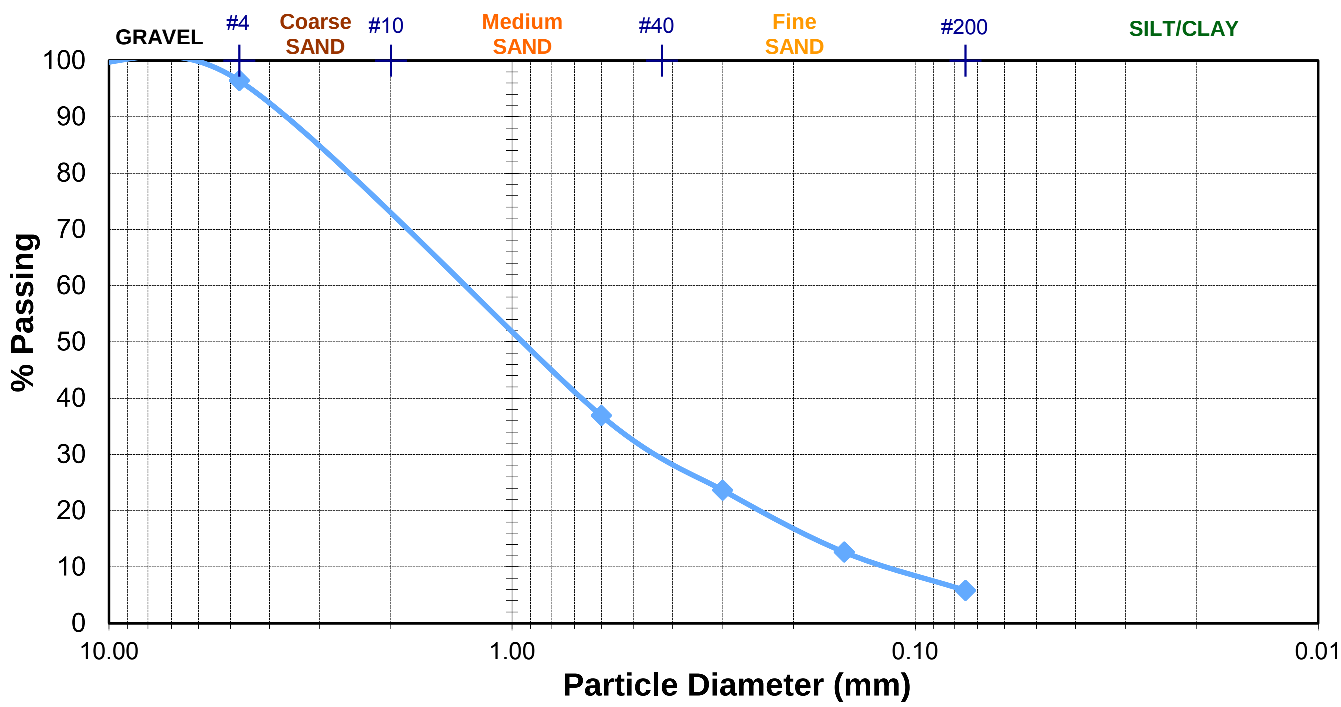
Sample Depth: ______ **Gnd Elev.:** ______

Biochar Type: Agrosorb

Weight of Container (g): 3.2 **Weight of Container & Soil (g):** 175.3

Weight of Dry Sample (g): 172.1

Sieve Number	Diameter (mm)	Mass of Container (g)	Mass of Container & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
0.5	12.70	1.5896	3.1261	1.5	0.9	99.1
4	4.75	1.5896	6.1437	4.6	2.7	96.4
30	0.60	3.1792	104.6093	101.4	59.6	36.9
50	0.30	1.5896	24.1144	22.5	13.2	23.6
100	0.15	1.5896	20.3184	18.7	11.0	12.7
200	0.075	1.5896	13.1978	11.6	6.8	5.8
Pan		1.5896	11.5284	9.9	5.8	0.0
			TOTAL:	**170.3**	**100.0**	



Grain Size Distribution Curve Results:

% Gravel: 0.9 **D_{10}:** 0.11 **C_u:** 10.9

% Sand: 93.3 **D_{30}:** 0.43 **C_c:** 1.40

% Fines: 5.8 **D_{60}:** 1.2

Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name: ____ **Tested By:** RH & JB **Date:** 7/10/2018

Location: ____ **Checked By:** ____ **Date:** ____

Boring No: ____ **Test Number:** ____

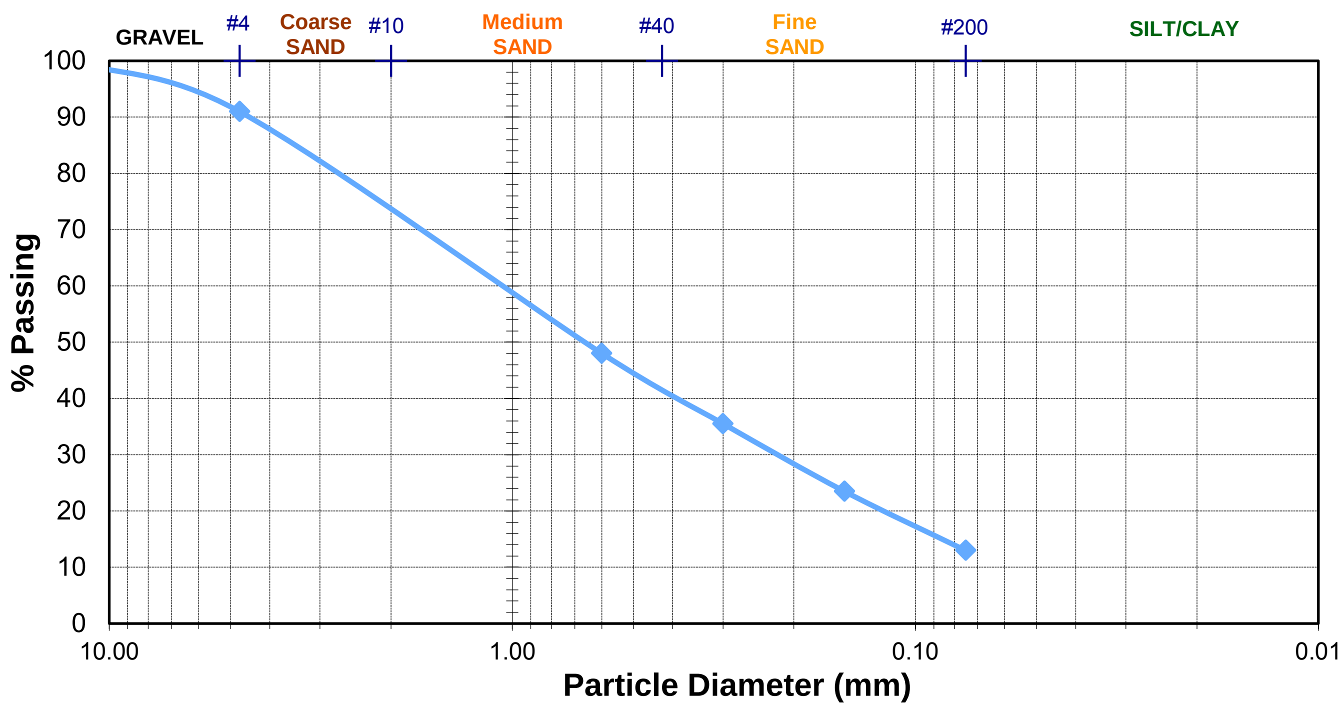
Sample Depth: ____ **Gnd Elev.:** ____

Biochar Type: Phoenix

Weight of Container (g): 2.8 **Weight of Container & Soil (g):** 241.2

Weight of Dry Sample (g): 238.4

Sieve Number	Diameter (mm)	Mass of Container (g)	Mass of Container & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
0.5	12.70	0.7018	0.7018	0.0	0.0	100.0
4	4.75	0.7018	23.5505	22.8	9.0	91.0
30	0.60	13.9837	122.8911	108.9	43.0	48.0
50	0.30	1.5896	33.2888	31.7	12.5	35.5
100	0.15	1.5896	32.0522	30.5	12.0	23.5
200	0.075	1.5896	28.2517	26.7	10.5	13.0
Pan		1.5896	34.4933	32.9	13.0	0.0
			TOTAL:	**253.5**	**100.0**	



Grain Size Distribution Curve Results:

% Gravel: 0 D_{10}: ____ C_u: ____

% Sand: 87 D_{30}: 0.21 C_c: ____

% Fines: 13 D_{60}: 1.03

Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name: ______ **Tested By:** RH & JB **Date:** 7/10/2018

Location: ______ **Checked By:** ______ **Date:** ______

Boring No: ______ **Test Number:** ______

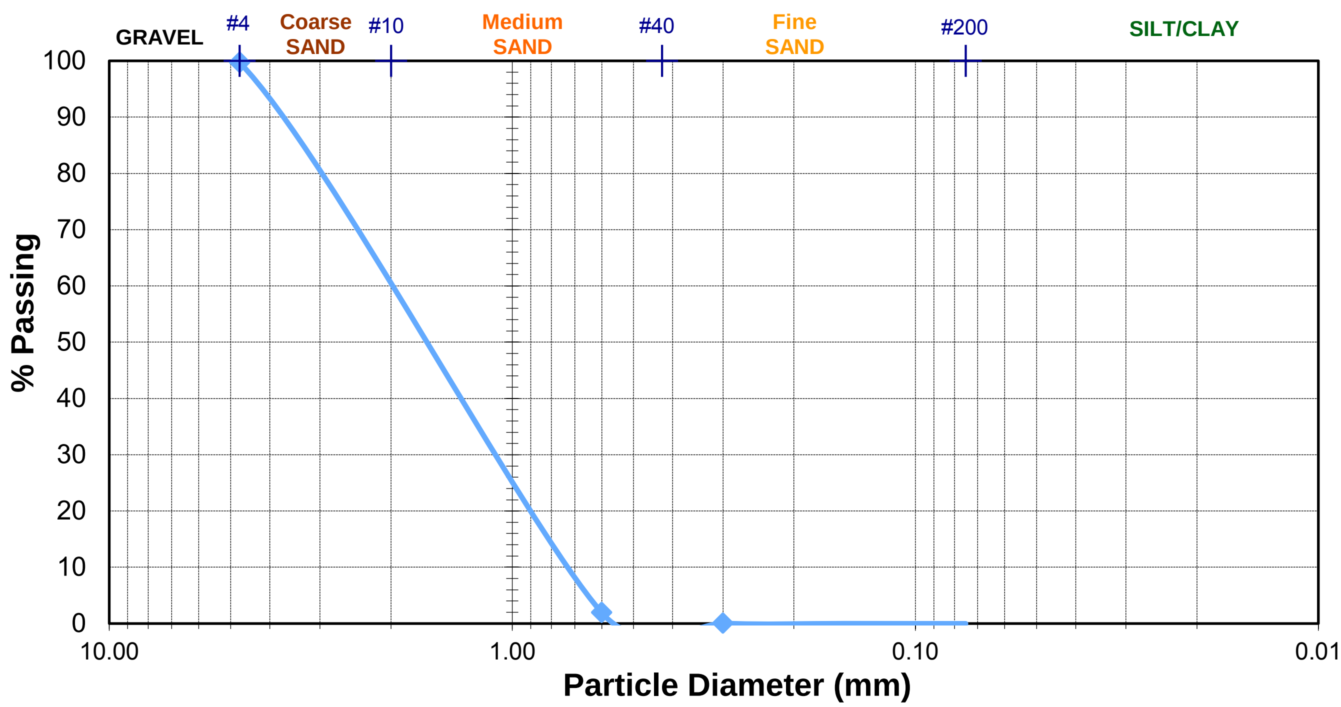
Sample Depth: ______ **Gnd Elev.:** ______

Biochar Type: Rogue

Weight of Container (g): 52.3 **Weight of Container & Soil (g):** 173.8

Weight of Dry Sample (g): 121.5

Sieve Number	Diameter (mm)	Mass of Container (g)	Mass of Container & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
0.5	12.70	1.5896	1.5896	0.00	0.00	100.00
4	4.75	1.5896	1.9089	0.32	0.27	99.73
30	0.60	3.1792	119.5292	116.35	97.79	1.94
50	0.30	1.5896	3.8304	2.24	1.88	0.05
100	0.15	1.5896	1.6583	0.07	0.06	0.00
200	0.075	1.5896	1.6115	0.02	0.02	-0.02
Pan		1.5896	1.5635	-0.03	-0.02	0.00
			TOTAL:	**119.0**	**100.0**	



Grain Size Distribution Curve Results:

% Gravel: ______ **D_{10}:** ______ **C_u:** ______

% Sand: ______ **D_{30}:** ______ **C_c:** ______

% Fines: ______ **D_{60}:** ______

Sieve Analysis Data Sheet

ASTM D422-63(2007)

Project Name: ______ **Tested By:** RH & JB **Date:** 7/10/2018

Location: ______ **Checked By:** ______ **Date:** ______

Boring No: ______ **Test Number:** ______

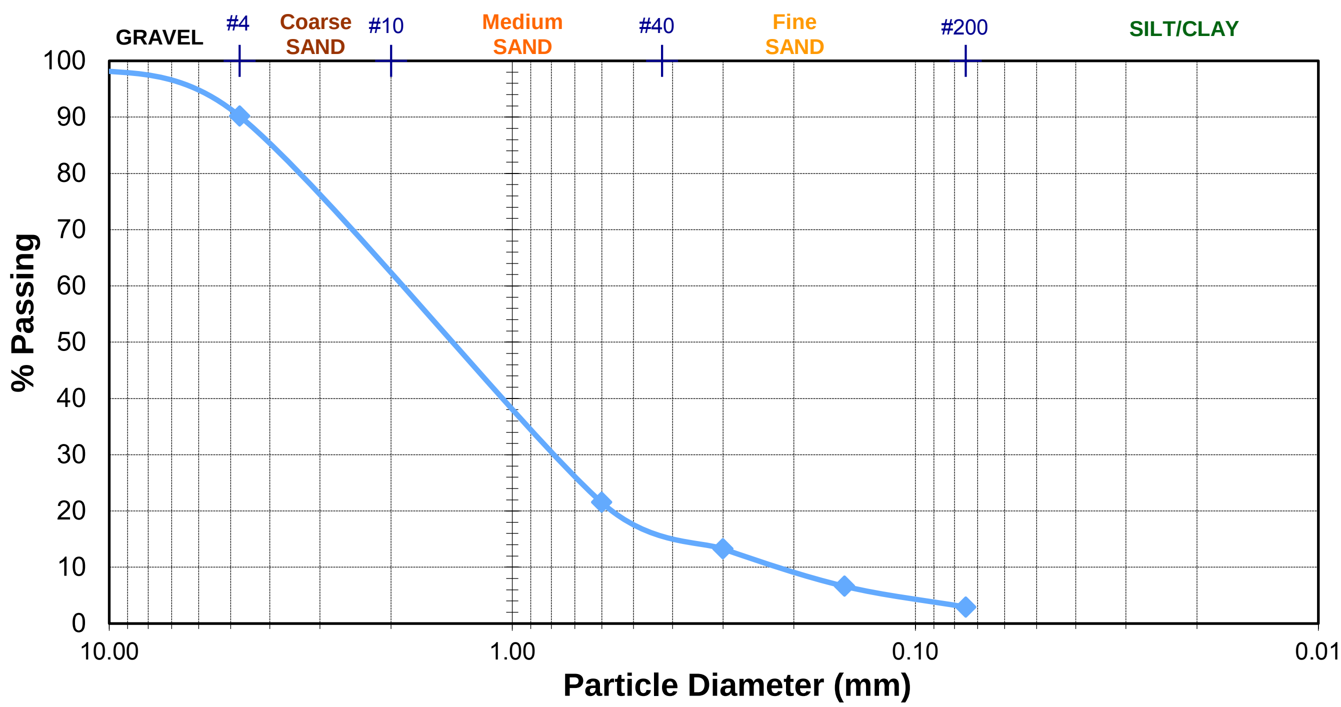
Sample Depth: ______ **Gnd Elev.:** ______

Biochar Type: Sun River

Weight of Container (g): 52.3 **Weight of Container & Soil (g):** 153.2

Weight of Dry Sample (g): 100.9

Sieve Number	Diameter (mm)	Mass of Container (g)	Mass of Container & Soil (g)	Soil Retained (g)	Soil Retained (%)	Soil Passing (%)
0.5	12.70	1.5896	2.4228	0.8	0.8	99.2
4	4.75	1.5896	10.6182	9.0	9.0	90.2
30	0.60	1.5896	70.5872	69.0	68.7	21.5
50	0.30	1.5896	9.8777	8.3	8.2	13.3
100	0.15	1.5896	8.2566	6.7	6.6	6.6
200	0.075	1.5896	5.3083	3.7	3.7	2.9
Pan		1.5896	4.5286	2.9	2.9	0.0
			TOTAL:	**100.5**	**100.0**	

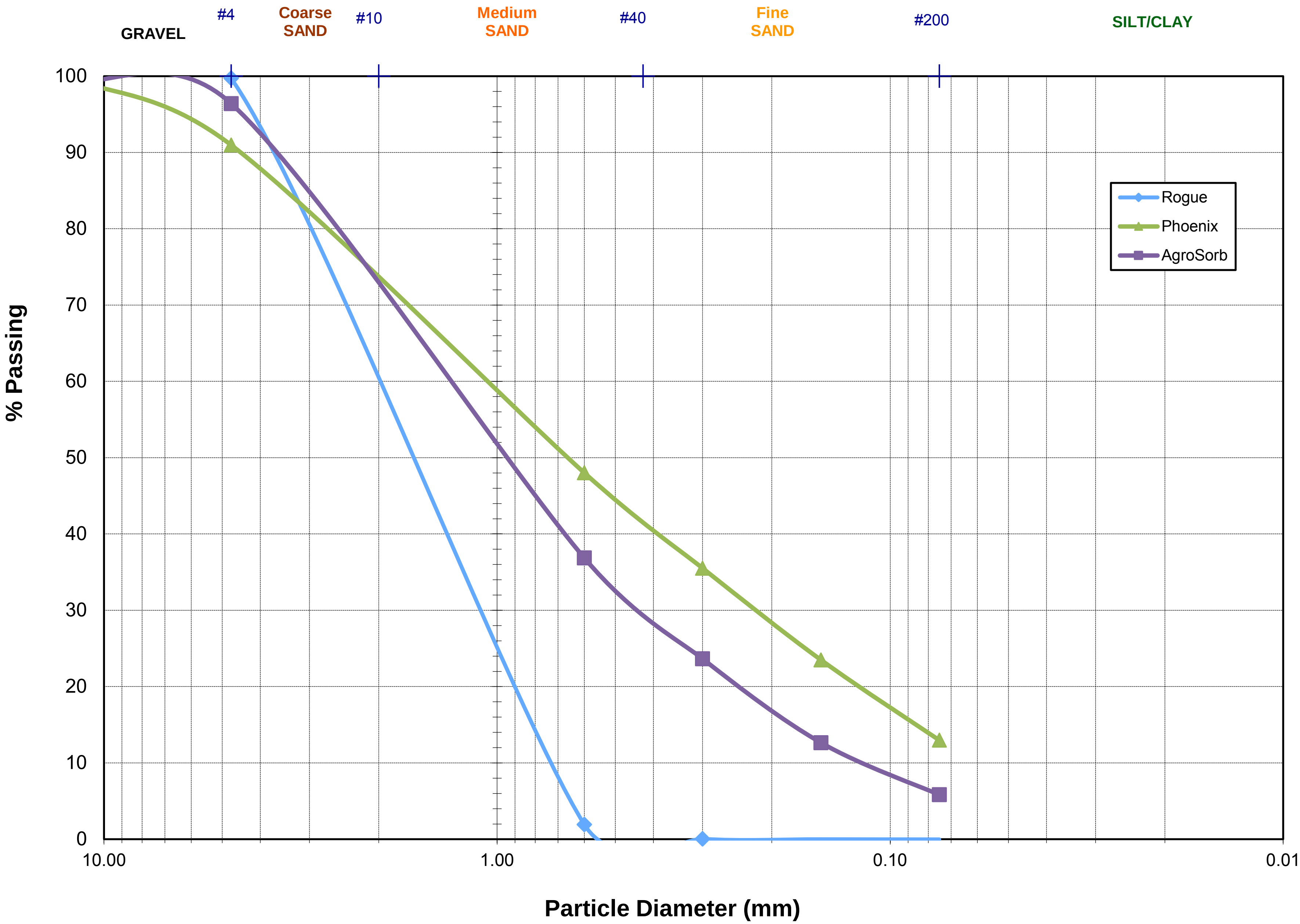


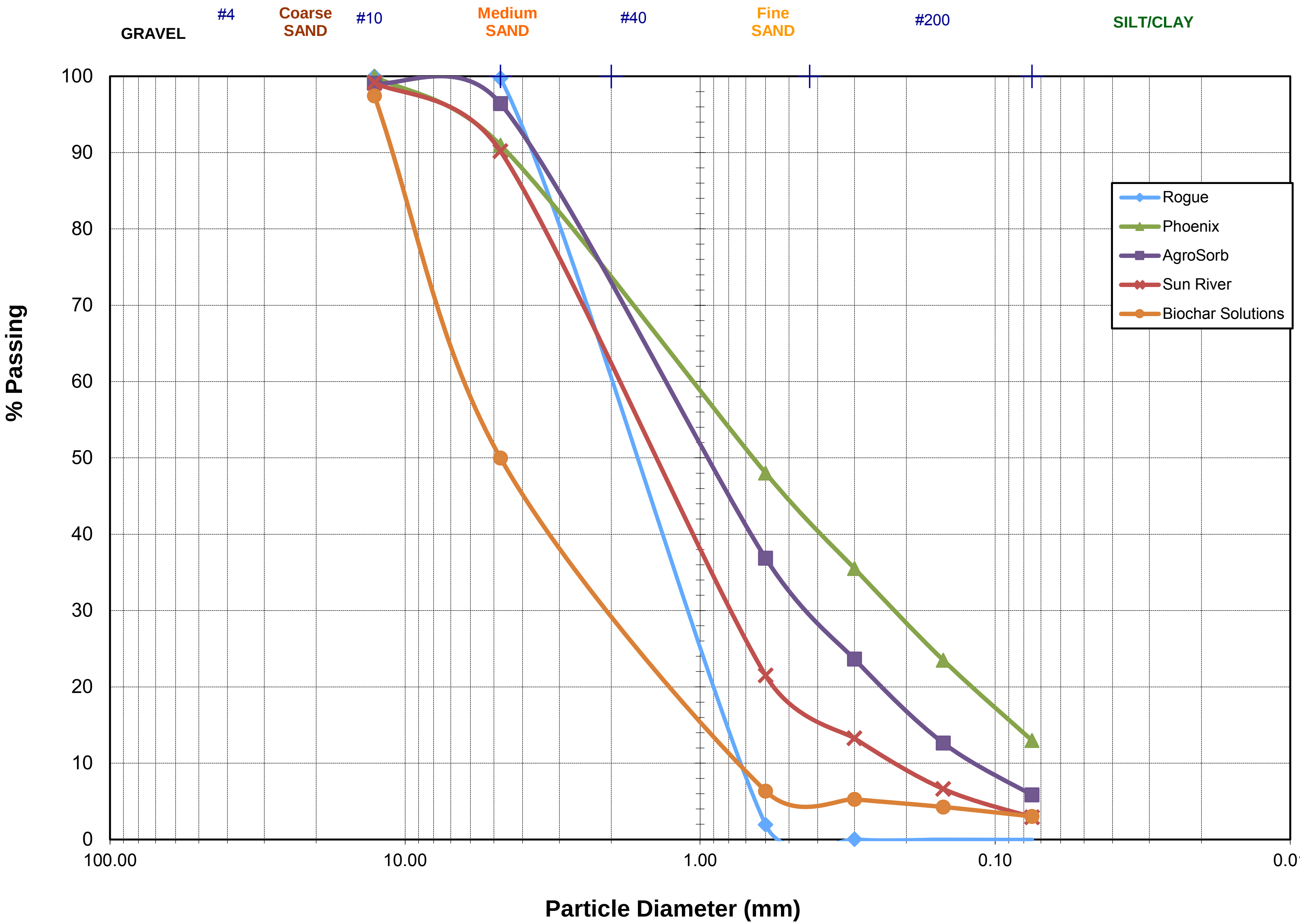
Grain Size Distribution Curve Results:

% Gravel: 0.8 **D_{10}:** 0.22 **C_u:** 8.18

% Sand: 96.3 **D_{30}:** 0.78 **C_c:** 1.54

% Fines: 2.9 **D_{60}:** 1.8


GRAVEL
#4
Coarse SAND
#10
Medium SAND
#40
Fine SAND
#200
SILT/CLAY
100
90
80
70
60
50
40
30
20
10
0
% Passing
10.00
1.00
0.10
0.01
Particle Diameter (mm)
Rogue
Phoenix
AgroSorb


GRAVEL
#4
Coarse SAND
#10
Medium SAND
#40
Fine SAND
#200
SILT/CLAY
% Passing
100
90
80
70
60
50
40
30
20
10
0
100.00
10.00
1.00
0.10
0.01
Particle Diameter (mm)
Rogue
Phoenix
AgroSorb
Sun River
Biochar Solutions

APPENDIX F: COLUMN TEST OBSERVATION FORMS

4/10/18 First Run

Stormwater Column Tests – Office of Water Programs

Sampling Run			
Date (mm/dd/yy):	Time (24 hr) :	Team Member's Initials:	Column ID: CO

During Test - Timed Measurements

Time	Water Depth	Media Condition	Other Observations

Grab Sample - Beginning of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
4:25	2"	20.6			

Grab Sample - Middle of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
5:49	2"	18.7			

Grab Sample - End of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Mercury

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Stormwater Column Tests – Office of Water Programs

Sampling Run			
Date (mm/dd/yy):	Time (24 hr) :	Team Member's Initials:	Column ID: C02

During Test - Timed Measurements

Time	Water Depth	Media Condition	Other Observations

Grab Sample - Beginning of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
4:28	9"	210			

Grab Sample - Middle of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
5:49	9"	204			

Grab Sample - End of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Mercury

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Stormwater Column Tests – Office of Water Programs

Sampling Run			
Date (mm/dd/yy):	Time (24 hr) :	Team Member's Initials:	Column ID: C03

During Test - Timed Measurements

Time	Water Depth	Media Condition	Other Observations

Grab Sample - Beginning of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
4:26	1"	138			

Grab Sample - Middle of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
5:41	4"	181			

Grab Sample - End of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Mercury

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Stormwater Column Tests – Office of Water Programs

Sampling Run			
Date (mm/dd/yy):	Time (24 hr) :	Team Member's Initials:	Column ID: CO^C(

During Test - Timed Measurements

Time	Water Depth	Media Condition	Other Observations

Grab Sample - Beginning of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
4:28	0"	289			

Grab Sample - Middle of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
5:42	1"	212			

Grab Sample - End of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Mercury

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Stormwater Column Tests – Office of Water Programs

Sampling Run			
Date (mm/dd/yy):	Time (24 hr) :	Team Member's Initials:	Column ID: C05

During Test - Timed Measurements

Time	Water Depth	Media Condition	Other Observations

Grab Sample - Beginning of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
4:31	2"	283			

Grab Sample - Middle of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
5:52	2"	234			

Grab Sample - End of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Mercury

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Stormwater Column Tests – Office of Water Programs

Sampling Run			
Date (mm/dd/yy):	Time (24 hr) :	Team Member's Initials:	Column ID: C06

During Test - Timed Measurements

Time	Water Depth	Media Condition	Other Observations

Grab Sample - Beginning of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
1028	1"	212			

Grab Sample - Middle of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
5:55	3"	335			

Grab Sample - End of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Mercury

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Stormwater Column Tests – Office of Water Programs

Sampling Run			
Date (mm/dd/yy):	Time (24 hr) :	Team Member's Initials:	Column ID: EN Fluent

During Test - Timed Measurements

Time	Water Depth	Media Condition	Other Observations

Grab Sample - Beginning of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
4:18	–	24.			

Grab Sample - Middle of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations
5:56	–	21.4			

Grab Sample - End of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Mercury

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Technician__________________ Appendix F: Column Test Observation Forms Sampling Sheet Column ID: TW2 Date: 4/10/18

Column Description Influent

Sample Run 1 Water 2-2

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	X			
2	X			
3	X → Start of Sampling			
4	X			
5	X			
6	X			
7	X			
8	3:41			
9	3:58			
10	4:18	Turb		
11	4:46			
12	5:02			
13	6:29			
14	X			
15	5:36			
16	5:[illegible]			
17	5:46			
18	5:55			

Observations:

Technician________________

Sampling Sheet

Column ID: C02 Date: 4/10/18

Column Description Rogue

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	2:45			
2	2:48			
3	3:20			
4	3:27			
5	3:30			
6	3:34			
7	3:41			
8	3:44			
9	3:48			
10	4:15			
11	4:20	Turb		
12	4:42			
13	4:50	Mercury		
14	5:21			
15	5:31			
16	5:37	.5?		
17	5:41			
18	5:51			

Observations:

Technician________________ **Sampling Sheet** Column ID: C01 Date: 4/10/18

Column Description Sun river

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	3:45			
2	3:48			
3	3:19			
4	3:26	Shallow ponding of		
5	3:30	4" → dry before	next pour	
6	3:33	2"	"	
7	3:40	1"		
8	3:44	.75"		
9	3:47	.5" →	dry before	next pour
10	4:15			
11	4:19	Turb		
12	4:41			
13	4:48	mercury	grab	
14	5:20			
15	5:30			
16	5:36	.75		
17	5:40			
18	5:50			

Observations:

Technician________________ **Sampling Sheet** Column ID: C03 Date: 6/10/18

Column Description Phoenix

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	2:45			
2	2:49			
3	3:20	Ponding		
4	3:27			
5	3:30	1.5"		
6	3:34	2.0"		
7	3:41	2.0"		
8	3:45	2.5		
9	3:49	2.75		
10	4:15	1"		
11	4:20	1.5	Turb	
12	4:43	1"		
13	4:52	[illegible]		
14	5:25	1"		
15	5:32	1"		
16	5:38	1		
17	5:41	1.5"		
18	5:51			

Observations:

Technician____________ Appendix F: Column Test Observation Forms Sampling Sheet Column ID: C04 Date: 4/10/18

Column Description Biochar Solutions

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	3:45			
2	3:49			
3	3:21			
4	3:28			
5	3:31	1"		
6	3:34	1.5"		
7	3:42	1"		
8	3:45	1.5"		
9	3:50	2"		
10	4:16	.75"		
11	4:21	Turb		
12	4:44	.5"		
13	4:58	murky		
14	5:26	1"		
15	5:33	.5"		
16	5:38			
17	5:42	2"		
18	5:57			

Observations:

Technician__________ **Sampling Sheet** Column ID: C05 Date: 4/10/18

Column Description Black Sorb

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	2:45			
2	2:50			
3	3:22	Ponding		
4	3:28	1"		
5	3:31	1.25		
6	3:34	2.75"		
7	3:42	1.5		
8	3:46	2"		
9	3:50	2.75		
10	4:17	1"		
11	4:22	1.5"	Turb	
12	4:44	1"		
13	5:02	"		
14	5:26	.75"		
15	5:34	1.5"		
16	5:38			
17	5:43	3"		
18	5:53	1.5"		

Observations:

Technician____________________ Sampling Sheet Column ID: C06 Date: 4/10/18

Column Description control

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	2:45			
2	2:51			
3	3:23	[illegible]		
4	3:28			
5	3:32	1.75"		
6	3:35	2.5"		
7	3:43	2.75"		
8	3:46	3.5"		
9	3:50	4"		
10	4:18	1.75"		
11	4:22	2"	Turb →	dropped for 0" before next sample
12	4:45	4"		
13	5:03	1"		
14	5:29	1		
15	5:34	1.5"		
16	5:40			
17	5:44	2.5"		
18	5:50	3.5"		

Observations:

Technician Michelle

Sampling Sheet

Column ID: 6 Date: 4/11/18

Column Description

Media flushing w/2-2 & 2-1

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	1:06	1		
2	/	1		
3	/	1		
4	/	2		
5	/	2.5		
6	/	2		88.5
7	2:02	1		
8	/	2		
9	/	2.5		
10	/	3		
11	/	4		
12	/	5		
13	/	3.5		
14	3:08	1		
15	/	2		
16	/	2.5		
17	3:31	2.5		
18	3:40	2		155

Site 2 Storm 1 (doses 1–6)

Break @ 2:35 (dose 13)

Mix of 2-1 & 2-2 half dose (doses 17–18)

9 X

Observations:

Technician Michelle **Sampling Sheet** Column ID: 5 Date: 4/11/18

Column Description

Media flushing w/ 2-2

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	1:05	Ø		
2	/	1		
3	/	1		
4	/	1.5		
5	/	2		
6	/	2		91.1
7	2:01	1		
8	/	2		
9	/	2.5		
10	/	3		
11	/	4		
12	/	4.5		
13	/	3		
14	3:07	0		
15	/	1		
16	/	2		
17	3:29	1		
18	3:39	0		160
19	X			

Site 2 Storm 1

Break @ 2:35

Mix of 2-1 & 2-2 half dose

Observations:

Sampling Sheet

Technician Michelle

Column ID: 4 Date: 9/11/18

Column Description
Media flushing w/ 2-2

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	1:04	ø		
2	/	|		
3	/	|		
4	/	|		
5	/	|		
6	/	|		105
7	2:00	1		
8	/	1.5		
9	/	2.5		
10	/	3		
11	/	4		
12	/	5		
13	/	5		
14	3:06	1		
15	/	1.5		
16	/	2		
17	3:28	1		
18	3:38	0.5		122

site 2 storm 1

Break @ 2:35

Mix of 2-1 $ 2-2 half dose

Kf X

Observations:

Technician Michelle

Sampling Sheet

Column ID: 3 Date: 4/11/18

Column Description

Media Fishing w/ 2-2

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)	
1	12:56	Ø			
2	/	1			
3	/	1			
4	/	1.5			
5	/	1.5			
6	/	1		75.4	
7	2:00	1			Site 2 Storm 1
8	/	1.5			
9	/	2.5			
10	/	3			
11	/	4			
12	/	5			
13	/	5			Break @ 2:35
14	3:05	1			
15	/	1.5			
16	/	2.5			
17	3:27	2			Mix of 2-1 & 2-2
18	3:38	1.5		96.1	half dose

Observations:

Technician Michelle   **Sampling Sheet**   Column ID: 2   Date: 4/11/18

Column Description
Site 2 Flushing w/ 2-2

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	12:55	8		
2	—	1		
3	/	1		
4	/	1		
5	/	1		
6	/	1		105
7	1:59	1		
8	/	1		
9	/	2		
10	/	2.5		
11	/	3		
12	/	4		
13	/	4		
14	3:05	1		
15	/	1		
16	/	1		
17	3:27	1		
18	3:37	0		143

Site R storm 1 (dose 7)

Break @ 2:35 (dose 13)

Mix of 2-1 & 2-2 half dose (doses 17–18)

17   X

Observations:

Technician Michele Sampling Sheet Column ID: 1 Date: 4/11/18

Column Description

Media flushing w/ 2-2 Site 2 Storm 2

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	12:54	Ø		
2	/	Ø		
3	/	Ø		
4	/	|		
5	/	|		
6	/	|		87.5
7	1:58	Ø		
8	/	0		
9	/	|		
10	/	|		
11	/	|		
12	/	0		
13	/	|		
14	3:05	0		
15	/	0		
16	/	~~3~~ 1		
17	3:25	0		
18	3:34	0		~~98.5~~ 1024

Site 2 Storm 1 (doses 1–6)

Break @ 2:35 (doses 12–14)

Mix of 2-1 & 2-2 half dose (doses 17–18)

Observations:

Technician Jessica/Audrey Sampling Sheet Column ID: C01 Date: 4/12/18

Column Description Media flushing

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	12:45			
2	/			
3	/	1		
4	/	2		
5	/	2.2		
6	1:14	2.8		16.5
7	1:33	1.9		
8	/	2.8		
9	/	3		
10	/	4		
11	/	4.4		21.6
12	2:31	[illegible]		
13	—	1		
14	—	1		
15	—	2		
16	—	2.4		
17	—	2.4		
18	—	4		47.7

3:14

Break

Observations:

Technician Jessica/Audrey Sampling Sheet Column ID: C172 Date: 4/10/18

Column Description

Observations:

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	12:45			
2	/	1		
3	/	1.5		
4	/	2.2		
5	/	2.5		
6	1:15	3		15.4
7	1:34	2		
8	/	2.2		
9	/	3		
10	/	4		
11	/	4.3		28.3
12	2:31			
13	—	1.75		
14	—	2.5		
15	—	3.4		
16	—	4.0		
17	—	4.9		
18	3:14	4		45.6

BREAK

Technician Jessica/Aubrey

Sampling Sheet

Column ID: CD3 Date: 4/18/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	12:45			
2	/	1		
3	/	1		
4	/	1		
5	/	1.5		
6	1:15	1.6		34.4
7	1:34	1		
8	/	1.8		
9	/	1.5		
10	/	1.8		
11	/	2.2		61.1
12	2:31	1		
13	—	1.5		
14	—	2		
15	—	3		
16	—	3.4		
17	—	3.4		
18	3:14	1.7		63.7

BREAK

Observations:

Technician Jessica / Audrey

Sampling Sheet

Column ID: C04 Date: 4/10/19

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	12:45			
2	/			
3	/	1		
4	/	1.2		
5	/	1.7		
6	1:16	2		33.1
7	1:36	2		
8	/	1.2		
9	/	2		
10	/	2.5		
11	/	2.9		48.0
12	2:32	–		
13	–	1		
14	–	1.3		
15	–	2		
16	–	2.8		
17	–	2.8		
18	3:14	1		67.2

BREAK

Observations:

Technician Jessica/Andrey **Sampling Sheet** Column ID: C05 Date: 4/11/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	12:45			
2	/			
3	/	1.5		
4	/	2		
5	/	2.8		
6	1:16	3.3		32.4
7	1:36	2		
8	/	2.5		
9	/	3		
10	/	3.8		
11	/	4.2		48.3
12	2:32	←		
13	—	1.2		
14	—	1.8		
15	—	2.3		
16	—	2.5		
17	—	3		
18	3:16	1		80.5

BREAK

Observations:

Technician Jessica/Audrey **Sampling Sheet** Column ID: 006 Date: 4/11/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	12:45			
2	/	1		
3	/	1.5		
4	/	1.75		
5	/	2		
6	1:17	2.75		29.3
7	1:37	1		
8	/	1.8		
9	/	2.1		
10	/	3		
11	1:53	3.6		76.5
12	2:32	1		
13	—	1.75		
14	—	2		
15	—	3		
16	—	3.5		
17	—	4		
18	—	2.8		102

— BREAK

Observations:

Technician Joel

Sampling Sheet
Appendix F: Column Test Observation Forms

Column ID: Inf Date: 4/13/18

Column Description

Sample Run 2

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:05			
2	9:10			✓
3	9:38			
4	9:40		21	
5	9:48			
6	9:51			
7	10:32			
8	10:37			✓
9	10:42			
10	10:56			
11	11:58			
12	11:49			
13	11:53			
14	11:57			
15	[illegible]			
16	1:03			
17	1:09			
18	1:12		20°C	

→ ponding (dose 14)

Observations: pH: 6.80 Temp: 20.2°C

Technician [illegible signature]

Sampling Sheet
Appendix F: Column Test Observation Forms

Column ID: C01 Date: 4/13/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:01			
2	9:08			✓
3	9:27			
4	9:38			
5	9:46			
6	9:49	.54		
7	10:29			
8	10:31			✓
9	10:40			
10	10:46			
11	11:15			
12	11:42			
13	11:50			
14	11:55			
15	12:08			
16	12:59			
17	1:04			
18	1:11	1.29		

→ ponding (beside dose 15)

Observations: 19.2°C & pH = 7.66

Technician ~~Dave~~ Date: 6/13/18

Sampling Sheet

Column ID: C02

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:05			
2	9:09	1"		Stopped draining, no turb sample
3	9:25	1.25"		✓
4	9:38	2"		
5	9:46	2.75		
6	9:49	3.25"		→ removed 3 screws → flow start to drain
7	10:29	1.1"		
8	10:35	1.75		
9	10:40	2.5		✓
10	10:49	3.25		
11	11:30			
12	11:42			
13	11:50			
14	11:55			
15	12:00			→ ponding
16	1:00			
17	1:05	1.5"		
18	1:17	2.25		

Observations: Very slow this run, very clear effluent

pH=7.97 Temp=19.2°C

Technician JDC / **Sampling Sheet** Column ID: C03 Date: 4/13/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:04			
2	9:09			√
3	9:28			
4	9:39	1"		
5	9:47	1.25"		
6	9:49	1.75		
7	10:31			
8	10:35	?		✓
9	10:41	1.75		
10	10:50	2.1		
11	11:31			
12	11:43			
13	11:51			
14	11:55			
15	12:00			→ ponding
16	1:09			
17	1:06	1.25"		
18	1:13	1.75"		

Observations:

pH= 7.65 Temp: 19.2°C

Technician Joel

Sampling Sheet

Column ID: 01 Date: 9/13/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:01			
2	9:09			✓
3	9:28			
4	9:34	0.75		
5	9:48	— ?		
6	9:49	1.5		
7	10:31			
8	10:52			
9	10:41	1		✓
10	10:53	1"		
11	11:32			
12	11:43			
13	11:51			
14	11:56			
15	12:02			
16	1:01			
17	1:06			
18	1:14	~~#~~ .20		

→ ponding (beside dose 15)

Observations: pH= 7.78 temp: 19.2°C

Technician Joel

Sampling Sheet

Column ID: C05 Date: 9/13/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:04			✓
2	9:10			
3	9:28			
4	9:40			
5	9:48	2"		
6	9:50	1.75		
7	10:31			
8	10:36	1"		
9	10:48	1.75		✓
10	10:55	1.75		
11	11:35			
12	11:44			
13	11:52			
14	11:56			
15	12:04			
16	1:02			
17	1:07	1"		
18	1:15	2"		

→ remove 3 screws (at dose 6)

→ Ponding (at dose 15)

Observations: pH = 7.77 Temp: 19.5°C

Technician Joel

Sampling Sheet

Column ID: C06 Date: 4/13/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:14			
2	9:10			✓
3	9:29			
4	9:40	.75"		
5	9:48	1.5"		
6	9:50	2"		
7	10:32			
8	10:36	1"		
9	10:42	1.5		✓
10	10:56	1.5"		
11	11:26			
12	11:44			
13	11:53			
14	11:57			
15	12:03p			
16	1:03			
17	1:08	1"		
18	1:16	1.5"		

Observations: pH: 7.94 Temp: 19.5°C

Technician Joel **Sampling Sheet** Column ID: C01 Date: 4/17/18

Column Description

Sample Run 5

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	10:14			
2	10:16			
3	10:20	0.50		10.5
4	10:36			
5	10:45			
6	11:27			
7	11:32	0.50		
8	11:35	1.25		
9	11:40	1.75	✓	✓
10	12:18			
11	12:25	0.75		
12	12:35	1.25		
13	12:39	2.25		
14	12:47	2.75		
15	12:50	3.50		
16	12:53	4.25		
17	1:02	4.00		
18	1:06	4.50		

12

20

Observations:

Technician Joel

Sampling Sheet

Column ID: C02 Date: 4/17/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	10:14	0.25		
2	10:16	0.75		
3	10:20	1.5		
4	10:36	1.75		
5	10:45	2.50		2.27
6	11:27	0.75		
7	11:32	1.5		
8	11:35	2.25		
9	11:41	2.75	✓	✓
10	12:18	1.50		
11	12:25	2.00		
12	12:36	2.50		
13	12:39	3.25		
14	12:47	3.75		
15	12:50	4.00		
16	12:54	5.25		
17	1:02	5.25		
18	1:06	5.75		

Observations:

Technician Joel Sampling Sheet Column ID: C03 Date: 4/17/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	10:14			
2	10:17			
3	10:20	0.25		14.5
4	10:42			
5	10:45			
6	11:27			
7	11:33	0.50		
8	11:35	1.00		/
9	11:42	1.25	\	/
10	12:18			
11	12:25	0.25		
12	12:36	0.50		
13	12:40	1.50		
14	12:47	2.50		
15	12:50	3.50		
16	12:54	4.00		
17	1:03	3.75		
18	1:06	4.50		

27

57

Observations:

Technician Sell

Sampling Sheet

Column ID C04 Date: 4/17/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	10:15			
2	10:17	0.25		
3	10:20	0.50		8.02
4	10:42			
5	10:46	0.50		
6	11:28	0.25		
7	11:33	0.75		
8	11:36	1.75		
9	11:44	2.00	✓	✓
10	12:19	0.25		
11	12:26	0.50		
12	12:37	0.75		
13	12:40	1.75		
14	12:48	2.25		
15	12:50	3.00		
16	12:54	3.75		
17	1:03	4.00		
18	1:07	4.75		

14

36

Observations:

Technician Joel

Sampling Sheet

Column ID: C05 Date: 4/17/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	10:15			
2	10:18	0.5		
3	10:21	1		6.27
4	10:42			
5	10:41	0.50		
6	11:28			
7	11:33	0.25		
8	11:36	0.75		
9	11:44	0.75	✓	✓
10	12:19	0.25		
11	12:26	0.50		
12	12:37	1.00		
13	12:40	1.75		
14	12:48	2.25		
15	12:50	3.00		
16	12:55	4.00		
17	1:03	4.00		
18	1:07	4.50		

22

22

Observations:

Technician Joel **Sampling Sheet** Column ID: 06 Date: 4/17/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	10:15			
2	10:18	0.25		
3	10:21	0.25		11.7
4	10:43			
5	10:46	0.50		
6	11:29	0.50		
7	11:34	1.00		
8	11:37	1.75		
9	11:45	2.00	✓	✓
10	12:19	0.50		
11	12:27	0.50		
12	12:38	0.75		
13	12:40	1.75		
14	12:48	2.25		
15	12:52	3.00		
16	12:55	4.00		
17	1:04	4.00		
18	1:07	4.75		

26

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Observations:

Technician Joel

Sampling Sheet

Column ID: INF TW6 Date: 4/17/18

Column Description
Storm 2

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	10:15			
2	10:18			
3	10:22			5.51
4	10:43			
5	10:46			
6	11:28			
7	11:34			
8	11:37			
9	11:41		✓	✓
10	12:20			
11	12:38			
12	12:40			
13	12:48			
14	12:52			
15	12:55			
16	1:04			
17	1:08			
18				

12:27 → shift down

Observations: Missed 12:27 time record
shift Dose 11 through Dose 17 down
one cell & insert 12:27 for Dose 11

Technician Joel Appendix F: Column Test Observation Forms **Sampling Sheet** Column ID: TW2 Date: 4/19/18

Column Description

Dillution Run

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:41			
2	9:42			
3	9:46			
4	9:55			
5	9:56		✓	✓
6	10:15			
7	10:17			
8	10:19			
9	10:22			
10	10:24			
11	10:26		✓	✓
12	11:04			
13	11:05			
14	11:06			
15	11:07			
16	11:08			
17	11:10			
18	11:16			

Gagbureve

Observations:

Technician: Joel **Sampling Sheet** Column ID: CO6 Date: 4/19/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:41			
2	9:43	0.5		
3	9:46	0.75		
4	9:54	~~1~~ 0		
5	9:56	1.5	✓	✓
6	10:15	.5		
7	10:16	1.5		
8	10:18	2.25		
9	10:22	3.00		
10	10:23	4.		
11	10:26	5	✓	✓
12	11:04	1		
13	11:05	2		
14	11:06	2.5		
15	11:07	3.75		
16	11:08	4.85		
17	11:10	5.5		
18	11:16	5.8		

→ Start effluent collection (Dose 4)

Grab Merc (Dose 11)

Observations:

Technician Joel

Sampling Sheet

Column ID: C04 Date: 4/19/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	9:40			
2	9:42	1		
3	9:45	1.75		
4	9:54	2.0		
5	9:56	2.75	✓	✓
6	10:14	1		
7	10:15	2		
8	10:18	2.75		
9	10:21	3.5		
10	10:23	4.25		
11	10:25	5	✓	✓
12	11:04			
13	11:05	2		
14	11:06	2.75		
15	11:07	3.75		
16	11:08	4.75		
17	11:10	5.5		
18	11:16	5.9		

Start → ~~Begin~~ Effluent Collection

Grab Here

Observations:

4/19/18 fOC Columns

Sample ID	Turb	Time	pH	Temp
~~CO4~~ OOC	13.6	10:02	6.99	18.7
CO4	6.46	10:03	7.09	19.3
CO6	7.75	10:06	6.96	18.9
Influent	2.02	10:10	7.63	19.1
COC1	9.75	1029	6.89	19.4
CO6	13.8	1034	7.08	19.2
Influent	1.93	1036	7.77	19.3
Co6	21.8	11:18	6.55	19.1°C
Co4	21.7	11:22	6.93	19.2°C
Influent	2.08	11:24	7.68	18.8°C

Technician Joel S.

Sampling Sheet

Column ID: INF Date: 5/9/18

Column Description TW2 influent

Retest

replacement Storm.
2-1 used for majority of influent,
2-2 mixed in for last part

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)
1	10:02a			
2	10:03a			
3	10:04a			
4	10:05a			
5	10:17a			
6	10:18a			
7	10:19a			
8	10:20a			
9	10:29a			
10	10:30a			
11	10:31a			
12	10:32a			
13	10:41a			
14	10:42a			
15	10:43a			
16	10:45a			
17	10:46a			
18	10:5[illegible]a			

Side notes: Doses 1–3 → Turb; Doses 5–8 → Mercury Grab; Doses 9–12 → Grab taken; Doses 13–18 → Grab taken

Observations:

Technician Joel G. **Sampling Sheet** Column ID: C01 Date: 5/9/18

Column Description

Dose	Time	Height of water (in)	Temp (C)	Turbidity (NTU)	
1	10:02a				
2	10:03a				
3	10:04a				
4	10:05a			✓	→ grab taken
5	10:17a				
6	10:18a				
7	10:19a				
8	10:19a	3"			→ mercury grab
9	10:29a				
10	10:29a				
11	10:31a	3.5			
12	10:32a			✓	→ Grab taken
13	10:41a				
14	10:42a				
15	10:43a				
16	10:45a				
17	10:46a				
18	10:50a	6"			

Observations:

Tae 1

4/13/18	Turb / POC Column	
OOC	13.6	9:11
Influent	17.1	9:13
CO1	27.0	9:14
CO3	69.5	9:15
CO4	48.9	9:17
CO5	55.3	9:17
CO6	46.0	9:20
CO2	63.3	9:36

Round 2

CO1	59.8	10:44am
CO2	22.5	10:44am
CO3	52.3	10:46am
CO4	47.8	10:47am
CO5	54.0	10:51am
CO6	82.8	10:54am
Influent	13.2	10:55am

Round 3

CO1	56.9	1:14pm
CO2	74.3	1:20pm
CO3	84.2	1:21pm
CO4	82.4	1:22pm
CO5	81.9	1:23pm
CO6	122	1:24pm
Influent	18.0	

4/17/18 POC Columns

	Sample ID	Turb	Time	pH	temp
	COC	13.6	9:47		
	TW6	5.51	10:23am	6.10	19°C
	C06	11.7	10:24am	6.86	19.2°C
	C03	14.5	10:27am	7.01	19.1°C
	C04	8.02	10:28am	6.83	19.3°C
	C05	6.27	10:30am	7.05	18.9°C
	C01	10.5	10:36am	6.95	19.2°C
	C02 (Dose 5)	2.27	10:57am	7.26	18.9°C
Round 2 (Dose 4)	TW6	7.95	11:46am	6.04	20.1°C
	C01	13.0	11:56am	6.88	19.4°C
	C02	4.05	12:00pm	7.23	19.3°C
	C03	27.6	11:58am	6.98	19.1°C
	C04	14.9	12:01pm	7.16	19.2°C
	C05	22.8	12:11pm	7.02	19.1°C
	C06	26.1	12:15pm	7.03	19.4°C
Round 3	TW6	6.60	1:27pm	6.40	20.2°C
	C01	20.0	1:42pm	7.13	19.2°C
	C02	21.5	1:38pm	7.30	19.3°C
	C03	57.7	1:32	7.06	19.6°C
	C04	36.4	1:35	7.19	19.5°C
	C05	22.2	1:28	6.90	19.5°C
	C06	61.4	1:25pm	6.90	19.4°C

4/19/18 Pore Columns

Sample ID	Turb	Time	pH	Temp
~~C0?~~ OCC	15.6	10:02	6.99	18.7
C04	6.46	10:03	7.09	19.3
C06	7.75	10:06	6.96	18.9
Influent	2.02	10:10	7.63	19.1
C04	9.75	1029	6.89	19.4
C06	13.8	1034	7.08	19.2
Influent	1.93	1036	7.77	19.3
C06	21.8	11:18	6.55	19.1°C
C04	21.7	11:22	6.93	19.2°C
Influent	2.08	11:24	7.68	18.8°C

5/9/18

	Turb	time	pH	temp
[illegible] (1) OCV	14.5	10:09	[illegible]	22.8 °C
Col	14.0	~~[illegible]~~ 10:15	7.54	
Influent	16.8	10:10	6.59	22.0 °C
(2)				
Col	22.0	10:35a	6.84	22.7 °C
Influent	16.0	10:34a	6.08	22 °C
Col	24.3	10:54am	6.59	22.3 °C
Influent	18.4	10:54am	6.28	22 °C

APPENDIX G: WATER QUALITY Data

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO2-EF-04102018-01	PCB 008	pg/L	76.2	18.3	48	NBC,VIL,VJ
CO2-EF-04102018-01	PCB 018/30	pg/L	69.5	28.6	48	NBC
CO2-EF-04102018-01	PCB 020/28	pg/L	90	42.2	48	JA,NBC
CO2-EF-04102018-01	PCB 021/33	pg/L	69.1	44.7	48	NBC
CO2-EF-04102018-01	PCB 031	pg/L	87.8	40.1	48	NBC
CO2-EF-04102018-01	PCB 044/47/65	pg/L	206	38.5	97	NBC,VIU
CO2-EF-04102018-01	PCB 049/69	pg/L	167	35.9	97	NBC,VIU
CO2-EF-04102018-01	PCB 052	pg/L	370	36.1	48	NBC,VIL,VIU
CO2-EF-04102018-01	PCB 056	pg/L		35.5	48	NBC
CO2-EF-04102018-01	PCB 060	pg/L		34.6	48	NBC
CO2-EF-04102018-01	PCB 066	pg/L	67.3	30.5	48	NBC,VIU
CO2-EF-04102018-01	PCB 070/61/74/76	pg/L	131	32.9	193	J,NBC,VIL,VIU,VJ
CO2-EF-04102018-01	PCB 083/99	pg/L	519	23.3	97	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 086/87/97/109/119/125	pg/L	209	20.3	193	NBC,VIL,VIU
CO2-EF-04102018-01	PCB 090/101/113	pg/L	424	20.3	193	NBC,VIL,VIU
CO2-EF-04102018-01	PCB 093/95/100	pg/L	362	23.2	193	NBC,VIL,VIU
CO2-EF-04102018-01	PCB 105	pg/L	63.6	27.7	28	NBC,VIU
CO2-EF-04102018-01	PCB 110/115	pg/L	162	18.4	97	NBC
CO2-EF-04102018-01	PCB 118	pg/L	191	25.8	26	NBC,VIL
CO2-EF-04102018-01	PCB 128/166	pg/L	113	14.4	97	JA,NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 129/138/163	pg/L	1440	19.6	193	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 132	pg/L	116	17.8	48	NBC,VIL,VIU
CO2-EF-04102018-01	PCB 135/151/154	pg/L	1050	10.6	97	VRIU,NBC,VIL,VJ
CO2-EF-04102018-01	PCB 141	pg/L	116	15.1	48	VRIU,NBC,VIL,VJ
CO2-EF-04102018-01	PCB 147/149	pg/L	670	15.1	97	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 153/168	pg/L	5360	12.9	97	VIP,NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 156/157	pg/L	62	18	39	NBC,VIU
CO2-EF-04102018-01	PCB 158	pg/L	78.2	11.2	48	VRIU,NBC,VIL,VJ
CO2-EF-04102018-01	PCB 170	pg/L	525	29.1	48	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 174	pg/L	163	23.8	48	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 177	pg/L	262	25.6	48	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 180/193	pg/L	1960	22.8	97	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 183/185	pg/L	626	24.3	97	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 187	pg/L	2270	14.1	48	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 194	pg/L	734	28.4	48	NBC,VIL,VJ
CO2-EF-04102018-01	PCB 195	pg/L	172	25.9	48	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	PCB 201	pg/L	79.1	14.9	48	VRIU,NBC,VIL,VJ
CO2-EF-04102018-01	PCB 203	pg/L	317	22.3	48	NBC,VIL,VJ,VIU
CO2-EF-04102018-01	Total DiCB	pg/L	76.2	18.3	19	NBC,VIL,VJ
CO2-EF-04102018-01	Total HeptaCB	pg/L	5170	14.1	19	NBC,VIL,VJ
CO2-EF-04102018-01	Total HexaCB	pg/L	9000	10.6	19	VIP,NBC,VIL,VJ
CO2-EF-04102018-01	Total MonoCB	pg/L		19.3	19	NBC
CO2-EF-04102018-01	Total NonaCB	pg/L		19.3	19	NBC
CO2-EF-04102018-01	Total OctaCB	pg/L	1300	14.9	19	NBC,VIL,VJ
CO2-EF-04102018-01	Total PCBs	pg/L	19400	10.6	193	VIP,NBC,VIL,VJ
CO2-EF-04102018-01	Total PentaCB	pg/L	1930	18.4	193	NBC,VIL

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO2-EF-04102018-01	Total TetraCB	pg/L	941	30.5	193	NBC,VIL
CO2-EF-04102018-01	Total TriCB	pg/L	316	28.6	48	NBC,VIL
CO3-EF-04102018-01	PCB 008	pg/L	76.3	2.87	49	NBC,VIL,VJ
CO3-EF-04102018-01	PCB 018/30	pg/L	62.3	6.37	49	NBC
CO3-EF-04102018-01	PCB 020/28	pg/L	114	7.02	49	NBC
CO3-EF-04102018-01	PCB 021/33	pg/L	56.1	7	49	NBC
CO3-EF-04102018-01	PCB 031	pg/L	91.5	6.49	49	NBC
CO3-EF-04102018-01	PCB 044/47/65	pg/L	78.7	6.23	98	J,NBC,VIU
CO3-EF-04102018-01	PCB 049/69	pg/L	41.8	5.86	98	J,NBC,VIU
CO3-EF-04102018-01	PCB 052	pg/L	107	6.17	49	NBC,VIL,VIU
CO3-EF-04102018-01	PCB 056	pg/L	23.8	7.96	49	J,JA,NBC
CO3-EF-04102018-01	PCB 060	pg/L	16.8	7.8	49	J,NBC
CO3-EF-04102018-01	PCB 066	pg/L	47.5	4.83	49	J,NBC,VIU
CO3-EF-04102018-01	PCB 070/61/74/76	pg/L	108	5.19	197	J,NBC,VIL,VIU,VJ
CO3-EF-04102018-01	PCB 083/99	pg/L	50.1	4.37	98	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 086/87/97/109/119/125	pg/L	63.1	3.83	197	J,NBC,VIL,VIU
CO3-EF-04102018-01	PCB 090/101/113	pg/L	91.5	3.78	197	J,NBC,VIL,VIU
CO3-EF-04102018-01	PCB 093/95/100	pg/L	66.3	3	197	J,NBC,VIL,VIU
CO3-EF-04102018-01	PCB 105	pg/L	37.2	3.04	20	NBC,VIU
CO3-EF-04102018-01	PCB 110/115	pg/L	102	3.49	98	NBC
CO3-EF-04102018-01	PCB 118	pg/L	68.4	2.83	20	NBC,VIL
CO3-EF-04102018-01	PCB 128/166	pg/L	14.6	2.84	98	J,JA,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 129/138/163	pg/L	133	3.7	197	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 132	pg/L	29.6	3.38	49	J,NBC,VIL,VIU
CO3-EF-04102018-01	PCB 135/151/154	pg/L	28.9	2.59	98	VRIU,J,NBC,VIL,VJ
CO3-EF-04102018-01	PCB 141	pg/L	18.5	2.85	49	VRIU,J,NBC,VIL,VJ
CO3-EF-04102018-01	PCB 147/149	pg/L	60.1	2.8	98	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 153/168	pg/L	92.8	2.44	98	VIP,J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 156/157	pg/L	11.1	8.04	39	J,JA,NBC,VIU
CO3-EF-04102018-01	PCB 158	pg/L	10.3	2.14	49	VRIU,J,NBC,VIL,VJ
CO3-EF-04102018-01	PCB 170	pg/L	28.8	5.59	49	J,JA,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 174	pg/L	25.8	4.2	49	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 177	pg/L	16.3	4.54	49	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 180/193	pg/L	81	4.19	98	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 183/185	pg/L	21.7	4.11	98	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 187	pg/L	45.1	3.29	49	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 194	pg/L	36	4.35	49	J,NBC,VIL,VJ
CO3-EF-04102018-01	PCB 195	pg/L	11.9	3.71	49	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	PCB 201	pg/L	3.28	1.86	49	VRIU,J,JA,NBC,VIL,VJ
CO3-EF-04102018-01	PCB 203	pg/L	28.2	3.07	49	J,NBC,VIL,VJ,VIU
CO3-EF-04102018-01	Total DiCB	pg/L	76.3	2.87	20	NBC,VIL,VJ
CO3-EF-04102018-01	Total HeptaCB	pg/L	197	3.29	20	NBC,VIL,VJ
CO3-EF-04102018-01	Total HexaCB	pg/L	399	2.14	20	VIP,NBC,VIL,VJ
CO3-EF-04102018-01	Total MonoCB	pg/L		19.7	20	NBC
CO3-EF-04102018-01	Total NonaCB	pg/L		19.7	20	NBC
CO3-EF-04102018-01	Total OctaCB	pg/L	79.4	1.86	20	NBC,VIL,VJ

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO3-EF-04102018-01	Total PCBs	pg/L	2000	1.86	197	VIP,NBC,VIL,VJ
CO3-EF-04102018-01	Total PentaCB	pg/L	479	2.83	197	NBC,VIL
CO3-EF-04102018-01	Total TetraCB	pg/L	424	4.83	197	NBC,VIL
CO3-EF-04102018-01	Total TriCB	pg/L	324	6.37	49	NBC,VIL
CO4-EF-04102018-01	PCB 008	pg/L	104	4.41	48	NBC,VIL,VJ
CO4-EF-04102018-01	PCB 018/30	pg/L	105	8.46	48	NBC
CO4-EF-04102018-01	PCB 020/28	pg/L	162	10.8	48	NBC
CO4-EF-04102018-01	PCB 021/33	pg/L	98.2	10.8	48	NBC
CO4-EF-04102018-01	PCB 031	pg/L	130	9.97	48	NBC
CO4-EF-04102018-01	PCB 044/47/65	pg/L	127	6.12	96	NBC,VIU
CO4-EF-04102018-01	PCB 049/69	pg/L	75.6	5.75	96	J,NBC,VIU
CO4-EF-04102018-01	PCB 052	pg/L	161	6.05	48	NBC,VIL,VIU
CO4-EF-04102018-01	PCB 056	pg/L	44.7	8.87	48	J,JA,NBC
CO4-EF-04102018-01	PCB 060	pg/L	29.9	8.69	48	J,NBC
CO4-EF-04102018-01	PCB 066	pg/L	80.2	4.74	48	NBC,VIU
CO4-EF-04102018-01	PCB 070/61/74/76	pg/L	185	5.09	192	J,NBC,VIL,VIU,VJ
CO4-EF-04102018-01	PCB 083/99	pg/L	84.1	5.33	96	J,NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 086/87/97/109/119/125	pg/L	130	4.67	192	J,NBC,VIL,VIU
CO4-EF-04102018-01	PCB 090/101/113	pg/L	146	4.61	192	J,NBC,VIL,VIU
CO4-EF-04102018-01	PCB 093/95/100	pg/L	112	5.15	192	J,NBC,VIL,VIU
CO4-EF-04102018-01	PCB 105	pg/L	64.5	8.66	19	NBC,VIU
CO4-EF-04102018-01	PCB 110/115	pg/L	186	4.26	96	NBC
CO4-EF-04102018-01	PCB 118	pg/L	114	8.16	19	NBC,VIL
CO4-EF-04102018-01	PCB 128/166	pg/L	34.1	4.91	96	J,NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 129/138/163	pg/L	226	6.41	192	NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 132	pg/L	54.8	5.85	48	NBC,VIL,VIU
CO4-EF-04102018-01	PCB 135/151/154	pg/L	50.3	3.6	96	VRIU,J,NBC,VIL,VJ
CO4-EF-04102018-01	PCB 141	pg/L	31.8	4.94	48	VRIU,J,NBC,VIL,VJ
CO4-EF-04102018-01	PCB 147/149	pg/L	104	4.85	96	NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 153/168	pg/L	138	4.22	96	VIP,NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 156/157	pg/L	28.1	9.81	38	J,NBC,VIU
CO4-EF-04102018-01	PCB 158	pg/L	20.2	3.7	48	VRIU,J,NBC,VIL,VJ
CO4-EF-04102018-01	PCB 170	pg/L	45	8.2	48	J,NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 174	pg/L	45.6	6.17	48	J,NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 177	pg/L	24.3	6.65	48	J,NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 180/193	pg/L	118	6.15	96	NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 183/185	pg/L	38.6	6.03	96	J,NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 187	pg/L	65.4	3.19	48	NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 194	pg/L	49.5	6.04	48	NBC,VIL,VJ
CO4-EF-04102018-01	PCB 195	pg/L	16.3	5.15	48	J,JA,NBC,VIL,VJ,VIU
CO4-EF-04102018-01	PCB 201	pg/L	9.17	2.59	48	VRIU,J,NBC,VIL,VJ
CO4-EF-04102018-01	PCB 203	pg/L	34.6	4.26	48	J,NBC,VIL,VJ,VIU
CO4-EF-04102018-01	Total DiCB	pg/L	104	4.41	19	NBC,VIL,VJ
CO4-EF-04102018-01	Total HeptaCB	pg/L	298	3.19	19	NBC,VIL,VJ
CO4-EF-04102018-01	Total HexaCB	pg/L	687	3.6	19	VIP,NBC,VIL,VJ
CO4-EF-04102018-01	Total MonoCB	pg/L		19.2	19	NBC

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO4-EF-04102018-01	Total NonaCB	pg/L		19.2	19	NBC
CO4-EF-04102018-01	Total OctaCB	pg/L	110	2.59	19	NBC,VIL,VJ
CO4-EF-04102018-01	Total PCBs	pg/L	3270	2.59	192	VIP,NBC,VIL,VJ
CO4-EF-04102018-01	Total PentaCB	pg/L	837	4.26	192	NBC,VIL
CO4-EF-04102018-01	Total TetraCB	pg/L	704	4.74	192	NBC,VIL
CO4-EF-04102018-01	Total TriCB	pg/L	496	8.46	48	NBC,VIL
CO5-EF-04102018-01	PCB 008	pg/L	135	48	48	NBC,VIL,VJ
CO5-EF-04102018-01	PCB 018/30	pg/L	117	97.6	98	JA,NBC
CO5-EF-04102018-01	PCB 020/28	pg/L	206	116	116	NBC
CO5-EF-04102018-01	PCB 021/33	pg/L		116	116	NBC
CO5-EF-04102018-01	PCB 031	pg/L	149	107	107	JA,NBC
CO5-EF-04102018-01	PCB 044/47/65	pg/L	137	80.3	96	NBC,VIU
CO5-EF-04102018-01	PCB 049/69	pg/L	129	75.4	96	NBC,VIU
CO5-EF-04102018-01	PCB 052	pg/L	306	79.4	79	NBC,VIL,VIU
CO5-EF-04102018-01	PCB 056	pg/L		89.9	90	NBC
CO5-EF-04102018-01	PCB 060	pg/L		88	88	NBC
CO5-EF-04102018-01	PCB 066	pg/L		62.2	62	NBC,VIU
CO5-EF-04102018-01	PCB 070/61/74/76	pg/L	139	66.8	191	J,NBC,VIL,VIU,VJ
CO5-EF-04102018-01	PCB 083/99	pg/L		70.6	96	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 086/87/97/109/119/125	pg/L		61.8	191	NBC,VIL,VIU
CO5-EF-04102018-01	PCB 090/101/113	pg/L		61	191	NBC,VIL,VIU
CO5-EF-04102018-01	PCB 093/95/100	pg/L		87.1	191	NBC,VIL,VIU
CO5-EF-04102018-01	PCB 105	pg/L		57.5	58	NBC,VIU
CO5-EF-04102018-01	PCB 110/115	pg/L	121	56.4	96	NBC
CO5-EF-04102018-01	PCB 118	pg/L	78.3	53.8	54	NBC,VIL
CO5-EF-04102018-01	PCB 128/166	pg/L		44	96	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 129/138/163	pg/L	182	57.4	191	J,NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 132	pg/L		52.4	52	NBC,VIL,VIU
CO5-EF-04102018-01	PCB 135/151/154	pg/L		48.9	96	VRIU,NBC,VIL,VJ
CO5-EF-04102018-01	PCB 141	pg/L		44.2	48	VRIU,NBC,VIL,VJ
CO5-EF-04102018-01	PCB 147/149	pg/L	76.7	43.4	96	J,NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 153/168	pg/L	219	37.7	96	VIP,NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 156/157	pg/L		78.7	79	NBC,VIU
CO5-EF-04102018-01	PCB 158	pg/L		33.1	48	VRIU,NBC,VIL,VJ
CO5-EF-04102018-01	PCB 170	pg/L		129	129	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 174	pg/L		96.7	97	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 177	pg/L		105	105	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 180/193	pg/L	103	96.4	96	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 183/185	pg/L		94.5	96	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 187	pg/L	61.8	46	48	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 194	pg/L		106	106	NBC,VIL,VJ
CO5-EF-04102018-01	PCB 195	pg/L		89.9	90	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	PCB 201	pg/L		45.1	48	VRIU,NBC,VIL,VJ
CO5-EF-04102018-01	PCB 203	pg/L		74.4	74	NBC,VIL,VJ,VIU
CO5-EF-04102018-01	Total DiCB	pg/L	135	48	48	NBC,VIL,VJ
CO5-EF-04102018-01	Total HeptaCB	pg/L	165	46	46	NBC,VIL,VJ

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO5-EF-04102018-01	Total HexaCB	pg/L	478	33.1	33	VIP,NBC,VIL,VJ
CO5-EF-04102018-01	Total MonoCB	pg/L		19.1	19	NBC
CO5-EF-04102018-01	Total NonaCB	pg/L		19.1	19	NBC
CO5-EF-04102018-01	Total OctaCB	pg/L		45.1	45	NBC,VIL,VJ
CO5-EF-04102018-01	Total PCBs	pg/L	2160	33.1	191	VIP,NBC,VIL,VJ
CO5-EF-04102018-01	Total PentaCB	pg/L	199	53.8	191	NBC,VIL
CO5-EF-04102018-01	Total TetraCB	pg/L	711	62.2	191	NBC,VIL
CO5-EF-04102018-01	Total TriCB	pg/L	473	97.6	98	NBC,VIL
CO6-EF-04102018-01	PCB 008	pg/L	99.7	1.26	48	NBC,VIL,VJ
CO6-EF-04102018-01	PCB 018/30	pg/L	125	5.01	48	NBC
CO6-EF-04102018-01	PCB 020/28	pg/L	164	7.93	48	NBC
CO6-EF-04102018-01	PCB 021/33	pg/L	86.3	7.9	48	NBC
CO6-EF-04102018-01	PCB 031	pg/L	130	7.33	48	NBC
CO6-EF-04102018-01	PCB 044/47/65	pg/L	133	3.68	96	NBC,VIU
CO6-EF-04102018-01	PCB 049/69	pg/L	70.8	3.46	96	J,NBC,VIU
CO6-EF-04102018-01	PCB 052	pg/L	169	3.64	48	NBC,VIL,VIU
CO6-EF-04102018-01	PCB 056	pg/L	40.8	7.08	48	J,NBC
CO6-EF-04102018-01	PCB 060	pg/L	24.5	6.93	48	J,NBC
CO6-EF-04102018-01	PCB 066	pg/L	74.2	2.85	48	NBC,VIU
CO6-EF-04102018-01	PCB 070/61/74/76	pg/L	167	3.07	192	J,NBC,VIL,VIU,VJ
CO6-EF-04102018-01	PCB 083/99	pg/L	67.3	2.9	96	J,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 086/87/97/109/119/125	pg/L	102	2.54	192	J,NBC,VIL,VIU
CO6-EF-04102018-01	PCB 090/101/113	pg/L	135	2.51	192	J,NBC,VIL,VIU
CO6-EF-04102018-01	PCB 093/95/100	pg/L	113	2.35	192	J,NBC,VIL,VIU
CO6-EF-04102018-01	PCB 105	pg/L	49.3	4.61	19	NBC,VIU
CO6-EF-04102018-01	PCB 110/115	pg/L	159	2.32	96	NBC
CO6-EF-04102018-01	PCB 118	pg/L	106	4.17	19	NBC,VIL
CO6-EF-04102018-01	PCB 128/166	pg/L	23.3	2.94	96	J,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 129/138/163	pg/L	187	3.84	192	J,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 132	pg/L	45.1	3.5	48	J,NBC,VIL,VIU
CO6-EF-04102018-01	PCB 135/151/154	pg/L	42	2.57	96	VRIU,J,NBC,VIL,VJ
CO6-EF-04102018-01	PCB 141	pg/L	24.2	2.96	48	VRIU,J,NBC,VIL,VJ
CO6-EF-04102018-01	PCB 147/149	pg/L	96.5	2.91	96	NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 153/168	pg/L	115	2.52	96	VIP,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 156/157	pg/L	16.9	5.34	39	J,NBC,VIU
CO6-EF-04102018-01	PCB 158	pg/L	15.3	2.22	48	VRIU,J,NBC,VIL,VJ
CO6-EF-04102018-01	PCB 170	pg/L	35.9	5.28	48	J,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 174	pg/L	33.8	3.97	48	J,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 177	pg/L	21.2	4.29	48	J,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 180/193	pg/L	84.8	3.96	96	J,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 183/185	pg/L	27.2	3.88	96	J,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 187	pg/L	51.6	2.29	48	NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 194	pg/L	35.8	4.57	48	J,NBC,VIL,VJ
CO6-EF-04102018-01	PCB 195	pg/L	14.6	3.9	48	J,NBC,VIL,VJ,VIU
CO6-EF-04102018-01	PCB 201	pg/L	5.85	1.96	48	VRIU,J,NBC,VIL,VJ
CO6-EF-04102018-01	PCB 203	pg/L	27.3	3.23	48	J,JA,NBC,VIL,VJ,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO6-EF-04102018-01	Total DiCB	pg/L	99.7	1.26	19	NBC,VIL,VJ
CO6-EF-04102018-01	Total HeptaCB	pg/L	227	2.29	19	NBC,VIL,VJ
CO6-EF-04102018-01	Total HexaCB	pg/L	565	2.22	19	VIP,NBC,VIL,VJ
CO6-EF-04102018-01	Total MonoCB	pg/L		19.2	19	NBC
CO6-EF-04102018-01	Total NonaCB	pg/L		19.2	19	NBC
CO6-EF-04102018-01	Total OctaCB	pg/L	83.6	1.96	19	NBC,VIL,VJ
CO6-EF-04102018-01	Total PCBs	pg/L	2920	1.26	192	VIP,NBC,VIL,VJ
CO6-EF-04102018-01	Total PentaCB	pg/L	732	2.32	192	NBC,VIL
CO6-EF-04102018-01	Total TetraCB	pg/L	680	2.85	192	NBC,VIL
CO6-EF-04102018-01	Total TriCB	pg/L	506	5.01	48	NBC,VIL
TW2-IN-04102018-01	PCB 008	pg/L	130	10.7	49	NBC,VIL,VJ
TW2-IN-04102018-01	PCB 018/30	pg/L	218	37.4	49	NBC
TW2-IN-04102018-01	PCB 020/28	pg/L	489	44.4	49	NBC
TW2-IN-04102018-01	PCB 021/33	pg/L	337	47	49	NBC
TW2-IN-04102018-01	PCB 031	pg/L	397	42.2	49	NBC
TW2-IN-04102018-01	PCB 044/47/65	pg/L	545	52.3	98	NBC,VIU
TW2-IN-04102018-01	PCB 049/69	pg/L	275	48.7	98	NBC,VIU
TW2-IN-04102018-01	PCB 052	pg/L	508	49	49	NBC,VIL,VIU
TW2-IN-04102018-01	PCB 056	pg/L	223	32.4	49	NBC
TW2-IN-04102018-01	PCB 060	pg/L	128	31.6	49	NBC
TW2-IN-04102018-01	PCB 066	pg/L	322	41.4	49	NBC,VIU
TW2-IN-04102018-01	PCB 070/61/74/76	pg/L	717	44.7	195	NBC,VIL,VIU,VJ
TW2-IN-04102018-01	PCB 083/99	pg/L	367	27.3	98	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 086/87/97/109/119/125	pg/L	443	23.8	195	NBC,VIL,VIU
TW2-IN-04102018-01	PCB 090/101/113	pg/L	527	23.8	195	JA,NBC,VIL,VIU
TW2-IN-04102018-01	PCB 093/95/100	pg/L	470	31.8	195	NBC,VIL,VIU
TW2-IN-04102018-01	PCB 105	pg/L	325	21.3	21	NBC,VIU
TW2-IN-04102018-01	PCB 110/115	pg/L	822	21.5	98	NBC
TW2-IN-04102018-01	PCB 118	pg/L	554	19.5	20	NBC,VIL
TW2-IN-04102018-01	PCB 128/166	pg/L	186	23.9	98	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 129/138/163	pg/L	1690	32.5	195	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 132	pg/L	368	29.6	49	NBC,VIL,VIU
TW2-IN-04102018-01	PCB 135/151/154	pg/L	584	16.6	98	VRIU,NBC,VIL,VJ
TW2-IN-04102018-01	PCB 141	pg/L	213	25	49	VRIU,NBC,VIL,VJ
TW2-IN-04102018-01	PCB 147/149	pg/L	963	25.1	98	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 153/168	pg/L	1710	21.3	98	VIP,NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 156/157	pg/L	145	44.6	45	NBC,VIU
TW2-IN-04102018-01	PCB 158	pg/L	110	18.6	49	VRIU,NBC,VIL,VJ
TW2-IN-04102018-01	PCB 170	pg/L	540	36.4	49	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 174	pg/L	608	29.8	49	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 177	pg/L	361	32	49	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 180/193	pg/L	1550	28.6	98	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 183/185	pg/L	529	30.4	98	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 187	pg/L	1100	17.1	49	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	PCB 194	pg/L	560	35.7	49	NBC,VIL,VJ
TW2-IN-04102018-01	PCB 195	pg/L	192	32.6	49	JA,NBC,VIL,VJ,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
TW2-IN-04102018-01	PCB 201	pg/L	69.4	18.8	49	VRIU,NBC,VIL,VJ
TW2-IN-04102018-01	PCB 203	pg/L	365	28	49	NBC,VIL,VJ,VIU
TW2-IN-04102018-01	Total DiCB	pg/L	130	10.7	20	NBC,VIL,VJ
TW2-IN-04102018-01	Total HeptaCB	pg/L	4160	17.1	20	NBC,VIL,VJ
TW2-IN-04102018-01	Total HexaCB	pg/L	5970	16.6	20	VIP,NBC,VIL,VJ
TW2-IN-04102018-01	Total MonoCB	pg/L		19.5	20	NBC
TW2-IN-04102018-01	Total NonaCB	pg/L		19.5	20	NBC
TW2-IN-04102018-01	Total OctaCB	pg/L	1190	18.8	20	NBC,VIL,VJ
TW2-IN-04102018-01	Total PCBs	pg/L	19600	10.7	195	VIP,NBC,VIL,VJ
TW2-IN-04102018-01	Total PentaCB	pg/L	3510	19.5	195	NBC,VIL
TW2-IN-04102018-01	Total TetraCB	pg/L	2720	31.6	195	NBC,VIL
TW2-IN-04102018-01	Total TriCB	pg/L	1440	37.4	49	NBC,VIL
CO1-EF-04132018-01	PCB 008	pg/L	74.8	2.31	48	NBC,VIL,VJ
CO1-EF-04132018-01	PCB 018/30	pg/L	60.3	5.02	48	NBC
CO1-EF-04132018-01	PCB 020/28	pg/L	84.8	12	48	NBC
CO1-EF-04132018-01	PCB 021/33	pg/L	50.6	12	48	NBC
CO1-EF-04132018-01	PCB 031	pg/L	65.8	11.1	48	NBC
CO1-EF-04132018-01	PCB 044/47/65	pg/L	105	5.15	96	NBC,VIU
CO1-EF-04132018-01	PCB 049/69	pg/L	74.9	4.84	96	J,NBC,VIU
CO1-EF-04132018-01	PCB 052	pg/L	160	5.09	48	NBC,VIL,VIU
CO1-EF-04132018-01	PCB 056	pg/L	38.2	27.4	48	J,NBC
CO1-EF-04132018-01	PCB 060	pg/L		26.8	48	NBC
CO1-EF-04132018-01	PCB 066	pg/L	52.8	3.99	48	NBC,VIU
CO1-EF-04132018-01	PCB 070/61/74/76	pg/L	111	4.28	192	J,NBC,VIL,VIU,VJ
CO1-EF-04132018-01	PCB 083/99	pg/L	531	4.87	96	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 086/87/97/109/119/125	pg/L	184	4.26	192	J,NBC,VIL,VIU
CO1-EF-04132018-01	PCB 090/101/113	pg/L	405	4.21	192	NBC,VIL,VIU
CO1-EF-04132018-01	PCB 093/95/100	pg/L	211	3.39	192	NBC,VIL,VIU
CO1-EF-04132018-01	PCB 105	pg/L	82.7	12	19	NBC,VIU
CO1-EF-04132018-01	PCB 110/115	pg/L	147	3.89	96	NBC
CO1-EF-04132018-01	PCB 118	pg/L	277	10.9	19	NBC,VIL
CO1-EF-04132018-01	PCB 128/166	pg/L	224	5.47	96	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 129/138/163	pg/L	2450	7.14	192	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 132	pg/L	142	6.51	48	NBC,VIL,VIU
CO1-EF-04132018-01	PCB 135/151/154	pg/L	1360	3.39	96	VRIU,NBC,VIL,VJ
CO1-EF-04132018-01	PCB 141	pg/L	176	5.5	48	VRIU,NBC,VIL,VJ
CO1-EF-04132018-01	PCB 147/149	pg/L	980	5.4	96	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 153/168	pg/L	9440	4.69	96	VIP,NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 156/157	pg/L	115	14.9	38	NBC,VIU
CO1-EF-04132018-01	PCB 158	pg/L	125	4.12	48	VRIU,NBC,VIL,VJ
CO1-EF-04132018-01	PCB 170	pg/L	1160	8.02	48	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 174	pg/L	308	6.03	48	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 177	pg/L	520	6.5	48	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 180/193	pg/L	4090	6.01	96	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 183/185	pg/L	1250	5.89	96	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 187	pg/L	4380	3.23	48	NBC,VIL,VJ,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO1-EF-04132018-01	PCB 194	pg/L	1480	6.25	48	NBC,VIL,VJ
CO1-EF-04132018-01	PCB 195	pg/L	348	5.33	48	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	PCB 201	pg/L	152	2.68	48	VRIU,NBC,VIL,VJ
CO1-EF-04132018-01	PCB 203	pg/L	622	4.41	48	NBC,VIL,VJ,VIU
CO1-EF-04132018-01	Total DiCB	pg/L	74.8	2.31	19	NBC,VIL,VJ
CO1-EF-04132018-01	Total HeptaCB	pg/L	10500	3.23	19	NBC,VIL,VJ
CO1-EF-04132018-01	Total HexaCB	pg/L	15000	3.39	19	VIP,NBC,VIL,VJ
CO1-EF-04132018-01	Total MonoCB	pg/L		19.2	19	NBC
CO1-EF-04132018-01	Total NonaCB	pg/L		19.2	19	NBC
CO1-EF-04132018-01	Total OctaCB	pg/L	2610	2.68	19	NBC,VIL,VJ
CO1-EF-04132018-01	Total PCBs	pg/L	32000	2.31	192	VIP,NBC,VIL,VJ
CO1-EF-04132018-01	Total PentaCB	pg/L	1840	3.39	192	NBC,VIL
CO1-EF-04132018-01	Total TetraCB	pg/L	542	3.99	192	NBC,VIL
CO1-EF-04132018-01	Total TriCB	pg/L	261	5.02	48	NBC,VIL
CO2-EF-04132018-01	PCB 008	pg/L	19.4	1.28	48	J,NBC,VIL,VJ
CO2-EF-04132018-01	PCB 018/30	pg/L	21.6	3.12	48	J,NBC
CO2-EF-04132018-01	PCB 020/28	pg/L	33.3	3.86	48	J,NBC
CO2-EF-04132018-01	PCB 021/33	pg/L	21.6	3.94	48	J,NBC
CO2-EF-04132018-01	PCB 031	pg/L	28.7	3.6	48	J,NBC
CO2-EF-04132018-01	PCB 044/47/65	pg/L	46.5	2.79	96	J,NBC,VIU
CO2-EF-04132018-01	PCB 049/69	pg/L	24.9	2.65	96	J,NBC,VIU
CO2-EF-04132018-01	PCB 052	pg/L	73.3	2.72	48	NBC,VIL,VIU
CO2-EF-04132018-01	PCB 056	pg/L	8.37	4.63	48	J,NBC
CO2-EF-04132018-01	PCB 060	pg/L	5.01	4.55	48	J,NBC
CO2-EF-04132018-01	PCB 066	pg/L	15	2.26	48	J,NBC,VIU
CO2-EF-04132018-01	PCB 070/61/74/76	pg/L	37.5	2.42	191	J,NBC,VIL,VIU,VJ
CO2-EF-04132018-01	PCB 083/99	pg/L	19.8	2.74	96	J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 086/87/97/109/119/125	pg/L	28.1	2.39	191	J,NBC,VIL,VIU
CO2-EF-04132018-01	PCB 090/101/113	pg/L	39.5	2.36	191	J,NBC,VIL,VIU
CO2-EF-04132018-01	PCB 093/95/100	pg/L	39.8	1.83	191	J,NBC,VIL,VIU
CO2-EF-04132018-01	PCB 105	pg/L	11.3	3.41	19	J,JA,NBC,VIU
CO2-EF-04132018-01	PCB 110/115	pg/L	39.6	2.17	96	J,NBC
CO2-EF-04132018-01	PCB 118	pg/L	23.1	3.13	19	NBC,VIL
CO2-EF-04132018-01	PCB 128/166	pg/L	8.08	2.45	96	J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 129/138/163	pg/L	69.7	3.24	191	J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 132	pg/L	14.9	2.83	48	J,NBC,VIL,VIU
CO2-EF-04132018-01	PCB 135/151/154	pg/L	19.9	1.26	96	VRIU,J,NBC,VIL,VJ
CO2-EF-04132018-01	PCB 141	pg/L	8.4	2.45	48	VRIU,J,NBC,VIL,VJ
CO2-EF-04132018-01	PCB 147/149	pg/L	31.7	2.33	96	J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 153/168	pg/L	60.6	2.07	96	VIP,J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 156/157	pg/L	9.15	5.15	38	J,JA,NBC,VIU
CO2-EF-04132018-01	PCB 158	pg/L	5.91	1.83	48	VRIU,J,NBC,VIL,VJ
CO2-EF-04132018-01	PCB 170	pg/L	18.2	4.4	48	J,JA,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 174	pg/L	12.8	3.11	48	J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 177	pg/L	9.24	3.44	48	J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 180/193	pg/L	42.4	3.33	96	J,NBC,VIL,VJ,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO2-EF-04132018-01	PCB 183/185	pg/L	16.2	3.24	96	J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 187	pg/L	26.9	1.6	48	J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 194	pg/L	17.5	2.9	48	J,NBC,VIL,VJ
CO2-EF-04132018-01	PCB 195	pg/L	6.09	2.5	48	J,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	PCB 201	pg/L	2.47	1.28	48	VRIU,J,JA,NBC,VIL,VJ
CO2-EF-04132018-01	PCB 203	pg/L	9.22	2.1	48	J,JA,NBC,VIL,VJ,VIU
CO2-EF-04132018-01	Total DiCB	pg/L	19.4	1.28	19	NBC,VIL,VJ
CO2-EF-04132018-01	Total HeptaCB	pg/L	109	1.6	19	NBC,VIL,VJ
CO2-EF-04132018-01	Total HexaCB	pg/L	228	1.26	19	VIP,NBC,VIL,VJ
CO2-EF-04132018-01	Total MonoCB	pg/L		19.1	19	NBC
CO2-EF-04132018-01	Total NonaCB	pg/L		19.1	19	NBC
CO2-EF-04132018-01	Total OctaCB	pg/L	35.3	1.28	19	NBC,VIL,VJ
CO2-EF-04132018-01	Total PCBs	pg/L	926	1.26	191	VIP,NBC,VIL,VJ
CO2-EF-04132018-01	Total PentaCB	pg/L	201	1.83	191	NBC,VIL
CO2-EF-04132018-01	Total TetraCB	pg/L	211	2.26	191	NBC,VIL
CO2-EF-04132018-01	Total TriCB	pg/L	105	3.12	48	NBC,VIL
CO3-EF-04132018-01	PCB 008	pg/L	40.9	0.85	48	J,NBC,VIL,VJ
CO3-EF-04132018-01	PCB 018/30	pg/L	45.7	3.09	48	J,NBC
CO3-EF-04132018-01	PCB 020/28	pg/L	52.3	5.23	48	NBC
CO3-EF-04132018-01	PCB 021/33	pg/L	30.9	5.34	48	J,NBC
CO3-EF-04132018-01	PCB 031	pg/L	46.2	4.88	48	J,NBC
CO3-EF-04132018-01	PCB 044/47/65	pg/L	68	2.8	96	J,NBC,VIU
CO3-EF-04132018-01	PCB 049/69	pg/L	39.8	2.66	96	J,NBC,VIU
CO3-EF-04132018-01	PCB 052	pg/L	108	2.73	48	NBC,VIL,VIU
CO3-EF-04132018-01	PCB 056	pg/L	12.4	4.81	48	J,NBC
CO3-EF-04132018-01	PCB 060	pg/L	8.03	4.72	48	J,NBC
CO3-EF-04132018-01	PCB 066	pg/L	24.9	2.27	48	J,NBC,VIU
CO3-EF-04132018-01	PCB 070/61/74/76	pg/L	56.7	2.43	191	J,NBC,VIL,VIU,VJ
CO3-EF-04132018-01	PCB 083/99	pg/L	62.8	1.89	96	J,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 086/87/97/109/119/125	pg/L	41.9	1.65	191	J,NBC,VIL,VIU
CO3-EF-04132018-01	PCB 090/101/113	pg/L	70.9	1.63	191	J,NBC,VIL,VIU
CO3-EF-04132018-01	PCB 093/95/100	pg/L	65.8	2.54	191	J,NBC,VIL,VIU
CO3-EF-04132018-01	PCB 105	pg/L	17.5	3.94	19	J,JA,NBC,VIU
CO3-EF-04132018-01	PCB 110/115	pg/L	53.2	1.5	96	J,NBC
CO3-EF-04132018-01	PCB 118	pg/L	46.1	3.55	19	NBC,VIL
CO3-EF-04132018-01	PCB 128/166	pg/L	15.2	3.6	96	J,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 129/138/163	pg/L	169	4.77	191	J,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 132	pg/L	20.8	4.16	48	J,NBC,VIL,VIU
CO3-EF-04132018-01	PCB 135/151/154	pg/L	69.5	1.6	96	VRIU,J,NBC,VIL,VJ
CO3-EF-04132018-01	PCB 141	pg/L	17.7	3.6	48	VRIU,J,NBC,VIL,VJ
CO3-EF-04132018-01	PCB 147/149	pg/L	59.4	3.43	96	J,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 153/168	pg/L	427	3.05	96	VIP,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 156/157	pg/L	11	5.5	38	J,JA,NBC,VIU
CO3-EF-04132018-01	PCB 158	pg/L	9.79	2.69	48	VRIU,J,NBC,VIL,VJ
CO3-EF-04132018-01	PCB 170	pg/L	51.1	3.92	48	JA,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 174	pg/L	24.7	2.77	48	J,NBC,VIL,VJ,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO3-EF-04132018-01	PCB 177	pg/L	24.4	3.07	48	J,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 180/193	pg/L	166	2.96	96	NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 183/185	pg/L	53.5	2.88	96	J,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 187	pg/L	166	2.02	48	NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 194	pg/L	48.3	5	48	NBC,VIL,VJ
CO3-EF-04132018-01	PCB 195	pg/L	15.8	4.31	48	J,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	PCB 201	pg/L	6.08	2.21	48	VRIU,J,NBC,VIL,VJ
CO3-EF-04132018-01	PCB 203	pg/L	22.3	3.63	48	J,JA,NBC,VIL,VJ,VIU
CO3-EF-04132018-01	Total DiCB	pg/L	40.9	0.85	19	NBC,VIL,VJ
CO3-EF-04132018-01	Total HeptaCB	pg/L	432	2.02	19	NBC,VIL,VJ
CO3-EF-04132018-01	Total HexaCB	pg/L	799	1.6	19	VIP,NBC,VIL,VJ
CO3-EF-04132018-01	Total MonoCB	pg/L		19.1	19	NBC
CO3-EF-04132018-01	Total NonaCB	pg/L		19.1	19	NBC
CO3-EF-04132018-01	Total OctaCB	pg/L	92.4	2.21	19	NBC,VIL,VJ
CO3-EF-04132018-01	Total PCBs	pg/L	2270	0.85	191	VIP,NBC,VIL,VJ
CO3-EF-04132018-01	Total PentaCB	pg/L	358	1.5	191	NBC,VIL
CO3-EF-04132018-01	Total TetraCB	pg/L	318	2.27	191	NBC,VIL
CO3-EF-04132018-01	Total TriCB	pg/L	175	3.09	48	NBC,VIL
CO4-EF-04132018-01	PCB 008	pg/L	47.3	1.41	50	J,NBC,VIL,VJ
CO4-EF-04132018-01	PCB 018/30	pg/L	65.4	3.95	50	NBC
CO4-EF-04132018-01	PCB 020/28	pg/L	75	4.57	50	NBC
CO4-EF-04132018-01	PCB 021/33	pg/L	42.4	4.67	50	J,NBC
CO4-EF-04132018-01	PCB 031	pg/L	59.7	4.27	50	NBC
CO4-EF-04132018-01	PCB 044/47/65	pg/L	82.9	2.72	101	J,NBC,VIU
CO4-EF-04132018-01	PCB 049/69	pg/L	40.7	2.57	101	J,NBC,VIU
CO4-EF-04132018-01	PCB 052	pg/L	108	2.64	50	NBC,VIL,VIU
CO4-EF-04132018-01	PCB 056	pg/L	18.8	7.34	50	J,NBC
CO4-EF-04132018-01	PCB 060	pg/L	11.4	7.21	50	J,NBC
CO4-EF-04132018-01	PCB 066	pg/L	38	2.2	50	J,NBC,VIU
CO4-EF-04132018-01	PCB 070/61/74/76	pg/L	79.6	2.36	201	J,NBC,VIL,VIU,VJ
CO4-EF-04132018-01	PCB 083/99	pg/L	36.2	4.47	101	J,NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 086/87/97/109/119/125	pg/L	58.2	3.91	201	J,NBC,VIL,VIU
CO4-EF-04132018-01	PCB 090/101/113	pg/L	78.9	3.86	201	J,JA,NBC,VIL,VIU
CO4-EF-04132018-01	PCB 093/95/100	pg/L	76.2	2.89	201	J,NBC,VIL,VIU
CO4-EF-04132018-01	PCB 105	pg/L	25.4	8.33	20	JA,NBC,VIU
CO4-EF-04132018-01	PCB 110/115	pg/L	88.3	3.55	101	J,NBC
CO4-EF-04132018-01	PCB 118	pg/L	52.6	7.21	20	NBC,VIL
CO4-EF-04132018-01	PCB 128/166	pg/L	15.3	3.12	101	J,JA,NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 129/138/163	pg/L	202	4.13	201	NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 132	pg/L	43.2	3.6	50	J,NBC,VIL,VIU
CO4-EF-04132018-01	PCB 135/151/154	pg/L	57	2.64	101	VRIU,J,NBC,VIL,VJ
CO4-EF-04132018-01	PCB 141	pg/L	36	3.12	50	VRIU,J,NBC,VIL,VJ
CO4-EF-04132018-01	PCB 147/149	pg/L	126	2.97	101	NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 153/168	pg/L	151	2.64	101	VIP,NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 156/157	pg/L	17.2	6.85	40	J,NBC,VIU
CO4-EF-04132018-01	PCB 158	pg/L	15.7	2.33	50	VRIU,J,NBC,VIL,VJ

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO4-EF-04132018-01	PCB 170	pg/L	66.3	5.84	50	NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 174	pg/L	65.4	4.13	50	NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 177	pg/L	39	4.57	50	J,NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 180/193	pg/L	166	4.41	101	NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 183/185	pg/L	51.6	4.29	101	J,NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 187	pg/L	80.7	2.88	50	NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 194	pg/L	41.1	8.32	50	J,JA,NBC,VIL,VJ
CO4-EF-04132018-01	PCB 195	pg/L	19.2	7.16	50	J,JA,NBC,VIL,VJ,VIU
CO4-EF-04132018-01	PCB 201	pg/L	5.22	3.67	50	VRIU,J,JA,NBC,VIL,VJ
CO4-EF-04132018-01	PCB 203	pg/L	32.6	6.03	50	J,NBC,VIL,VJ,VIU
CO4-EF-04132018-01	Total DiCB	pg/L	47.3	1.41	20	NBC,VIL,VJ
CO4-EF-04132018-01	Total HeptaCB	pg/L	417	2.88	20	NBC,VIL,VJ
CO4-EF-04132018-01	Total HexaCB	pg/L	663	2.33	20	VIP,NBC,VIL,VJ
CO4-EF-04132018-01	Total MonoCB	pg/L		20.1	20	NBC
CO4-EF-04132018-01	Total NonaCB	pg/L		20.1	20	NBC
CO4-EF-04132018-01	Total OctaCB	pg/L	98.1	3.67	20	NBC,VIL,VJ
CO4-EF-04132018-01	Total PCBs	pg/L	2310	1.41	201	VIP,NBC,VIL,VJ
CO4-EF-04132018-01	Total PentaCB	pg/L	416	2.89	201	NBC,VIL
CO4-EF-04132018-01	Total TetraCB	pg/L	379	2.2	201	NBC,VIL
CO4-EF-04132018-01	Total TriCB	pg/L	243	3.95	50	NBC,VIL
CO5-EF-04132018-01	PCB 008	pg/L	32.3	0.6	49	J,NBC,VIL,VJ
CO5-EF-04132018-01	PCB 018/30	pg/L	53.6	2.72	49	NBC
CO5-EF-04132018-01	PCB 020/28	pg/L	75.2	2.82	49	NBC
CO5-EF-04132018-01	PCB 021/33	pg/L	38	2.88	49	J,NBC
CO5-EF-04132018-01	PCB 031	pg/L	60.8	2.63	49	NBC
CO5-EF-04132018-01	PCB 044/47/65	pg/L	71.9	1.68	98	J,NBC,VIU
CO5-EF-04132018-01	PCB 049/69	pg/L	39.3	1.59	98	J,NBC,VIU
CO5-EF-04132018-01	PCB 052	pg/L	98	1.63	49	NBC,VIL,VIU
CO5-EF-04132018-01	PCB 056	pg/L	15.5	4.5	49	J,JA,NBC
CO5-EF-04132018-01	PCB 060	pg/L	12.6	4.42	49	J,NBC
CO5-EF-04132018-01	PCB 066	pg/L	37	1.36	49	J,NBC,VIU
CO5-EF-04132018-01	PCB 070/61/74/76	pg/L	82.3	1.45	196	J,NBC,VIL,VIU,VJ
CO5-EF-04132018-01	PCB 083/99	pg/L	58.8	2.74	98	J,NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 086/87/97/109/119/125	pg/L	55.3	2.39	196	J,NBC,VIL,VIU
CO5-EF-04132018-01	PCB 090/101/113	pg/L	82.6	2.36	196	J,NBC,VIL,VIU
CO5-EF-04132018-01	PCB 093/95/100	pg/L	69.7	1.64	196	J,NBC,VIL,VIU
CO5-EF-04132018-01	PCB 105	pg/L	27.8	3.43	20	NBC,VIU
CO5-EF-04132018-01	PCB 110/115	pg/L	80.2	2.17	98	J,NBC
CO5-EF-04132018-01	PCB 118	pg/L	61	3.07	20	NBC,VIL
CO5-EF-04132018-01	PCB 128/166	pg/L	22.6	1.78	98	J,NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 129/138/163	pg/L	215	2.36	196	NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 132	pg/L	28.4	2.06	49	J,NBC,VIL,VIU
CO5-EF-04132018-01	PCB 135/151/154	pg/L	84.6	1.64	98	VRIU,J,NBC,VIL,VJ
CO5-EF-04132018-01	PCB 141	pg/L	21.7	1.78	49	VRIU,J,NBC,VIL,VJ
CO5-EF-04132018-01	PCB 147/149	pg/L	93.2	1.7	98	J,NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 153/168	pg/L	507	1.51	98	VIP,NBC,VIL,VJ,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO5-EF-04132018-01	PCB 156/157	pg/L	13.5	5.87	39	J,NBC,VIU
CO5-EF-04132018-01	PCB 158	pg/L	12.6	1.33	49	VRIU,J,NBC,VIL,VJ
CO5-EF-04132018-01	PCB 170	pg/L	80.7	4.59	49	NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 174	pg/L	31.4	3.25	49	J,NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 177	pg/L	33.7	3.59	49	J,NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 180/193	pg/L	252	3.47	98	NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 183/185	pg/L	73.2	3.38	98	J,NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 187	pg/L	221	1.71	49	NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 194	pg/L	98.8	6.97	49	NBC,VIL,VJ
CO5-EF-04132018-01	PCB 195	pg/L	24.7	6	49	J,JA,NBC,VIL,VJ,VIU
CO5-EF-04132018-01	PCB 201	pg/L	8.22	3.08	49	VRIU,J,NBC,VIL,VJ
CO5-EF-04132018-01	PCB 203	pg/L	45	5.06	49	J,NBC,VIL,VJ,VIU
CO5-EF-04132018-01	Total DiCB	pg/L	32.3	0.6	20	NBC,VIL,VJ
CO5-EF-04132018-01	Total HeptaCB	pg/L	618	1.71	20	NBC,VIL,VJ
CO5-EF-04132018-01	Total HexaCB	pg/L	999	1.33	20	VIP,NBC,VIL,VJ
CO5-EF-04132018-01	Total MonoCB	pg/L		19.6	20	NBC
CO5-EF-04132018-01	Total NonaCB	pg/L		19.6	20	NBC
CO5-EF-04132018-01	Total OctaCB	pg/L	177	3.08	20	NBC,VIL,VJ
CO5-EF-04132018-01	Total PCBs	pg/L	2920	0.6	196	VIP,NBC,VIL,VJ
CO5-EF-04132018-01	Total PentaCB	pg/L	435	1.64	196	NBC,VIL
CO5-EF-04132018-01	Total TetraCB	pg/L	357	1.36	196	NBC,VIL
CO5-EF-04132018-01	Total TriCB	pg/L	228	2.63	49	NBC,VIL
CO6-EF-04132018-01	PCB 008	pg/L	52.5	1.12	48	NBC,VIL,VJ
CO6-EF-04132018-01	PCB 018/30	pg/L	82.9	3.3	48	NBC
CO6-EF-04132018-01	PCB 020/28	pg/L	105	5.3	48	NBC
CO6-EF-04132018-01	PCB 021/33	pg/L	54.1	5.41	48	NBC
CO6-EF-04132018-01	PCB 031	pg/L	80.7	4.94	48	NBC
CO6-EF-04132018-01	PCB 044/47/65	pg/L	145	3.11	97	NBC,VIU
CO6-EF-04132018-01	PCB 049/69	pg/L	96.4	2.95	97	J,NBC,VIU
CO6-EF-04132018-01	PCB 052	pg/L	264	3.03	48	NBC,VIL,VIU
CO6-EF-04132018-01	PCB 056	pg/L	22.8	4.1	48	J,NBC
CO6-EF-04132018-01	PCB 060	pg/L	14	4.03	48	J,NBC
CO6-EF-04132018-01	PCB 066	pg/L	43.1	2.52	48	J,NBC,VIU
CO6-EF-04132018-01	PCB 070/61/74/76	pg/L	94	2.7	193	J,NBC,VIL,VIU,VJ
CO6-EF-04132018-01	PCB 083/99	pg/L	146	2.94	97	NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 086/87/97/109/119/125	pg/L	74.2	2.57	193	J,NBC,VIL,VIU
CO6-EF-04132018-01	PCB 090/101/113	pg/L	157	2.54	193	J,NBC,VIL,VIU
CO6-EF-04132018-01	PCB 093/95/100	pg/L	175	2.24	193	J,NBC,VIL,VIU
CO6-EF-04132018-01	PCB 105	pg/L	30.1	5.13	19	NBC,VIU
CO6-EF-04132018-01	PCB 110/115	pg/L	87.3	2.33	97	J,NBC
CO6-EF-04132018-01	PCB 118	pg/L	72.4	4.41	19	NBC,VIL
CO6-EF-04132018-01	PCB 128/166	pg/L	26.6	3.31	97	J,NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 129/138/163	pg/L	284	4.39	193	NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 132	pg/L	33.2	3.82	48	J,NBC,VIL,VIU
CO6-EF-04132018-01	PCB 135/151/154	pg/L	221	1.5	97	VRIU,NBC,VIL,VJ
CO6-EF-04132018-01	PCB 141	pg/L	28.2	3.32	48	VRIU,J,NBC,VIL,VJ

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO6-EF-04132018-01	PCB 147/149	pg/L	157	3.15	97	NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 153/168	pg/L	926	2.81	97	VIP,NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 156/157	pg/L	17.7	5.92	39	J,NBC,VIU
CO6-EF-04132018-01	PCB 158	pg/L	16.6	2.48	48	VRIU,J,NBC,VIL,VJ
CO6-EF-04132018-01	PCB 170	pg/L	93	4.17	48	NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 174	pg/L	36.3	2.95	48	J,NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 177	pg/L	45.7	3.26	48	J,NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 180/193	pg/L	328	3.15	97	NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 183/185	pg/L	104	3.06	97	NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 187	pg/L	357	1.75	48	NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 194	pg/L	113	5.23	48	NBC,VIL,VJ
CO6-EF-04132018-01	PCB 195	pg/L	28.4	4.5	48	J,NBC,VIL,VJ,VIU
CO6-EF-04132018-01	PCB 201	pg/L	13.9	2.31	48	VRIU,J,NBC,VIL,VJ
CO6-EF-04132018-01	PCB 203	pg/L	51.9	3.79	48	NBC,VIL,VJ,VIU
CO6-EF-04132018-01	Total DiCB	pg/L	52.5	1.12	19	NBC,VIL,VJ
CO6-EF-04132018-01	Total HeptaCB	pg/L	859	1.75	19	NBC,VIL,VJ
CO6-EF-04132018-01	Total HexaCB	pg/L	1710	1.5	19	VIP,NBC,VIL,VJ
CO6-EF-04132018-01	Total MonoCB	pg/L		19.3	19	NBC
CO6-EF-04132018-01	Total NonaCB	pg/L		19.3	19	NBC
CO6-EF-04132018-01	Total OctaCB	pg/L	207	2.31	19	NBC,VIL,VJ
CO6-EF-04132018-01	Total PCBs	pg/L	4680	1.12	193	VIP,NBC,VIL,VJ
CO6-EF-04132018-01	Total PentaCB	pg/L	742	2.24	193	NBC,VIL
CO6-EF-04132018-01	Total TetraCB	pg/L	680	2.52	193	NBC,VIL
CO6-EF-04132018-01	Total TriCB	pg/L	323	3.3	48	NBC,VIL
TW2-IN-04132018-01	PCB 008	pg/L	81.6	1.5	48	NBC,VIL,VJ
TW2-IN-04132018-01	PCB 018/30	pg/L	111	3.77	48	NBC
TW2-IN-04132018-01	PCB 020/28	pg/L	311	7.05	48	NBC
TW2-IN-04132018-01	PCB 021/33	pg/L	214	7.23	48	NBC
TW2-IN-04132018-01	PCB 031	pg/L	252	6.63	48	NBC
TW2-IN-04132018-01	PCB 044/47/65	pg/L	340	9.11	96	NBC,VIU
TW2-IN-04132018-01	PCB 049/69	pg/L	173	8.61	96	NBC,VIU
TW2-IN-04132018-01	PCB 052	pg/L	330	8.88	48	NBC,VIL,VIU
TW2-IN-04132018-01	PCB 056	pg/L	167	3.54	48	NBC
TW2-IN-04132018-01	PCB 060	pg/L	92.1	3.37	48	NBC
TW2-IN-04132018-01	PCB 066	pg/L	302	7.66	48	NBC,VIU
TW2-IN-04132018-01	PCB 070/61/74/76	pg/L	664	8.02	192	NBC,VIL,VIU,VJ
TW2-IN-04132018-01	PCB 083/99	pg/L	351	4.32	96	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 086/87/97/109/119/125	pg/L	529	3.77	192	NBC,VIL,VIU
TW2-IN-04132018-01	PCB 090/101/113	pg/L	641	3.75	192	NBC,VIL,VIU
TW2-IN-04132018-01	PCB 093/95/100	pg/L	401	4.01	192	NBC,VIL,VIU
TW2-IN-04132018-01	PCB 105	pg/L	356	3.83	19	NBC,VIU
TW2-IN-04132018-01	PCB 110/115	pg/L	906	3.42	96	NBC
TW2-IN-04132018-01	PCB 118	pg/L	728	3.52	19	NBC,VIL
TW2-IN-04132018-01	PCB 128/166	pg/L	219	2.04	96	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 129/138/163	pg/L	2070	2.81	192	VIP,NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 132	pg/L	388	2.49	48	NBC,VIL,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
TW2-IN-04132018-01	PCB 135/151/154	pg/L	445	1.95	96	VRIU,NBC,VIL,VJ
TW2-IN-04132018-01	PCB 141	pg/L	256	2.15	48	VRIU,NBC,VIL,VJ
TW2-IN-04132018-01	PCB 147/149	pg/L	860	2.12	96	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 153/168	pg/L	2170	1.82	96	VIP,NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 156/157	pg/L	175	6.64	38	NBC,VIU
TW2-IN-04132018-01	PCB 158	pg/L	142	1.57	48	VRIU,NBC,VIL,VJ
TW2-IN-04132018-01	PCB 170	pg/L	548	3.84	48	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 174	pg/L	380	3.19	48	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 177	pg/L	271	3.44	48	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 180/193	pg/L	1490	3.02	96	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 183/185	pg/L	434	3.3	96	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 187	pg/L	1030	1.76	48	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 194	pg/L	367	3.01	48	VIP,NBC,VIL,VJ
TW2-IN-04132018-01	PCB 195	pg/L	107	3.16	48	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	PCB 201	pg/L	46.2	2.03	48	VRIU,J,NBC,VIL,VJ
TW2-IN-04132018-01	PCB 203	pg/L	227	2.87	48	NBC,VIL,VJ,VIU
TW2-IN-04132018-01	Total DiCB	pg/L	81.6	1.5	19	NBC,VIL,VJ
TW2-IN-04132018-01	Total HeptaCB	pg/L	3720	1.76	19	NBC,VIL,VJ
TW2-IN-04132018-01	Total HexaCB	pg/L	6720	1.57	19	VIP,NBC,VIL,VJ
TW2-IN-04132018-01	Total MonoCB	pg/L		19.2	19	NBC
TW2-IN-04132018-01	Total NonaCB	pg/L		19.2	19	NBC
TW2-IN-04132018-01	Total OctaCB	pg/L	747	2.03	19	VIP,NBC,VIL,VJ
TW2-IN-04132018-01	Total PCBs	pg/L	18600	1.5	192	VIP,NBC,VIL,VJ
TW2-IN-04132018-01	Total PentaCB	pg/L	3910	3.42	192	NBC,VIL
TW2-IN-04132018-01	Total TetraCB	pg/L	2070	3.37	192	NBC,VIL
TW2-IN-04132018-01	Total TriCB	pg/L	889	3.77	48	NBC,VIL
BLNK-EF-04172018-01	PCB 008	pg/L	13.7	1.82	48	J,NBC,VIL,VJ
BLNK-EF-04172018-01	PCB 018/30	pg/L	10.7	5.11	48	J,JA,NBC
BLNK-EF-04172018-01	PCB 020/28	pg/L	17.4	6.17	48	J,NBC
BLNK-EF-04172018-01	PCB 021/33	pg/L	12.8	6.3	48	J,NBC
BLNK-EF-04172018-01	PCB 031	pg/L	14.9	5.76	48	J,NBC
BLNK-EF-04172018-01	PCB 044/47/65	pg/L	37.3	4.52	95	J,NBC,VIU
BLNK-EF-04172018-01	PCB 049/69	pg/L	14.7	4.28	95	J,NBC,VIU
BLNK-EF-04172018-01	PCB 052	pg/L	52.6	4.39	48	NBC,VIL,VIU
BLNK-EF-04172018-01	PCB 056	pg/L		4.76	48	NBC
BLNK-EF-04172018-01	PCB 060	pg/L		4.68	48	NBC
BLNK-EF-04172018-01	PCB 066	pg/L	5.97	3.65	48	J,JA,NBC,VIU
BLNK-EF-04172018-01	PCB 070/61/74/76	pg/L	14.9	3.92	190	J,NBC,VIL,VIU,VJ
BLNK-EF-04172018-01	PCB 083/99	pg/L	10.9	6.88	95	J,JA,NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 086/87/97/109/119/125	pg/L		6.01	190	NBC,VIL,VIU
BLNK-EF-04172018-01	PCB 090/101/113	pg/L	22.7	5.93	190	J,NBC,VIL,VIU
BLNK-EF-04172018-01	PCB 093/95/100	pg/L	26.9	5.98	190	J,NBC,VIL,VIU
BLNK-EF-04172018-01	PCB 105	pg/L		5.78	19	NBC,VIU
BLNK-EF-04172018-01	PCB 110/115	pg/L	13.8	5.45	95	J,JA,NBC
BLNK-EF-04172018-01	PCB 118	pg/L		5.31	19	NBC,VIL
BLNK-EF-04172018-01	PCB 128/166	pg/L		5.28	95	NBC,VIL,VJ,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
BLNK-EF-04172018-01	PCB 129/138/163	pg/L	17.1	6.99	190	J,NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 132	pg/L		6.08	48	NBC,VIL,VIU
BLNK-EF-04172018-01	PCB 135/151/154	pg/L	10.1	3.04	95	VRIU,J,JA,NBC,VIL,VJ
BLNK-EF-04172018-01	PCB 141	pg/L		5.28	48	VRIU,NBC,VIL,VJ
BLNK-EF-04172018-01	PCB 147/149	pg/L	13.6	5.02	95	J,NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 153/168	pg/L	20.6	4.47	95	IP,J,JA,NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 156/157	pg/L		6.97	38	NBC,VIU
BLNK-EF-04172018-01	PCB 158	pg/L		3.94	48	VRIU,NBC,VIL,VJ
BLNK-EF-04172018-01	PCB 170	pg/L		8.48	48	NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 174	pg/L		5.99	48	NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 177	pg/L		6.63	48	NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 180/193	pg/L	13.7	6.41	95	J,NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 183/185	pg/L		6.23	95	NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 187	pg/L	8.14	4.81	48	J,NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 194	pg/L		8.64	48	NBC,VIL,VJ
BLNK-EF-04172018-01	PCB 195	pg/L		7.44	48	NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	PCB 201	pg/L		3.81	48	VRIU,NBC,VIL,VJ
BLNK-EF-04172018-01	PCB 203	pg/L		6.26	48	NBC,VIL,VJ,VIU
BLNK-EF-04172018-01	Total DiCB	pg/L	13.7	1.82	19	J,NBC,VIL,VJ
BLNK-EF-04172018-01	Total HeptaCB	pg/L	21.9	4.81	19	NBC,VIL,VJ
BLNK-EF-04172018-01	Total HexaCB	pg/L	61.4	3.04	19	VIP,NBC,VIL,VJ
BLNK-EF-04172018-01	Total MonoCB	pg/L		19	19	NBC
BLNK-EF-04172018-01	Total NonaCB	pg/L		19	19	NBC
BLNK-EF-04172018-01	Total OctaCB	pg/L		3.81	19	NBC,VIL,VJ
BLNK-EF-04172018-01	Total PCBs	pg/L	353	1.82	190	VIP,NBC,VIL,VJ
BLNK-EF-04172018-01	Total PentaCB	pg/L	74.4	5.31	190	J,NBC,VIL
BLNK-EF-04172018-01	Total TetraCB	pg/L	126	3.65	190	J,NBC,VIL
BLNK-EF-04172018-01	Total TriCB	pg/L	55.7	5.11	48	NBC,VIL
CO1-EF-04172018-01	PCB 008	pg/L		61.9	62	NBC,VIL,VJ
CO1-EF-04172018-01	PCB 018/30	pg/L		84.4	84	NBC
CO1-EF-04172018-01	PCB 020/28	pg/L		103	103	NBC
CO1-EF-04172018-01	PCB 021/33	pg/L		106	106	NBC
CO1-EF-04172018-01	PCB 031	pg/L		96.5	97	NBC
CO1-EF-04172018-01	PCB 044/47/65	pg/L		96.1	99	NBC,VIU
CO1-EF-04172018-01	PCB 049/69	pg/L		90.9	99	NBC,VIU
CO1-EF-04172018-01	PCB 052	pg/L		93.7	94	NBC,VIL,VIU
CO1-EF-04172018-01	PCB 056	pg/L		44.9	50	NBC
CO1-EF-04172018-01	PCB 060	pg/L		42.7	50	NBC
CO1-EF-04172018-01	PCB 066	pg/L		80.8	81	NBC,VIU
CO1-EF-04172018-01	PCB 070/61/74/76	pg/L		84.6	199	NBC,VIL,VIU,VJ
CO1-EF-04172018-01	PCB 083/99	pg/L		32.4	99	NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 086/87/97/109/119/125	pg/L		28.3	199	NBC,VIL,VIU
CO1-EF-04172018-01	PCB 090/101/113	pg/L	47.8	28.1	199	J,NBC,VIL,VIU
CO1-EF-04172018-01	PCB 093/95/100	pg/L		40.1	199	NBC,VIL,VIU
CO1-EF-04172018-01	PCB 105	pg/L		23	23	NBC,VIU
CO1-EF-04172018-01	PCB 110/115	pg/L	49.6	25.7	99	J,NBC

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO1-EF-04172018-01	PCB 118	pg/L		24.1	24	NBC,VIL
CO1-EF-04172018-01	PCB 128/166	pg/L		14.8	99	NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 129/138/163	pg/L	95.2	20.3	199	IP,J,NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 132	pg/L		18	50	NBC,VIL,VIU
CO1-EF-04172018-01	PCB 135/151/154	pg/L		15.2	99	VRIU,NBC,VIL,VJ
CO1-EF-04172018-01	PCB 141	pg/L		15.5	50	VRIU,NBC,VIL,VJ
CO1-EF-04172018-01	PCB 147/149	pg/L		15.3	99	NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 153/168	pg/L	92	13.2	99	IP,J,NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 156/157	pg/L		26.3	40	NBC,VIU
CO1-EF-04172018-01	PCB 158	pg/L		11.4	50	VRIU,NBC,VIL,VJ
CO1-EF-04172018-01	PCB 170	pg/L		38.5	50	NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 174	pg/L		31.9	50	NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 177	pg/L		34.5	50	NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 180/193	pg/L	61.2	30.3	99	J,JA,NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 183/185	pg/L		33	99	NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 187	pg/L	36.9	16.1	50	J,NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 194	pg/L		22.2	50	VRIP,NBC,VIL,VJ
CO1-EF-04172018-01	PCB 195	pg/L		23.4	50	NBC,VIL,VJ,VIU
CO1-EF-04172018-01	PCB 201	pg/L		15	50	VRIU,NBC,VIL,VJ
CO1-EF-04172018-01	PCB 203	pg/L		21.2	50	NBC,VIL,VJ,VIU
CO1-EF-04172018-01	Total DiCB	pg/L		61.9	62	NBC,VIL,VJ
CO1-EF-04172018-01	Total HeptaCB	pg/L	98.1	16.1	20	NBC,VIL,VJ
CO1-EF-04172018-01	Total HexaCB	pg/L	187	11.4	20	VIP,NBC,VIL,VJ
CO1-EF-04172018-01	Total MonoCB	pg/L		19.9	20	NBC
CO1-EF-04172018-01	Total NonaCB	pg/L		19.9	20	NBC
CO1-EF-04172018-01	Total OctaCB	pg/L		15	20	VRIP,NBC,VIL,VJ
CO1-EF-04172018-01	Total PCBs	pg/L	383	11.4	199	VIP,NBC,VIL,VJ
CO1-EF-04172018-01	Total PentaCB	pg/L	97.4	23	199	J,NBC,VIL
CO1-EF-04172018-01	Total TetraCB	pg/L		42.7	199	NBC,VIL
CO1-EF-04172018-01	Total TriCB	pg/L		84.4	84	NBC,VIL
CO2-EF-04172018-01	PCB 008	pg/L	35.5	3.22	48	J,NBC,VIL,VJ
CO2-EF-04172018-D	PCB 008	pg/L	10.9	1.78	49	J,NBC,VIL,VJ
CO2-EF-04172018-01	PCB 018/30	pg/L	14.9	5.25	48	J,NBC
CO2-EF-04172018-D	PCB 018/30	pg/L	9.84	5.62	49	J,NBC
CO2-EF-04172018-01	PCB 020/28	pg/L	20	13.2	48	J,JA,NBC
CO2-EF-04172018-D	PCB 020/28	pg/L	15.6	8.61	49	J,NBC
CO2-EF-04172018-01	PCB 021/33	pg/L		13.5	48	NBC
CO2-EF-04172018-D	PCB 021/33	pg/L		8.54	49	NBC
CO2-EF-04172018-01	PCB 031	pg/L	14.4	12.4	48	J,NBC
CO2-EF-04172018-D	PCB 031	pg/L		8.22	49	NBC
CO2-EF-04172018-01	PCB 044/47/65	pg/L	34.6	8.19	96	J,NBC,VIU
CO2-EF-04172018-D	PCB 044/47/65	pg/L	27.7	6.27	98	J,NBC,VIU
CO2-EF-04172018-01	PCB 049/69	pg/L	20.2	7.75	96	J,JA,NBC,VIU
CO2-EF-04172018-D	PCB 049/69	pg/L	9.7	6.09	98	J,NBC,VIU
CO2-EF-04172018-01	PCB 052	pg/L	38.7	7.98	48	J,NBC,VIL,VIU
CO2-EF-04172018-D	PCB 052	pg/L	20	6.72	49	J,NBC,VIL,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO2-EF-04172018-01	PCB 056	pg/L		17.3	48	NBC
CO2-EF-04172018-D	PCB 056	pg/L		4.36	49	NBC
CO2-EF-04172018-01	PCB 060	pg/L		16.5	48	NBC
CO2-EF-04172018-D	PCB 060	pg/L		4.03	49	NBC
CO2-EF-04172018-01	PCB 066	pg/L	15.4	6.89	48	J,NBC,VIU
CO2-EF-04172018-D	PCB 066	pg/L	7.41	4.39	49	J,NBC,VIU
CO2-EF-04172018-01	PCB 070/61/74/76	pg/L	32.3	7.21	192	J,NBC,VIL,VIU,VJ
CO2-EF-04172018-D	PCB 070/61/74/76	pg/L	18.2	4.76	195	J,JA,NBC,VIL,VIU,VJ
CO2-EF-04172018-01	PCB 083/99	pg/L	73.6	4.1	96	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 083/99	pg/L	11.3	3.35	98	J,JA,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 086/87/97/109/119/125	pg/L	38.1	3.58	192	J,NBC,VIL,VIU
CO2-EF-04172018-D	PCB 086/87/97/109/119/125	pg/L	22.2	2.87	195	J,NBC,VIL,VIU
CO2-EF-04172018-01	PCB 090/101/113	pg/L	60.7	3.56	192	J,NBC,VIL,VIU
CO2-EF-04172018-D	PCB 090/101/113	pg/L	22.1	2.95	195	J,NBC,VIL,VIU
CO2-EF-04172018-01	PCB 093/95/100	pg/L	44.5	3.08	192	J,NBC,VIL,VIU
CO2-EF-04172018-D	PCB 093/95/100	pg/L	15.9	3.61	195	J,NBC,VIL,VIU
CO2-EF-04172018-01	PCB 105	pg/L		12.7	19	NBC,VIU
CO2-EF-04172018-D	PCB 105	pg/L	7.29	4.52	20	J,JA,NBC,VIU
CO2-EF-04172018-01	PCB 110/115	pg/L	34	3.25	96	J,NBC
CO2-EF-04172018-D	PCB 110/115	pg/L	25.8	2.55	98	J,NBC
CO2-EF-04172018-01	PCB 118	pg/L	42.7	12	19	NBC,VIL
CO2-EF-04172018-D	PCB 118	pg/L	14.8	4.15	20	J,NBC,VIL
CO2-EF-04172018-01	PCB 128/166	pg/L	33	2.49	96	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 128/166	pg/L	5.12	1.81	98	J,JA,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 129/138/163	pg/L	367	3.43	192	VIP,NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 129/138/163	pg/L	36.1	2.6	195	IP,J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 132	pg/L	22.5	3.04	48	J,NBC,VIL,VIU
CO2-EF-04172018-D	PCB 132	pg/L	10.2	2.43	49	J,NBC,VIL,VIU
CO2-EF-04172018-01	PCB 135/151/154	pg/L	149	2.25	96	VRIU,NBC,VIL,VJ
CO2-EF-04172018-D	PCB 135/151/154	pg/L	11.8	2.28	98	VRIU,J,NBC,VIL,VJ
CO2-EF-04172018-01	PCB 141	pg/L	30.6	2.62	48	VRIU,J,NBC,VIL,VJ
CO2-EF-04172018-D	PCB 141	pg/L	5.88	1.98	49	VRIU,J,NBC,VIL,VJ
CO2-EF-04172018-01	PCB 147/149	pg/L	120	2.59	96	NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 147/149	pg/L	20.5	2.13	98	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 153/168	pg/L	1190	2.22	96	VIP,NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 153/168	pg/L	24	1.71	98	VRIP,IP,J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 156/157	pg/L	19.1	8.29	38	J,NBC,VIU
CO2-EF-04172018-D	PCB 156/157	pg/L	5.08	3.9	39	J,JA,NBC,VIU
CO2-EF-04172018-01	PCB 158	pg/L	19.8	1.92	48	VRIU,J,NBC,VIL,VJ
CO2-EF-04172018-D	PCB 158	pg/L	3.24	1.4	49	VRIU,J,NBC,VIL,VJ
CO2-EF-04172018-01	PCB 170	pg/L	185	3.98	48	NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 170	pg/L	6.79	3.44	49	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 174	pg/L	48.3	3.3	48	NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 174	pg/L	7.59	3.29	49	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 177	pg/L	78	3.57	48	NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 177	pg/L	4.44	3.32	49	J,NBC,VIL,VJ,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO2-EF-04172018-01	PCB 180/193	pg/L	608	3.13	96	NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 180/193	pg/L	17.2	2.84	98	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 183/185	pg/L	174	3.42	96	NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 183/185	pg/L	7.22	3.3	98	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 187	pg/L	585	2.28	48	NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 187	pg/L	9.87	2.25	49	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 194	pg/L	203	2.9	48	VIP,NBC,VIL,VJ
CO2-EF-04172018-D	PCB 194	pg/L	5.75	2.75	49	VRIP,IP,J,JA,NBC,VIL,VJ
CO2-EF-04172018-01	PCB 195	pg/L	51.3	3.04	48	NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 195	pg/L	3.92	2.79	49	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	PCB 201	pg/L	20.8	1.95	48	VRIU,J,NBC,VIL,VJ
CO2-EF-04172018-D	PCB 201	pg/L		1.99	49	VRIU,NBC,VIL,VJ
CO2-EF-04172018-01	PCB 203	pg/L	87.7	2.76	48	NBC,VIL,VJ,VIU
CO2-EF-04172018-D	PCB 203	pg/L	5.23	2.57	49	J,NBC,VIL,VJ,VIU
CO2-EF-04172018-01	Total DiCB	pg/L	35.5	3.22	19	NBC,VIL,VJ
CO2-EF-04172018-D	Total DiCB	pg/L	10.9	1.78	20	J,NBC,VIL,VJ
CO2-EF-04172018-01	Total HeptaCB	pg/L	1500	2.28	19	NBC,VIL,VJ
CO2-EF-04172018-D	Total HeptaCB	pg/L	45.9	2.25	20	NBC,VIL,VJ
CO2-EF-04172018-01	Total HexaCB	pg/L	1950	1.92	19	VIP,NBC,VIL,VJ
CO2-EF-04172018-D	Total HexaCB	pg/L	122	1.4	20	VIP,NBC,VIL,VJ
CO2-EF-04172018-01	Total MonoCB	pg/L		19.2	19	NBC
CO2-EF-04172018-D	Total MonoCB	pg/L		19.5	20	NBC
CO2-EF-04172018-01	Total NonaCB	pg/L		19.2	19	NBC
CO2-EF-04172018-D	Total NonaCB	pg/L		19.5	20	NBC
CO2-EF-04172018-01	Total OctaCB	pg/L	362	1.95	19	VIP,NBC,VIL,VJ
CO2-EF-04172018-D	Total OctaCB	pg/L	14.9	1.99	20	VRIP,J,NBC,VIL,VJ
CO2-EF-04172018-01	Total PCBs	pg/L	4510	1.92	192	VIP,NBC,VIL,VJ
CO2-EF-04172018-D	Total PCBs	pg/L	429	1.4	195	VIP,NBC,VIL,VJ
CO2-EF-04172018-01	Total PentaCB	pg/L	294	3.08	192	NBC,VIL
CO2-EF-04172018-D	Total PentaCB	pg/L	119	2.55	195	J,NBC,VIL
CO2-EF-04172018-01	Total TetraCB	pg/L	141	6.89	192	J,NBC,VIL
CO2-EF-04172018-D	Total TetraCB	pg/L	83	4.03	195	J,NBC,VIL
CO2-EF-04172018-01	Total TriCB	pg/L	49.3	5.25	48	NBC,VIL
CO2-EF-04172018-D	Total TriCB	pg/L	25.4	5.62	49	J,NBC,VIL
CO3-EF-04172018-01	PCB 008	pg/L		25.7	48	NBC,VIL,VJ
CO3-EF-04172018-01	PCB 018/30	pg/L		42.9	48	NBC
CO3-EF-04172018-01	PCB 020/28	pg/L		54.9	55	NBC
CO3-EF-04172018-01	PCB 021/33	pg/L		56.4	56	NBC
CO3-EF-04172018-01	PCB 031	pg/L		51.6	52	NBC
CO3-EF-04172018-01	PCB 044/47/65	pg/L		53.2	97	NBC,VIU
CO3-EF-04172018-01	PCB 049/69	pg/L		50.4	97	NBC,VIU
CO3-EF-04172018-01	PCB 052	pg/L		51.9	52	NBC,VIL,VIU
CO3-EF-04172018-01	PCB 056	pg/L		26.5	48	NBC
CO3-EF-04172018-01	PCB 060	pg/L		25.2	48	NBC
CO3-EF-04172018-01	PCB 066	pg/L		44.8	48	NBC,VIU
CO3-EF-04172018-01	PCB 070/61/74/76	pg/L		46.9	194	NBC,VIL,VIU,VJ

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO3-EF-04172018-01	PCB 083/99	pg/L		15.9	97	NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 086/87/97/109/119/125	pg/L		13.9	194	NBC,VIL,VIU
CO3-EF-04172018-01	PCB 090/101/113	pg/L	37.1	13.8	194	J,JA,NBC,VIL,VIU
CO3-EF-04172018-01	PCB 093/95/100	pg/L		23.4	194	NBC,VIL,VIU
CO3-EF-04172018-01	PCB 105	pg/L		16.9	19	NBC,VIU
CO3-EF-04172018-01	PCB 110/115	pg/L	54.1	12.6	97	J,NBC
CO3-EF-04172018-01	PCB 118	pg/L	38.7	17	19	NBC,VIL
CO3-EF-04172018-01	PCB 128/166	pg/L		8.58	97	NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 129/138/163	pg/L	69.9	11.9	194	IP,J,NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 132	pg/L		10.5	48	NBC,VIL,VIU
CO3-EF-04172018-01	PCB 135/151/154	pg/L	15.1	8.16	97	VRIU,J,JA,NBC,VIL,VJ
CO3-EF-04172018-01	PCB 141	pg/L		9.02	48	VRIU,NBC,VIL,VJ
CO3-EF-04172018-01	PCB 147/149	pg/L	17.9	8.91	97	J,JA,NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 153/168	pg/L	41.4	7.65	97	IP,J,NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 156/157	pg/L		11.9	39	NBC,VIU
CO3-EF-04172018-01	PCB 158	pg/L		6.6	48	VRIU,NBC,VIL,VJ
CO3-EF-04172018-01	PCB 170	pg/L	26	16	48	J,NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 174	pg/L	17.5	13.2	48	J,NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 177	pg/L		14.3	48	NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 180/193	pg/L	48.9	12.6	97	J,NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 183/185	pg/L		13.7	97	NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 187	pg/L	19.4	8.47	48	J,NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 194	pg/L	15.4	7.39	48	VRIP,IP,J,JA,NBC,VIL,VJ
CO3-EF-04172018-01	PCB 195	pg/L		7.77	48	NBC,VIL,VJ,VIU
CO3-EF-04172018-01	PCB 201	pg/L		4.98	48	VRIU,NBC,VIL,VJ
CO3-EF-04172018-01	PCB 203	pg/L	10	7.05	48	J,NBC,VIL,VJ,VIU
CO3-EF-04172018-01	Total DiCB	pg/L		25.7	26	NBC,VIL,VJ
CO3-EF-04172018-01	Total HeptaCB	pg/L	112	8.47	19	NBC,VIL,VJ
CO3-EF-04172018-01	Total HexaCB	pg/L	144	6.6	19	VIP,NBC,VIL,VJ
CO3-EF-04172018-01	Total MonoCB	pg/L		19.4	19	NBC
CO3-EF-04172018-01	Total NonaCB	pg/L		19.4	19	NBC
CO3-EF-04172018-01	Total OctaCB	pg/L	25.4	4.98	19	VRIP,NBC,VIL,VJ
CO3-EF-04172018-01	Total PCBs	pg/L	411	4.98	194	VIP,NBC,VIL,VJ
CO3-EF-04172018-01	Total PentaCB	pg/L	130	12.6	194	J,NBC,VIL
CO3-EF-04172018-01	Total TetraCB	pg/L		25.2	194	NBC,VIL
CO3-EF-04172018-01	Total TriCB	pg/L		42.9	48	NBC,VIL
CO4-EF-04172018-01	PCB 008	pg/L	27.9	2.36	48	J,NBC,VIL,VJ
CO4-EF-04172018-01	PCB 018/30	pg/L	35.8	5.41	48	J,NBC
CO4-EF-04172018-01	PCB 020/28	pg/L	34.3	7.76	48	J,NBC
CO4-EF-04172018-01	PCB 021/33	pg/L	19.5	7.96	48	J,NBC
CO4-EF-04172018-01	PCB 031	pg/L	27.9	7.29	48	J,NBC
CO4-EF-04172018-01	PCB 044/47/65	pg/L	37.8	8.16	97	J,NBC,VIU
CO4-EF-04172018-01	PCB 049/69	pg/L	16.9	7.72	97	J,NBC,VIU
CO4-EF-04172018-01	PCB 052	pg/L	33.8	7.96	48	J,JA,NBC,VIL,VIU
CO4-EF-04172018-01	PCB 056	pg/L	12.1	6.33	48	J,NBC
CO4-EF-04172018-01	PCB 060	pg/L		6.02	48	NBC

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO4-EF-04172018-01	PCB 066	pg/L	19.7	6.86	48	J,NBC,VIU
CO4-EF-04172018-01	PCB 070/61/74/76	pg/L	43.3	7.19	193	J,NBC,VIL,VIU,VJ
CO4-EF-04172018-01	PCB 083/99	pg/L	17.8	2.99	97	J,JA,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 086/87/97/109/119/125	pg/L	31.6	2.61	193	J,NBC,VIL,VIU
CO4-EF-04172018-01	PCB 090/101/113	pg/L	38.5	2.59	193	J,NBC,VIL,VIU
CO4-EF-04172018-01	PCB 093/95/100	pg/L	29.1	4.92	193	J,NBC,VIL,VIU
CO4-EF-04172018-01	PCB 105	pg/L	16	4.73	19	J,NBC,VIU
CO4-EF-04172018-01	PCB 110/115	pg/L	49.7	2.37	97	J,NBC
CO4-EF-04172018-01	PCB 118	pg/L	29.7	4.35	19	NBC,VIL
CO4-EF-04172018-01	PCB 128/166	pg/L	6.79	3.24	97	J,JA,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 129/138/163	pg/L	63.2	4.46	193	IP,J,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 132	pg/L	14	3.95	48	J,NBC,VIL,VIU
CO4-EF-04172018-01	PCB 135/151/154	pg/L	15.2	2.51	97	VRIU,J,NBC,VIL,VJ
CO4-EF-04172018-01	PCB 141	pg/L	8.6	3.4	48	VRIU,J,NBC,VIL,VJ
CO4-EF-04172018-01	PCB 147/149	pg/L	31.1	3.36	97	J,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 153/168	pg/L	51.6	2.89	97	IP,J,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 156/157	pg/L	7.15	6.26	39	J,NBC,VIU
CO4-EF-04172018-01	PCB 158	pg/L	4.99	2.49	48	VRIU,J,NBC,VIL,VJ
CO4-EF-04172018-01	PCB 170	pg/L	11.9	4.86	48	J,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 174	pg/L	10.8	4.03	48	J,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 177	pg/L	6.01	4.35	48	J,JA,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 180/193	pg/L	33.1	3.82	97	J,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 183/185	pg/L	12.6	4.17	97	J,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 187	pg/L	23.7	3.17	48	J,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 194	pg/L	10.6	3.59	48	VRIP,IP,J,NBC,VIL,VJ
CO4-EF-04172018-01	PCB 195	pg/L		3.77	48	NBC,VIL,VJ,VIU
CO4-EF-04172018-01	PCB 201	pg/L		2.42	48	VRIU,NBC,VIL,VJ
CO4-EF-04172018-01	PCB 203	pg/L	6.36	3.42	48	J,JA,NBC,VIL,VJ,VIU
CO4-EF-04172018-01	Total DiCB	pg/L	27.9	2.36	19	NBC,VIL,VJ
CO4-EF-04172018-01	Total HeptaCB	pg/L	85.6	3.17	19	NBC,VIL,VJ
CO4-EF-04172018-01	Total HexaCB	pg/L	203	2.49	19	VIP,NBC,VIL,VJ
CO4-EF-04172018-01	Total MonoCB	pg/L		19.3	19	NBC
CO4-EF-04172018-01	Total NonaCB	pg/L		19.3	19	NBC
CO4-EF-04172018-01	Total OctaCB	pg/L	16.9	2.42	19	VRIP,J,NBC,VIL,VJ
CO4-EF-04172018-01	Total PCBs	pg/L	839	2.36	193	VIP,NBC,VIL,VJ
CO4-EF-04172018-01	Total PentaCB	pg/L	212	2.37	193	NBC,VIL
CO4-EF-04172018-01	Total TetraCB	pg/L	164	6.02	193	J,NBC,VIL
CO4-EF-04172018-01	Total TriCB	pg/L	117	5.41	48	NBC,VIL
CO5-EF-04172018-01	PCB 008	pg/L	19.6	1.35	49	J,NBC,VIL,VJ
CO5-EF-04172018-01	PCB 018/30	pg/L	27.1	2.91	49	J,NBC
CO5-EF-04172018-01	PCB 020/28	pg/L	33.9	3.59	49	J,NBC
CO5-EF-04172018-01	PCB 021/33	pg/L	16	3.69	49	J,JA,NBC
CO5-EF-04172018-01	PCB 031	pg/L	24.3	3.38	49	J,NBC
CO5-EF-04172018-01	PCB 044/47/65	pg/L	30.5	5.41	98	J,NBC,VIU
CO5-EF-04172018-01	PCB 049/69	pg/L	14.2	5.12	98	J,NBC,VIU
CO5-EF-04172018-01	PCB 052	pg/L	29.9	5.28	49	J,NBC,VIL,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO5-EF-04172018-01	PCB 056	pg/L	8.04	5	49	J,NBC
CO5-EF-04172018-01	PCB 060	pg/L		4.76	49	NBC
CO5-EF-04172018-01	PCB 066	pg/L	15.1	4.55	49	J,NBC,VIU
CO5-EF-04172018-01	PCB 070/61/74/76	pg/L	33.1	4.76	197	J,NBC,VIL,VIU,VJ
CO5-EF-04172018-01	PCB 083/99	pg/L	13.6	2.87	98	J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 086/87/97/109/119/125	pg/L	23.9	2.51	197	J,NBC,VIL,VIU
CO5-EF-04172018-01	PCB 090/101/113	pg/L	28.1	2.49	197	J,NBC,VIL,VIU
CO5-EF-04172018-01	PCB 093/95/100	pg/L	19.9	2.66	197	J,NBC,VIL,VIU
CO5-EF-04172018-01	PCB 105	pg/L	11.6	4.63	20	J,NBC,VIU
CO5-EF-04172018-01	PCB 110/115	pg/L	30.8	2.28	98	J,NBC
CO5-EF-04172018-01	PCB 118	pg/L	20.6	4.24	20	JA,NBC,VIL
CO5-EF-04172018-01	PCB 128/166	pg/L	5.1	2.12	98	J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 129/138/163	pg/L	38.2	2.92	197	IP,J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 132	pg/L	8.85	2.58	49	J,JA,NBC,VIL,VIU
CO5-EF-04172018-01	PCB 135/151/154	pg/L	7.19	1.59	98	VRIU,J,NBC,VIL,VJ
CO5-EF-04172018-01	PCB 141	pg/L	4.64	2.23	49	VRIU,J,NBC,VIL,VJ
CO5-EF-04172018-01	PCB 147/149	pg/L	20	2.2	98	J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 153/168	pg/L	24.8	1.89	98	VRIP,IP,J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 156/157	pg/L	4.32	3.83	39	J,NBC,VIU
CO5-EF-04172018-01	PCB 158	pg/L	2.76	1.63	49	VRIU,J,JA,NBC,VIL,VJ
CO5-EF-04172018-01	PCB 170	pg/L	6.83	2.82	49	J,JA,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 174	pg/L	7.9	2.34	49	J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 177	pg/L	4.04	2.52	49	J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 180/193	pg/L	20.6	2.22	98	J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 183/185	pg/L	7.29	2.42	98	J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 187	pg/L	12	1.63	49	J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 194	pg/L	6.34	2.15	49	VRIP,IP,J,NBC,VIL,VJ
CO5-EF-04172018-01	PCB 195	pg/L		2.25	49	NBC,VIL,VJ,VIU
CO5-EF-04172018-01	PCB 201	pg/L		1.45	49	VRIU,NBC,VIL,VJ
CO5-EF-04172018-01	PCB 203	pg/L	5.01	2.05	49	J,NBC,VIL,VJ,VIU
CO5-EF-04172018-01	Total DiCB	pg/L	19.6	1.35	20	J,NBC,VIL,VJ
CO5-EF-04172018-01	Total HeptaCB	pg/L	51.4	1.63	20	NBC,VIL,VJ
CO5-EF-04172018-01	Total HexaCB	pg/L	116	1.59	20	VIP,NBC,VIL,VJ
CO5-EF-04172018-01	Total MonoCB	pg/L		19.7	20	NBC
CO5-EF-04172018-01	Total NonaCB	pg/L		19.7	20	NBC
CO5-EF-04172018-01	Total OctaCB	pg/L	11.3	1.45	20	VRIP,J,NBC,VIL,VJ
CO5-EF-04172018-01	Total PCBs	pg/L	586	1.35	197	VIP,NBC,VIL,VJ
CO5-EF-04172018-01	Total PentaCB	pg/L	149	2.28	197	J,NBC,VIL
CO5-EF-04172018-01	Total TetraCB	pg/L	131	4.55	197	J,NBC,VIL
CO5-EF-04172018-01	Total TriCB	pg/L	101	2.91	49	NBC,VIL
CO6-EF-04172018-01	PCB 008	pg/L	43.7	3.44	48	J,NBC,VIL,VJ
CO6-EF-04172018-01	PCB 018/30	pg/L	49.8	7.74	48	NBC
CO6-EF-04172018-01	PCB 020/28	pg/L	48.2	11.1	48	NBC
CO6-EF-04172018-01	PCB 021/33	pg/L	27.8	11.4	48	J,NBC
CO6-EF-04172018-01	PCB 031	pg/L	37.8	10.5	48	J,NBC
CO6-EF-04172018-01	PCB 044/47/65	pg/L	47.9	13.9	96	J,NBC,VIU

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO6-EF-04172018-01	PCB 049/69	pg/L	20.2	13.2	96	J,JA,NBC,VIU
CO6-EF-04172018-01	PCB 052	pg/L	49.5	13.6	48	NBC,VIL,VIU
CO6-EF-04172018-01	PCB 056	pg/L	14.5	11.4	48	J,NBC
CO6-EF-04172018-01	PCB 060	pg/L		10.9	48	NBC
CO6-EF-04172018-01	PCB 066	pg/L	23.7	11.7	48	J,NBC,VIU
CO6-EF-04172018-01	PCB 070/61/74/76	pg/L	53.5	12.3	192	J,NBC,VIL,VIU,VJ
CO6-EF-04172018-01	PCB 083/99	pg/L	23.4	6.28	96	J,JA,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 086/87/97/109/119/125	pg/L	37.7	5.49	192	J,NBC,VIL,VIU
CO6-EF-04172018-01	PCB 090/101/113	pg/L	47.3	5.45	192	J,NBC,VIL,VIU
CO6-EF-04172018-01	PCB 093/95/100	pg/L	29.5	8.33	192	J,NBC,VIL,VIU
CO6-EF-04172018-01	PCB 105	pg/L	15	7.25	19	J,NBC,VIU
CO6-EF-04172018-01	PCB 110/115	pg/L	53.5	4.98	96	J,NBC
CO6-EF-04172018-01	PCB 118	pg/L	35	6.82	19	NBC,VIL
CO6-EF-04172018-01	PCB 128/166	pg/L	8.2	3.23	96	J,JA,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 129/138/163	pg/L	71.8	4.45	192	IP,J,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 132	pg/L	14	3.94	48	J,JA,NBC,VIL,VIU
CO6-EF-04172018-01	PCB 135/151/154	pg/L	16.5	3.43	96	VRIU,J,NBC,VIL,VJ
CO6-EF-04172018-01	PCB 141	pg/L	10.9	3.4	48	VRIU,J,NBC,VIL,VJ
CO6-EF-04172018-01	PCB 147/149	pg/L	34.4	3.36	96	J,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 153/168	pg/L	44.2	2.88	96	IP,J,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 156/157	pg/L		7.1	39	NBC,VIU
CO6-EF-04172018-01	PCB 158	pg/L	5.53	2.49	48	VRIU,J,NBC,VIL,VJ
CO6-EF-04172018-01	PCB 170	pg/L	10.7	7.54	48	J,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 174	pg/L	11.6	6.25	48	J,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 177	pg/L	6.75	6.75	48	J,JA,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 180/193	pg/L	33.5	5.93	96	J,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 183/185	pg/L	8.35	6.47	96	J,JA,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 187	pg/L	17	3.17	48	J,NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 194	pg/L	8.43	5.44	48	VRIP,IP,J,JA,NBC,VIL,VJ
CO6-EF-04172018-01	PCB 195	pg/L		5.71	48	NBC,VIL,VJ,VIU
CO6-EF-04172018-01	PCB 201	pg/L		3.66	48	VRIU,NBC,VIL,VJ
CO6-EF-04172018-01	PCB 203	pg/L		5.18	48	NBC,VIL,VJ,VIU
CO6-EF-04172018-01	Total DiCB	pg/L	43.7	3.44	19	NBC,VIL,VJ
CO6-EF-04172018-01	Total HeptaCB	pg/L	79.6	3.17	19	NBC,VIL,VJ
CO6-EF-04172018-01	Total HexaCB	pg/L	206	2.49	19	VIP,NBC,VIL,VJ
CO6-EF-04172018-01	Total MonoCB	pg/L		19.2	19	NBC
CO6-EF-04172018-01	Total NonaCB	pg/L		19.2	19	NBC
CO6-EF-04172018-01	Total OctaCB	pg/L	8.43	3.66	19	VRIP,J,NBC,VIL,VJ
CO6-EF-04172018-01	Total PCBs	pg/L	960	2.49	192	VIP,NBC,VIL,VJ
CO6-EF-04172018-01	Total PentaCB	pg/L	241	4.98	192	NBC,VIL
CO6-EF-04172018-01	Total TetraCB	pg/L	209	10.9	192	NBC,VIL
CO6-EF-04172018-01	Total TriCB	pg/L	164	7.74	48	NBC,VIL
TW6-IN-04172018-01	PCB 008	pg/L	35.9	3.61	55	J,NBC,VIL,VJ
TW6-IN-04172018-01	PCB 018/30	pg/L	47	6.31	55	J,NBC
TW6-IN-04172018-01	PCB 020/28	pg/L	176	8.1	55	NBC
TW6-IN-04172018-01	PCB 021/33	pg/L	71	8.31	55	NBC

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
TW6-IN-04172018-01	PCB 031	pg/L	107	7.61	55	NBC
TW6-IN-04172018-01	PCB 044/47/65	pg/L	222	10.5	109	NBC,VIU
TW6-IN-04172018-01	PCB 049/69	pg/L	107	9.88	109	J,NBC,VIU
TW6-IN-04172018-01	PCB 052	pg/L	282	10.2	55	NBC,VIL,VIU
TW6-IN-04172018-01	PCB 056	pg/L	91	6.89	55	NBC
TW6-IN-04172018-01	PCB 060	pg/L	43.4	6.56	55	J,NBC
TW6-IN-04172018-01	PCB 066	pg/L	172	8.78	55	NBC,VIU
TW6-IN-04172018-01	PCB 070/61/74/76	pg/L	377	9.19	218	NBC,VIL,VIU,VJ
TW6-IN-04172018-01	PCB 083/99	pg/L	205	5.09	109	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 086/87/97/109/119/125	pg/L	338	4.44	218	NBC,VIL,VIU
TW6-IN-04172018-01	PCB 090/101/113	pg/L	437	4.42	218	NBC,VIL,VIU
TW6-IN-04172018-01	PCB 093/95/100	pg/L	302	4.61	218	NBC,VIL,VIU
TW6-IN-04172018-01	PCB 105	pg/L	228	2.88	22	NBC,VIU
TW6-IN-04172018-01	PCB 110/115	pg/L	630	4.03	109	NBC
TW6-IN-04172018-01	PCB 118	pg/L	454	2.64	22	NBC,VIL
TW6-IN-04172018-01	PCB 128/166	pg/L	138	2.47	109	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 129/138/163	pg/L	1180	3.41	218	VIP,NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 132	pg/L	256	3.01	55	NBC,VIL,VIU
TW6-IN-04172018-01	PCB 135/151/154	pg/L	193	2.25	109	VRIU,NBC,VIL,VJ
TW6-IN-04172018-01	PCB 141	pg/L	166	2.6	55	VRIU,NBC,VIL,VJ
TW6-IN-04172018-01	PCB 147/149	pg/L	512	2.57	109	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 153/168	pg/L	664	2.21	109	VIP,NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 156/157	pg/L	109	6.21	44	NBC,VIU
TW6-IN-04172018-01	PCB 158	pg/L	87.7	1.9	55	VRIU,NBC,VIL,VJ
TW6-IN-04172018-01	PCB 170	pg/L	285	6.02	55	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 174	pg/L	246	4.99	55	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 177	pg/L	150	5.39	55	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 180/193	pg/L	668	4.73	109	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 183/185	pg/L	188	5.17	109	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 187	pg/L	321	2.6	55	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 194	pg/L	160	3.94	55	IP,NBC,VIL,VJ
TW6-IN-04172018-01	PCB 195	pg/L	55.9	4.15	55	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	PCB 201	pg/L	22.9	2.66	55	VRIU,J,NBC,VIL,VJ
TW6-IN-04172018-01	PCB 203	pg/L	134	3.76	55	NBC,VIL,VJ,VIU
TW6-IN-04172018-01	Total DiCB	pg/L	35.9	3.61	22	NBC,VIL,VJ
TW6-IN-04172018-01	Total HeptaCB	pg/L	1670	2.6	22	NBC,VIL,VJ
TW6-IN-04172018-01	Total HexaCB	pg/L	3310	1.9	22	VIP,NBC,VIL,VJ
TW6-IN-04172018-01	Total MonoCB	pg/L		21.8	22	NBC
TW6-IN-04172018-01	Total NonaCB	pg/L		21.8	22	NBC
TW6-IN-04172018-01	Total OctaCB	pg/L	373	2.66	22	VIP,NBC,VIL,VJ
TW6-IN-04172018-01	Total PCBs	pg/L	9860	1.9	218	VIP,NBC,VIL,VJ
TW6-IN-04172018-01	Total PentaCB	pg/L	2590	2.64	218	NBC,VIL
TW6-IN-04172018-01	Total TetraCB	pg/L	1300	6.56	218	NBC,VIL
TW6-IN-04172018-01	Total TriCB	pg/L	401	6.31	55	NBC,VIL
CO4-EF-04192018-01	PCB 008	pg/L	37.8	1.74	48	J,NBC,VIL,VJ
CO4-EF-04192018-01	PCB 018/30	pg/L	38	4.44	48	J,NBC

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO4-EF-04192018-01	PCB 020/28	pg/L	36.1	8.56	48	J,NBC
CO4-EF-04192018-01	PCB 021/33	pg/L	24.1	8.53	48	J,JA,NBC
CO4-EF-04192018-01	PCB 031	pg/L	33.5	7.91	48	J,NBC
CO4-EF-04192018-01	PCB 044/47/65	pg/L	47.2	4.23	96	J,NBC,VIU
CO4-EF-04192018-01	PCB 049/69	pg/L	24.9	3.97	96	J,NBC,VIU
CO4-EF-04192018-01	PCB 052	pg/L	66.1	4.18	48	NBC,VIL,VIU
CO4-EF-04192018-01	PCB 056	pg/L		12.3	48	NBC
CO4-EF-04192018-01	PCB 060	pg/L		12.1	48	NBC
CO4-EF-04192018-01	PCB 066	pg/L	17.7	3.27	48	J,NBC,VIU
CO4-EF-04192018-01	PCB 070/61/74/76	pg/L	45.9	3.52	192	J,NBC,VIL,VIU,VJ
CO4-EF-04192018-01	PCB 083/99	pg/L	21.5	4.34	96	J,JA,NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 086/87/97/109/119/125	pg/L	30.2	3.8	192	J,JA,NBC,VIL,VIU
CO4-EF-04192018-01	PCB 090/101/113	pg/L	43	3.75	192	J,NBC,VIL,VIU
CO4-EF-04192018-01	PCB 093/95/100	pg/L	36.4	3.18	192	J,NBC,VIL,VIU
CO4-EF-04192018-01	PCB 105	pg/L	10	6.39	19	J,NBC,VIU
CO4-EF-04192018-01	PCB 110/115	pg/L	41.8	3.47	96	J,NBC
CO4-EF-04192018-01	PCB 118	pg/L	22.9	5.91	19	JA,NBC,VIL
CO4-EF-04192018-01	PCB 128/166	pg/L	6.91	4.6	96	J,NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 129/138/163	pg/L	47.5	5.99	192	J,NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 132	pg/L	11	5.47	48	J,NBC,VIL,VIU
CO4-EF-04192018-01	PCB 135/151/154	pg/L	15	2.55	96	VRIU,J,NBC,VIL,VJ
CO4-EF-04192018-01	PCB 141	pg/L	5.69	4.62	48	VRIU,J,JA,NBC,VIL,VJ
CO4-EF-04192018-01	PCB 147/149	pg/L	24.5	4.54	96	J,NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 153/168	pg/L	36	3.94	96	IP,J,NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 156/157	pg/L		6.32	38	NBC,VIU
CO4-EF-04192018-01	PCB 158	pg/L		3.46	48	VRIU,NBC,VIL,VJ
CO4-EF-04192018-01	PCB 170	pg/L		5.97	48	NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 174	pg/L	8.3	4.49	48	J,NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 177	pg/L		4.84	48	NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 180/193	pg/L	20.4	4.47	96	J,NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 183/185	pg/L	9.78	4.39	96	J,NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 187	pg/L	11.1	2.53	48	J,JA,NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 194	pg/L	8.43	5.4	48	J,NBC,VIL,VJ
CO4-EF-04192018-01	PCB 195	pg/L		4.61	48	NBC,VIL,VJ,VIU
CO4-EF-04192018-01	PCB 201	pg/L		2.31	48	VRIU,NBC,VIL,VJ
CO4-EF-04192018-01	PCB 203	pg/L		3.81	48	NBC,VIL,VJ,VIU
CO4-EF-04192018-01	Total DiCB	pg/L	37.8	1.74	19	NBC,VIL,VJ
CO4-EF-04192018-01	Total HeptaCB	pg/L	39.8	2.53	19	NBC,VIL,VJ
CO4-EF-04192018-01	Total HexaCB	pg/L	147	2.55	19	VIP,NBC,VIL,VJ
CO4-EF-04192018-01	Total MonoCB	pg/L		19.2	19	NBC
CO4-EF-04192018-01	Total NonaCB	pg/L		19.2	19	NBC
CO4-EF-04192018-01	Total OctaCB	pg/L	8.43	2.31	19	J,NBC,VIL,VJ
CO4-EF-04192018-01	Total PCBs	pg/L	782	1.74	192	VIP,NBC,VIL,VJ
CO4-EF-04192018-01	Total PentaCB	pg/L	206	3.18	192	NBC,VIL
CO4-EF-04192018-01	Total TetraCB	pg/L	202	3.27	192	NBC,VIL
CO4-EF-04192018-01	Total TriCB	pg/L	132	4.44	48	NBC,VIL

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
TW2-IN-04192018-01	PCB 008	pg/L	19.9	2.59	48	J,NBC,VIL,VJ
TW2-IN-04192018-01	PCB 018/30	pg/L	49.1	7.77	48	NBC
TW2-IN-04192018-01	PCB 020/28	pg/L	91.5	6.35	48	NBC
TW2-IN-04192018-01	PCB 021/33	pg/L	37.1	6.33	48	J,NBC
TW2-IN-04192018-01	PCB 031	pg/L	74.5	5.87	48	NBC
TW2-IN-04192018-01	PCB 044/47/65	pg/L	115	5.83	96	NBC,VIU
TW2-IN-04192018-01	PCB 049/69	pg/L	55.8	5.47	96	J,NBC,VIU
TW2-IN-04192018-01	PCB 052	pg/L	125	5.76	48	NBC,VIL,VIU
TW2-IN-04192018-01	PCB 056	pg/L	39.2	5.48	48	J,NBC
TW2-IN-04192018-01	PCB 060	pg/L	20.6	5.37	48	J,JA,NBC
TW2-IN-04192018-01	PCB 066	pg/L	63.3	4.51	48	NBC,VIU
TW2-IN-04192018-01	PCB 070/61/74/76	pg/L	136	4.85	192	J,NBC,VIL,VIU,VJ
TW2-IN-04192018-01	PCB 083/99	pg/L	50.3	5.21	96	J,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 086/87/97/109/119/125	pg/L	67.6	4.56	192	J,NBC,VIL,VIU
TW2-IN-04192018-01	PCB 090/101/113	pg/L	74.4	4.51	192	J,NBC,VIL,VIU
TW2-IN-04192018-01	PCB 093/95/100	pg/L	58.4	5.1	192	J,NBC,VIL,VIU
TW2-IN-04192018-01	PCB 105	pg/L	35.6	4.34	19	NBC,VIU
TW2-IN-04192018-01	PCB 110/115	pg/L	105	4.16	96	NBC
TW2-IN-04192018-01	PCB 118	pg/L	66.3	4.03	19	NBC,VIL
TW2-IN-04192018-01	PCB 128/166	pg/L	17.8	4.24	96	J,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 129/138/163	pg/L	150	5.53	192	J,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 132	pg/L	29.4	5.05	48	J,NBC,VIL,VIU
TW2-IN-04192018-01	PCB 135/151/154	pg/L	34.3	3.07	96	VRIU,J,NBC,VIL,VJ
TW2-IN-04192018-01	PCB 141	pg/L	15.7	4.26	48	VRIU,J,JA,NBC,VIL,VJ
TW2-IN-04192018-01	PCB 147/149	pg/L	52.2	4.19	96	J,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 153/168	pg/L	171	3.64	96	VIP,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 156/157	pg/L	13.9	6.31	38	J,NBC,VIU
TW2-IN-04192018-01	PCB 158	pg/L	8.3	3.2	48	VRIU,J,JA,NBC,VIL,VJ
TW2-IN-04192018-01	PCB 170	pg/L	38	7.21	48	J,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 174	pg/L	18.1	5.42	48	J,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 177	pg/L	16.2	5.85	48	J,JA,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 180/193	pg/L	88.8	5.4	96	J,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 183/185	pg/L	24.5	5.3	96	J,JA,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 187	pg/L	73.2	3.48	48	NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 194	pg/L	32.7	6.48	48	J,NBC,VIL,VJ
TW2-IN-04192018-01	PCB 195	pg/L	8.1	5.53	48	J,JA,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	PCB 201	pg/L	3.5	2.78	48	VRIU,J,NBC,VIL,VJ
TW2-IN-04192018-01	PCB 203	pg/L	17.9	4.57	48	J,NBC,VIL,VJ,VIU
TW2-IN-04192018-01	Total DiCB	pg/L	19.9	2.59	19	NBC,VIL,VJ
TW2-IN-04192018-01	Total HeptaCB	pg/L	234	3.48	19	NBC,VIL,VJ
TW2-IN-04192018-01	Total HexaCB	pg/L	493	3.07	19	VIP,NBC,VIL,VJ
TW2-IN-04192018-01	Total MonoCB	pg/L		19.2	19	NBC
TW2-IN-04192018-01	Total NonaCB	pg/L		19.2	19	NBC
TW2-IN-04192018-01	Total OctaCB	pg/L	62.2	2.78	19	NBC,VIL,VJ
TW2-IN-04192018-01	Total PCBs	pg/L	2100	2.59	192	VIP,NBC,VIL,VJ
TW2-IN-04192018-01	Total PentaCB	pg/L	458	4.03	192	NBC,VIL

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
TW2-IN-04192018-01	Total TetraCB	pg/L	556	4.51	192	NBC,VIL
TW2-IN-04192018-01	Total TriCB	pg/L	252	5.87	48	NBC,VIL
CO1-EF-05092018-01	PCB 008	pg/L	31.9	7.11	48	J,NBC,VIL,VJ
CO1-EF-05092018-01	PCB 018/30	pg/L	18.9	9.26	48	J,NBC
CO1-EF-05092018-01	PCB 020/28	pg/L	23.1	10.9	48	J,JA,NBC
CO1-EF-05092018-01	PCB 021/33	pg/L	27.4	11.1	48	J,NBC
CO1-EF-05092018-01	PCB 031	pg/L		10.2	48	NBC
CO1-EF-05092018-01	PCB 044/47/65	pg/L	23.3	12.4	96	J,JA,NBC,VIU
CO1-EF-05092018-01	PCB 049/69	pg/L		11.7	96	NBC,VIU
CO1-EF-05092018-01	PCB 052	pg/L	21	12.1	48	J,NBC,VIL,VIU
CO1-EF-05092018-01	PCB 056	pg/L		19.4	48	NBC
CO1-EF-05092018-01	PCB 060	pg/L		19.4	48	NBC
CO1-EF-05092018-01	PCB 066	pg/L		10.5	48	NBC,VIU
CO1-EF-05092018-01	PCB 070/61/74/76	pg/L	105	43.6	191	J,NBC,VIL,VIU,VJ
CO1-EF-05092018-01	PCB 083/99	pg/L	13.3	6.37	96	J,JA,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 086/87/97/109/119/125	pg/L	25.5	5.66	191	J,NBC,VIL,VIU
CO1-EF-05092018-01	PCB 090/101/113	pg/L	27.1	5.52	191	J,NBC,VIL,VIU
CO1-EF-05092018-01	PCB 093/95/100	pg/L	32.6	4.44	191	J,NBC,VIL,VIU
CO1-EF-05092018-01	PCB 105	pg/L		11.8	19	NBC,VIU
CO1-EF-05092018-01	PCB 110/115	pg/L	48.9	5.19	96	J,NBC
CO1-EF-05092018-01	PCB 118	pg/L	12.5	10.8	19	J,NBC,VIL
CO1-EF-05092018-01	PCB 128/166	pg/L	9.24	4.56	96	J,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 129/138/163	pg/L	50	4.98	191	J,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 132	pg/L	14.1	5.15	48	J,NBC,VIL,VIU
CO1-EF-05092018-01	PCB 135/151/154	pg/L	14.6	3.33	96	VRIU,J,NBC,VIL,VJ
CO1-EF-05092018-01	PCB 141	pg/L	7.76	4.62	48	VRIU,J,JA,NBC,VIL,VJ
CO1-EF-05092018-01	PCB 147/149	pg/L	26.6	4.19	96	J,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 153/168	pg/L	32.7	3.92	96	J,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 156/157	pg/L		7.24	38	NBC,VIU
CO1-EF-05092018-01	PCB 158	pg/L	7.17	3.45	48	VRIU,J,NBC,VIL,VJ
CO1-EF-05092018-01	PCB 170	pg/L	11.9	8.21	48	J,JA,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 174	pg/L	13.3	6.26	48	J,JA,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 177	pg/L		6.69	48	NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 180/193	pg/L	34.2	6.4	96	J,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 183/185	pg/L	12.5	6.13	96	J,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 187	pg/L	17.6	3.55	48	J,NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 194	pg/L		10.4	48	NBC,VIL,VJ
CO1-EF-05092018-01	PCB 195	pg/L		9.39	48	NBC,VIL,VJ,VIU
CO1-EF-05092018-01	PCB 201	pg/L		5.12	48	VRIU,NBC,VIL,VJ
CO1-EF-05092018-01	PCB 203	pg/L		8.14	48	NBC,VIL,VJ,VIU
CO1-EF-05092018-01	Total DiCB	pg/L	31.9	7.11	19	NBC,VIL,VJ
CO1-EF-05092018-01	Total HeptaCB	pg/L	77	3.55	19	NBC,VIL,VJ
CO1-EF-05092018-01	Total HexaCB	pg/L	162	3.33	19	NBC,VIL,VJ
CO1-EF-05092018-01	Total MonoCB	pg/L		19.1	19	NBC
CO1-EF-05092018-01	Total NonaCB	pg/L		19.1	19	NBC
CO1-EF-05092018-01	Total OctaCB	pg/L		5.12	19	NBC,VIL,VJ

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO1-EF-05092018-01	Total PCBs	pg/L	662	3.33	191	NBC,VIL,VJ
CO1-EF-05092018-01	Total PentaCB	pg/L	160	4.44	191	J,NBC,VIL
CO1-EF-05092018-01	Total TetraCB	pg/L	149	10.5	191	J,NBC,VIL
CO1-EF-05092018-01	Total TriCB	pg/L	69.5	9.26	48	NBC,VIL
TW2-IN-05092018-01	PCB 008	pg/L	37.8	2.15	48	J,NBC,VIL,VJ
TW2-IN-05092018-01	PCB 018/30	pg/L	29.2	4.43	48	J,NBC
TW2-IN-05092018-01	PCB 020/28	pg/L	93.6	4.35	48	NBC
TW2-IN-05092018-01	PCB 021/33	pg/L	44.8	4.45	48	J,NBC
TW2-IN-05092018-01	PCB 031	pg/L	62.1	4.08	48	NBC
TW2-IN-05092018-01	PCB 044/47/65	pg/L	123	5.66	96	NBC,VIU
TW2-IN-05092018-01	PCB 049/69	pg/L	52	5.33	96	J,NBC,VIU
TW2-IN-05092018-01	PCB 052	pg/L	247	5.5	48	NBC,VIL,VIU
TW2-IN-05092018-01	PCB 056	pg/L	26.9	10.1	48	J,JA,NBC
TW2-IN-05092018-01	PCB 060	pg/L	17.3	10.2	48	J,NBC
TW2-IN-05092018-01	PCB 066	pg/L	85.3	4.8	48	NBC,VIU
TW2-IN-05092018-01	PCB 070/61/74/76	pg/L	501	20	192	NBC,VIL,VIU,VJ
TW2-IN-05092018-01	PCB 083/99	pg/L	204	3.25	96	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 086/87/97/109/119/125	pg/L	310	2.89	192	NBC,VIL,VIU
TW2-IN-05092018-01	PCB 090/101/113	pg/L	414	2.82	192	NBC,VIL,VIU
TW2-IN-05092018-01	PCB 093/95/100	pg/L	410	3.36	192	NBC,VIL,VIU
TW2-IN-05092018-01	PCB 105	pg/L	191	5.48	19	NBC,VIU
TW2-IN-05092018-01	PCB 110/115	pg/L	795	2.65	96	NBC
TW2-IN-05092018-01	PCB 118	pg/L	401	5.03	19	NBC,VIL
TW2-IN-05092018-01	PCB 128/166	pg/L	166	3.43	96	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 129/138/163	pg/L	914	3.75	192	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 132	pg/L	270	3.87	48	NBC,VIL,VIU
TW2-IN-05092018-01	PCB 135/151/154	pg/L	159	2.21	96	VRIU,NBC,VIL,VJ
TW2-IN-05092018-01	PCB 141	pg/L	132	3.47	48	VRIU,NBC,VIL,VJ
TW2-IN-05092018-01	PCB 147/149	pg/L	437	3.15	96	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 153/168	pg/L	520	2.95	96	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 156/157	pg/L	101	6.26	38	NBC,VIU
TW2-IN-05092018-01	PCB 158	pg/L	87.8	2.6	48	VRIU,NBC,VIL,VJ
TW2-IN-05092018-01	PCB 170	pg/L	178	5.62	48	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 174	pg/L	142	4.28	48	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 177	pg/L	84.6	4.58	48	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 180/193	pg/L	372	4.38	96	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 183/185	pg/L	107	4.19	96	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 187	pg/L	185	2.73	48	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 194	pg/L	110	8.51	48	NBC,VIL,VJ
TW2-IN-05092018-01	PCB 195	pg/L	35.9	7.71	48	J,NBC,VIL,VJ,VIU
TW2-IN-05092018-01	PCB 201	pg/L	18.1	4.2	48	VRIU,J,NBC,VIL,VJ
TW2-IN-05092018-01	PCB 203	pg/L	93.2	6.68	48	NBC,VIL,VJ,VIU
TW2-IN-05092018-01	Total DiCB	pg/L	37.8	2.15	19	NBC,VIL,VJ
TW2-IN-05092018-01	Total HeptaCB	pg/L	962	2.73	19	NBC,VIL,VJ
TW2-IN-05092018-01	Total HexaCB	pg/L	2790	2.21	19	NBC,VIL,VJ
TW2-IN-05092018-01	Total MonoCB	pg/L		19.2	19	NBC

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
TW2-IN-05092018-01	Total NonaCB	pg/L		19.2	19	NBC
TW2-IN-05092018-01	Total OctaCB	pg/L	257	4.2	19	NBC,VIL,VJ
TW2-IN-05092018-01	Total PCBs	pg/L	8160	2.15	192	NBC,VIL,VJ
TW2-IN-05092018-01	Total PentaCB	pg/L	2730	2.65	192	NBC,VIL
TW2-IN-05092018-01	Total TetraCB	pg/L	1050	4.8	192	NBC,VIL
TW2-IN-05092018-01	Total TriCB	pg/L	230	4.08	48	NBC,VIL
QA Codes	http://www.ceden.org/CEDEN_Checker/Checker/DisplayCEDENLookUp.php?List=QALookUp					

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO1-EF-04102018-01	Mercury	ng/L	24.4	0.06	0.5	VIP,NBC
CO1-EF-04102018-01	Suspended Sediment Concentration	mg/L	116	0.91	0.9	NBC
CO1-EF-04102018-01	Total Organic Carbon	mg/L	26.7	0.3	2	D,NBC
CO2-EF-04102018-01	Mercury	ng/L	16.3	0.06	0.5	VIP,NBC
CO2-EF-04102018-01	Suspended Sediment Concentration	mg/L	104	0.9	0.9	NBC
CO2-EF-04102018-01	Total Organic Carbon	mg/L	11	0.07	0.5	NBC
CO3-EF-04102018-01	Mercury	ng/L	6.77	0.06	0.5	VIP,NBC
CO3-EF-04102018-01	Suspended Sediment Concentration	mg/L	50.3	0.92	0.9	NBC
CO3-EF-04102018-01	Total Organic Carbon	mg/L	42	0.3	2	D,NBC
CO4-EF-04102018-01	Mercury	ng/L	15.2	0.06	0.5	VIP,NBC
CO4-EF-04102018-01	Suspended Sediment Concentration	mg/L	89.1	0.96	1	NBC
CO4-EF-04102018-01	Total Organic Carbon	mg/L	28.9	0.3	2	D,NBC
CO5-EF-04102018-01	Mercury	ng/L	7.57	0.06	0.5	VIP,NBC
CO5-EF-04102018-01	Suspended Sediment Concentration	mg/L	78	0.92	0.9	NBC
CO5-EF-04102018-01	Total Organic Carbon	mg/L	27.7	0.3	2	D,NBC
CO6-EF-04102018-01	Mercury	ng/L	14	0.06	0.5	VIP,NBC
CO6-EF-04102018-01	Suspended Sediment Concentration	mg/L	118	0.91	0.9	NBC
CO6-EF-04102018-01	Total Organic Carbon	mg/L	32.9	0.3	2	D,NBC
TW2-IN-04102018-01	Mercury	ng/L	9.99	0.06	0.5	VIP,NBC
TW2-IN-04102018-01	Suspended Sediment Concentration	mg/L	19.4	0.9	0.9	NBC
TW2-IN-04102018-01	Total Organic Carbon	mg/L	5.39	0.07	0.5	NBC
CO1-EF-04132018-01	Mercury	ng/L	9.68	0.06	0.5	VIP,NBC
CO1-EF-04132018-01	Suspended Sediment Concentration	mg/L	21.9	0.89	0.9	NBC
CO1-EF-04132018-01	Total Organic Carbon	mg/L	12.3	0.3	2	D,NBC
CO2-EF-04132018-01	Mercury	ng/L	8.58	0.06	0.5	VIP,NBC
CO2-EF-04132018-01	Suspended Sediment Concentration	mg/L	13.3	0.9	0.9	NBC
CO2-EF-04132018-01	Total Organic Carbon	mg/L	5.72	0.07	0.5	NBC
CO3-EF-04132018-01	Mercury	ng/L	5.69	0.06	0.5	VIP,NBC
CO3-EF-04132018-01	Suspended Sediment Concentration	mg/L	14.5	0.89	0.9	NBC
CO3-EF-04132018-01	Total Organic Carbon	mg/L	19.1	0.3	2	D,NBC
CO4-EF-04132018-01	Mercury	ng/L	11.2	0.06	0.5	VIP,NBC
CO4-EF-04132018-01	Suspended Sediment Concentration	mg/L	17	0.93	0.9	NBC
CO4-EF-04132018-01	Total Organic Carbon	mg/L	13.8	0.3	2	D,NBC
CO5-EF-04132018-01	Mercury	ng/L	4.53	0.06	0.5	VIP,NBC
CO5-EF-04132018-01	Suspended Sediment Concentration	mg/L	17.3	0.92	0.9	NBC
CO5-EF-04132018-01	Total Organic Carbon	mg/L	12.5	0.3	2	D,NBC
CO6-EF-04132018-01	Mercury	ng/L	13.1	0.06	0.5	VIP,NBC
CO6-EF-04132018-01	Suspended Sediment Concentration	mg/L	35	0.93	0.9	NBC
CO6-EF-04132018-01	Total Organic Carbon	mg/L	15.9	0.3	2	D,NBC
TW2-IN-04132018-01	Mercury	ng/L	10.2	0.06	0.5	VIP,NBC
TW2-IN-04132018-01	Suspended Sediment Concentration	mg/L	40.2	0.89	0.9	NBC
TW2-IN-04132018-01	Total Organic Carbon	mg/L	1.71	0.07	0.5	NBC
BLNK-EF-04172018-01	Mercury	ng/L	1.96	0.06	0.5	VIP,NBC
BLNK-EF-04172018-01	Suspended Sediment Concentration	mg/L	1.4	0.9	0.9	NBC
BLNK-EF-04172018-01	Total Organic Carbon	mg/L	0.19	0.07	0.5	J,NBC

Sample ID	Analyte Name	Unit Name	Result	MDL	RL	QA Code
CO1-EF-04172018-01	Mercury	ng/L	9.74	0.06	0.5	VIP,NBC
CO1-EF-04172018-01	Suspended Sediment Concentration	mg/L	12.5	0.93	0.9	NBC
CO1-EF-04172018-01	Total Organic Carbon	mg/L	12.1	0.07	0.5	NBC
CO2-EF-04172018-01	Mercury	ng/L	2.17	0.06	0.5	VIP,NBC
CO2-EF-04172018-01	Suspended Sediment Concentration	mg/L	8.4	0.91	0.9	NBC
CO2-EF-04172018-01	Total Organic Carbon	mg/L	5.12	0.07	0.5	NBC
CO2-EF-04172018-D	Suspended Sediment Concentration	mg/L	9.1	0.92	0.9	NBC
CO2-EF-04172018-D	Total Organic Carbon	mg/L	5.15	0.07	0.5	NBC
CO3-EF-04172018-01	Mercury	ng/L	6.02	0.06	0.5	VIP,NBC
CO3-EF-04172018-01	Suspended Sediment Concentration	mg/L	19.3	0.96	1	NBC
CO3-EF-04172018-01	Total Organic Carbon	mg/L	21.6	0.3	2	D,NBC
CO4-EF-04172018-01	Mercury	ng/L	7.58	0.06	0.5	VIP,NBC
CO4-EF-04172018-01	Suspended Sediment Concentration	mg/L	16.5	0.94	0.9	NBC
CO4-EF-04172018-01	Total Organic Carbon	mg/L	14.4	0.3	2	D,NBC
CO5-EF-04172018-01	Mercury	ng/L	7.36	0.06	0.5	VIP,NBC
CO5-EF-04172018-01	Suspended Sediment Concentration	mg/L	11.7	0.92	0.9	NBC
CO5-EF-04172018-01	Total Organic Carbon	mg/L	12	0.3	2	D,NBC
CO6-EF-04172018-01	Mercury	ng/L	11.3	0.06	0.5	VIP,NBC
CO6-EF-04172018-01	Suspended Sediment Concentration	mg/L	26.7	0.95	1	NBC
CO6-EF-04172018-01	Total Organic Carbon	mg/L	17.2	0.3	2	D,NBC
TW6-IN-04172018-01	Mercury	ng/L	9.86	0.06	0.5	VIP,NBC
TW6-IN-04172018-01	Suspended Sediment Concentration	mg/L	16.3	0.89	0.9	NBC
TW6-IN-04172018-01	Total Organic Carbon	mg/L	1.64	0.07	0.5	NBC
CO4-EF-04192018-01	Mercury	ng/L	5.26	0.06	0.5	VIP,NBC
CO4-EF-04192018-01	Suspended Sediment Concentration	mg/L	9.7	0.9	0.9	NBC
CO6-EF-04192018-01	Mercury	ng/L	7.41	0.06	0.5	VIP,NBC
CO6-EF-04192018-01	Suspended Sediment Concentration	mg/L	11.1	0.94	0.9	NBC
CO6-EF-04192018-01	Total Organic Carbon	mg/L	10.9	0.3	2	D,NBC
TW2-IN-04192018-01	Mercury	ng/L	3	0.06	0.5	VIP,NBC
TW2-IN-04192018-01	Suspended Sediment Concentration	mg/L	1.9	0.89	0.9	NBC
QA Codes	http://www.ceden.org/CEDEN_Checker/Checker/DisplayCEDENLookUp.php?List=QALookUp					

Pollutants of Concern Monitoring for Management Action Effectiveness

Evaluation of Mercury and PCBs Removal Effectiveness of Full Trash Capture Hydrodynamic Separator Units

Project Report

Prepared for:

Bay Area Stormwater Management Agencies Association

Prepared by:

EOA inc.

WATER PROGRAMS SACRAMENTO STATE

KINNETIC LABORATORIES INCORPORATED

SFEI

FINAL

February 20, 2019

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LIST OF ACRONYMS

ACCWP	Alameda Countywide Clean Water Program
BASMAA	Bay Area Stormwater Management Agencies Association
CCCWP	Contra Costa Clean Water Program
EPA	Environmental Protection Agency
FSURMP	Fairfield-Suisun Urban Runoff Management Program
GC/MS	Gas Chromatography/Mass Spectroscopy
HDS	Hydrodynamic Separator
KLI	Kinnetic Laboratories, Inc.
LCS	Laboratory Control Sample
MDL	Method Detection Limit
MRL	Method Reporting Limits
MRP	Municipal Regional Stormwater NPDES Permit
MS	Matrix Spike
MS4	Municipal Separate Storm Sewer System
na	not applicable
nr	not reported
ND	Non-Detect
NPDES	National Pollutant Discharge Elimination System
PCBs	Polychlorinated Biphenyl
PMT	Project Management Team
POC	Pollutants of Concern
ppb	parts per billion
ppm	parts per million
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RWSM	Regional Watershed Spreadsheet Model
ROW	Right-of-Way
SAP	Sampling and Analysis Plan
SCVURPPP	Santa Clara Valley Urban Runoff Pollution Prevention Program
SFEI	San Francisco Estuary Institute
SMCWPPP	San Mateo Countywide Water Pollution Prevention Program
SOP	Standard Operating Procedure
TMDL	Total Maximum Daily Loads
VSFCD	City of Vallejo and the Vallejo Sanitation and Flood Control District

EXECUTIVE SUMMARY

INTRODUCTION

The Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit (MRP; Order No. R2-2015-0049) implements the municipal stormwater portion of the mercury and polychlorinated biphenyls (PCBs) Total Maximum Daily Loads (TMDLs) for the San Francisco Bay. Provisions C.11 and C.12 of the MRP require mercury and PCBs load reductions and the development of a Reasonable Assurance Analysis (RAA) demonstrating that control measures will be sufficient to attain the TMDL wasteload allocations within specified timeframes. In compliance with the MRP, Permittees have implemented a number of source control measures in recent years designed to reduce pollutants of concern (POCs) in urban stormwater and achieve the wasteload allocations described in the mercury and PCBs TMDLs. For all control measures, an Interim Accounting Methodology for TMDL Loads Reduced has been developed to determine POC load reductions achieved based on relative mercury and PCBs yields from different land use categories (BASMAA, 2017a). Provision C.8.f of the MRP further supports implementation of the mercury and PCBs TMDLs by requiring that Permittees conduct POC monitoring to address management action effectiveness, one of the five priority information needs identified in the MRP. Management action effectiveness monitoring is intended to provide support for planning future management actions or evaluating the effectiveness or impacts of existing management actions.

To achieve compliance with the above permit requirements, the Bay Area Stormwater Management Agencies Association (BASMAA[1]) implemented a regional project on behalf of its member agencies. The goal of the ***BASMAA POC Monitoring for Management Action Effectiveness -Evaluation of Mercury and PCBs Removal Effectiveness of Full Trash Capture Hydrodynamic Separator (HDS) Units*** project (the Project) was to evaluate the mercury and PCBs removal effectiveness of HDS units associated with removal of solids captured within the sump. The information provided by this monitoring effort will be used to support ongoing efforts by MRP Permittees and the California Regional Water Quality Control Board, San Francisco Bay Region (Regional Water Board) to better quantify the pollutant load reductions achieved by existing and future HDS units installed in urban watersheds of the Bay Area. This project was conducted between March 2017 and December 2018 in the portion of the San Francisco Bay Area subject to the MRP. The project was implemented by a project team comprised of EOA Inc., the Office of Water Programs at Sacramento State University (OWP), Kinnetic Laboratories, Inc. (KLI), and the San Francisco Estuary Institute (SFEI). A BASMAA Project Management Team (PMT) consisting of

[1] BASMAA is a 501(c)(3) non-profit organization that coordinates and facilitates regional activities of municipal stormwater programs in the San Francisco Bay Area. BASMAA programs support implementation of the MRP (Order No. R2-2015-0049). BASMAA is comprised of all 76 identified MRP municipalities and special districts, the Alameda Countywide Clean Water Program (ACCWP), Contra Costa Clean Water Program (CCCWP), the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), the San Mateo Countywide Water Pollution Prevention Program (SMCWPPP), the Fairfield-Suisun Urban Runoff Management Program (FSURMP), the City of Vallejo and the Vallejo Sanitation and Flood Control District (VSFCD).

representatives from BASMAA stormwater programs and municipalities provided oversight and guidance to the project team.

METHODS

The Project combined sampling and modeling efforts to evaluate the mercury and PCBs removal performance of HDS units as follows. First, samples of the solids captured and removed from eight different HDS unit sumps during cleanout were collected and analyzed for PCBs and mercury. Second, maintenance records and construction plans for these HDS units were reviewed to develop estimates of the average volume of solids removed per cleanout. This information was combined with the monitoring data to calculate the mass of POCs removed during cleanouts. Third, the annual mercury and PCBs loads discharged from each HDS unit catchment were estimated using two different load calculation methods. Method #1 used the land use-based POC yields described in the BASMAA Interim Accounting Methodology (BASMAA 2017a) to estimate catchment loads. Method #2 used the Regional Watershed Spreadsheet Model (RWSM, Wu et al. 2017) to estimate runoff volumes and stormwater concentrations and calculate catchment loads. Finally, HDS unit performance was evaluated for both catchment load estimates by calculating the average annual percent removal of POCs as a result of the removal of solids from the HDS unit sumps.

RESULTS

Samples were collected from HDS units located in the cities of Palo Alto, Oakland, San Jose and Sunnyvale. These HDS units were selected opportunistically, based on the units that were scheduled for cleanout during the project sampling period (fall 2017 – spring 2018). The types of solid samples that were collected depended on the solids that were found in each sump, and included 3 sediment-only samples, and 5 sediment and organic/leafy debris samples. All samples were analyzed for the RMP 40 PCB congeners[2], total mercury, total solids (TS), total organic carbon (TOC), and bulk density. The sediment-only samples were also analyzed for grain size and were sieved at 2 millimeters (mm) prior to analysis for PCBs and mercury. The sediment and organic/leaf debris samples were analyzed as whole samples (not sieved) and were also analyzed for total organic matter in order to calculate the inorganic fraction (i.e., the mineral fraction assumed to be associated with POCs). Total PCBs concentrations across the 8 samples ranged from 0.01 to 0.41 milligram/kilogram (mg/kg) dry weight (dw). Total mercury concentrations ranged from 0.005 to 0.31 mg/kg dw. Overall, the range of mercury and PCBs concentrations measured in the HDS unit solids in the present study were similar to the average concentrations found in storm drain sediments and street dirt across the Bay Area, as reported elsewhere (BASMAA 2017a).

Based on review of maintenance records for 38 cleanout events, as well as construction details for each unit which provided information on each unit's storage capacity, the estimated average solids removed per cleanout ranged from 2.4 cubic yards (CY) to 37 CY. These numbers indicate the HDS unit sumps were on average 97% full when a cleanout was conducted. The calculated annual mass of PCBs removed

[2] The 40 individual congeners routinely quantified by the Regional Monitoring Program (RMP) for Water Quality in San Francisco Bay include: PCBs 8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, 105, 110, 118, 128, 132, 138, 141, 149, 151, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203

from each unit ranged from 2 mg/year up to 2,600 mg/yr, while the annual mass of mercury removed from each unit ranged from 9 mg/year up to 6,500 mg/year. Differences in catchment sizes do not explain the high degree of variability observed across the different units. When normalized to catchment size, the mass of POCs removed per acre treated for the HDS units in this study remained highly variable, ranging from 0.01 mg/acre to 29 mg/acre for PCBs, and 0.03 mg/acre to 50 mg/acre for mercury.

PCBs Removal Rates (Table ES-1): For catchment loads calculated using Method #1 (land use-based yields), the median percent PCBs removal across all 8 units ranged from 5% to 10%. For catchment loads calculated using Method #2 (RWSM runoff volume x concentration), the median percent PCBs removal ranged from 15% to 32%. Variability in removal rates was high between individual units, ranging from almost no removal to 100% removal of the estimated loads.

Table ES-1. HDS Unit Performance - Annual Percent Removal Calculated For Two Catchment Load Estimates.

HDS Unit ID	PCBs Removal				Mercury Removal			
	Method #1		Method #2		Method #1		Method #2	
	Low	High	Low	High	Low	High	Low	High
1	80%	100%	100%	100%	26%	40%	100%	100%
2	8%	18%	10%	22%	4%	6%	65%	98%
3	4%	9%	21%	45%	2%	3%	8%	12%
4	38%	83%	27%	59%	5%	7%	17%	26%
5	0.06%	0.13%	0.21%	0.46%	0.1%	0.2%	1.1%	1.6%
6	5%	11%	20%	43%	0.01%	0.02%	0.1%	0.2%
7	0.6%	1.4%	0.5%	1.1%	0.06%	0.09%	2%	3%
8	1.4%	3.1%	7%	16%	3%	4%	27%	41%
Median	**5%**	**10%**	**15%**	**32%**	**3%**	**4%**	**13%**	**19%**

Mercury Removal Rates (Table ES-1): Across all 8 units, the median percent removal for catchment loads calculated using Method #1 (land use-based yields) ranged from 3% to 4%. For all units under Method #1, the removal rates were lower for mercury than for PCBs. For catchment loads calculated using Method #2 (RWSM runoff volume x concentration) the median removal ranged from 13% to 19%. Similar to PCBs, removal rates for mercury in individual HDS units were highly variable.

CONCLUSIONS

For both PCBs and mercury, the data from this study indicate the percent removals achieved by HDS unit cleanouts are highly variable across units, and likely variable within the same unit over time. The conclusions on pollutant removal effectiveness of HDS unit sump cleanouts based on the results of this study are limited by the small number of HDS units that were sampled (n=8) and the limited, and often incomplete, maintenance records that were available at the time of this study. Nevertheless, the results of this study provide new information on the range of pollutant concentrations measured in HDS unit sump solids. Additional data would be needed to fully characterize the range of pollutant load reductions achieved by HDS units over longer periods of time and across varying urban environments.

The results from this study will be considered in the update of the Interim Accounting Methodology that is being conducted as part of the BASMAA regional project *Source Control Load Reduction Accounting for Reasonable Assurance Analysis*, and will include methods for estimating POC reductions associated with stormwater control measures, including HDS units.

Additional recommendations on options for potentially improving the pollutant removal effectiveness of HDS unit maintenance practices, as well as improving the estimates presented in this report include the following:

- Develop site-specific standard operating procedures (SOPs) for each HDS unit, including suggested cleanout frequency and cleanout methods to ensure efficient and consistent practices over time.
- To improve pollutant removal effectiveness, cleanouts should occur well before sumps reach capacity. Frequent inspections of HDS unit sumps may also provide the information needed to determine an appropriate cleanout frequency for each HDS unit.
- To improve estimates of the solids removal achieved per cleanout (and the associated pollutant removals achieved), provide consistent recording of the following information: cleanout dates, measured depth of solids and water in the sump prior to a cleanout, estimates of the volumes of solids and water removed from the sump during cleanout, and a description of the types of solids removed.

1 INTRODUCTION

1.1 BACKGROUND

Fish tissue monitoring in San Francisco Bay (Bay) has revealed bioaccumulation of polychlorinated biphenyls (PCBs) and mercury. The measured fish tissue concentrations are thought to pose a health risk to people consuming fish caught in the Bay. As a result of these findings, California has issued an interim advisory on the consumption of fish from the Bay. The advisory led to the Bay being designated as an impaired water body on the Clean Water Act "Section 303(d) list" due to PCBs and mercury. In response, the California Regional Water Quality Control Board, San Francisco Bay Region (Regional Water Board) adopted total maximum daily loads (TMDLs) to address these pollutants of concern (POCs) (SFBRWQCB 2012).

Provisions C.11 and C.12 of the Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit (MRP; Order No. R2-2015-0049) implements the municipal stormwater portion of the Mercury and PCBs TMDLs for the San Francisco Bay Area. These provisions require mercury and PCBs load reductions and the development of a Reasonable Assurance Analysis (RAA) demonstrating that control measures will be sufficient to attain the TMDL wasteload allocations within specified timeframes. In compliance with the MRP, Permittees have implemented a number of source control measures in recent years designed to reduce POCs in urban stormwater and achieve the wasteload allocations described in the mercury and PCBs TMDLs. For all control measures, the Bay Area Stormwater Management Agencies Association (BASMAA[3]) developed an Interim Accounting Methodology to define POC load reductions achieved based on relative mercury and PCBs yields from different land use categories (BASMAA 2017a).

Provision C.8.f of the MRP further supports implementation of the mercury and PCBs TMDLs by requiring that Permittees conduct POC monitoring to address management action effectiveness, one of the five priority information needs identified in the MRP. Management action effectiveness monitoring is intended to provide support for planning future management actions or evaluating the effectiveness or impacts of existing management actions. Although individual Countywide monitoring programs can meet all MRP monitoring requirements on their own, some requirements are conducted more efficiently, and likely yield more valuable information, when coordinated and implemented on a regional basis.

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[3] BASMAA is a 501(c)(3) non-profit organization that coordinates and facilitates regional activities of municipal stormwater programs in the San Francisco Bay Area. BASMAA programs support implementation of the MRP (Order No. R2-2015-0049). BASMAA is comprised of all 76 identified MRP municipalities and special districts, the Alameda Countywide Clean Water Program (ACCWP), Contra Costa Clean Water Program (CCCWP), the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), the San Mateo Countywide Water Pollution Prevention Program (SMCWPPP), the Fairfield-Suisun Urban Runoff Management Program (FSURMP), the City of Vallejo and the Vallejo Sanitation and Flood Control District (VSFCD).

1.2 Problem Statement

During the previous MRP permit term (2009 – 2015), BASMAA pilot tested a number of different stormwater control measures for pollutant removal effectiveness through the Clean Watersheds for a Clean Bay (CW4CB) project (BASMAA 2017b). One treatment option that was pilot-tested during CW4CB includes hydrodynamic separator (HDS) units. HDS units have been installed for trash control throughout the Bay Area. An HDS unit typically consists of a circular concrete manhole structure that is installed underground, either inline or offline within the existing storm drainage system. As an example, the features of an inline Contech Continuous Deflective Separator (CDS) Unit are shown in Figure 1.1. Stormwater flows from the HDS catchment (up to the treatment design capacity) enter the device tangentially, which initiates a swirling motion to the water. This is enhanced by a curved deflection plate. The flows are then guided into the separation chamber, where swirl concentration and screen deflection force solids to the center of the chamber. The flow continues through the separation screen, under the oil baffle and exits the unit. All of the solids and debris larger than the screen apertures are trapped within the unit. Floatables (i.e., buoyant solids) will typically remain suspended in the water that is retained within the unit near the top of the treatment screen, while the heavier solids settle into the storage sump located directly below the screening area. These units are designed to collect trash, sediment and other solid debris. POC removal is expected to occur through capture of POC-containing solids in the HDS unit sumps, and subsequent removal and disposal of these solids during cleanouts. Generally, the net solids removal is expected to vary by site-specific conditions, and the removal efficiency for solids smaller than the screen apertures varies depending on the model selected and the flow characteristics of the site.

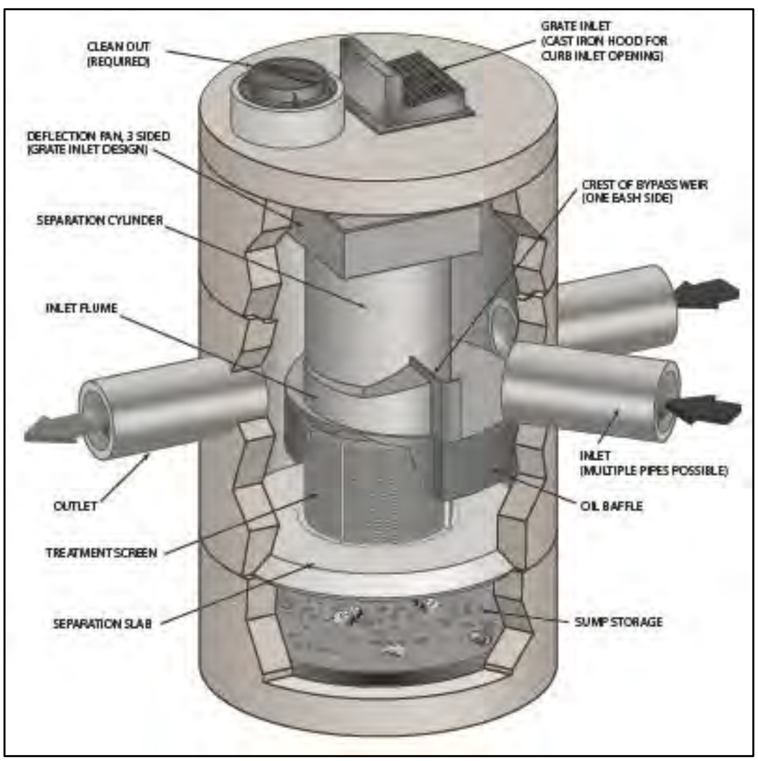


Figure 1.1 Basic features of a Contech Continuous Deflective Separator (CDS) Hydrodynamic Separator (HDS) Unit. Source: Contech Engineered Solutions 2014.

For HDS units and other stormwater control measures, BASMAA developed the ***Interim Accounting Methodology for TMDL Loads Reduced*** (Interim Accounting Methodology, BASMAA 2017a) to calculate load reductions achieved by these measures during the current permit term (2016 – 2020). The Interim Accounting Methodology is based on relative mercury and PCBs yields from different land use categories. For HDS units, the methodology assumes a default 20% reduction of the area-weighted land use-based pollutant yields for a given catchment. This default value was based on average percent removal of total suspended solids (TSS) from HDS units from an analysis of paired influent/effluent data reported in the International Stormwater Best Management Practices (BMP) Database (www.bmpdatabase.org), as described in Appendix C of the Interim Accounting Methodology (BASMAA 2017a). However, significant data gaps remain in determining the effectiveness of this practice and expected load reductions.

The CW4CB results suggested that the materials retained within the HDS unit sumps and removed during routine cleanouts provide reductions of POC mass that would otherwise remain in the municipal separate storm sewer system (MS4). However, the CW4CB pilot tests were limited to 2 data points, collected from a single HDS unit that drains a catchment with elevated mercury and PCBs concentrations. The monitoring performed to-date is not sufficient to characterize pollutant concentrations of solids captured in HDS units that drain catchments with different loading scenarios (e.g., land uses, stormwater volumes, source areas, etc.), nor to estimate the percent removal based on the pollutant load captured and removed from the HDS unit during ongoing maintenance practices.

1.3 Project Goal

The overall goal of this project is to evaluate the mercury and PCBs removal effectiveness of HDS units due to solids capture within the sumps and subsequent removal during cleanouts. The monitoring conducted through this project provides partial fulfilment of MRP monitoring requirements for management action effectiveness under provision C.8.f., while also addressing some of the data gaps identified by the CW4CB project (BASMAA 2017b). The information provided by this project will be used by MRP Permittees and the Regional Water Board to support ongoing efforts to better quantify the pollutant load reductions achieved by existing and future HDS units installed in urban watersheds of the Bay Area.

To accomplish the project goal, BASMAA implemented a regional project on behalf of its member agencies to collect samples of the solids removed from HDS Unit sumps during cleanout events to estimate the mass of POCs removed. This report presents the results of the ***BASMAA POC Monitoring for Management Action Effectiveness - Evaluation of Mercury and PCBs Removal Effectiveness of Full Trash Capture Hydrodynamic Separator Units*** project (the Project) that was conducted during 2017 and 2018 in the portion of the San Francisco Bay Area subject to the MRP. The project was implemented by a project team comprised of EOA Inc., the Office of Water Programs (OWP) at Sacramento State University, Kinnetic Laboratories, Inc. (KLI), and the San Francisco Estuary Institute (SFEI). A BASMAA Project Management Team (PMT) consisting of representatives from BASMAA stormwater programs and municipalities provided oversight and guidance to the project team throughout the project.

Section 2 of this report presents the overall approach and details methods that were used to implement the project, including a description of the sampling and chemical analysis methods, and descriptions of the methodology used to estimate the POC percent removals achieved through cleanouts. Section 3 presents the project results and discussion, including the location and description of each HDS unit that was sampled, a summary of the chemical analysis results for each unit, a summary of the cleanout events identified in maintenance records, the modeled estimates of the annual average POC stormwater loads within each HDS unit catchment, and the annual loads reduced (and percent removals achieved) through HDS unit maintenance practices. Section 4 summarizes the conclusions based on the results of the project.

2 METHODS

This section presents the overall approach and methods that were used to implement the Project. Under the guidance and oversight of the PMT, the project team developed a study design (Appendix A) and a SAP/QAPP (Appendix B), which were followed throughout implementation of the sampling program.

2.1 OVERALL PROJECT APPROACH

The overall approach to the Project involved a combined sampling and modeling effort to evaluate the mercury and PCBs removal performance of the sampled HDS units. The project implemented the following 4 tasks:

1. Collect samples of the solids captured in HDS unit sumps in Bay Area urban catchments and analyze them for mercury and PCBs;
2. Quantify the volume and mass of solids (and associated mercury and PCBs) removed from HDS unit sumps during cleanouts;
3. Estimate annual average mercury and PCBs stormwater loads for each HDS unit catchment of interest (i.e., the HDS unit catchments that were sampled in task 1);
4. Calculate the annual mercury and PCBs percent removals due to HDS unit cleanouts for each catchment of interest.

It is important to note this project was not designed to fully characterize the range of POC concentrations and masses captured in Bay Area HDS unit sumps. Nor was this project intended to provide highly accurate stormwater loading estimates for the catchments of interest. Rather, this project was intended to provide additional data to better quantify the mercury and PCBs load reduction effectiveness of HDS unit maintenance practices and support future development of source control RAAs.

The remainder of this section provides additional details on the methods and assumptions employed to implement the project tasks.

2.2 HDS UNIT SAMPLING

Across the Bay Area, at least 37 large, public HDS units have been installed in public right-of-way (ROW) locations over the past 10+ years. These units were primarily installed for trash controls. These units treat stormwater runoff from more than 13,000 acres spread across nine Bay Area municipalities. The size of the catchments treated by individual units in the Bay Area ranges from about 3 acres up to more than 900 acres. Selection of HDS units for sampling during this project was primarily opportunistic, based on the units that were scheduled for cleanouts during the project. The project team worked cooperatively with the PMT and multiple Bay Area municipal agencies to identify public HDS units that were scheduled for maintenance during the project sampling period (Fall 2017 through spring 2018). Additional selection criteria included cooperation of the appropriate municipal staff and safety considerations for the monitoring team. All field sampling was conducted during dry weather, when urban runoff flows through the HDS units were minimal and did not present safety hazards or other logistical concerns.

During sampling, HDS units were typically dewatered by municipal staff to remove standing water in the units and any floatables suspended in that water prior to sump cleanout. The monitoring team then collected multiple samples of the solids (sediment and organic debris) contained within each unit's sump, avoiding trash and other large debris. The solid samples were then combined and thoroughly homogenized in a stainless steel or Kynar-coated bucket, from which a composite sample was removed and aliquoted into separate jars for chemical analysis. Sample collection techniques varied between units due to the unique characteristics of each unit (i.e., sump depth and volume, safety considerations, etc.). For the majority of units, a stainless steel scoop on the end of a long pole was used to collect samples of the solids in the sump. However, in cases where the sump was too deep and/or too large to collect a representative sample using this method, samples were collected after the solids were removed from the sump by maintenance staff as the cleanout proceeded. Any confined space entry to remove solids from HDS unit sumps was performed by city maintenance staff trained and certified in such activities. One composite sample of the solids was collected for each HDS unit. The solid samples that were collected consisted of either sediment-only, or a combination of sediment and organic/leafy debris, depending on the type of solids that were found in each sump. The latter type of samples were collected in cases where this type of material dominated the solids content of the HDS unit sump, and collection of a sediment-only sample would not be representative of the solids in the sump.

2.3 Laboratory Methods

All solid samples were analyzed for the RMP 40 PCB congeners[4], total mercury, total solids (TS), total organic carbon (TOC), and bulk density by the methods identified in Table 2.1. All sediment-only samples were also analyzed for grain size by the methods in Table 2.1. With the exception of grain size and bulk density, sediment-only samples were sieved by the laboratory at 2 mm prior to analysis. The sediment and organic/leaf debris samples were not sieved but were analyzed as whole samples. These samples were also analyzed for total organic matter (TOM) by the method identified in Table 2.1, in order to estimate the percent of the solid material that was organic (e.g., leaf debris) vs. inorganic (e.g., mineral content) because POCs in sump solids were assumed to be predominantly associated with the mineral fraction (i.e., the leafy material is expected to add few POCs but a large contribution to the total solids mass, and the relative proportion of organic-matter vs. mineral fractions provides assessment of the degree of dilution by organic matter).

Additional details about the field sampling and laboratory analysis methods are provided in the project SAP/QAPP (Appendix B).

[4] The 40 individual congeners routinely quantified by the Regional Monitoring Program (RMP) for Water Quality in the San Francisco Estuary include: PCBs 8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, 105, 110, 118, 128, 132, 138, 141, 149, 151, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203

Table 2.1. Laboratory Analytical Methods for Analytes in Sediment and Sediment/Organic Leaf debris.

Sample Type	Analyte	Sampling Method	Analytical Method	Reporting Units
All	Total Organic Carbon (TOC)	Grab	EPA 415.1, 440.0, 9060, or ASTM D4129M	%
Sediment-Only	Grain Size	Grab	ASTM D422M/PSEP	%
All	Bulk Density	Grab	ASTM E1109-86	g/cm^3
All	Mercury	Grab	EPA 7471A, 7473, or 1631	µg/kg
All	PCBs (RMP 40 Congeners)	Grab	EPA 1668	µg/kg
All	Total Solids	Grab	EPA160.3	%
Sediment + Organic/Leaf Debris	Total Organic Matter (TOM)	Grab	EPA160.4	%

2.4 Data Analysis and Reporting

The data collected during sampling was combined with estimated catchment loads to evaluate the POC removal performance of each HDS unit as follows. First, the annual mass of POCs reduced due to cleanouts was calculated from the measured POC concentrations in sump solids and the estimated average volume of solids removed per cleanout, and the total number of cleanouts per year. Next, the annual stormwater loads of POCs discharged from each HDS unit catchment were estimated using two different methods to calculate the catchment loads. Finally, HDS unit performance was evaluated by calculating the POC percent removals due to HDS Unit cleanouts for both catchment load estimates. Additional details about each of these steps are presented here.

2.4.1 Annual Mass of POCs Reduced Due to Cleanouts

The annual mass of POCs reduced due to removal of sump solids from HDS units during cleanouts was calculated using Equation 2-1.

$$M_{HDS\text{-}i} = V_{HDS\text{-}i} \times \rho_{HDS\text{-}i} \times F_{POC\text{-}HDS\text{-}i} \times C_{POC,\ HDS\text{-}i} \times N_{HDS\text{-}i} \quad (2\text{-}1)$$

Where:

$M_{HDS\text{-}i}$ the total annual POC mass removed from the sump of HDS Unit i (mg/year);

$V_{HDS\text{-}i}$ the volume of solids removed from HDS Unit i during a cleanout (cubic yards (CY) per cleanout;

$P_{HDS\text{-}i}$ the bulk density of solids removed from HDS Unit i during a cleanout (kg/CY);

$F_{POC\text{-}HDS\text{-}i}$ the mass fraction of solids removed from HDS Unit i during a cleanout that is associated with POCs;

$C_{POC,\ HDS\text{-}i}$ the concentration of POCs in the solids removed from HDS Unit i during a cleanout (mg/kg dw);

$N_{HDS\text{-}i}$ the number of cleanouts of HDS Unit i each year (cleanouts/year).

In order to provide the inputs required for Equation 2-1, additional information was gathered from the appropriate municipalities for each HDS unit that was sampled, including construction details (as-builts) and maintenance records on past cleanouts. Maintenance records were reviewed to gather information on the number and frequency of past cleanouts, and the volume of solids typically removed from sumps during cleanouts. Information on the types of materials removed during each cleanout was generally limited. However, any cleanout that only recorded removal of floatables (i.e., buoyant solids suspended in the water layer above the sump) was excluded from these evaluations, as the focus here was on removal of solid sediment and debris captured in the sumps. Although organic materials such as leaves are generally buoyant, these solids were frequently found in HDS unit sumps, likely because a sufficient mass of soil particles attached to the organic debris and caused the materials to settle in the sump. Additional assumptions described below were used to provide the inputs required for Equation 2-1.

- The average volume of solids removed from the sump per cleanout (V_{HDS-i}) was calculated for each unit from maintenance records or was assumed to be equivalent to the volume of the unit's solids storage sump if maintenance records were not available. Where available, maintenance records were reviewed to identify the volume of solids removed from a given unit's sump during each cleanout, and an average volume per cleanout calculated for each unit. Where not available, construction details (i.e., as-built drawings) were reviewed to calculate the sump storage capacity for each unit. The full sump capacity was selected as a reasonable estimate of the volume of solids removed during a cleanout because (1) the recorded volumes removed during cleanouts were typically near or even exceeded sump capacity; and (2) information provided by municipal staff indicated solids in the sumps were typically not removed unless the sumps were well over 50% full. This later information was further corroborated by maintenance records that identified a number of cleanouts were performed where only floatables were removed from the top layer of water in the unit's screening area, and no solids were removed from the sumps. As stated previously, cleanouts that only removed these floatables were not included in the calculation of the average volume of solids removed per cleanout. Initial attempts to further refine and/or improve the estimates of the average volumes of solids removed per cleanout based on maintenance records were evaluated, including (for example) normalizing the volume of solids removed in a given cleanout to the rainfall amounts within that catchment since the previous cleanout. However, because the maintenance data were limited, highly uncertain, and in many cases, incomplete, the outcomes of these efforts were inconclusive at best, and they were not pursued further.

- The fraction of solids removed during cleanouts that was associated with POCs ($F_{POC-HDS-i}$) was estimated from measurement data for each HDS unit. For sediment-only samples, the fraction associated with POCs was assumed to be the dry fraction of solids removed that was < 2 mm in grain size, where %TS accounts for the moisture content of the solids, and the % < 2 mm accounts for the small particle size fraction of the solids. For the sediment + organic/leaf samples, the fraction associated with POCs was assumed to be the dry fraction of solids removed that was inorganic, where % TOM measurement allows for calculation of the % inorganic (i.e., mineral content of the sample). These assumptions are consistent with catchment loads calculated in Section 2.4.2 for each HDS unit catchment. Catchment loads calculated using the BASMAA land use-based POC yields (BASMAA 2017a) or using the Regional Watershed Spreadsheet Model (RWSM, Wu et al. 2017), both rely on inputs that assume POCs are associated with the smaller (i.e., < 2 mm) particle size fractions in stormwater.

- All of the measurement data used as inputs to Equation 2-1 (POC concentrations, bulk density, etc.) were assumed to be representative of the values of these parameters for typical sump solids removed during cleanouts over time for a given HDS Unit. This assumption was necessary because the data needed to evaluate the temporal and spatial variability in these parameters are currently unavailable. Multiple samples from the same HDS unit over a number of years would be needed to quantify the variability over time, while this project provided only 1 sample per unit. To account for some degree of variability in the measured POC concentrations, the average relative percent differences (RPDs) between field duplicate sediment samples collected from storm drain structures over the past 5+ years across the Bay Area were used (SCVURPPP 2018, SMCWPPP 2018, BASMAA 2017b). The RPD was calculated for 27 field duplicate pairs, and for PCBs, ranged from <1% to 185%, with an average of 37%. For mercury, the RPDs ranged from 4% to 43%, with an average of 17%. The average RPDs for PCBs and mercury were applied to the concentrations measured in this study to develop a low and high concentration estimate (and associated low and high POC mass removed per cleanout) for each unit.

- Two cleanouts per year were assumed. Although maintenance records provided some information on cleanout frequencies, it appears from both the information provided, and further discussion with municipal staff that cleanout frequency is highly variable from unit to unit and from year to year. A default assumption of two cleanouts per year was selected as a reasonable approximation based on the typical cleanout frequencies reported by maintenance staff.

2.4.2 Annual POC Stormwater loads discharged from each HDS Unit Catchment

For each HDS Unit, the annual average POC loads discharged from its catchment were calculated using two different methods. Method #1 is based on catchment-specific land use multiplied by land use-based POC yields described in the BASMAA Interim Accounting Methodology (BASMAA 2017a). Method #2 is based on RWSM estimates of annual stormwater runoff volumes and land use-based POC event mean concentrations (Wu et al. 2017). Additional details about the inputs and assumptions used to calculate annual average catchments POC loads using each of these methods are provided below.

2.4.2.1 HDS Catchment Loads – Method #1: BASMAA Land Use-Based Yields

This method relies on the land use-based mercury and PCBs yields that form the basis for the stormwater control measure load reduction accounting methodology described in the BASMAA Interim Accounting Methodology (BASMAA 2017a). These yields, presented in Table 2.2, provide an estimate of the mass of POCs contributed by an area of a given land use each year.

Table 2.2 Land Use-Based PCBs and Mercury Yields.

Land Use Category	PCBs Yield (mg/acre/year)	Mercury Yield (mg/acre/year)
Old Industrial	86.5	1,300
Old Urban	30.3	215
New Urban	3.5	33
Other	3.5	26
Open Space	4.3	33

For each of the HDS Unit catchments in this study, the area of each land use category identified in Table 2.2 was multiplied by the associated POC yield for that land use. The total POC load for each land use was summed to provide the total POC catchment loads for an average year.

2.4.2.2 HDS Catchment Loads - Method #2: RWSM Runoff Volume X Concentration

For this method, outputs of the RWSM were used to estimate annual average POC loads for each of the eight HDS unit catchments in this study. The RWSM was developed by SFEI (Wu et al., 2017) to serve as a regional scale planning tool for estimating average annual loads from small tributaries and sub-watersheds of San Francisco Bay. The RWSM includes a hydrology model that provides an estimate of runoff volumes for Bay Area watersheds and sub-watersheds, and pollutant models for PCBs and mercury that are driven by the hydrology and provide water concentration maps tied to land use classifications. The hydrology model calculates annual average runoff using rainfall data from PRISM (Parameter Elevation Regression on Independent Slopes Model, which is based on climate data from 1981 – 2010, www.prismclimate.org), and runoff coefficients developed from land use-soil-slope combinations. The hydrological calibration was based on 19 watersheds evenly distributed across three micro-climate sub-regions (East Bay, South Bay/ Peninsula, and North Bay for independent calibrations that averaged a mean bias of +1%, a median bias of 0% and a range of +/- 30%). One of the outputs from the model is a continuous estimate of runoff for the entire Bay area in GIS format which can be used to estimate flow from any spatial extent of interest (parcel, storm, sub-watershed, watershed, sub-region (e.g. county), or for the Bay area as a whole (Wu et al., 2017). This GIS map was used here to support this project. The RWSM PCBs and mercury pollutant models were calibrated using data from eight (PCBs) and six (mercury) well sampled watersheds. The calibration was deemed reasonable for PCBs and less good for mercury (Wu et al., 2017). One of the outputs from the model provides event mean concentration (EMC) data for stormwater by land use classification, as shown in Table 2.3.

Table 2.3 Event Mean Concentrations in Water for PCBs and Mercury by Land Use Classification from the Regional Watershed Spreadsheet Model[1].

<table>
<tr><th rowspan="2">Land Use Classification</th><th colspan="2">Event Mean Concentrations (EMCs)</th></tr>
<tr><th>PCBs ng/L</th><th>Mercury (ng/L)</th></tr>
<tr><td>Ag and Open Space</td><td rowspan="2">0.2</td><td>72</td></tr>
<tr><td>New Urban</td><td>3</td></tr>
<tr><td>Old Residential</td><td>4</td><td rowspan="2">63</td></tr>
<tr><td>Old Commercial and Transportation</td><td>50</td></tr>
<tr><td>Old Industrial</td><td rowspan="2">201</td><td rowspan="2">40</td></tr>
<tr><td>Source Areas</td></tr>
</table>

[1]Wu et al. 2017

It is important to note that the land use classifications shown in Table 2.3 are not exactly the same for PCBs and mercury, nor are they identical for the same pollutant in Tables 2.2 and 2.3. The differences include the following:

- The “old urban” classification in Table 2.2 combines the “old residential” and “old commercial and transportation” categories for PCBs, while these are distinct categories in Table 2.3;
- New Urban, Ag and Open space classifications in Table 2.3 all have the same EMC for PCBs, but are split into two separate categories (New Urban, and Ag/Open Space) with different EMCs for mercury, and with different PCBs yields for each category in Table 2.2.

For each HDS Unit catchment in this study, Equation 2-2 was used to calculate the average annual POC loads for the catchment, using RWSM inputs as described below.

$$M_{\text{Catchment-i}} = Q_{\text{Catchment-i}} \times C \times EMC_{\text{Catchment-i}} \quad (2\text{-}2)$$

Where:

$M_{\text{Catchment-i}}$ the total POC mass discharged from Catchment-i (the catchment draining to HDS Unit-i) over the time period of interest (mg/year);

$Q_{\text{Catchment-i}}$ the average annual runoff volume in catchment-i from the RWSM (liters/year);

C unit conversion factor (ng to mg);

$EMC_{\text{Catchment-i}}$ the area-weighted stormwater pollutant event mean concentration (EMC, ng/l) for Catchment-i based on land use. The RWSM land use-based EMCs in Table 2.3 (Wu et. al. 2017) were used to calculate an area-weighted pollutant EMC for each catchment based on the acreage of each land use classification in the catchment.

2.4.3 Evaluation of HDS Unit Performance

The HDS Unit performance was evaluated by calculating the annual percent removals of POCs due to cleanout of solids from HDS unit sumps. The percent removal of PCBs and mercury from the total estimated catchment mass for both of the catchment load estimate methods was calculated using Equation 2-3.

$$\text{(2-3)} \quad \text{Total Catchment Pollutant Mass Removed (\%)} = [M_{HDS\text{-}i}/M_{Catchment\text{-}i}] \times 100\%$$

Where:

$M_{HDS\text{-}i}$ the total POC mass captured in the sump of HDS Unit i over the time period of interest (mg/year);

$M_{Catchment\text{-}i}$ the total POC mass discharged from Catchment-i (the catchment draining to HDS Unit-i) over the time period of interest (mg/year) calculated using Method #1 or Method #2.

Two pollutant percent removals were calculated for each HDS unit catchment using Equation 2-3, including one for the catchment loads calculated using Method #1 (BASMAA land use-based yields) and the second for the catchment loads calculated using Method #2 (RWSM runoff volume x concentration).

3 RESULTS AND DISCUSSION

3.1 HDS UNIT SAMPLING

Figure 3.1 presents the range of catchment sizes treated by the 37 existing public HDS units in the Bay Area at the time of this project, and showing the land use distributions of each catchment. The cities of Oakland, Palo Alto, San Jose, and Sunnyvale all had HDS units that were scheduled for maintenance during the project period and met the logistical and safety constraints of the project. Between September 2017 and March 2018, sampling was attempted at 10 HDS units in these cities and competed successfully at the 8 units identified on Figure 3.1 and on the map in Figure 3.2. Although HDS units were selected for sampling opportunistically, the HDS units that were sampled span the range of catchment sizes treated by existing public HDS units in the Bay Area. The majority of HDS unit catchments (both sampled and not sampled) were dominated by old urban land use.

Additional information about each of the sampled HDS units is presented in Table 3.1. Figures 3.2 - 3.7 provide maps of the catchments for each of the sampled HDS units in this project.

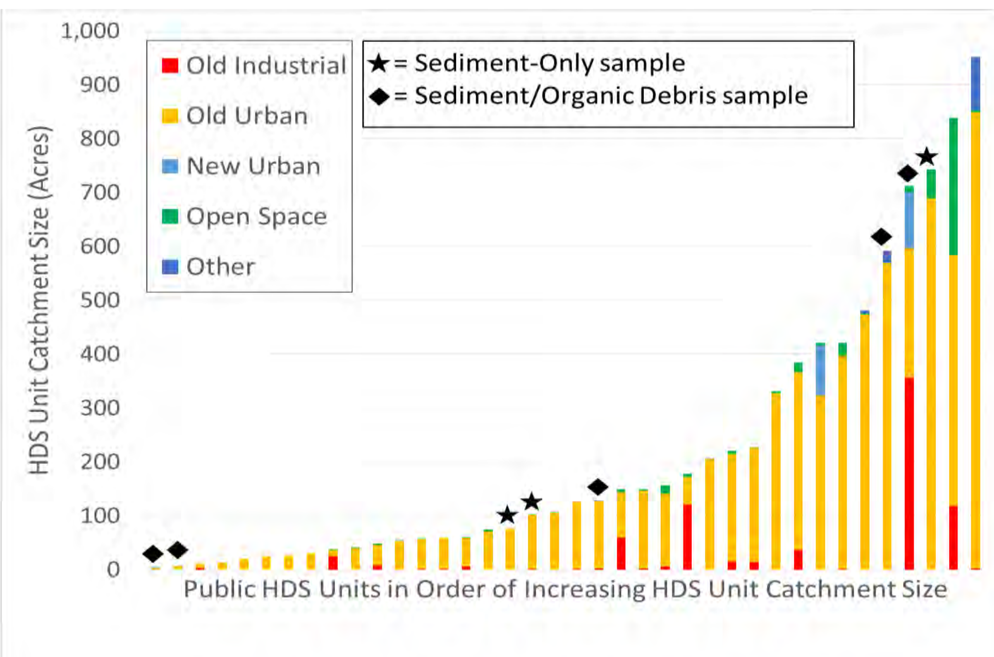
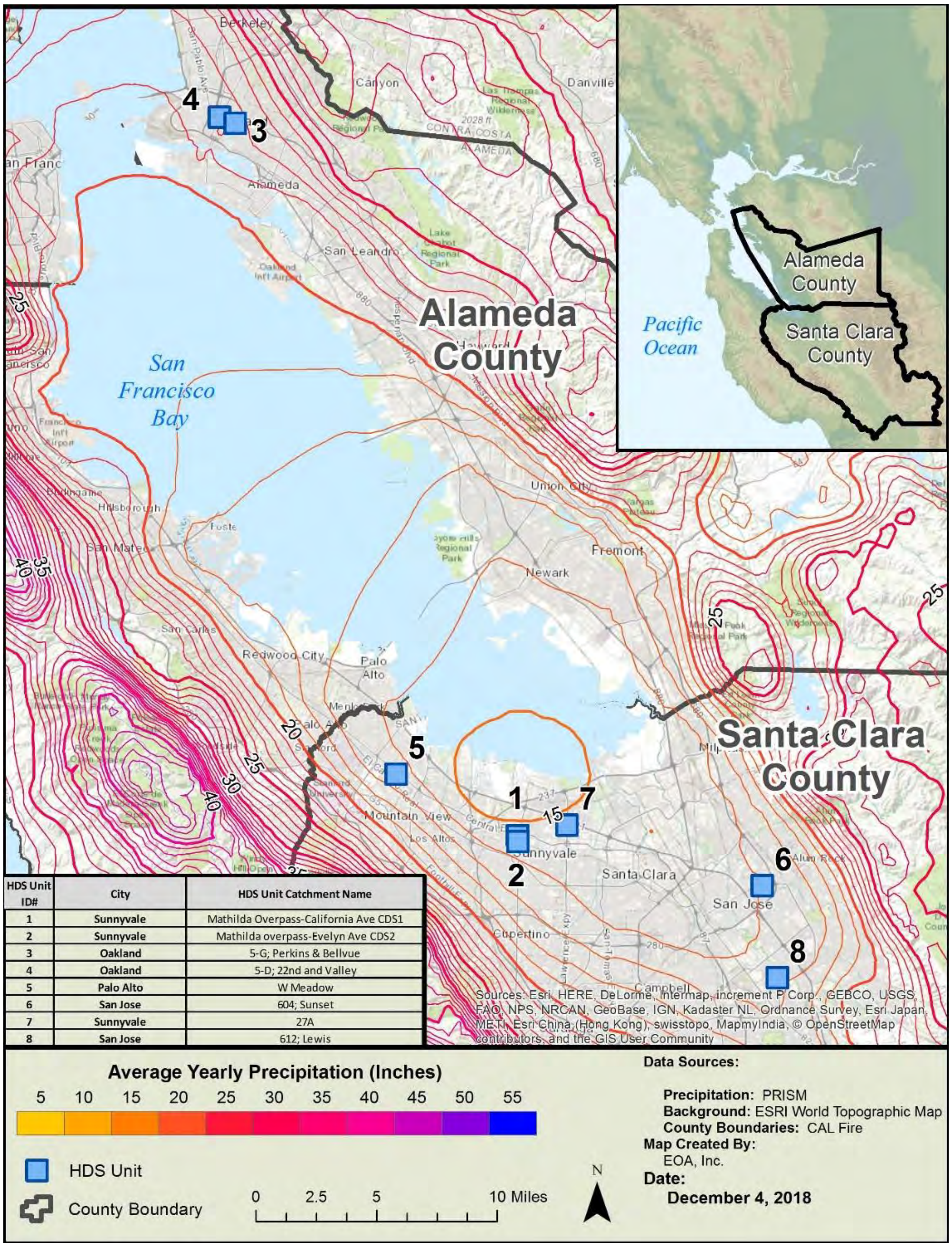


Figure 3.1 Catchment Sizes and Land Use Distributions for Existing Public HDS Units in the San Francisco Bay Area. The HDS units that were sampled in this study are identified with a black star (sediment-only samples collected) or diamond (sediment/organic debris samples collected).



HDS Unit ID#	City	HDS Unit Catchment Name
1	Sunnyvale	Mathilda Overpass-California Ave CDS1
2	Sunnyvale	Mathilda overpass-Evelyn Ave CDS2
3	Oakland	5-G; Perkins & Bellvue
4	Oakland	5-D; 22nd and Valley
5	Palo Alto	W Meadow
6	San Jose	604; Sunset
7	Sunnyvale	27A
8	San Jose	612; Lewis

Figure 3.2 Overview Map of the 8 HDS Units Sampled in the San Francisco Bay Area as Part of the BASMAA BMP Effectiveness Study.

Table 3.1 HDS Units that were sampled in the San Francisco Bay Area as part of the BASMAA POC Monitoring for Management Action Effectiveness Study.

HDS ID	Date Installed	HDS Description	Lat	Long	Land Use Classification (Acres)					Total Area (Acres)
					Old Industrial	Old Urban[1]		New Urban	Ag/ Open	
						Old Commercial/ Other	Old Residential/ Parks			
1	**Sep-2014**	Mathilda overpass project CDS1 at California Ave Sunnyvale, CA	37.38224	-122.03306	0.0	0.0	1.5	1.5	0.2	3.3
2	**Sep-2014**	Mathilda overpass project CDS2 at Evelyn Ave Sunnyvale, CA	37.37891	-122.03271	1.1	0.3	2.2	3.6	0.0	7.2
3	**Aug-2010**	HDS 5-G; Perkins & Bellevue (Nature Center) Oakland, CA	37.80744	-122.25597	0.0	5.3	70.0	0.0	0.0	75.3
4	**Jul-2012**	HDS 5-D; 22nd and Valley Oakland, CA	37.81109	-122.26787	1.8	73.2	27.0	0.0	0.3	102.3
5	**Jun-2012**	W. Meadow Drive and Park Blvd Palo Alto, CA	37.41816	-122.12538	2.9	17.6	73.9	32.5	0.8	127.5
6	**Sep-2012**	HDS 604; Sunset Avenue SW of Alum Rock Avenue San Jose, CA	37.35447	-121.84814	23.0	127.0	441.1	1.6	0.0	592.7
7	**Sep-2015**	HDS 27A -2 units (East Unit and West Unit) San Jose, CA	37.38922	-121.99592	269.6	136.2	11.3	282.6	11.9	711.6
8	**Jun-2016**	HDS 612; Lewis Road and Lone Bluff Way - Los Lagos Golf Course (2 units) San Jose, CA	37.29923	-121.83591	0.0	171.9	503.2	14.4	53.3	742.8

[1]The "Old Urban" land use category in the Interim Accounting Methodology (2017a) was further divided into "Old commercial/other" and "Old Urban residential/parks" to provide consistency with the land use categories in the RWSM (Wu et al. 2017).

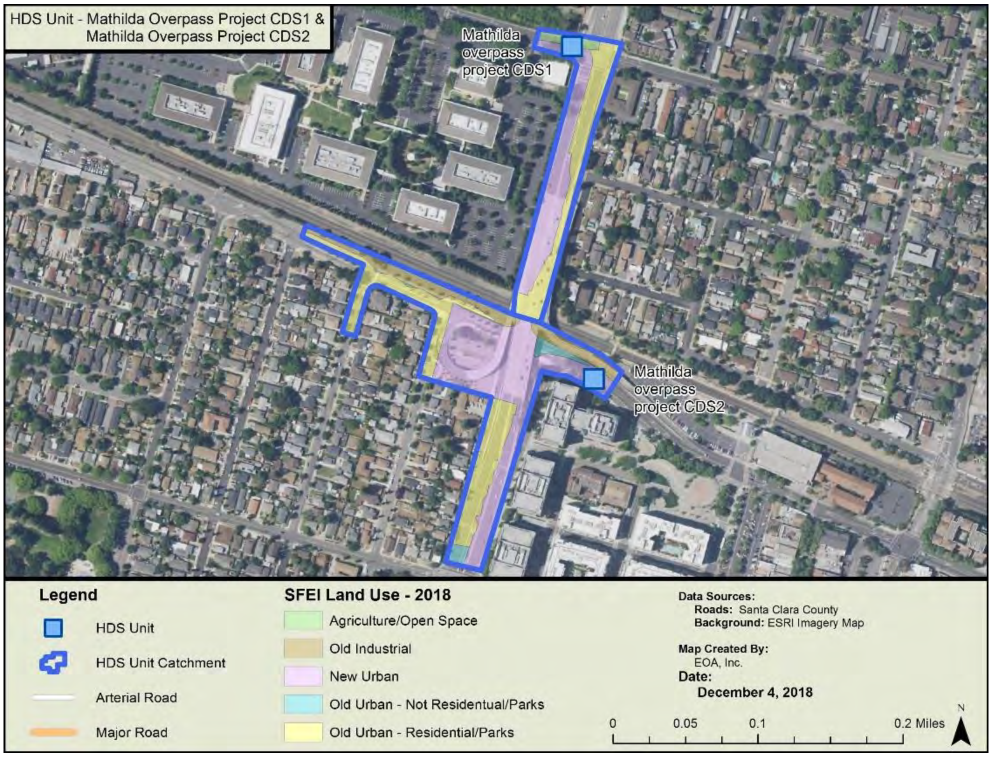


Figure 3.3 Map of HDS Units #1 and #2 Catchments in Sunnyvale, CA.

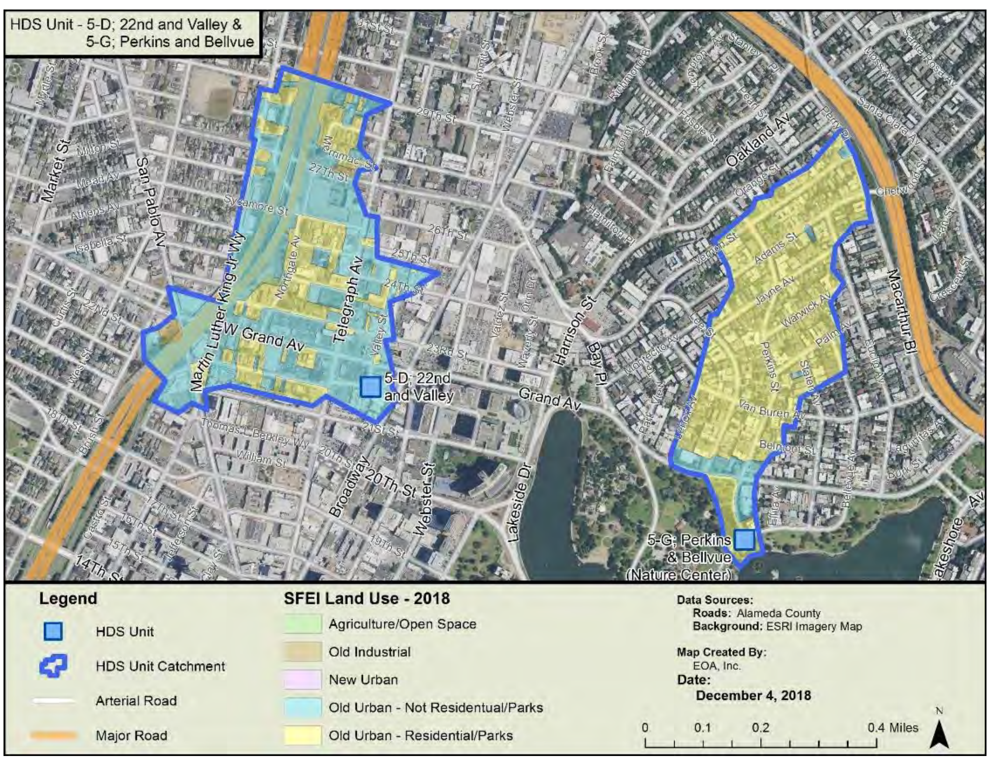


Figure 3.4 Map of HDS Units #3 and #4 Catchments in Oakland, CA

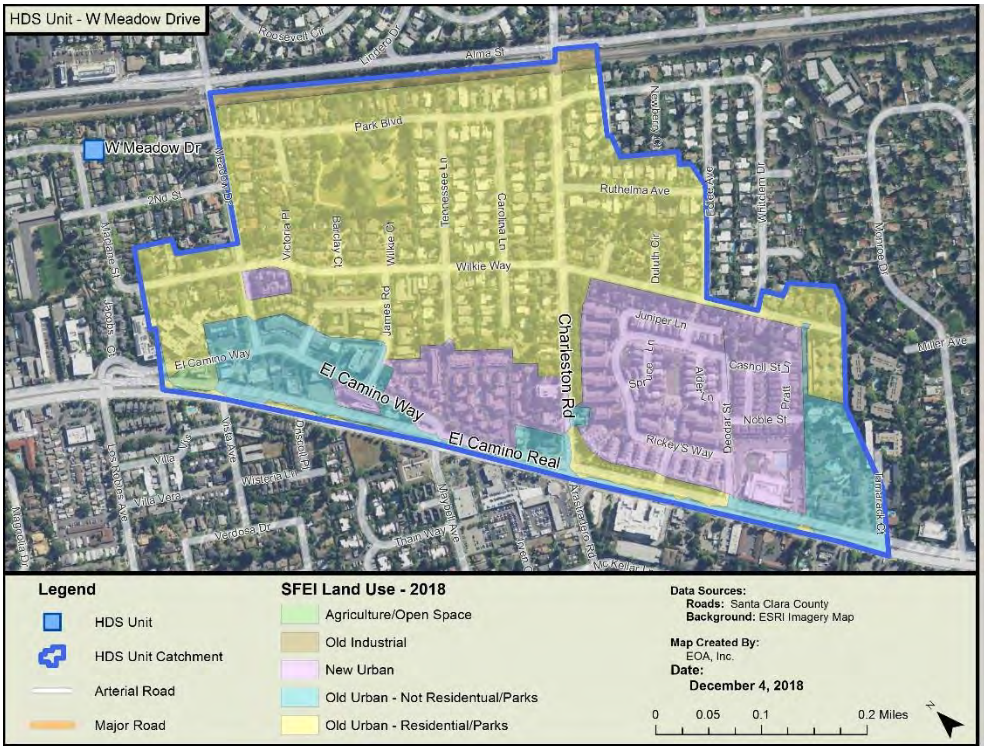


Figure 3.5 Map of HDS Unit #5 Catchment in Palo Alto, CA

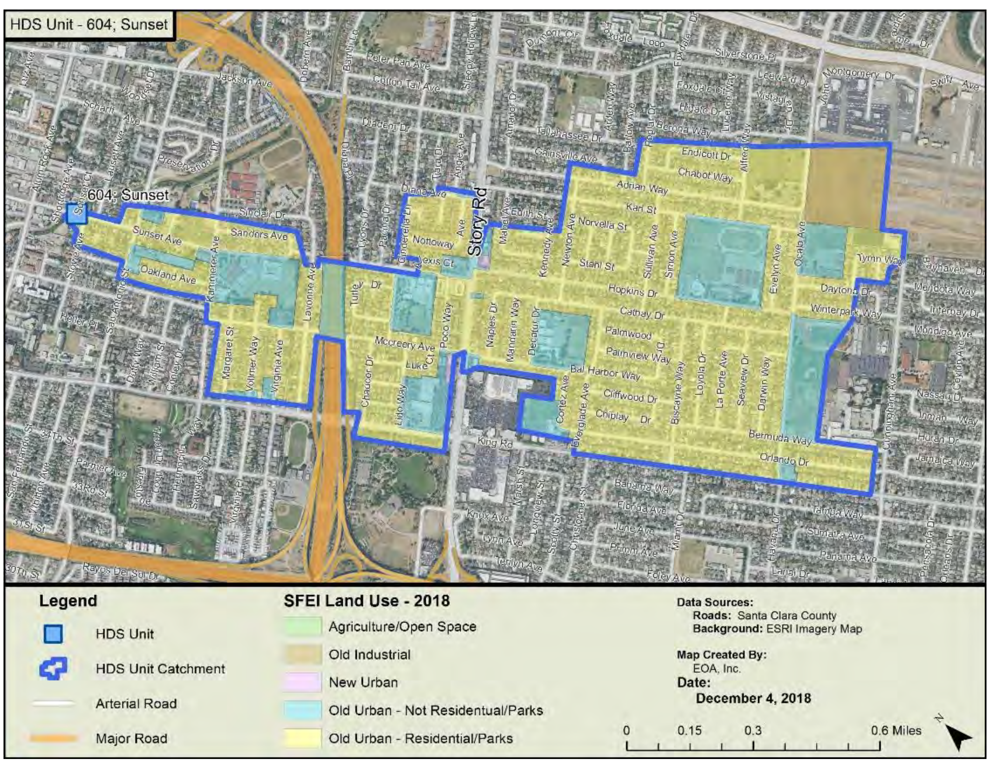


Figure 3.6 Map of HDS Unit #6 Catchment in San Jose, CA

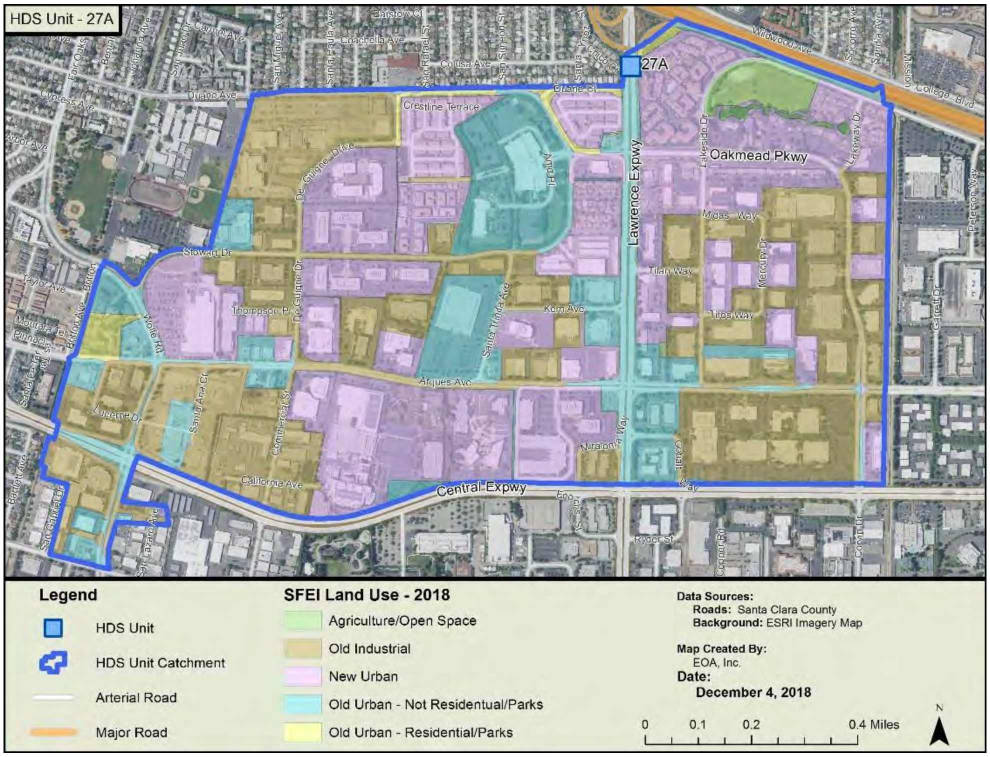


Figure 3.7 Map of HDS Unit #7 Catchment in Sunnyvale, CA

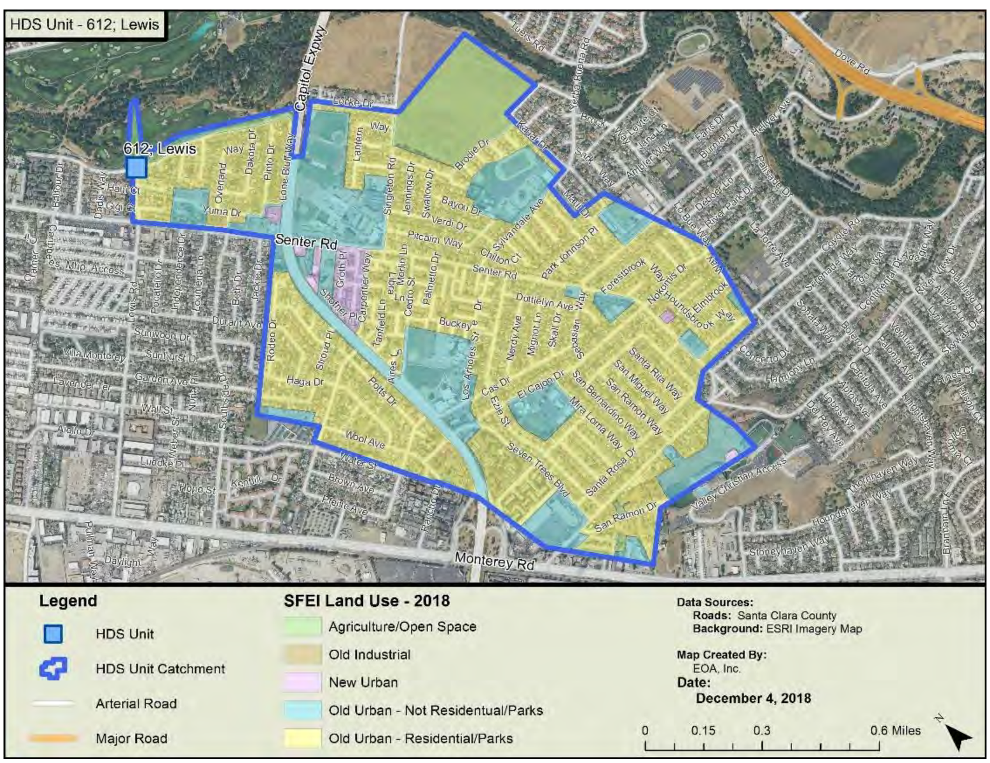


Figure 3.8 Map of HDS Unit #8 Catchment in San Jose, CA

3.1.1 Laboratory Analysis

3.1.1.1 Quality Assurance and Quality Control

Data Quality Assurance (QA) and Quality Control (QC) was performed in accordance with the project's SAP/QAPP (Appendix B). The SAP/QAPP established Data Quality Objectives (DQOs) to ensure that data collected are sufficient and of adequate quality for their intended use. These DQOs include both quantitative and qualitative assessments of the acceptability of data. The qualitative goals include representativeness and comparability, and the quantitative goals include completeness, sensitivity (detection and quantization limits), precision, accuracy, and contamination. Measurement Quality Objectives (MQOs) are the acceptance thresholds or goals for the data.

<u>PCBs</u>: The dataset included 8 field samples, with 3 blanks, and 5 laboratory control samples (LCS), some in duplicate, meeting the minimum number of QC samples required. Results were reported for the RMP 40 PCB analytes (with their coeluters, yielding 38 unique analytes). One sample was flagged for a hold time of one week too long but considered unlikely to affect results. Eight of the analytes were detected in blanks, but field sample concentrations were over 3-fold higher, so no results were censored. Two of the analytes had recovery with average >35% deviation from target values in the LCS, and one (PCB 183/185) had average error >70%, so was censored. PCB 183/185 was also flagged for poor precision (RSD 53%), but that analyte was already rejected for poor recovery, so the precision flag is largely moot. Overall the data quality was acceptable.

<u>Mercury/TOC/TS/bulk density/TOM</u>: The HDS sediment and sediment/organic debris dataset included eight field samples reported for total mercury, total solids, and bulk density, but only seven for TOC, and four (missing SJC-604) for sediment/organic debris for total volatile solids (total organic matter, TOM). MS/D pairs were reported for two sites for TOC, and mercury. Nine lab blanks were reported for mercury, and 6 for TOC, meeting the one per batch requirement. Three LCSs were also reported for TOC. Nearly all density and total solids were analyzed past the 1-one week QAPP listed hold times, and flagged VH, but so long as initial masses were recorded well, it is unlikely to affect results. Only Hg was occasionally detected in the blanks, but averaged <MDL so results were not flagged. Precision (<25% RPD) and recovery targets (±20% for conventional analytes and ±25% for Hg) were met for all QC samples, so no other flags were added. Overall the data quality was acceptable.

<u>Grain Size</u>: The sediment dataset included three field samples reported for grainsize, all analyzed in replicate. No blanks or recovery samples were reported, which is common for grainsize analysis. Fourteen size fractions were reported, with results normalized from the raw lab reported percentages to yield sums of 100% for each analysis. Nominal percent differences in lab replicates for any given sample were always <5%, so no qualifier flags were added. Overall, the data quality was acceptable.

Additional details about the data quality review are provided in Appendix C. The laboratory QA/QC data are available upon request.

3.1.1.2 POC Concentrations

Chemical analysis results are summarized in Table 3.2. PCBs concentrations in this report are presented as the sum of the RMP-40 congeners; individual congener data are available in Appendix D. The laboratory reports from this project are available upon request. Of the eight samples collected, three were sediment-only samples that were sieved at 2 mm prior to POC analysis. The remaining five samples were mixtures of sediment and organic debris (e.g., leaves). These samples were treated as a whole sample and not sieved at 2 mm prior to POC analysis. Upon consultation with the PMT, the project team decided to analyze these mixed sediment/organic debris samples as part of this study because these types of solids (i.e., leaf debris) appeared to be commonly captured in HDS unit sumps.

Total PCBs ranged from 0.01 to 0.41 mg/kg dry weight. The PCBs concentrations observed in the present study are at least an order of magnitude lower than PCBs concentrations observed in the solids removed from the 7th Street HDS Unit that drains the Leo Avenue area of San Jose observed in the CW4CB project in 2013 , where a known source property is located (BASMAA 2017c). Total mercury concentrations ranged from 0.005 to 0.31 mg/kg dry weight. Overall, the range of mercury and PCBs concentrations measured in the HDS unit solids in the present study were similar to the average concentrations found in storm drain sediments and street dirt across the Bay Area, as reported in Appendix B of the Interim Accounting Methodology (BASMAA 2017a). All laboratory data from this project are available upon request.

Table 3.2 Chemical Analysis Results of Solids Collected from HDS Unit Sumps.[1]

HDS Unit ID	Sample ID	Sample Date	Sample Type	Bulk Density (g/cm^3)	Mercury (mg/kg dw)	TOC (%)	Total PCBs (mg/kg dw)	Total Solids (%)	Total Organic Matter (%)	Sediment Fraction < 2mm (%)
1	SUN-MatCDS1	3/8/18	Whole-Sediment/ organic debris	0.66	0.11	187	0.053	16.3	53.3	na
2	SUN-MatCDS2	3/8/18	Whole-Sediment/ organic debris	0.57	0.19	283	0.044	13.9	72.6	na
3	OAK-5-G	10/16/17	Sediment Only	0.53	0.25	3.64	0.092	88.5	na	67
4	OAK-5-D	2/2/18	Sediment Only	0.81	0.31	5.85	0.408	99.2	na	95
5	PAL-Meadow	10/25/17	Whole-Sediment/ organic debris	0.47	0.21	222	0.015	19.2	85.4	na
6	SJC-604	10/5/17	Whole-Sediment/ organic debris	0.99	0.04	nr	0.294	10.1	na	na
7	SUN-27A	3/8/18	Whole-Sediment/ organic debris	0.76	0.005	375	0.060	8.3	60.3	na
8	SJC-612-01	9/13/17	Sediment Only	0.74	0.14	3.78	0.012	98.3	na	93

[1]na=not applicable; nr= not reported

3.2 Evaluation of HDS Unit Performance

3.2.1 HDS Unit Construction Details and Maintenance Records

Additional information was gathered about each of the sampled HDS units, including construction details and maintenance records provided by the corresponding municipality. The quantity and quality of the maintenance records varied greatly from city-to-city and even within a city, from unit to unit. After careful review of all the available data, relevant information on cleanout frequencies, volumes of solids removed, and the types of materials contained in the solids was compiled and used to estimate the volume of solids removed per cleanout (Table 3.3). These data include information on a total of 38 cleanouts at 7 HDS units (2 to 13 cleanouts for each HDS unit in this study with the exception of Palo Alto, for which no maintenance records were available at the time of this report). In most cases, the maintenance records provided estimates of the volume of solids removed from the sumps during cleanouts, as well as the volume of floatables and trash. Both the cities of Sunnyvale and San Jose also provided the depth of solids in the sump prior to cleanout. This later information was combined with the known dimensions of each unit's sump taken from the construction details to calculate the total volume of solids contained in the sump just prior to cleanout. Some records also provided basic descriptions of the types of solid materials that were removed from sumps during a cleanout and a rough estimate of the volume(s) of each type. Excluding cleanouts that only removed floatables, the average volume of solids removed per cleanout was calculated for each unit and reported in Table 3.3. These estimates ranged between 2.4 cubic yards (CY) and 37 CY. Interestingly, for five of the HDS units, the volume of solids removed exceeded the maximum storage capacity of the sumps, indicating solids were likely overflowing the sump and also contained within the neck and screening area above the sumps of these units. This suggests sump cleanouts may be needed more frequently at these units, which were typically cleaned once per year. In contrast, the average solids removed per cleanout for the two Oakland units ranged from 55% to 60% of the sump capacity, indicating the current cleanout frequency of 2 to 3 times per year appears adequate for these units.

When normalized to the total area of the catchment, the average volume of solids removed per cleanout ranged from 0.01 CY to 0.8 CY of solids per acre treated. The solids storage capacity for these 8 units had a similar range of 0.01 CY to 0.7 CY per acre treated. The similarities between measured storage capacity and estimated solids removed provides further corroboration that, on average, cleanouts were occurring when the sumps were full. This supports the use of the total sump storage capacity to represent the volume removed during a cleanout in cases where maintenance data were unavailable. This also suggests more frequent cleanouts may be warranted.

Table 3.3 Summary of Information on Storage Capacity, Cleanout Frequencies, and Volumes of Solids Removed from HDS Unit Sumps.

HDS Unit ID	HDS Catchment Description	Total Storage Capacity (CY)[a]	Sump Storage Capacity (CY)[b]	Cleanout Date	Description of Solids Removed From Unit	Solids Removed per Cleanout (CY)	Average Solids Removed per Cleanout (CY)
1	Mathilda overpass project CDS1 at California Avenue	4.9	2.2	12/19/2016	leaves/trash/debris	2.5	2.7
				8/29/2017	leaves/trash/debris	2.1	
				10/23/2018	leaves/trash/debris	3.5	
2	Mathilda overpass project CDS2 at Evelyn Ave	3.0	1.5	12/19/2016	leaves/trash/debris	1.8	2.4
				8/29/2017	leaves/trash/debris	2.8	
				10/23/2018	leaves/trash/debris	2.5	
3	HDS 5-G; Perkins & Bellvue (Nature Center)	17	5.8	4/12/2010	60% debris/20% organic/20%trash	2	3.5
				5/25/2010	floatables/organic debris	3	
				7/19/2010	25% sediment/75% Debris	1	
				2/2/2011	5% floatables/95% organic debris	3	
				4/25/2011	debris	3	
				1/12/2012	organic debris and floatables	3	
				4/18/2012	dirt and debris	1	
				10/18/2012	sediment debris	12	
				9/30/2014	sediment/trash	3	
				5/20/2015	floatables and sediment	3	
				5/22/2015	floatables and sediment	4	
				5/19/2017	debris	7	
				10/18/2017	sediment	1.1	
4	HDS 5-D; 22nd and Valley	28	7.3	7/7/2010	dirt/debris/organics	3	4.1
				2/4/2011	90% floatables/10% organic debris	4	
				1/10/2012	dirt/debris/organics	2.5	
				4/6/2012	dirt/debris/organics	3	
				10/17/2012	floatables/trash/debris	8	
				8/27/2013	debris	5	
				1/27/2015	sediment/trash	1	
				2/17/2016	sediment/debris	8	
				4/29/2018	sediment debris	2	

Table 3.3 Cont…

HDS Unit ID	HDS Catchment Description	Total Storage Capacity (CY)[a]	Sump Storage Capacity (CY)[b]	Cleanout Date	Description of Solids Removed From Unit	Solids Removed per Cleanout (CY)	Average Solids Removed per Cleanout (CY)
5	W. Meadow Dr and Park Blvd	6.5	1.9	No Maintenance Data Available			
6	HDS 604; Sunset Avenue SW of Alum Rock Avenue	31	9.2	9/24/2016	trash/solids	14	10
				3/26/2017	trash/solids	9.5	
				10/5/2017	trash/solids	3.2	
				12/13/2017	trash/solids	12	
				3/6/2018	trash/solids	11	
7	HDS 27A -2 units (East Unit and West Unit)	68	18	12/21/2016	leaves/trash/debris	18	10.5
				8/30/2017	leaves/trash/debris	4.4	
				10/25/2018	leaves/trash/debris	8.7	
8	HDS 612; Lewis Road and Lone Bluff Way - Los Lagos Golf Course (2 units)	116	38	9/14/2017	trash/solids	37	37
				4/24/2018	trash/solids	37	

[a]The total storage capacity of each HDS unit was calculated from the dimensions of the solids storage sump and the screening area above the sump, as provided in construction plans.
[b]The sump storage capacity was calculated from the dimensions of the solids storage sump provided in the construction plans.

3.2.2 Mass of POCs Removed During Cleanouts

The estimated mass of POCs removed during HDS unit sump cleanouts is presented in Table 3.4 for the following assumed cleanout conditions (i.e., volumes of solids removed during each cleanout):

- the average volume of solids removed per cleanout from maintenance records; or
- for the Palo Alto HDS Unit #5 only, the volume of solids removed per cleanout was assumed to be equal to the sump capacity (because no maintenance data were available for this HDS unit);

For each HDS unit, the estimated mass of PCBs removed per cleanout ranged from < 1 mg to > 1,300 mg of PCBs. If we assume a cleanout rate of twice per year, the calculated mass of PCBs removed per year from all of these eight HDS units combined ranged from ~2,800 mg to ~6,000 mg of PCBs. When normalized to the catchment area, the mass of PCBs removed per acre treated ranged from 0.01 mg/acre/yr to 29 mg/acre/yr. The estimated mass of mercury removed per cleanout ranged from ~9 mg to > 3,200 mg, while the total mass of mercury removed per year from all eight HDS units combined (again, assuming 2 cleanouts per year) ranged from ~6,300 mg to 9,500 mg. The mass of mercury removed per acre treated ranged from 0.03 mg/acre/yr to 50 mg/acre/yr. For both PCBs and mercury, the larger catchments more frequently had lower rates of POCs per acre, although there was not a consistent correlation between catchment size and the mass of POCs in the sump.

Table 3.4 PCBs and Mercury Mass Removed During HDS Unit Sump Cleanouts.[1]

HDS Unit ID	Total PCBs						Total Mercury					
	Mass of PCBs per CY of solids removed (mg)		Mass of PCBs removed per cleanout (mg)		Annual Mass of PCBs Removed (mg/Year)		Mass of Mercury per CY of solids removed (mg)		Mass of Mercury removed per cleanout (mg)		Annual Mass of Mercury Removed (mg/Year)	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1	8	17	21	47	43	93	20	30	54	82	109	163
2	3	7	8	17	16	34	18	27	43	65	87	130
3	14	30	49	107	98	213	47	71	167	250	333	500
4	149	325	606	1,318	1,212	2,636	146	218	591	886	1,181	1,772
5	0.5	1.1	1.0	2.1	1.9	4.1	9	13	17	25	33	50
6	48	104	480	1,044	960	2,088	1.0	1.4	9.7	15	19	29
7	9	19	90	197	181	393	11	16	113	170	227	340
8	4	9	147	321	295	641	59	88	2,179	3,268	4,357	6,536
				Total Sum	**2,807**	**6,104**				**Total Sum**	**6,347**	**9,520**

[1]The low and high estimates of mass of PCBs and mercury removed were calculated from the measured PCBs and mercury concentrations in this study and +/- mean RPD of Bay Area sediment PCBs concentrations of +/- 37% (PCBs) and +/- 17% (mercury), as described in Section 2.4.1.

3.2.3 HDS Catchment POC Loads and Calculated Percent Removals Due to Cleanouts

The annual POC loads discharged from each HDS Unit catchment calculated using Method #1 and Method #2, along with the calculated percent removals are presented in Tables 3.5 and 3.6 for PCBs and mercury, respectively. For the purpose of calculating descriptive statistics, percent removal was capped at 100%.

Table 3.5 HDS Unit Percent Removal of PCBs for Catchment Loads Calculated using Method #1 (Land use-based Yields) and Method #2 (RWSM Runoff Volume x Concentration).

	Method #1 Catchment Load Land Use-Based Yields				Method #2 Catchment Load RWSM Runoff Volume x Concentration			
	HDS Catchment Info		HDS Performance Annual Percent Removal		HDS Catchment Info		HDS Performance Annual Percent Removal	
HDS Unit ID	**PCBs Yield (mg/acre/yr)**	**PCBs Load (mg/yr)**	**Low**	**High**	**PCBs Yield (mg/acre/yr)**	**PCBs Load (mg/yr)**	**Low**	**High**
1	16	53	80%	100%	3	9	100%	100%
2	26	187	8%	18%	22	158	10%	22%
3	30	2,281	4%	9%	6	478	21%	45%
4	31	3,192	38%	83%	44	4,478	27%	59%
5	25	3,135	0.06%	0.13%	7	898	0.2%	0.5%
6	32	19,209	5%	11%	8	4,832	20%	43%
7	41	28,828	0.6%	1.4%	49	34,806	0.5%	1.1%
8	28	20,735	1.4%	3.1%	5	3,997	7%	16%
Median	**29**	**3,164**	**5%**	**10%**	**8**	**2,447**	**15%**	**32%**
Range	**16 - 41**	**53 - 28,828**	**0.06%**	**100%**	**3 - 49**	**9 - 34,806**	**0.2%**	**100%**

With the catchment loads calculated using Method #1, the PCBs percent removal varied greatly between HDS units, ranging from a low of <1% removal to a high of 100% removal. The median percent removal across all 8 units ranged from 5% to 10%.

With the catchment loads calculated using Method #2, the PCBs percent removal also varied greatly between HDS units, ranging from a low of <1% removal to a high of 100% removal. However, the median removal rate across all eight units was higher, ranging from 15% to 32%. Again, the variability in removal rates between individual HDS units was high. Generally, the percent removals were lower for a given HDS unit when the catchment loads were calculated using Method #1 compared with Method #2. Only HDS Unit #4 had a higher percent removal under Method #1.

Table 3.6 HDS unit Percent Removal of Mercury for Catchment Loads Calculated using Method #1 (BASMAA Land use-based Yields) and Method #2 (RWSM Runoff Volume x Concentration).

	Catchment Load for Method #1 BASMAA Land Use-Based Sediment Yields				Catchment Load for Method #2 RWSM Runoff Volume x Concentration			
	HDS Catchment Info		HDS Performance Annual Percent Removal		HDS Catchment Info		HDS Performance Annual Percent Removal	
HDS Unit ID	**Mercury Yield (mg/acre/yr)**	**Mercury Load (mg/yr)**	**Low**	**High**	**Mercury Yield (mg/acre/yr)**	**Mercury Load (mg/yr)**	**Low**	**High**
1	126	412	26%	40%	21.0	69	100%	100%
2	297	2,140	4%	6%	18.4	133	65%	98%
3	215	16,188	2%	3%	55.4	4,174	8%	12%
4	233	23,876	5%	7%	67.7	6,928	17%	26%
5	192	24,479	0.14%	0.20%	23.9	3,055	1.1%	1.6%
6	257	152,118	0.01%	0.02%	23.5	13,922	0.1%	0.2%
7	551	391,874	0.06%	0.09%	16.8	11,940	1.9%	2.8%
8	198	147,379	2%	3%	21.7	16,084	27%	41%
Median	**224**	**24,177**	**2%**	**3%**	**23**	**5,551**	**13%**	**19%**
Range	**126 - 551**	**412-391,874**	**0.01%**	**40%**	**21 - 68**	**69 - 16,084**	**0.13%**	**100%**

For mercury, the removal rates for catchment loads calculated using Method #1 ranged from 0.01% to 40% removal, and the median percent removal across all eight units ranged from 2% to 3%. The mercury removal rates for catchment loads calculated using Method #2 ranged from a low of <1% removal to a high of 100% removal. The median removal rate across all 8 units ranged from 13% to 19%. These results show the percent of mercury capture for both catchment load calculation methods was typically lower than for PCBs, which is consistent with observations in other studies of BMP effectiveness in the Bay Area (Gilbreath et al. 2019, David et al. 2015, Yee and McKee 2010).

One notable difference between the catchment load calculation methods presented in Tables 3.5 and 3.6 is that the catchment-specific yields (POC mass per acre per year) calculated for the same HDS unit catchment under each method are substantially different. The RPDs for the paired catchment-specific yields calculated under Scenario 1 and Scenario 2 ranged from 3% to 67%, with an average of 39% for PCBs. Also, for PCBs the differences in catchment yields for a given unit were not consistently higher or lower for Method #1 vs. Method #2 catchment load estimates. The RPDs between catchment yields under the 2 loading scenarios for each HDS unit were generally larger for mercury, ranging from 47% to 90%, with an average of 68%.

Overall, the results of this study indicate the HDS unit performance appears to vary substantially between units, regardless of the method used to estimate the catchment loads. Even when normalized to the area of the HDS unit catchment, the POCs removed per acre treated were highly variable between units, ranging up to over a thousand fold difference between the highest and lowest capture rates. The method used to calculate the catchment annual loads also impacts the calculated performance of the individual HDS units.

3.2.4 Limitations

It is important to note, that all of the assumptions that were used in the calculations described in this report represent important limitations of this study and highlight the paucity of data that are currently available to evaluate HDS Unit performance for PCBs and mercury removals. Although this study provided new data on the concentrations of POCs in the solids removed from HDS unit sumps during cleanouts, the data set remains small (n=8), especially in comparison to the expected (and observed) variability between each unit. The calculated removal rates, even under the same loading scenario, were highly variable across different HDS Units, ranging from almost zero POC removal, to 100% removal of all POCs discharged from the catchment. Although an estimate of variability in POC concentrations was applied based on information about the variability in street dirt and storm drain sediments, the authors of this report acknowledge this estimated variability likely falls far short of accounting for the full range of variability and error in the input parameters used to calculate the POC removal rates presented here. Much more data would be needed to improve these estimates and better characterize the true variability in removal rates between units, and within the same unit over time.

One data input that proved particularly difficult to account for was the volume of solids (and associated mass) that was removed from HDS units during each cleanout. This study relied on the limited information recorded in maintenance records provided by individual cities for each of the HDS units in this study. The information that was provided varied from cleanout to cleanout, and from city to city. Although some cities provided measurements of the depth of solids in a unit at cleanout, which allowed a more accurate calculation of the total solids volume, in many cases, the information provided was likely based on a visual assessment by the maintenance staff onsite at the time of the cleanout, and thus subject to a large degree of error.

Nevertheless, this study increased the number of data points on POC concentrations in the solids removed from HDS Unit sumps during cleanouts from n=2 (the Leo Ave HDS data from CW4CB) to n=10, an increase of 500%. Furthermore, because of the careful review of maintenance records that was performed as part of this study, the authors were able to identify a number of recommendations (provided in Section 4) for improving the removal effectiveness of HDS unit maintenance practices, and improving the quality of maintenance records for the purpose of quantifying solids removed, and. the volume of solids associated with pollutants.

4 CONCLUSIONS

The Project combined sampling and modeling efforts to evaluate the mercury and PCBs removal performance of HDS units. Samples of the solids captured in 8 HDS units in the Bay Area were collected and analyzed for PCBs and mercury. The monitoring data collected by this project provided partial fulfilment of MRP monitoring requirements for management action effectiveness under provision C.8.f., and also addressed some of the data gaps on BMP effectiveness that were identified by the CW4CB project (BASMAA, 2017b). This study also reviewed information on HDS Unit maintenance practices, including the frequency of cleanouts, the volumes of solids removed during these cleanouts, and the types of materials contained within the solids. This information was used to develop estimates of the average solids removal per cleanout, and combined with concentration data, the mass of mercury and PCBs removed per cleanout. Finally, the percent removals achieved by HDS unit cleanouts were calculated using two different methods to estimate the catchment loads, including BASMAA land use-based pollutant yields (BASMAA 2017a), and RWSM runoff-concentration load estimates (Wu et al. 2017).

Based on median values, the results of this study suggest HDS unit maintenance practices reduce loads of PCBs from 5% to 32%, while mercury load reductions are lower, ranging from 3% to 19%. For both PCBs and mercury, the data from this study demonstrate the percent removals achieved by HDS unit cleanouts are highly variable across units, and likely variable within the same unit over time.

The conclusions on pollutant removal effectiveness of HDS unit sump cleanouts based on the results of this study are limited by the small number of HDS units that were sampled (n=8) and the limited, and often incomplete, maintenance records that were available at the time of this study. Nevertheless, the results of this study provide new information on the range of pollutant concentrations measured in HDS unit sump solids. Much more data would be needed to fully characterize the range of pollutant load reductions achieved by HDS units over longer periods of time and across varying urban environments.

In addition to the conclusions above, this study also identified the following suggestions for potentially increasing the PCBs and mercury removal effectiveness of HDS unit maintenance practices, and to improve the quality of the data available for calculating loads reduced. First, review of maintenance records indicated that the HDS unit sumps were often full or nearly full when the cleanouts occurred. Because no pollutant removal can occur after the sumps are 100% full, conducting cleanouts well before capacity is reached would likely improve pollutant removal rates for a given unit. However, given the site-specific nature of sump loading and variability across time, both the cleanout frequency and the cleanout methods required are likely to be highly site-specific. Development of site-specific standard operating procedures (SOPs) for cleanout frequency and cleanout methods for each HDS unit may be needed to ensure efficient and consistent practices over time. Frequent inspections of HDS unit sumps may also provide the information needed to determine an appropriate cleanout frequency for each HDS unit.

Second, review of maintenance records highlighted the need for more detailed and consistent reporting on each cleanout. The maintenance records provided by municipalities in this study varied considerably in the quantity and quality of the information provided. The variability was high both between cities, and within cities for the same unit over time. To improve estimates of the solids removal achieved per cleanout (and the associated pollutant removals achieved), consistent recording of the following information for each cleanout would be useful.

- cleanout date
- measured depth of solids in the sump prior to cleanout;
- measured depth of water in the sump prior to cleanout;
- an estimate of the volume of water removed during the cleanout;
- an estimate of the volume of solids removed during the cleanout;
- a description of the materials contained in the sump solids – including estimates of the percent contribution by volume of sediment, organic materials (leaves and vegetation), trash and large debris, and floatables;
- clearly identify all cleanouts that ONLY remove floatables;

The information above would provide better estimates of the solids removed per cleanout, and a better understanding of the solids captured in HDS units that are likely associated with POCs. Both pieces of information are important for improving estimates of pollutant removal effectiveness of HDS unit cleanouts. This information could also be reviewed periodically to determine if the appropriate cleanout frequencies are being maintained.

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APPENDIX A: FINAL STUDY DESIGN

POC Monitoring for Management Action Effectiveness

Monitoring Study Design

Final, September 2017

Prepared for:

Bay Area Stormwater Management Agencies Association

Prepared by:

EOA inc.
1410 Jackson Street
Oakland, California
94612

Water Programs, Sacramento State
6000 J Street
Sacramento, California
95819

SFEI
4911 Central Avenue
Richmond, California
94804

Kinnetic Laboratories Incorporated
307 Washington Street
Santa Cruz, California
95060

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1. Introduction

Discharges of PCBs and mercury in stormwater have caused impairment to the San Francisco Bay estuary. In response, the Regional Water Board adopted total maximum daily loads (TMDLs) to address these pollutants of concern (POC) (SFBRWQCB, 2012). Provisions C.11 and C.12 the Municipal Regional Stormwater NPDES Permit, MRP (SFBRWQCB, 2015) implement the Mercury and PCB Total Maximum Daily Loads (TMDLs) for the San Francisco Bay Area. These provisions require mercury and PCB load reductions and the development of a Reasonable Assurance Analysis (RAA) demonstrating that control measures will be sufficient to attain the TMDL waste load allocations within specified timeframes. Provision C.8.f of the MRP supports implementation of the mercury and PCB TMDLs provisions by requiring that Permittees conduct pollutants of concern (POC) monitoring to address the five priority information needs listed below.

1. *Source Identification* – identifying which sources or watershed source areas provide the greatest opportunities for reductions of POCs in urban stormwater runoff;
2. *Contributions to Bay Impairment* – identifying which watershed source areas contribute most to the impairment of San Francisco Bay beneficial uses (due to source intensity and sensitivity of discharge location);
3. *Management Action Effectiveness* – providing support for planning future management actions or evaluating the effectiveness or impacts of existing management actions;
4. *Loads and Status* – providing information on POC loads, concentrations, and presence in local tributaries or urban stormwater discharges; and
5. *Trends* – evaluating trends in POC loading to the Bay and POC concentrations in urban stormwater discharges or local tributaries over time.

Table 8.2 of Provision C.8.f identifies the minimum number of samples that each MRP Countywide Program (i.e., Santa Clara, San Mateo, Alameda, and Contra Costa) must collect and analyze to address each monitoring priority. Although individual Countywide monitoring programs can meet these monitoring requirements, some requirements can be conducted more efficiently and will likely yield more valuable information if coordinated and implemented on a regional basis. The minimum of eight (8) PCB and mercury samples required by each Program to address information priority #3 is one such example. Findings from a regionally-coordinated monitoring effort would better support development of the RAA.

This Study Design describes monitoring and sample collection activities designed to meet the requirements of information priority #3 of Provision C.8.f of the MRP. The activities planned include field sampling of hydrodynamic separators and laboratory experiments with amended bioretention soils. Study planning is important to ensure that the right type of data are collected and there is a sufficient sample size and power to help address the management questions within the available time and budget constraints. Essential components of the study plan include describing problems, defining study goals, identifying important study parameters, specifying methodologies, and validating and optimizing the study design.

2. Problem Definition

Studies conducted to date have identified PCB source areas in the Bay Area where pollutant management options may be feasible and beneficial. Enhanced municipal operational PCB management options (e.g., street sweeping, storm drain line cleanout) have the advantage of being familiar and well-practiced, address multiple benefits, and the cost-benefit may exceed that for stormwater treatment (BASMAA, 2017a). Site-specific stormwater treatment via bioretention, however, is now commonly implemented to meet new and redevelopment (MRP Provision C.3) requirements. An added benefit of redevelopment is that PCB-laden sediment sources can be immobilized. However, many areas where certain land uses or activities generate higher PCB concentrations in runoff are unlikely to undergo near-term redevelopment, and instead may only be subject to maintenance operations or stormwater BMP retrofit projects implemented by the municipality. Consequently it is valuable to maximize cost effective PCB removal benefit of both operations and maintenance, and stormwater treatment.

Two treatment options that have the potential to reduce PCB discharges include hydrodynamic separators (HDS units) and enhanced bioretention filters. These options were pilot-tested in the Clean Watersheds for a Clean Bay (CW4CB) Project (BASMAA, 2017a). HDS units are being implemented for trash control throughout the Bay Area and collect sediment to some extent along with trash and other debris. Quantifying PCB mass removed by these units will help MRP Permittees account for the associated load reductions. For these and other control measures, an Interim Accounting Methodology has been developed based on relative mercury and PCBs yields from different land use categories (BASMAA, 2017c). Bioretention is a common treatment practice for new development and redevelopment in the San Francisco Bay Area, so enhancing the performance of bioretention is also attractive.

At this time reducing mercury loads in stormwater runoff is a lower priority than PCBs load reduction. The assumption during the MRP 2.0 permit term is that actions taken to reduce PCBs loads in stormwater runoff are generally sufficient to address mercury. Therefore, optimizing stormwater controls for PCBs is the primary focus in this study.

2.1 HDS Units

Limited CW4CB monitoring conducted at two HDS sites was used to calculate the mass of PCBs in trapped sediment (BASMAA, 2017a). The two sites sampled were Leo Avenue in San Jose and City of Oakland Alameda and High Street. The Leo Avenue HDS unit treats runoff from approximately 178 acres of watershed with a long history of industrial land uses, including auto repair and salvage yards, metal recyclers, and historic rail lines. The City of Oakland Alameda and High Street HDS has a tributary drainage area of approximately 35 acres with a high concentration of old industrial and commercial land uses, including historic rail lines.

Sampling of the two CW4CB HDS units was opportunistic and associated with scheduled cleanouts. Two sump cleanout events took place in August 2013, one at the Leo Avenue HDS unit and one at the Alameda and High Street HDS unit. However, due to a lack of captured sediment the samples collected were aqueous phase samples instead of sediment samples. An additional cleanout took place at Leo Avenue in October 2014. A sump sediment sample collected and analyzed during this cleanout contained total PCB concentrations of 1.5 mg/kg and mercury concentrations of 0.33 mg/kg for sediment less than 2 mm in size, and estimated annual total PCB and mercury removals were 375 mg and 82.4 mg, respectively (Table 2.1). The HDS sediment concentrations are comparable to previous Leo Avenue watershed measurements in sediments from piping assessed via manholes, drop inlets/catch basins, streets/gutters, and private properties (ND to 27 mg/kg for PCBs and 0.089 to 6.2 mg/kg for mercury) (BASMAA, 2014). At the Alameda and High Street HDS unit, tidal influences of Bay water prevented additional monitoring.

Table 2.1 Summary of Data Collected from Leo Avenue HDS during October, 2014 Annual Cleanout Event

Parameter	Result	Units
Volume of Sediment Removed	4	Cubic yards
Total PCBs Concentration	1.5	mg/Kg
Mercury Concentration	0.33	mg/Kg
Bulk density	0.67	g/cm^3
Percent solids	39	%
Particle Size (< 2 mm)	31	%

There are no known published studies characterizing HDS sediment for PCBs or mercury, so the Leo Avenue results are compared to relevant drain inlet/catch basin sediment studies. In the Bay Area, different municipalities have collected and analyzed drain inlet cleaning sediment samples. The analytical results for these drain inlet sediment samples are summarized in Table 2.2 (BASMAA, 2014). As can be seen from Table 2.2, the Leo Avenue sediment PCB concentrations are higher than those measured in Bay Area drain inlet sediment by up to an order-of-magnitude, but mercury concentrations are comparable.

Table 2.2 Summary of Bay Area Drain Inlet Sediment Concentration Data

(Based on readily available data; see BASMAA (2016b) for additional summaries for street and storm drain sediment)

	PCBs			Mercury		
Municipality	No. Drain Inlet Sediment Samples	Mean PCB DI Sediment Concentration (mg/Kg)	Median PCB DI Sediment Concentration (mg/Kg)	No. Drain Inlet Sediment Samples	Mean Mercury DI Sediment Concentration (mg/Kg)	Median Mercury DI Sediment Concentration (mg/Kg)
Fairfield & Suisun	8	0.244	0.055	16	0.510	0.228
San Mateo County Municipalities	29	0.318	0.123	28	0.160	0.147
San Carlos	22	0.267	0.129	25	0.167	0.147
Alameda County Municipalities	47	0.294	0.122	75	0.384	0.204
Berkeley	8	0.147	0.122	11	0.343	0.241
Oakland	24	0.402	0.155	28	0.539	0.297
San Leandro	11	0.219	0.106	21	0.230	0.151
Contra Costa County Municipalities	46	0.515	0.168	48	0.413	0.308
Richmond	31	0.736	0.482	28	0.460	0.349

Notes:

Mean and median drain inlet sediment concentrations were calculated from the SFEI database (SFEI 2010, KLI and EOA 2002; City of San Jose and EOA 2003).

Monitoring by the City of Spokane, Washington, showed total PCBs in catch basin sediment ranged between 0.025 mg/kg and 1.7 mg/kg for an industrial area with known PCB contamination (City of Spokane, 2015). A City of San Diego study characterized sediments in eight catch basins in a 9.5 acre area of downtown San Diego classified as high density mixed use with roads, sidewalks, and parking lots (City of San Diego, 2012). Concentrations of common aroclors in the catch basin sediments varied from about 0.040 to over 0.9 mg/kg. Monitoring by the City of Tacoma showed PCB concentrations in stormwater sediment traps varied from nondetect to a maximum near 2 mg/kg (City of Tacoma, 2015). The highest PCB concentrations in catch basin sediments ranged from 16 mg/kg in downtown Tacoma to 18 mg/kg in East Tacoma. These published drain inlet/catch basin studies show that PCB and mercury concentrations can vary substantially in storm drain sediments depending on the characteristics of the watershed.

Sampling of captured sediment at the Leo Avenue HDS in San Jose highlighted the potential of HDS maintenance as a management practice for controlling PCB and mercury loads. The BASMAA Interim Accounting Methodology that is currently being used to calculate load reductions assumes a default 20% reduction of the area-weighted land-used based pollutant yields for a given catchment. This default value was based on average percent removal of TSS from HDS units based on analysis of paired influent/effluent data. However, significant data gaps remain in determining the effectiveness of this practice and expected load reductions. HDS sediment sampling has been limited to a few samples. PCB concentrations in the Leo Avenue HDS sample were much higher than average concentrations in Bay Area drain inlet sediment. Drain inlet/catch basin sediment sampling by others suggests that sediment PCB and mercury concentrations can vary substantially from watershed to watershed. **The monitoring performed to date is not sufficient to characterize pollutant concentrations of sediment captured in HDS units that drain catchments with different loading scenarios (e.g., land-uses, stormwater volumes, etc.), nor to estimate the percent removal based on the pollutant load captured by the HDS unit. Additional sampling is needed to better quantify the PCB and mercury loads capture by these devices, and calculate the percent removal achieved**. Consequently, quantification of PCBs removed at other HDS locations and evaluation of the percent load reduction achieved is needed to provide better estimates of PCB load reductions from existing HDS unit maintenance practices.

2.2 Bioretention

The results of monitoring the performance of bioretention soil media (BSM) amended with biochar at one CW4CB pilot site suggest that the addition of biochar to BSM is likely to increase removal of PCBs in bioretention BMPs. Biochar is a highly porous, granular material similar to charcoal. In the CW4CB study, the effect of adding biochar to BSM was evaluated using data collected from two bioretention cells (LAU 3 and LAU 4) at the Richmond PG&E Substation 1st and Cutting site. At this site, cell LAU 3 contains standard engineered soil mix (60% sand and 40% compost) while cell LAU 4 contains a mix of 75% standard engineered soil and 25% pine wood-based biochar (by volume).

Figure 2.1 shows a cumulative frequency plot of influent and effluent PCB concentrations for the two bioretention cells. Although influent PCB concentrations at the two cells were generally similar, effluent PCB concentrations were much lower for the enhanced bioretention cell (LAU 4) compared to those for the standard bioretention cell (LAU 3). The results for total mercury were different from those for PCBs, with both cells demonstrating little difference between influent and effluent concentrations. These CW4CB monitoring results suggest that the addition of biochar to BSM may increase removal of PCBs but not mercury from stormwater. However, analysis of methylmercury indicated that BSM may encourage methylation while biochar may mitigate the effect such that there is no substantial transformation of mercury to methylmercury. Tidal influences at 1st and Cutting also may be a contributing factor that should be controlled in future study.

The majority of biochar research conducted to date has focused on agricultural applications, where biochar has been shown to improve plant growth, soil fertility, and soil water holding, especially in sandier soils. Only a handful of field-scale projects have investigated the effects of biochar in stormwater treatment and no known field studies have investigated removal of mercury or PCBs from stormwater by biochar-amended media.

A recent laboratory study on the effect of biochar addition to contaminated sediments showed that biochar is one to two orders of magnitude more effective at removing PCBs from soil pore water than natural organic matter, and may be effective at removing methylmercury but not total mercury (Gomez-Eyles et al., 2013). A laboratory column testing study to determine treatment effectiveness of 10 media mixtures showed that a mixture of 70% sand/20% coconut coir/10% biochar was one of the top performers and cheaper than similarly effective mixtures using activated carbon (Kitsap County, 2015). Liu et al (2016) tested 36 different biochars for their potential to remove mercury from aqueous solution and found that concentrations of total mercury decreased by >90% for biochars produced at >600◦C but about 40–90% for biochars produced at 300◦C.

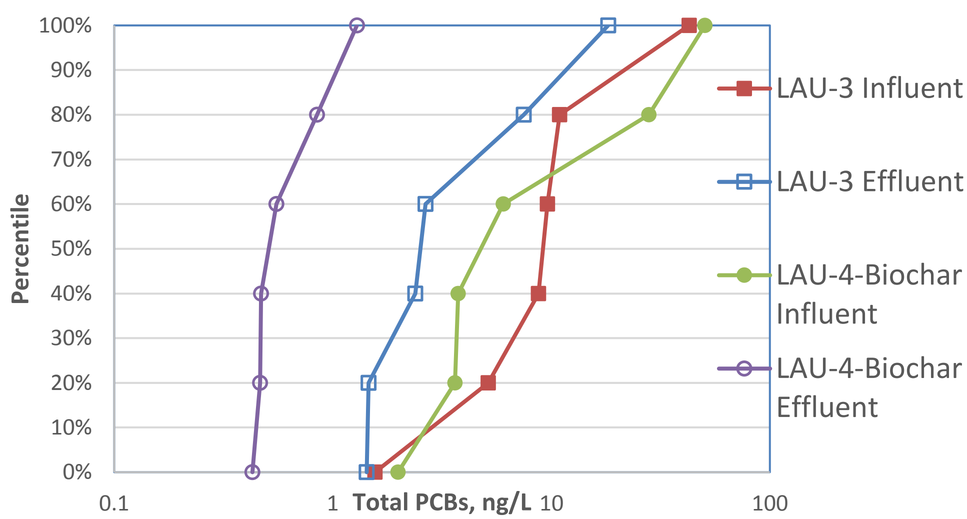

Figure 2.1 Cumulative Frequency Distribution of Total PBCs Influent Concentrations for Bioretention Media with and without Biochar

Monitoring of two bioretention cells at the Richmond PG&E Substation 1st and Cutting pilot site showed greater PCB removal for a biochar-amended BSM than that for standard BSM.

However, to date sampling has been limited to one test site and one biochar amendment, and the operational life of the amended media is unknown. **Besides the CW4CB study, there are no published literature studies on field PCB and mercury removal for biochars. Additional field testing can confirm the effectiveness of bioretention implementation in more typical conditions, and laboratory testing is recommended as an initial screening to help identify potential biochars for field testing**. Laboratory testing using actual stormwater from the Bay Area can be a cost-effective screening tool to identify biochar media that are effective for PCB removal, do not exacerbate mercury problems or even improve mercury removal, and meet operational requirements, including an initial maximum infiltration rate of 12 in/h and a minimum long-term infiltration capacity of 5 in/h.

3. Study Goals

The goals of this study identified from the problem statements are as follows:

1. Quantify annual PCB and mercury load removals during maintenance (cleanout) of HDS units
2. Identify biochar media amendments that improve PCB and mercury load removal by bioretention BMPs

To reach these goals, the following management questions are prioritized as primary or secondary management questions.

3.1 Primary Management Questions

A properly conceived study will address the study goals in a manner that supports planning for future management actions or evaluating the effectiveness or impacts of existing management actions. The resulting primary management questions focus on performance and are:

1. What are the average annual PCB and mercury loads captured by existing HDS units in Bay Area urban watersheds?
2. Are there readily available biochar-amended BSM that provide significantly better PCB and mercury load reductions than standard BSM and meet MRP infiltration rate requirements?

The MRP infiltration rate requirements are described in Provision C.3.c of the MRP (SFBRWQCB, 2015). This provision states the following: "Biotreatment (or bioretention) systems shall be designed to have a surface area no smaller than what is required to accommodate a 5 inches/hour stormwater runoff surface loading rate, infiltrate runoff through biotreatment soil media at a minimum of 5 inches per hour, and maximize infiltration to the native soil during the life of the Regulated Project. In addition to the 5 inches/hour MRP requirement, for non-standard BSM the recently updated BASMAA specification requires "certification from an accredited geotechnical testing laboratory that the bioretention soil has an infiltration rate between 5 and 12 inches per hour" (BASMAA, 2016a).

3.2 Secondary Management Questions

Secondary management questions are helpful, but they are not critical to the usefulness of the study. Study scope, budget, and schedule constraints limit the extent to which they can be addressed. Possible secondary management questions include the following:

HDS

1. How does sizing of HDS units affect annual PCB and mercury loads captured in HDS sediment?
2. Do design differences between HDS units (e.g., single vs multiple chambers) result in significant differences in pollutant capture?
3. How does the frequency of cleanout of HDS units affect load capture?

4. If present, does washout of HDS sediment depend on remaining sediment volume capacity?
5. Are there significant concentrations of PCBs in the pore (interstitial) water of HDS sediment?
6. Are PCBs and mercury removal correlated to removal of better-studied surrogate constituents, such as TSS?
7. Is there evidence of increased methylation within HDS sediment chambers?

Enhanced Bioretention

1. How does biochar performance vary with feedstock?
2. How does biochar performance vary with manufacturing method?
3. Should the biochar be mixed with the BSM or provided as a separate layer below the standard BSM?
4. Does biochar have leaching issues or require conditioning before use?
5. How long does the improved performance of biochar-amended BSM last?
6. Does the promising media increase methylation of mercury?
7. What is the expected increase in BSM costs due to inclusion of media amendment?
8. Does knowledge of the association of PCBs and mercury to specific particle sizes improve understanding of performance?
9. Is mass removal comparable to that expected from a conceptual understanding of removal mechanisms?

The above secondary management questions are provided as examples, and the questions answered will depend on budget, schedule, and actual data collected.

3.3 Level of Confidence

The level of confidence in the answers to the above management questions depends on sample representativeness and size. Samples are considered representative if they are derived from sites or test conditions that are representative of the watershed or treatment being considered. A power analysis can be used after monitoring commences or at the end of a study to determine if sample size is sufficient to draw statistically valid conclusions at a pre-selected level of confidence. Power analysis can also be used prior to study commencement, but its usefulness in estimating sample size requirements may be limited by lack of knowledge of variability in the biochar-amended BSM data to be collected.

Level of confidence can also be assessed in terms of consistency of treatment (e.g., a particular biochar consistently shows better removals than other biochars for a variety of stormwaters), which can be assessed with non-parametric approaches such as a sign-rank test.

Data analysis approaches are discussed in Section 8.5.

4. Study Design Options

An overview of the available study designs is presented here to understand the methods, value, and constraints of each design. This information is helpful in identifying which study designs are appropriate for the various management questions. To answer the primary management questions, the mass of pollutants captured must be quantified. This is accomplished by monitoring pollutant input and export for each HDS unit or media option, or directly quantifying captured pollutant. For example, the typical input and output pathways for a stormwater treatment measure (i.e., BMP) are illustrated in **Error! Reference source not found.**4.1. This overview describes how data are collected and how they are used to answer the primary study questions.

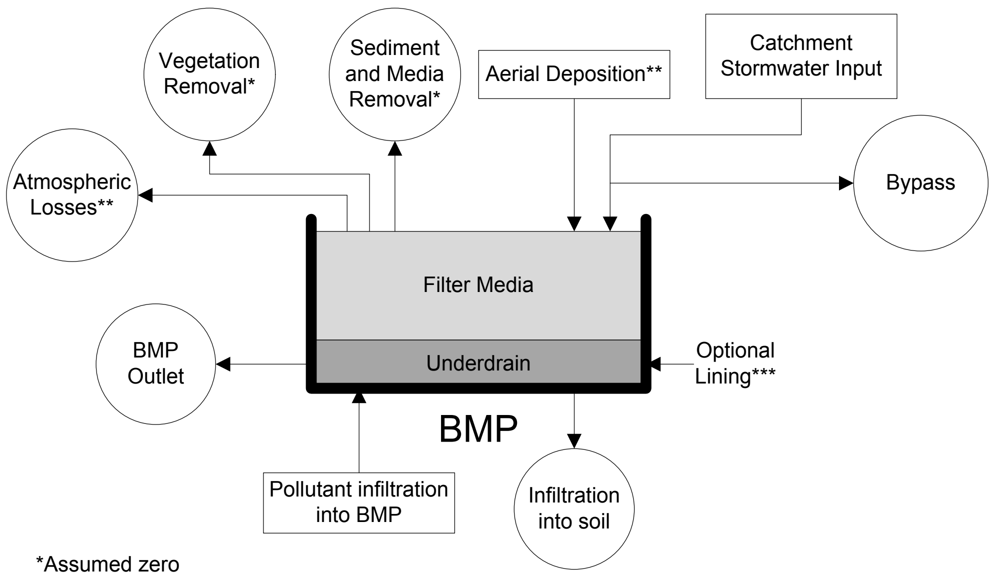

Figure 4.1 Typical BMP system and pollutant pathways

The study designs discussed here address major inputs and losses, but not all. Selection of study design is based on the management questions, the type of BMP(s), the study constraints, and the current and historic conditions of the study area. Each type of study has associated strengths and weaknesses as described below:

- Influent-effluent monitoring
  Influent and effluent monitoring tests water going into and discharging from a selected BMP or treatment option for a particular storm event. This approach is typically used to assess BMP effectiveness. An advantage of this approach is its ability to discern differences in limited data sets. A weakness of this approach is that measured load reductions may not be representative of true load reductions if there is infiltration to the native soil, baseflow entering the BMP, or bypass flows that are not monitored

- Sediment sampling
  Sediment sampling occurs within the BMP or treatment option and is used to estimate cumulative load removed over several storms. Sediment sampling can occur in dry periods.
- Before-after monitoring
  Before-after monitoring occurs at the same location. In the before-after approach, data are collected at some location, a change is made (i.e., a BMP is implemented or modified), and additional data are then collected at the same location. This introduces variability because in field monitoring the storms monitored before BMP implementation may not have the same characteristics as those after implementation.
- Paired watershed monitoring
  Paired watershed attempts to characterize two watersheds that are as similar as possible, except one has BMP treatment (e.g., an HDS unit). The paired watershed approach is typically used when monitoring the influent of the BMP is infeasible. While the storms monitored are the same, inevitable differences in the watersheds often lead to unexplainable variability.

  Paired watershed monitoring is not discussed further because it is not applicable to this study. The scope of work does not require influent monitoring at field sites or monitoring of paired sites without BMPs.

Volume measurement is critical to estimating load removal efficiency for BMPs that have volume losses. Volumes can be measured at influent, effluent, and bypass locations and within the BMP for individual storms or over a longer period.

The following subsections provide more detail on each monitoring approach.

4.1 Influent-Effluent Monitoring

Comparison of influent and effluent water quality and load is the method most often used in studies of treatment BMPs. This method is used to estimate the pollutant removal capability of field devices such as individual BMPs or a series of in-line BMPs (i.e., a treatment train) or laboratory treatment systems such as filter media columns. This type of study results in paired samples. Paired samples are beneficial because fewer samples are needed to show statistically significant levels of pollutant reduction compared to unpaired samples. This can result in substantial cost savings for sample collection and sample analysis.

Comparison of performance among BMPs may not be possible if there are only a limited number of locations because of different influent qualities. This is illustrated in **Error! Reference source not found.** for two non-overlapping BMP data sets, which show confidence intervals for effluent estimates (vertical dashed and dotted lines with arrows) expand as the distance between the hypothetical influent *x*-value and the mean *x*-value of the data increases. Although the effluent estimates at a common influent concentration (solid black square and diamond) may reflect true effluent qualities, confidence in these predictions is low because of this extrapolation and the performance of the two BMPs may not be statistically distinguishable. A better study design is one that selects sites with similar influent characteristics or ensures collection of a sufficient number of samples at or close to the common influent level.

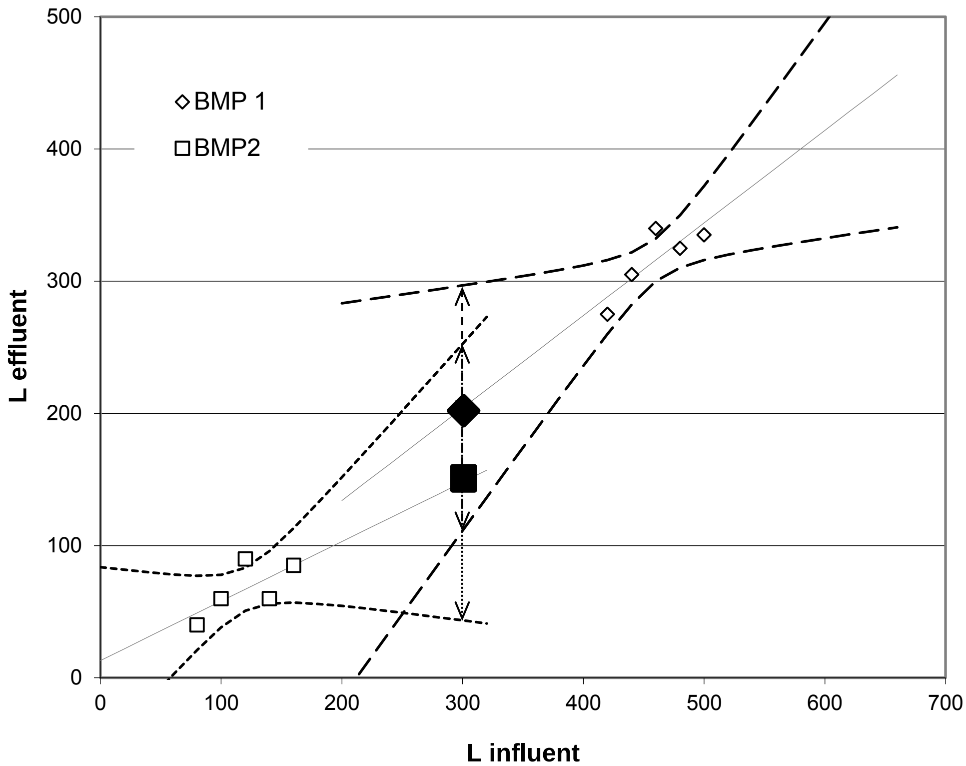

Figure 4.2 Comparison of two hypothetical non-overlapping BMP regressions

4.2 Sediment Sampling

Sediment sampling involves taking samples of actual sediment captured in a BMP in lieu of influent and effluent monitoring. Analysis of the accumulated sediment can provide estimates of the total mass of conservative pollutants removed[1]. An advantage of sediment sampling is reduced cost because expensive storm event sampling is not required. Another advantage is that the measure of pollutants is direct and it is not possible to obtain negative results as in the case of sampling highly variable influent/effluent.

There are a number of limitations to sediment sampling. Annual sediment sampling during a maintenance interval generates fewer data points than influent-effluent sampling throughout a storm season, so comparisons among BMP factors (design, loading, etc.) may require a greater number of monitoring sites. Another limitation is that influent monitoring data are not available to describe how the mass removal estimates may be sensitive to influent loading, and influent monitoring may be required in addition to sediment sampling to

[1] In the context of sediment sampling, "conservative pollutants" are those that are not substantially lost to volatilization or plant uptake in between periods of sediment analysis. Sediment analysis underestimates performance where volatilization or plant uptake is substantial.

characterize pollutant loading. This limitation is addressed in this study during the data analysis by using model estimates of stormwater flows and pollutant loads from each HDS unit catchment to provide estimates of the influent and associated percent removals achieved.

Another limitation of sediment sampling is the potential error resulting in non-homogeneous pollutant distribution within the sediment. Compositing multiple samples will better characterize the sediment, much as the collection of several aliquots throughout a stormwater runoff event can better represent the total volume of water. Mixing the removed sediment before compositing can provide samples that are more homogeneous.

Consequently, the effectiveness of sediment sampling depends on the type of BMP. HDS are the best candidates for sediment sampling. The sumps are cleaned and empty at the start of the study, and the entire mass of retained sediment is removed at each maintenance event (sump cleanout). Conversely, bioretention has background sediment (planting media) that obscure pollutant accumulation. Since pollutants tend to accumulate on the surface of media (typically within the first few inches), surface sediments should be targeted when sampling these systems. Coring these systems and compositing the core sediments will most likely result in further dilution of the PCBs retained in the media, making quantification more difficult. For all systems, larger pieces of litter and vegetation may be difficult to include in the analysis. A conservative approach is to exclude larger material and assume these have little association with PCBs.

4.3 Before-After Monitoring

Pollutant removal can also be estimated by monitoring discharge quality for treatment devices before and after installation. This may be attractive for green street projects that have multiple BMPs with multiple influent and effluent locations. Monitoring all of these individual systems is almost impossible because of space constraints. Note that since the data from before/after implementation are unpaired, variability is expected to be larger and the number of samples required to show significant removal much higher than for paired samples.

Before-after monitoring is also applicable to laboratory test systems in which water quality is measured before and after a change is made. For example, the rate of adsorption or the adsorptive capacity of media can be determined by measuring the water quality before and after addition of a known quantity of media.

5. Primary Data Objectives

The study design options discussed previously are matched to the primary management questions. The primary management questions require two data objectives: determine annual mass captured by HDS units and load removal by biochar-amended BSM. The primary management questions are:

1. What are the **annual PCB and mercury loads captured** by existing HDS units in Bay Area urban watersheds?
2. Are there readily available biochar-amended BSM that provide significantly better **PCB and mercury load reductions** than standard BSM and meet MRP infiltration rate requirements?

Monitoring to address the first management question should at minimum provide the average annual PCB and mercury loads captured by HDS units.

5.1 Data Objective 1: Annual Loads Captured by HDS Units

Determined by influent-effluent monitoring for individual storm events over one or more seasons or filter media/sediment sampling at end of each season.

Options:

- ❖ Influent-effluent monitoring. Requires monitoring of as many storms as possible over a season and flow measurement in addition to water quality sampling. Flow measurement is a critical component for estimating stormwater volumes treated, retained, and bypassed, and is often associated with additional measurements such as water depth within a BMP to estimate bypass and retention.
- ❖ Filter media/sediment sampling. Requires sampling at end of season but does not require influent/effluent water quality or flow measurement. Sediment sampling has a high value for estimating annual mass removal because a single composite sample of retained sediment over a season can yield an estimate of load removal for the constituents analyzed. However, influent characterization would also help explain mass removal performance. This method is most appropriate when applied to HDS systems because they can isolate retained sediment.

5.2 Data Objective 2: Loads Reduced by Biochar-Amended BSM

Determined by influent-effluent monitoring or filter media/sediment sampling for individual events until sufficient data are available for statistical analysis.

Options:

- ❖ Influent-effluent monitoring. Requires monitoring of multiple individual events and flow measurement in addition to water quality sampling. Accurate flow measurement in BMPs is difficult because flows can vary an order of magnitude during individual events and measurements may be required at multiple locations within a device because of bypass, infiltration etc. (see Figure 4.2). This complexity introduces a great degree of variability in the monitored data that can substantially increase the number of data points required to show statistically significant load removals, particularly for BMPs such as HDS units that show relatively small differences between influent and effluent load reductions. This option is most appropriate for testing filter media, for example in laboratory experiments, in which accurate flow measurements are possible and sampling of accumulated sediment is infeasible.

- Filter media/sediment sampling. Requires sampling after individual events but does not require influent/effluent water quality or flow measurement. This method is not feasible for filter media because the retained sediment cannot be isolated from the filter media.

6. BMP Processes and Key Study Variables

The treatment mechanisms that occur in a BMP help inform selection and control of the study variables. These treatment mechanisms, also called *unit processes*, may include physical, chemical, or biological processes. The primary physical, chemical, and biological processes that are responsible for removing contaminants include the following:

- Sedimentation – The physical process by which suspended solids and other particulate matter are removed by gravity settling. Sedimentation is highly sensitive to many factors, including size of BMP, flow rate/regime, particle size, and particle concentration, and it does not remove dissolved contaminants. Treated water quality is less consistent compared to other mechanisms due to high dependence on flow regime, particle characteristics, and scour potential.
- Flocculation – Flocculation is a process by which colloidal size particles come out of suspension in the form of larger flocs either spontaneously or due to the addition of a flocculating agent. The process of sedimentation can physically remove flocculated particles.
- Filtration – The physical process by which suspended solids and other particulate matter are removed from water by passage through layers of porous media. Filtration provides physical screening of particles and trapping of particles within the porous media. Filtration depends on a number of factors, including hydraulic loading and head, media type and physical properties (composition, media depth, grain size, permeability), and water quality (proportion of dissolved contaminants, particle size, particle size distribution). Compared to sedimentation, filtration provides a more consistent treated quality over a wider range of contaminant concentrations.
- Infiltration – The physical process by which water percolates into underlying soils. Infiltration is similar to filtration except it results in overall volume reduction.
- Screening – The physical process by which suspended solids and other particulate matter are removed by means of a screen. Unlike filtration, screening is used to occlude and remove relatively larger particles and provide little or no removal for particles smaller than the screen opening size and for dissolved contaminants.
- Sorption – The processes of absorption and adsorption occur when water enters a permeable material and contaminants are brought into contact with the surfaces of substrate media, plant roots, and sediments, resulting in short-term retention or long-term immobilization of contaminants. The effectiveness of sorptive processes depends on many factors, including the properties of the water (contaminant concentration, particle concentration, organic matter, proportion of dissolved contaminants, particle size, pH, particle size and charge), media type (surface charge, absorptive capacity), and contact time.

- Chemical Precipitation – The conversion of contaminants in the influent stream, through contact with the substrate or root zone, to an insoluble solid form that settles out. Consistent performance often depends on controlling other parameters such as pH.
- Aerobic/Anaerobic Biodegradation – The metabolic processes of microorganisms, which play a significant role in removing organic compounds and nitrogen in filters.
- Phytoremediation – The uptake, accumulation, and transpiration of organic and inorganic contaminants, especially nutrients, by plants.

The relative importance of individual treatment mechanisms depend to a large extent on the chemical and physical properties of the contaminant(s) to be removed i.e. the influent quality. The two contaminants of interest in this study are PCBs and mercury. PCBs are relatively inert hydrophobic compounds that have very limited solubility and a strong affinity for organic matter. They are often associated with fine and medium-grained particles in stormwater runoff, making them subject to removal through gravitational settling or filtering through sand, soils, media or vegetation. Most of the mercury in water, soil, and sediments is in the form of inorganic mercury salts and organic forms of mercury such as methylmercury that are strongly adsorbed to organic matter (e.g., humic materials). In general, mercury is most strongly associated with fine particles while PCBs are generally associated with relatively larger and/or heavier particles. It is therefore expected that sedimentation, flocculation, and related processes will be less effective for mercury removal than for removal of PCBs (Yee and McKee, 2010).

The following subsections provide a brief description of the BMP types being evaluated in this study, the unit processes involved in each, and key variables that indicate possible data collection approaches. The final selection of the quantity and type of data to collect is presented in the "Optimized Study Design" section.

6.1 HDS Units

Hydrodynamic separators rely on sedimentation and screening as the primary removal mechanism for sediment and particulate pollutants. Treatment performance is highly dependent on the following:

- Influent quality (contaminant concentration, proportion of dissolved contaminants, particle size, particle size distribution, and particle density)
- BMP design and hydraulic loading/flow regime (size of unit versus catchment area)
- Operational factors (remaining sediment capacity)

HDS effluent quality is highly variable, particularly for contaminants such as mercury that are associated with fine particles that are not as effectively removed in HDS. These devices are expected to require a relatively large number of influent-effluent samples to demonstrate statistically significant reductions in pollutant concentrations. Therefore, analysis of retained sediment is an appropriate alternative to influent-effluent sampling for determining pollutant mass captured. Sediment can be analyzed when the device is cleaned.

6.2 Bioretention

Bioretention is a slow-rate filter bed system. It is planted with macrophytes (typically shrubs and smaller non-woody vegetation). The major sediment removal mechanism is physical filtration through the planting media. When retention time is sufficient, dissolved constituents can be removed by sorption to plant roots in the planting media, which typically contains clays and organics to enhance sorption. Treatment performance is highly dependent on the following variables:

- Influent quality (contaminant concentration, particle concentration, organic matter, proportion of dissolved contaminants, particle size, particle size distribution)
- BMP design and hydraulic loading rate/head (size of the unit in relation to catchment area and storm character)
- Media type and properties (composition, grain size, grain size distribution, adsorptive properties, and hydraulic conductivity)
- Volume reduction by infiltration
- Operational factors (surface clogging, short-circuiting)

The effluent quality from bioretention and enhanced bioretention is expected to be consistently higher than for sedimentation-type BMPs. These devices are expected to require a relatively fewer number of samples than HDS units to demonstrate statistically significant reduction because of better treatment of fine particles and dissolved contaminants.

It is important to note that laboratory and not field bioretention systems are of interest in this study. These laboratory systems, essentially cylindrical columns filled with the media being tested, attempt to simulate most, but not all, of the chemical, biological, and physical processes that occur in field devices. For example, volume reductions due to infiltration are not simulated in laboratory column experiments. The advantages of using media columns as proxies for field devices include improved control over operation, monitoring, and sample collection in ways that would be impractical in the field. This improved control makes it possible to test a large number of potential media and identify the most promising for future field testing.

7. Monitoring and Sampling Options

Key variables that affect water quality and sediment quality data are identified from knowledge of treatment processes. The following lists the process variables identified through knowledge of the treatment processes:

- Influent quality (contaminant concentration, particle concentration, organic matter, proportion of dissolved contaminants, particle size, particle size distribution, particle density)
- BMP design and hydraulic loading (flow rate, hydraulic head, flow regime)
- Media type and properties (composition, grain size, grain size distribution, adsorptive properties, and hydraulic conductivity)
- Operational factors (surface clogging, short-circuiting, remaining sediment capacity)

Some of the above variables can be controlled and others are measured to determine their effect on water quality and sediment quality. Inevitably, some variables will be beyond the control of the study but their expected impact should be considered based on theory, past experience, models, or observations from other studies.

7.1 HDS Units

7.1.1 Influent Quality

The location of the BMP can greatly affect influent water quality such as pollutant concentrations and particle characteristics because land use and land cover affect sediment mobilization and pollutant concentrations within the sediments. Land use is often used as an indicator of pollutant loading. The land uses of the areas of interest include industrial, commercial/mixed use, roads/rail, institutional, and residential. Because of past use of PCB and past PCB and mercury handling practices, age of the land use is also important, with generally higher concentrations from older industrial, commercial, and transportation areas, and lower concentrations from newer residential areas. However, PCB analysis by the San Francisco Estuary Institute (SFEI) showed that PCB concentration patterns were patchy within larger urban watersheds with higher concentrations. This finding indicates that mass reductions of PCBs may require site-specific sampling of influent loads or site-specific quantification of mass removed. Mercury data suggest areas with higher mercury concentrations are not as pronounced although generally where there is PCB contamination there is also high to moderate Hg contamination (Yee and McKee, 2010).

Since HDSs are primarily installed for trash capture, their distribution within the study area is assumed to be random. However, the primary interest is in watersheds with relatively high pollutant loads that are most likely to result in significant removal in HDSs (e.g., the Leo Avenue watershed). Land use or land use based pollutant yields can be used to represent average influent water quality when influent monitoring is not conducted.

Figure 7.1 shows the land use based PCB and mercury loadings for key designated land use types. It can be seen that unit PCB loading from watersheds with higher PCB concentrations and mercury loading from old industrial watersheds are substantially higher than the other land uses. Assuming particle size, particle size distribution, and other stormwater characteristics are similar for the different land uses, HDSs in higher concentration watersheds or old industrial watersheds are expected to capture much higher pollutant loads than those in other watersheds.

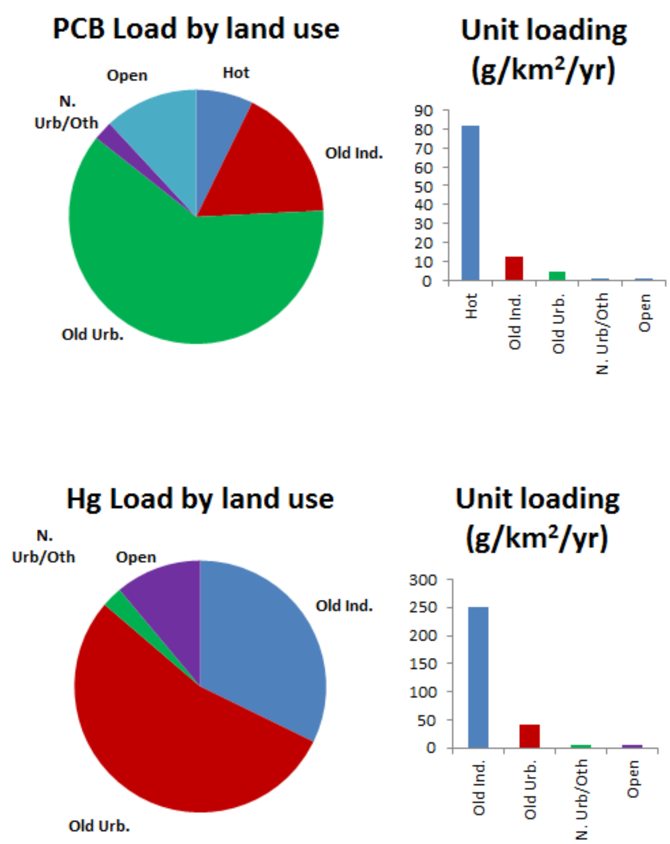

Figure 7.1 Land Use based PCB and Mercury Loading based on BASMAA Integrated Monitoring Reports (SFEI, 2015)

A preliminary land use based study design could categorize HDS sites as show in Table 7.1.

Table 7.1 HDS Sampling Design based on Watershed Land Use

Land Use	HDS Samples
Higher Concentration	X, X, X[1]
Old Industrial	X, X, X[1]
Old Urban	X, X, X[1]

1 – "X" represents a sample from a selected HDS unit in the specified land use category.

The above design is appropriate if HDS units can be categorized easily into one of the three land use categories. A review of the land uses within HDS watersheds indicates that most HDS units are in predominantly old urban watersheds, and it is unclear how many HDSs are within areas with higher PCB concentrations (Table 7.2).

Table 7.2 Percent of Land Use in HDS Watershed Areas

(Based on FY 2015-16 Co-permittee Annual Reports, Section 10 - Trash Load Reduction. Source: Chris Sommers Personal Communication)

HDS Catchment ID	New Urban	Old Industrial	Old Urban	Open Space	Other
287; Sonora Ave		16	84	1	
27A	15	50	34	2	
996; Parkmoor Ave		1	98	1	
1084; Oswego		0	89	0	10
600; Edwards Ave		33	39	28	
611; Balfour		14	55	30	
1082; Melody/33rd		0	97	3	
612; Lewis			93	7	
604; Sunset			96		4
1012; Blossom Hill/Shadowcrest			100	0	
1083; Lucretia		0	98	1	1
1002; Selma Olinder		10	86	5	
995; Dupont St.		9	91	0	
9-A; 73rd Ave and International Blvd		0	94	6	
475; 7th		68	29	3	
509; Coyote	22		77	1	
47			99	1	
8-A; Alameda Ave near Fruitvale		40	57	4	
575; Bulldog		6	93	1	
601; W. Virginia		7	90	3	
1504; Phelps			100	0	
390; Remillard		4	87	10	
Tennyson at Ward Creek		1	97	2	
W Meadow Dr		2	97	1	
Leland and Fair Oaks		1	99		
Ward and Edith			100	0	
5-D; 22nd and Valley		1	99	0	
8-C; High St @ Alameda Bridge		67	32	0	
5-G; Perkins & Bellvue (Nature Center)			100		
999; William		0	95	5	
Main St and Hwy 1			85	15	
Central Expy at Fair Oaks		11	89	0	
393; Wool Creek		18	78	4	
5-C; 27 St & Valdez Ave		2	98		
998; Pierce		1	96	3	
Maple and Ebensburg			98	2	
Ventura Ave			99	1	
Golden Gate and St Patrick			100	0	
5-A; Euclid Ave @ Grand Ave			100		
5-H; Lake Merritt (SD Outfall 11)			100		
5-B; Staten Ave & Bellvue			100		
Central Expy at De la Cruz		33	67		
5-I; Lake Merritt (SD Outfall 26)			100		
Mathilda overpass project CDS2		0	100		
Mathilda overpass project CDS1		10	84	7	

Given the few sites in categories other than old urban, an alternative study design based on mixed land uses may be more appropriate (Table 7.3).

Table 7.3 HDS Sampling Design based on Predominant Land Use

Predominant Land Use	HDS Samples
Higher Concentration/Old Industrial	X, X, X[1]
Old Urban/Old Industrial	X, X, X[1]
New Urban/Old Urban	X, X, X[1]

1 – "X" represents a sample from a selected HDS unit in the specified land use category.

The sampling design in Table 7.3 assumes that at least three HDS units are available for sampling in each PCB land use category. The sampling design may need to be modified further if there are an insufficient number of units available for sampling. For example, any site with more than 30% old industrial may be considered especially if it is a mixed zoned watershed (with industrial, commercial, residential and transportation land uses). The range of values in each land use category can be determined upon review of the most recent information. The design in Table 7.3 assumes that the characteristics of the runoff (e.g., particle sizes) are similar for the different land uses and only the yield is different.

Only sediment sampling is proposed for HDS. Since HDS influent-effluent monitoring is not required, variables such as proportion of dissolved contaminants, particle size, particle size distribution, and particle density are not measured or controlled, but their effect on influent quality and treatment is accounted for by randomly selecting HDSs within each land use category.

7.1.2 BMP Design and Hydraulic Loading

BMP design and hydraulic loading, which depends on the size of the BMP, can have a substantial impact on effluent water quality and the quantity of sediment retained in a BMP. Consequently, a full range of BMP designs and sizes are of interest. Properly sized, BMPs infrequently exceed their design capacity. However, BMPs are not always sized to standard specification, especially in retrofit environments in which typical hydraulic loading is much higher due to space constraints.

HDS units are typically proprietary and designs and sizing vary widely. Sediment capture may vary because of design differences such as number of chambers and design of overflow weirs and baffles, as well as different sizing criteria that can greatly affect both hydraulic loading and flow regime. The purpose of the study is to characterize sediment in HDS units in the study area. Since BMP design and sizing are important factors affecting HDS performance, it is necessary to include a range of HDS units in the study design and not just randomly select HDS units. A randomized blocked study design is therefore considered more appropriate than a completely random one that may result in an insufficient number of HDS units of a certain size.

In a randomized design, one factor or variable is of primary interest (e.g., land use), but there are one or more other confounding variables that may affect the measured result but are not of primary interest (e.g., HDS design, HDS size). Blocking is used to remove the effects of one or more of the most important confounding variables and randomization within blocks is then used to reduce the effects of the remaining confounding variables. An appropriate sampling design could therefore be land use as the primary factor and HDS size as the blocking factor. Since the population of HDS units in the land use categories of interest is limited, only two size blocks are used (≤ 50th percentile, > 50th percentile), and other variables such as design differences are accounted for by random selection within each block (Table 7.4).

Table 7.4 HDS Sampling Design based on Predominant Land Use and HDS Size

Predominant Land Use	HDS Size	
	≤50th percentile	>50th percentile
Higher Concentration/Old Industrial	X, X, X[1]	X, X, X[1]
Old Urban/Old Industrial	X, X, X[1]	X, X, X[1]
New Urban/Old Urban	X, X, X[1]	X, X, X[1]

1 – "X" represents a sample from a selected HDS unit in the specified land use category.

For the sampling design in Table 7.4, an HDS size factor is required to differentiate the two types of sizes that are of interest. In controlled field study of 4 different proprietary HDS units and laboratory testing of 2 other units, Wilson et al. (2009) developed a *performance function* (treatment factor) that reasonably predicted the removal efficiency of a given hydrodynamic separator. The performance function explained particle removal efficiency in terms of a Péclet number, P_e, which accounts for particle settling and turbulent diffusion. In the following equation, V_s is the particle settling velocity, h is the settling depth in the device, d is the device diameter, and Q is the flow through the device:

$$P_e = \frac{V_s h d}{Q}$$

The above Péclet number (Wilson et al's performance function) can be used in the sampling design as the HDS size factor. For grouping the available HDS units into the two blocks, information is required on the particle diameter and design parameters for each device (settling depth, diameter, and design flow). Particle diameter can be assumed to be 75 µm, which is the critical size used for partitioning PCB fractions in Yee and McKee (2010), and is also approximately the size separating silt and fine sand size particles. The design flow can be calculated from knowledge of the drainage area to the device and a standard design storm. Note that the design flow should not be based on manufacturer guidance because different manufacturers use different sizing criteria and device sizing may not always follow manufacturer guidance.

The final sampling design may need revision depending on the monitoring approach, availability of HDSs, information on watershed land use and sizing, and the level of participation from municipalities.

7.1.3 Operation and Maintenance

Maintenance frequency can greatly impact BMP performance. For sedimentation BMPs such as HDS, sediment levels may exceed the sediment capacity of the BMP, decreasing the volume for sedimentation and increasing scour.

Operation and maintenance (e.g., cleanout frequency) are not of direct interest in this study and their effect on treatment is not being tested. However, these are confounding variables that need to be excluded. In the HDS sediment sampling design, HDS units that are considered at capacity or will reach capacity during the study should be excluded from the population of interest. Field observations are required to make this determination (e.g., whether the screen is blocked). These units can be cleaned out and sampled in a subsequent year. For each selected HDS unit, maintenance schedules (past and current) will need to be reviewed to determine the time period over which sediment accumulated.

7.2 Enhanced Bioretention

7.2.1 Influent Quality

The purpose of the laboratory testing is to screen alternative biochar-amended BSM and identify the most promising for further field testing. The laboratory testing requires influent-effluent monitoring. Influent water characteristics can vary depending on the source of the test water. PCB and mercury loading is largely a result of historic activities that result in accumulation in sediments of pervious areas. Mobilization of these sediments may require exceeding site-specific intensity and volume thresholds. Storm intensity is critical to detach and mobilize particles and storm volume must exceed any depression storage within the pervious areas. However, the precise effect of storm intensity and volume on the mobilization of PCB-contaminated and mercury-contaminated sediments has not been established. Influent water characteristics also depend greatly on drainage area characteristics including traffic and industrial and commercial activity.

Since the purpose of the laboratory study is to screen alternative biochar-amended BSM that can be used throughout the Bay Area, collection and use of stormwater from one or more representative watersheds is preferred. A preliminary review of available Bay Area stormwater runoff monitoring data from 27 sites (Table 7 of SFEI 2015) suggests median PCB concentration is about 9 ng/L. Therefore, one or more previously monitored watersheds with mean PCB concentrations well above 10 ng/L may be appropriate for collection of stormwater for the laboratory testing. Since the relative treatment performance of the various media at even lower concentrations may be different, additional tests with diluted stormwater may be required to confirm study results.

Storms from the representative watershed should be targeted randomly without bias, thereby accounting for the effects of storm intensity and ensuring variability in contaminant concentration, proportion of dissolved contaminants, particle size, particle size distribution, and particle density. To achieve this, minimal mobilization criteria should be used to ensure predicted storm intensity and runoff volume are likely to yield the desired volume.

7.2.2 BMP Design and Hydraulic Loading

The design variables in the enhanced bioretention testing laboratory study include media type, media depth, and media configuration. Media type is a key variable that is discussed further below. Testing the effect of different media depths or media configurations is not a research objective of the laboratory study, so these can be fixed for all experiments. Typical bioretention media depth in the Bay Area is 18 inches, so all column experiments should use 18 inches of BSM. In the Richmond PG&E Substation 1st and Cutting enhanced BSM testing, the biochar was not installed as a separate layer but was instead mixed with the standard BSM. It is unclear how treatment is affected by these two media configurations, but for consistency with previous field work the biochar and standard BSM should be mixed.

Hydraulic loading is a controlled variable that can be kept constant for all columns. Since the laboratory study is attempting to replicate field bioretention, the hydraulic loading can be the design loading for bioretention. Bioretention designs in the Bay Area typically have a maximum ponding depth of 6 inches, so a loading of 6 inches could be used for the column tests. There are two options for loading the columns: pump and manual. Peristaltic pumps are ideal for controlled loading, but in this study manual loading (batch loading) is more appropriate because of the potential for PCBs and mercury to stick to tubing, pump parts, etc. For manual loading, up to 10 inches of stormwater may be needed each time to ensure sufficient sample volume.

7.2.3 Media Type and Properties

Media type and properties have a substantial effect on the treatment performance of filtration devices. This group of variables include composition, grain size, grain size distribution, adsorptive properties such as surface area, and hydraulic conductivity. Media composition is a primary variable that accounts for differences in the biochars used and the proportion of each biochar in the amended BSM mix. The other variables (grain size, grain size distribution, adsorptive properties, and hydraulic conductivity) are not of direct interest in this study and are assumed to vary randomly or are controlled through screening experiments that limit their variability.

Biochar is produced from nearly any biomass feedstock, such as crop residues (both field residues and processing residues such as nut shells, fruit pits, and bagasse); yard, food, and forestry wastes; animal manures, and solid waste. Biochar feedstock and production conditions can vary widely and significantly affect biochar properties and performance in different applications, making it difficult to compare performance results from one study to another (BASMAA, 2017a). A laboratory study that characterized the physical properties of six different waste wood derived biochars found particle sizes ranging from over 20mm to fine powder and surface areas ranging from 0.095 to 155.1 m^2/g (Yargicoglu et al., 2015). The variability in biochar types and properties is expected to result in large variation in treatment efficiency and infiltration rates. Given the large number of potential biochars that could be tested and the need to meet an initial maximum 12 in/h infiltration rate and a minimum long-term infiltration rate of 5 in/h, a phased study design is appropriate. In such a phased study, promising readily available biochars are first identified through a review of the literature, and hydraulic screening experiments are performed on biochar-BSM media mixes to ensure infiltration rates are met prior to performance testing. This approach is expected to be the most cost-effective because it reduces analytical costs.

There is little information on hydraulic properties of bioretention media amended with biochar, and it is not clear what percentage of the amended BSM should be biochar to maximize treatment benefit. Given the variable physical size of the biochar media, relatively fine biochars could result in a mix that does not meet the initial 12 in/h maximum infiltration rate or minimum 5 in/h long-term infiltration rate. Kitsap County (2015) tested a BSM mix containing 60% sand, 15% Compost, 15% Biochar, and 10% shredded bark, and found that the biochar mix had an infiltration rate of only 6.0 in/h. One conclusion of the study was that the reduction in infiltration rate with the biochar additive was most likely because of fines in the biochar. To overcome this, hydraulic screening experiments are required in which the infiltration rate for each media mix is measured prior to water quality testing to ensure that both the maximum and minimum rates are met. Initially, each biochar can be mixed with standard BSM at a rate of 25% biochar by volume (the same as that at the CW4CB Richmond PG&E Substation 1st and Cutting site). Hydraulic conductivity can be determined using the method stated in the BASMAA soil specification, method ASTM D2434, which requires measurement of water levels and drain times. If a mix does not meet the infiltration requirements, the percentage of biochar is adjusted and the new mix tested. Amended mixes that do not meet the infiltration rate requirements are removed from further consideration (i.e. the effect of hydraulic conductivity is controlled by screening).

The final phase of the laboratory study can be column testing to identify the most effective amended BSM mixes for field testing. An influent-effluent monitoring design is typically used in column testing and media effectiveness is assessed on a storm-to-storm basis with real stormwater collected in the Bay Area. Only media mixes that have passed the hydraulic screening should be tested. All media columns should be sufficiently large or replicated to account for or minimize the impact of variability in media installation and experimental technique. Standard BSM should be used as a control since the primary interest is to identify media mixes that perform significantly better than standard BSM. An example of the column sampling design for 5 new media mixes and one standard BSM control is shown in Table 7.5. The key variable of interest in the sampling design in Table 7.5 is the media mix (composition).

Table 7.5 Example Sampling Design for Laboratory Column Experiments

Biochar/BSM Mix	Column Samples
A Mix	X, X, X[1]
B Mix	X, X, X[1]
C Mix	X, X, X[1]
D Mix	X, X, X[1]
E Mix	X, X, X[1]
Control Mix	X, X, X[1]

1 – "X" represents an influent or effluent sample.

7.2.4 Operation and Maintenance Parameters

Operational life depends on the capacity to pass the minimum required stormwater flows. Like media life, operational life is important because it determines the frequency and cost of maintenance requirements. Maintenance frequency can greatly impact BMP performance, and lack of maintenance can lead to surface clogging and sediment clogging in the inlets which reduces treatment capacity and increases bypass and overflow. Operation and maintenance are not of direct interest in this study and their effect on treatment is not being tested. However, these are confounding variables that need to be excluded.

Media mixes that do not meet the maximum 12 in/h and minimum 5 in/h infiltration rates can be excluded by hydraulic screening experiments (discussed above). As well as meeting the maximum 12 in/h initial infiltration rate requirement, these screening experiments help ensure that the BSM mixes do not fail during the laboratory testing. However, operational performance in laboratory experiments is not expected to be representative of that in the field because of differences in influent quality, variability in loading, effects of vegetation, etc. Therefore, laboratory estimates of long term infiltration rate are of little use and field testing is required to confirm that selected media mixes meet the long-term minimum infiltration rate of 5 in/h. The laboratory testing, however, can provide relative comparisons of hydraulic performance that can be used to decide and screen out media mixes that are likely to hydraulically fail in the field.

7.3 Uncontrolled Variables and Study Assumptions

The following assumptions were adapted from the Caltrans PSGM (Caltrans, 2009):

- Site Assumptions
  - HDS sediment concentrations are representative of the land use within the watershed, i.e. there are no sources of sediment from adjoining watersheds, from illicit discharges, or from construction activities
  - HDS sediment or influent is not affected by base flow, groundwater, or saltwater intrusion
  - Differences in storm patterns throughout the Bay Area are not sufficient to change the HDS performance measurements
  - Water quality of stormwater collected for laboratory testing is representative of that observed in Bay Area urban watersheds
- BMP Operation Assumptions
  - Sampled HDS units operated as designed (e.g., no significant scouring)
  - Volatilization of pollutants is negligible
  - There is no short-circuiting of flows in laboratory column studies
- Media Selection Assumptions
  - The readily available biochars selected are representative of all biochars
  - Selected media do not leach contaminates and media conditioning (e.g., washing) is not required
- Monitoring Assumptions

- Data collected from a few sites over a relatively short time span will accurately represent sediment at all HDS sites over longer time frames
- There are minimal contaminant losses in collecting and transporting water for laboratory experiments
- Water quality of stormwater for laboratory tests does not change significantly during each test
- Stormwater loading of laboratory columns is representative of loading in the field
- Long-term infiltration performance of biochar mixes is to be tested in the field

8. Final Study Design

The study design is optimized to answer the primary management questions within the available budget. The design used prioritizes sampling of HDS units, but allocates sufficient funding for minimum sampling requirements for the laboratory media testing study. Monitoring that does not relate directly to the primary management questions is considered lower priority.

8.1 Statistical Testing & Sample Size

In a traditional test of a treatment, the null hypothesis is that there is no difference between the influent and effluent of a treatment (i.e., the treatment does not work). In the case of HDS sampling, influent-effluent sampling is not required, and interest is only in determining if HDS units remove PCBs and mercury and how the sediment concentrations and load removals vary for different land uses, and for different rainfall and stormwater flow characteristics. Statistical testing in the HDS study is therefore limited to testing if there is a difference in the concentrations and loads captured by HDS units in different watersheds. This testing will require sampling of a sufficient number of HDS units in each land use category associated with differing pollutant load yields.

In the laboratory study, influent-effluent sampling is required and traditional statistical tests can be used depending on sample size.

As well as traditional statistical testing, confidence in the conclusions can be established by comparing total PCB and mercury performance to that for other constituents that directly affect it (e.g., suspended solids, total organic carbon) or have similar chemistry (e.g., other organics). As stated previously, total PCB and mercury concentrations are expected to correlate to some extent with particulates and organics. Comparisons to other constituents are particularly useful for studies in which treatment is expected to be low and the corresponding sample size requirements very high.

Sample size requirements are smaller for paired sampling designs (i.e., influent and effluent sampling for the same storm event) than for independent sampling designs. Paired sampling is not possible for the HDS sampling study that has no influent-effluent monitoring, but is possible in the laboratory media testing study. Additionally, the number of samples required to show significant treatment are generally fewer for filtration-type BMPs than sedimentation-type BMPs because of their better and more consistent treatment.

8.2 Constituents for Sediment Analysis

Constituents selected for HDS sediment analysis must meet the data objectives discussed previously in "Primary Data Objectives", and be consistent with Table 8.3 of the MRP (SFRWQCB, 2015). Sediment samples will be screened using a 2 mm screen prior to analysis. Table 8.1 lists the constituents for sediment quality analysis. Total organic carbon (TOC) is included because it is a MRP requirement and can be useful for normalizing PCBs data collected for the sediment.

The primary objective of sediment analysis is quantification of the mass of PCBs and mercury accumulating within HDS units. Consequently, PCBs and total mercury are analyzed for all screened sediment samples. The secondary objective is to establish a relationship between total PCBs, mercury, and particle size. Correlating total PCBs and mercury to particle sizes will complement past studies and provide insight into the type of BMPs that are appropriate to achieve the most cost-effective mass removal.

Analysis of PCBs at the CW4CB Leo Avenue HDS showed that PCBs in the water above the sediment may be minor when compared to sediment-associated PCBs (BASMAA, 2017b). PCB concentrations in overlying water are expected to be low and sampling of this water is not included in this study design.

Table 8.1 Selected Constituents for HDS Sediment Monitoring

Constituent
TOC
Total Mercury[1]
PCBs (40 congeners) in Sediment
Particle Size Distribution
Bulk Density

1 – Only total mercury analyzed. Methyl mercury is not relevant for SF Bay TMDL.

8.3 Constituents for Water Quality Analysis

Constituents for analysis of water samples must meet the data objectives discussed previously in "Primary Data Objectives", and be consistent with Table 8.3 of the MRP (SFRWQCB, 2015). Table 8.2 lists the constituents for the laboratory media testing studies. The list of water quality constituents must provide data to address the primary management question to quantify total PCB and mercury reduction, so PCBs and total mercury are analyzed for all samples. Secondary management questions relate to understanding removal performance for total PCB and mercury.

In addition to PCBs and total mercury, the other constituents selected for influent and effluent analysis are SSC, turbidity, and TOC. SSC was selected because it more accurately characterizes larger size fractions within the water column, while turbidity was selected because it is an inexpensive and quick test to describe treatment efficiency where strong correlation to other pollutants has been established. As with the sediment analysis, TOC is included because it is a MRP requirement and can be useful for normalizing PCBs data collected for water samples.

Table 8.2 Selected Aqueous Constituents for Media Testing in Laboratory Columns

Constituent
SSC
Turbidity
TOC
Total Mercury[1]
PCBs (40 congeners) in Water

1 – Only total mercury analyzed. Methyl mercury is not relevant for SF Bay TMDL.

8.4 Budget and Schedule

The monitoring budget for the study is approximately $200,000. A contingency of 10 percent of the water quality monitoring budget is recommended to account for unforeseen costs such as equipment failure. Another constraint is that all sampling will occur in one wet season.

8.5 Optimized Study Design

The optimized study designs are presented in Tables 8.3 and 8.4 for the HDS Monitoring and Enhanced Bioretention studies, respectively. Several iterations were analyzed and the study designs shown are based on best professional judgment to allocate the budget to the various data collection options.

The final design for the HDS monitoring study is based on selection and sampling of 9 HDS units in key land use areas. The number of units that can be sampled is limited because sampling is expected to be opportunistic as part of regular maintenance programs. Therefore, a simple design with 9 units is appropriate. The data analysis will evaluate the percent removal achieved for each HDS unit during the time period of interest (i.e., the time period between the date of the previous cleanout, and the current cleanout date for each HDS unit sampled) by incorporating modeled estimates of stormwater volumes and associated pollutant loads for each HDS unit catchment. Because HDS units are sized to treat stormwater runoff from storms of a given size and intensity, excess flows for storms exceeding the design capacity will bypass the unit and are not treated. Storm by storm analysis of rainfall data during the time period of interest will allow estimation of the total stormwater volume and pollutant load to the catchment during each storm, as well as the volume and pollutant load that bypassed the HDS unit and was not treated. This information will then be combined with the measured pollutant mass captured by each HDS unit to quantify the percent removal of PCBs and mercury from the total catchment flow, and the percent removal of PCBs and mercury from the treated flow. For each HDS unit sampled in the study, the total and treated pollutant mass removed will be calculated using the following equations.

(1) Total Pollutant Mass Removed (%) = $[M_{HDS\text{-}i}/M_{Catchment\text{-}i}] \times 100\%$

(2) Treated Pollutant Mass Removed (%) = $[M_{HDS\text{-}i}/(M_{Catchment\text{-}i} - M_B)] \times 100\%$

Where:

M_{HDS-i}	the total POC mass captured in the sump of HDS Unit i over the time period of interest
$M_{Catchment-i}$	the total POC mass discharged from Catchment-A (the catchment draining to HDS unit A) over the time period of interest
M_B	the total POC mass that bypassed HDS unit A over the time period of interest

The following inputs will be measured or modeled for the time period of interest for use in the equations above:

- Total PCBs and mercury mass captured by a given HDS unit. This is the mass measured in each HDS unit during this project.
- The total stormwater volume and associated PCBs and mercury load from the HDS unit catchment. This will be modeled on a storm by storm basis using available rainfall data, catchment runoff coefficients, and assumed pollutant stormwater concentrations.
- The stormwater volume and associated PCBs and mercury load that bypassed the HDS unit. The bypass volume (and associated pollutant load) during each storm (if any) will be calculated based on the design criteria for a given HDS unit.
- The total PCBs and mercury load treated by a given HDS unit. This will be determined by subtracting the bypass load (if any) from the total pollutant load for the catchment.

The corresponding design for the enhanced BSM study is based on testing of readily available biochars in hydraulic screening experiments followed by column testing of up to five promising BSM mixes as well as a standard BSM control mix. The final number of BSM mixes will depend on availability and media properties (e.g., expected hydraulic conductivity). The optimized designs will yield 33 data points for the key data objectives, 9 from the HDS monitoring study and 24 from the enhanced BSM media testing column study.

Table 8.3 HDS Monitoring Study Design

Primary Management Question(s)	What are the annual PCB and mercury loads captured by existing HDS units in Bay Area urban watersheds and the associated percent removal?
Type of Study	Sediment monitoring; modeling stormwater volume and pollutant load
Data Objective(s)	Annual PCB and mercury mass captured in HDS units and percent removal
Description of Key Treatment Processes	Sedimentation, Flocculation & Screening • Removal by gravity settling and physical screening of particulates • Effectiveness depends on water quality, BMP design and hydraulic loading/flow regime, and operational factors
Key Variables	• Sediment quality and quantity • Influent quantity and quality (contaminant concentration,) • BMP design and hydraulic loading/flow regime • BMP maintenance (remaining sediment capacity)
Monitoring Needs	Monitored variables: sediment quality, sediment mass Controlled variables: influent quality, BMP maintenance (remaining sediment capacity) Uncontrolled variables: HDS design, hydraulic loading, flow regime
Monitoring Approach	Influent quantity and quality: based on rainfall/runoff characteristics and on land use pollutant yield (old urban, new urban, etc.) Hydraulic loading: base on HDS size (diameter and settling depth) and flow (design flow for known watershed size) BMP maintenance: base on remaining sump capacity
Sampling Design	Sampling expected to be opportunistic as part of regular maintenance programs. Targeted predominant land uses for HDS selection and corresponding data generation: (see sub-table below) • Exclude units at full sump capacity (cleanout and monitor subsequent year if possible)
Constituent List	TOC, total mercury, PCBs (40 congeners) in sediment, particle size distribution, and bulk density
Data Analysis	Independent (unpaired) samples. Present range of total PCB and mercury concentrations measured and mass removed/area treated. Analyze using ANOVA. Model estimates of catchment stormwater volumes and PCB and mercury stormwater loads combined with the measured mass captured in the unit to calculate the percent removal.

Predominant Land Use	HDS Samples	No. Samples (Total 9)
Higher Concentration/Old Industrial	X, X, X[1]	3
Old Urban/Old Industrial	X, X, X[1]	3
New Urban/Old Urban	X, X, X[1]	3

1 – "X" represents a sample from a selected HDS unit. Yield categories will be determined during site selection.

Table 8.4 Enhanced BSM Testing Study Design

<table>
<tr><td>Primary Management Question(s)</td><td>Are there readily available biochar-amended BSM that provide significantly better PCB and mercury load reductions than standard BSM and meet MRP infiltration rate requirements?</td></tr>
<tr><td>Type of Study</td><td>Influent-effluent monitoring</td></tr>
<tr><td>Data Objective(s)</td><td>PCB and mercury load removal</td></tr>
<tr><td>Description of Key Treatment Processes</td><td>Filtration and Adsorption
• Removal by physical screening, trapping in media, and retention on media surface
• Effectiveness depends on influent water quality, BMP design and hydraulic loading/flow regime, media type and properties, and operational factors</td></tr>
<tr><td>Key Variables</td><td>• Influent and effluent quality (PCB concentration, particle concentration, organic matter, proportion of dissolved contaminants, particle size, particle size distribution)
• BMP design (media depth) and hydraulic loading/head
• Media type and properties (composition, grain size/size distribution, adsorptive properties, hydraulic conductivity)
• BMP maintenance (surface clogging, short-circuiting)</td></tr>
<tr><td>Monitoring Needs</td><td>Monitored variables: Influent and effluent quality contaminant concentration, particle concentration, organic matter, surface clogging
Controlled variables: media depth, hydraulic loading/head, media composition and adsorptive properties, hydraulic conductivity
Uncontrolled variables: Influent and effluent proportion of dissolved contaminants, particle size, particle size distribution, short-circuiting</td></tr>
<tr><td>Monitoring Approach</td><td>Phased approach because of number of media/need to ensure MRP infiltration rates
1. Hydraulic tests to ensure amended media meet infiltration requirements
2. Influent-effluent column tests for select mixes with Bay Area stormwater
3. Influent-effluent column tests for best mix with Bay Area stormwater at lower concentrations</td></tr>
<tr><td>Sampling Design</td><td>Phase I Hydraulic Tests:
- Determine infiltration rates for media mixes with 25% biochar by volume
- If MRP infiltration rates not met, adjust biochar proportion and retest
- Target infiltration rate of 5 - 12 in/h for all mixes, attempt to control rate to +/- 1 in/hr.

Phase II Influent-Effluent Column Tests with Bay Area Stormwater (up to 5 mixes)
<table>
<tr><th>Biochar/BSM Mix</th><th>Column Samples</th><th>No. Samples (Total 21)</th></tr>
<tr><td>A Mix</td><td>X, X, X</td><td>3</td></tr>
<tr><td>B Mix</td><td>X, X, X</td><td>3</td></tr>
<tr><td>C Mix</td><td>X, X, X</td><td>3</td></tr>
<tr><td>D Mix</td><td>X, X, X</td><td>3</td></tr>
<tr><td>E Mix</td><td>X, X, X</td><td>3</td></tr>
<tr><td>Control Mix</td><td>X, X, X</td><td>3</td></tr>
<tr><td>Influent</td><td>X, X, X</td><td>3</td></tr>
</table>
Phase III Influent-Effluent Column Tests for Select Mix with Diluted Bay Area Stormwater
- Perform tests with diluted stormwater, if necessary, to confirm effectiveness at concentrations representative of New Urban and New Industrial land
- Test at one dilution (1 influent and 1 mix and 1 control effluent) (3 samples)</td></tr>
<tr><td>Constituent List</td><td>SSC, turbidity, TOC, total mercury, PCBs (40 congeners) in water</td></tr>
<tr><td>Data Analysis</td><td>Dependent (paired) samples. Present range of total PCB and mercury concentrations measured and mass removal efficiencies. Analyze using ANOVA and regressions of influent/effluent quality. Perform sign-rank test to compare consistency in relative performance among the columns.</td></tr>
</table>

8.6 Adequacy of Study Design

The primary management questions are reviewed in this section in light of the budgeted data collection efforts. The primary management questions are restated and followed by an analysis of the adequacy of the data collection effort.

1. *What are the annual PCB and mercury loads captured by existing HDS units in Bay Area urban watersheds?*

Table 8.3 lists the number of data points that are anticipated for the HDS monitoring study.

This selected design will provide 9 data points for each of the following: PCB sediment concentration, mercury sediment concentration, and sediment mass. This design will not be able to assess the effect of HDS size and hydraulic loading on pollutant removal, and may not be able to statistically differentiate load capture between different land uses because of the small sample count for each land use (3). However, this design is selected because of the lack of information available on HDS sizing and the opportunistic nature of the sampling which limits the number of HDS units that can be sampled. The effect of maintenance is eliminated by ensuring that samples are not collected from units that have no remaining sump capacity.

The HDS study design collects independent (unpaired) samples since each HDS unit is sampled independently and there is no relationship between the various HDS units. This limits ability to discern differences due to land use or HDS size, especially when sample size is relatively low and there is considerable variability in the data collected. Although the study design yields 9 data points for each data objective, it may not be sufficient to draw statistically-based conclusions. However, the study will provide point estimates of loads removed during cleanouts and how they vary for different land uses (e.g., X g of PCBs are removed per unit area of Y land use). This is the metric used for effectiveness of HDS cleanouts, so the study will provide a practical improvement in knowledge that can be applied to future HDS effectiveness estimates.

In addition, modeled stormwater flows and associated POC loads to each HDS unit catchment during the time period between cleanouts will be developed. These modeled estimates will be used along with the measured mass captured in the HDS unit between cleanouts to quantify the percent removal for each unit during the study.

2. *Are there readily available biochar-amended BSM that provide significantly better PCB and mercury load reductions than standard BSM and meet MRP infiltration rate requirements?*

Table 8.4 lists the number of data points that are anticipated for the enhanced BSM testing study. The sampling design will yield 19 data points for each of the following: effluent PCB concentration, effluent mercury concentration. Including influent analysis, a total of 24 samples will be analyzed. The purpose of this study is to identify the best biochar amended BSM mixes for field testing and not test the effect of confounding variables such as influent quality and hydraulic loading on load removals. The study design accounts for these confounding variables by either ensuring their effect is randomized (e.g., influent water quality) or keeps them fixed (e.g., hydraulic loading). To ensure influent stormwater concentrations are representative of typical Bay Area concentrations, an additional column test with diluted stormwater is performed on an effective media mix. Standard BSM controls are used for each column run so that removal by biochar amended mixes can be compared directly to removal by standard BSM. Infiltration experiments are performed prior to the column testing to ensure media selected for final column testing will meet the MRP infiltration rate requirements.

The enhanced BSM column study design collects dependent (paired) samples since each effluent sample is related to a corresponding influent sample. Additionally, standard BSM controls are used for each run which makes it possible to directly compare effluent quality for each amended BSM to standard BSM. The paired sampling design, use of standard BSM controls, and ability to control or fix many of the variables that effect load removal increase the ability to discern differences in treatment. Therefore, only 3 column runs are proposed, and available budget is instead used in initial hydraulic screening experiments to ensure selected media mixes meet MRP infiltration rate requirements. The study design may not be sufficient to draw statistically-based conclusions because it yields only 3 data points for each biochar mix tested. However, the study will enable direct comparisons of effluent quality and treatment between mixes for individual events and consistency of treatment between events. The information provided by the study is expected to be sufficient to identify the most promising biochar mixes for field testing.

The study designs for the HDS monitoring and enhanced bioretention studies meet MRP sample collection requirements. The sampling design for the HDS monitoring study will yield a minimum of 9 PCB and mercury data points, while the sampling design for the enhanced bioretention laboratory study will yield 24 PCB and mercury data points (including influent analysis). The minimum number of PCB samples for this study plan is 33 (9+24). Because 3 of the 32 BMP effectiveness samples required by the current MRP have already been collected, the minimum number required for this project is 29. This study must yield 29 of the 32 permit-required samples, per Provision C.8.f of the MRP. To ensure that at least 29 samples are collected to meet the MRP requirement, additional samples will be collected during the laboratory media testing runs if fewer than 5 HDS units are available for sampling.

9. Recommendations for Sampling and Analysis Plans

This section presents specific recommendations for the development of SAPs. More detailed information is available in Section 6 of the Caltrans Monitoring Guidance Manual (Caltrans, 2015) and in the Urban Stormwater BMP Performance Monitoring (WERF 2009). Analysis of constituents should follow the CW4CB Quality Assurance Project Plan (BASMAA 2013).

9.1 HDS Monitoring

The following SAP recommendations are based on the lessons learned from sampling the Leo Avenue HDS site (BASMAA, 2017b):

- Include equipment to determine sump capacity before sampling. The study design does not require sampling of units that are full (i.e., have no remaining sump capacity). The depth of the unit can make it difficult to inspect for sump basin contents, and use of a “sludge judge” or other similar equipment may not be possible because of difficulty penetrating through compacted organic materials.
- The sampling is expected to be opportunistic sampling during regular cleanouts. Since it coincides with regular maintenance patterns, the occurrence of a clean and empty vactor truck from which samples of the sediment can be taken is unlikely. To obtain representative samples, multiple grab samples that extend from the top of the sediment layer to the bottom of the sump will need to be collected and composited prior to analyses.
- Sediment samples will require screening to remove coarse particles, trash, etc. In the CW4CB study (BASMAA, 2007b), only sediment less than 2 mm in size was analyzed.

It is unclear how samples of the HDS sediment were taken in the Leo Avenue HDS sampling. Appropriate sampling methods should be developed to ensure the samples collected are representative of the sediment in the HDS units.

HDS sediment sampling is not expected to require additional handling/safety precautions beyond normal drain cleaning safety procedures. Human health criteria for PCBs are for exposure via ingestion or vapor intake and not for contact. OSHA directive STD 01-04-002 state that “repeated skin contact hazards with all PCB's could be addressed by the standards 1910.132 and 1910.133”. Both 1910.132 and 1910.133 OSHA standards require use of personal protective equipment, including eye and face protection.

9.2 Enhanced Bioretention Media Testing

The following SAP recommendations are based on past experience and specific guidance provided in DEMEAU (2014):

- The enhanced BSM testing will use real stormwater for the column experiments to account for the effect of influent water quality on load removal. A stormwater collection site will need to be identified in a watershed with typical PCB concentrations to ensure PCB concentrations are representative of those expected in Bay Area urban watersheds. Also, guidance will need to be developed on mobilization to ensure storms are targeted randomly.

- Stormwater properties are known to change significantly with time due to natural flocculation and settling of particles. Appropriate procedures should be developed to ensure collected stormwater is well mixed at all times, and experiments are performed in a timely manner to insure the stormwater used is representative.
- PCBs can readily attach to test equipment, including the inside of tubing that may be used for pumps and the inside of PVC columns. Alternatives should be considered that eliminate the need for pumping equipment and reduce attachment within columns (e.g., by use of glass columns).
- The results of column experiments can be affected by channeling and wall effects. Use a column diameter to particle diameter ratio greater than about 40 to minimize these.
- How media is packed in columns will affect infiltration rates and treatment performance. Therefore, detailed procedures should be developed for the packing of media in columns to ensure consistency between columns and between experiments.

9.3 Data Quality Objectives

Data quality objectives (DQOs) should follow standard stormwater monitoring protocols and be described in detail in individual SAPs. Both sampling and laboratory data quality objectives should be included. For sampling, the SAP should specify sediment and water collection procedures and equipment as well as sample volume and handling requirements. For laboratories, numeric DQOs are appropriate for sample blanks, duplicates (or field splits), and matrix spike recovery.

10. References

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APPENDIX B: SAMPLING AND ANALYSIS PLAN AND QUALITY ASSURANCE PROJECT PLAN

BASMAA
Regional Monitoring Coalition

Pollutants of Concern Monitoring for Source Identification and Management Action Effectiveness, 2017-2018

Sampling and Analysis Plan and Quality Assurance Project Plan

Prepared for:

The Bay Area Stormwater Management Agencies Association (BASMAA)

Prepared by:

1410 Jackson Street
Oakland, CA
94612

6000 J Street
Sacramento, CA
95819

4911 Central Avenue
Richmond, CA
94804

307 Washington Street
Santa Cruz, CA
95060

Version 2
September 29, 2017

Title and Approval Sheet

Program Title	Pollutants of Concern (POC) Monitoring for Source Identification and Management Action Effectiveness
Lead Organization	Bay Area Stormwater Management Agencies Association (BASMAA)
	P.O. Box 2385, Menlo Park, CA 94026, 510-622-2326
	info@basmaa.org
Primary Contact	Geoff Brosseau
Effective Date	September 29, 2017
Revision Number	Version 2

Approval Signatures:

A signature from the BASMAA Executive Director approving the BASMAA POC Monitoring for Source Identification and Management Action Effectiveness is considered approval on behalf of all Program Managers.

Geoff Brosseau	Date

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List of Acronyms

ACCWP	Alameda Countywide Clean Water Program
ALS	ALS Environmental Laboratory
BASMAA	Bay Area Stormwater Management Agencies Association
BSM	Bioretention Soil Media
CCCWP	Contra Costa Clean Water Program
CCV	continuing calibration verification
CEDEN	California Environmental Data Exchange Network
CEH	Center for Environmental Health
COC	Chain of Custody
Consultant-PM	Consultant Team Project Manager
CRM	Certified Reference Material
CSE	Confined Space Entry
ECD	Electron capture detection
EDD	Electronic Data Deliverable
EOA	Eisenberg, Olivieri & Associates, Inc.
EPA	Environmental Protection Agency (U.S.)
FD	Field duplicate
Field PM	Field Contractor Project Manager
FSURMP	Fairfield-Suisun Urban Runoff Management Program
GC-MS	Gas Chromatography-Mass Spectroscopy
IDL	Instrument Detection Limits
ICV	initial calibration verification
KLI	Kinnetic Laboratories Inc.
LCS	Laboratory Control Samples
Lab-PM	Laboratory Project Manager
MS/MSD	Matrix Spike/Matrix Spike Duplicate
MDL	Method Detection Limit
MQO	Measurement Quality Objective
MRL	Method Reporting Limit
MRP	Municipal Regional Permit
NPDES	National Pollutant Discharge Elimination System
OWP-CSUS	Office of Water Programs at California State University Sacramento
PCB	Polychlorinated Biphenyl
PM	Project Manager
PMT	Project Management Team
POC	Pollutants of Concern
QA	Quality Assurance
QA Officer	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QC	Quality Control
ROW	Right-of-way
RPD	Relative Percent Difference
RMC	Regional Monitoring Coalition
RMP	Regional Monitoring Program for Water Quality in the San Francisco Estuary
SFRWQCB	San Francisco Regional Water Quality Control Board (Regional Water Board)
SAP	Sampling and Analysis Plan
SCCVURPP	Santa Clara Valley Urban Runoff Pollution Prevention Program
SCVWD	Santa Clara Valley Water Department
SFEI	San Francisco Estuary Institute

SMCWPPP	San Mateo County Water Pollution Prevention Program
SOP	Standard Operating Procedure
SWAMP	California Surface Water Ambient Monitoring Program
TOC	Total Organic Carbon
TMDL	Total Maximum Daily Load
VSFCD	Vallejo Sanitation and Flood Control District

1. Problem Definition/Background

The Bay Area Stormwater Management Agencies Association (BASMAA) member agencies will implement a regional monitoring program for Pollutants of Concern (POC) Monitoring for Source Identification and Management Action Effectiveness (Monitoring Program). The Monitoring Program is intended to fulfill components of the Municipal Regional Stormwater NPDES Permit (MRP; Order No. R2-2015-0049), which implements the polychlorinated biphenyls (PCBs) and Mercury Total Maximum Daily Loads (TMDLs) for the San Francisco Bay Area. Monitoring for Source Identification and Management Action Effectiveness are two of five monitoring priorities for POCs identified in the MRP. Source identification monitoring is conducted to identify the sources or watershed source areas that provide the greatest opportunities for reductions of POCs in urban stormwater runoff. Management action effectiveness monitoring is conducted to provide support for planning future management actions or to evaluate the effectiveness or impacts of existing management actions.

BASMAA developed two study designs to implement each component of the Monitoring Program. The ***Evaluation of PCBs Presence in Public Roadway and Storm Drain Infrastructure Caulk and Sealants Study Design*** (BASMAA 2017a) addresses the source identification monitoring requirements of Provision C.8.f, as well as requirements of Provision C.12.e to investigate PCBs in infrastructure caulk and sealants. The ***POC Monitoring for Management Action Effectiveness Study Design*** (BASMAA 2017b) addresses the management action effectiveness monitoring requirements of Provision C.8.f. The results of the Monitoring Program will contribute to ongoing efforts by MRP Permittees to identify PCB sources and improve the PCBs and mercury treatment effectiveness of stormwater control measures in the Phase I permittee area of the Bay Area. This Sampling and Analysis Plan and Quality Assurance Project Plan (SAP/QAPP) was developed to guide implementation of both components of the Monitoring Program.

1.1. Problem Statement

Fish tissue monitoring in San Francisco Bay (Bay) has revealed bioaccumulation of PCBs and mercury. The measured fish tissue concentrations are thought to pose a health risk to people consuming fish caught in the Bay. As a result of these findings, California has issued an interim advisory on the consumption of fish from the Bay. The advisory led to the Bay being designated as an impaired water body on the Clean Water Act "Section 303(d) list" due to PCBs and mercury. In response, the California Regional Water Quality Control Board, San Francisco Bay Region (Regional Water Board) has developed TMDL water quality restoration programs targeting PCBs and mercury in the Bay. The general goals of the TMDLs are to identify sources of PCBs and mercury to the Bay and implement actions to control the sources and restore water quality.

Since the TMDLs were adopted, Permittees have conducted a number of projects to provide information that supports implementation of management actions designed to achieve the wasteload allocations described in the Mercury and PCBs TMDL, as required by Provisions of the MRP. The Clean Watersheds for a Clean Bay project (CW4CB) was a collaboration among BASMAA member agencies that pilot tested various stormwater control measures and provided estimates of the PCBs and mercury load reduction effectiveness of these controls (BASMAA, 2017c). However, the results of the CW4CB project identified a number of remaining data gaps on the load reduction effectiveness of the control measures that were tested. In addition, MRP Provisions C.8.f. and C.12.e require Permittees to conduct further source identification and management action effectiveness monitoring during the current permit term.

1.2. Outcomes

The Monitoring Program will allow Permittees to satisfy MRP monitoring requirements for source identification and management action effectiveness, while also addressing some of the data gaps identified by the CW4CB project (BASMAA, 2017c). Specifically, the Monitoring Program is intended to provide the following outcomes:

1. Satisfy MRP Provision C.8.f. requirements for POC monitoring for source identification; and Satisfy MRP Provision C.12.e.ii requirements to evaluate PCBs presence in caulks/sealants used in storm drain or roadway infrastructure in public ROWs;
    a. Report the range of PCB concentrations observed in 20 composite samples of caulk/sealant collected from structures installed or rehabilitated during the 1970's;
2. Satisfy MRP Provision C.8.f. requirements for POC monitoring for management action effectiveness;
    a. Quantify the annual mass of mercury and PCBs captured in HDS Unit sumps during maintenance; and
    b. Identify bioretention soil media (BSM) mixtures for future field testing that provide the most effective mercury and PCBs treatment in laboratory column tests.

The information generated from the Monitoring Program will be used by MRP Permittees and the Regional Water Board to better understand potential PCB sources and better estimate the load reduction effectiveness of current and future stormwater control measures.

2. Distribution List and Contact Information

The distribution list for this BASMAA SAP/QAPP is provided in Table 2-1.

Table 2-1. BASMAA SAP/QAPP Distribution List.

Project Group	Title	Name and Affiliation	Telephone No.
BASMAA Project Management Team	BASMAA Project Manager, Stormwater Program Specialist	Reid Bogert, SMCWPPP	650-599-1433
	Program Manager	Jim Scanlin, ACCWP	510-670-6548
	Watershed Management Planning Specialist	Lucile Paquette, CCCWP	925-313-2373
	Program Manager	Rachel Kraai, CCCWP	925-313-2042
	Technical Consultant to ACCWP and CCCWP	Lisa Austin, Geosyntec Inc. CCCWP	510-285-2757
	Supervising Environmental Services Specialist	James Downing, City of San Jose	408-535-3500
	Senior Environmental Engineer	Kevin Cullen, FSURMP	707-428-9129
	Pollution Control Supervisor	Doug Scott, VSFCD	707-644-8949 x269
Consultant Team	Project Manager	Bonnie de Berry, EOA Inc.	510-832-2852 x123
	Assistant Project Manager SAP/QAPP Author and Report Preparer	Lisa Sabin, EOA Inc.	510-832-2852 x108
	Technical Advisor	Chris Sommers, EOA Inc.	510-832-2852 x109
	Study Design Lead and Report Preparer	Brian Currier, OWP-CSUS	916-278-8109
	Study Design Lead and Report Preparer	Dipen Patel, OWP-CSUS	
	Technical Advisor	Lester McKee, SFEI	415-847-5095
	Quality Assurance Officer	Don Yee, SFEI	510-746-7369
	Data Manager	Amy Franz, SFEI	510-746-7394
	Field Contractor Project Manager	Jonathan Toal, KLI	831-457-3950
Project Laboratories	Laboratory Project Manager	Howard Borse, ALS	360-430-7733
	XRF Laboratory Project Manager	Matt Nevins, CEH	510-655-3900 x318

3. Program Organization

3.1. Involved Parties and Roles

BASMAA is a 501(c)(3) non-profit organization that coordinates and facilitates regional activities of municipal stormwater programs in the San Francisco Bay Area. BASMAA programs support implementation of the MRP (Order No. R2-2015-0049), which implements the PCBs and Mercury TMDLs for the San Francisco Bay Area. BASMAA is comprised of all 76 identified MRP municipalities and special districts, the Alameda Countywide Clean Water Program (ACCWP), Contra Costa Clean

Water Program (CCCWP), the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP), the San Mateo Countywide Water Pollution Prevention Program (SMCWPPP), the Fairfield-Suisun Urban Runoff Management Program (FSURMP), the City of Vallejo and the Vallejo Sanitation and Flood Control District (VSFCD) (Table 3-1).

MRP Permittees have agreed to collectively implement this Monitoring Program via BASMAA. The Program will be facilitated through the BASMAA Monitoring and Pollutants of Concern Committee (MPC). BASMAA selected a consultant team to develop and implement the Monitoring Program with oversight and guidance from a BASMAA Project Management Team (PMT), consisting of representatives from BASMAA stormwater programs and municipalities (Table 3-1).

Table 3-1. San Francisco Bay Area Stormwater Programs and Associated MRP Permittees Participating in the BASMAA Monitoring Program.

Stormwater Programs	MRP Permittees
Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)	Cities of Campbell, Cupertino, Los Altos, Milpitas, Monte Sereno, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, Sunnyvale, Los Altos Hills, and Los Gatos; Santa Clara Valley Water District; and, Santa Clara County
Alameda Countywide Clean Water Program (ACCWP)	Cities of Alameda, Albany, Berkeley, Dublin, Emeryville, Fremont, Hayward, Livermore, Newark, Oakland, Piedmont, Pleasanton, San Leandro, and Union City; Alameda County; Alameda County Flood Control and Water Conservation District; and, Zone 7 Water District
Contra Costa Clean Water Program (CCCWP)	Cities of, Clayton, Concord, El Cerrito, Hercules, Lafayette, Martinez, , Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon, Walnut Creek, Danville, and Moraga; Contra Costa County; and, Contra Costa County Flood Control and Water Conservation District
San Mateo County Wide Water Pollution Prevention Program (SMCWPPP)	Cities of Belmont, Brisbane, Burlingame, Daly City, East Palo Alto, Foster City, Half Moon Bay, Menlo Park, Millbrae, Pacifica, Redwood City, San Bruno, San Carlos, San Mateo, South San Francisco, Atherton, Colma, Hillsborough, Portola Valley, and Woodside; San Mateo County Flood Control District; and, San Mateo County
Fairfield-Suisun Urban Runoff Management Program (FSURMP)	Cities of Fairfield and Suisun City
Vallejo Permittees (VSFCD)	City of Vallejo and Vallejo Sanitation and Flood Control District

3.2. BASMAA Project Manager (BASMAA-PM)

The BASMAA Project Manager (BASMAA-PM) will be responsible for directing the activities of the below-described PMT, and will provide oversight and managerial level activities, including reporting status updates to the PMT and BASMAA, and acting as the liaison between the PMT and the Consultant Team. The BASMAA PM will oversee preparation, review, and approval of project deliverables, including the required reports to the Regional Water Board.

3.3. BASMAA Project Management Team (PMT)

The BASMAA PMT will assist the BASMAA-PM and the below described Consultant Team with the design and implementation of all project activities. PMT members will assist the BASMAA-PM and Consultant Team to complete project activities within scope, on-time, and within budget by having specific responsibility for planning and oversight of project activities within the jurisdiction of the BASMAA agency that they represent. In addition, the PMT will coordinate with the municipal project partners and key regional agencies, including the Regional Water Board. The PMT is also responsible for reviewing and approving project deliverables (e.g., draft and final project reports).

3.4. Consultant Team Project Manager (Consultant-PM)

The Consultant Team Project Manager (Consultant-PM) will be responsible for ensuring all work performed during the Monitoring Program is consistent with project goals, and provide oversight of all day-to-day operations associated with implementing all components of the Monitoring Program, including scheduling, budgeting, reporting, and oversight of subcontractors. The Consultant-PM will ensure that data generated and reported through implementation of the Monitoring Program meet measurement quality objectives (MQOs) described in this SAP/QAPP. The Consultant -PM will work with the Quality Assurance Officer as required to resolve any uncertainties or discrepancies. The Consultant -PM will also be responsible for overseeing development of draft and final reports for the Monitoring Program, as described in this SAP/QAPP.

3.5. Quality Assurance Officer (QA Officer)

The role of the Quality Assurance Officer (QA Officer) is to provide independent oversight and review of the quality of the data being generated. In this role, the QA Officer has the responsibility to require data that is of insufficient quality to be flagged, or not used, or for work to be redone as necessary so that the data meets specified quality measurements. The QA Officer will oversee the technical conduct of the field related components of the Monitoring Program, including ensuring field program compliance with the SAP/QAPP for tasks overseen at the programmatic level.

3.6. Data Manager (DM)

The Data Manager will be responsible for receipt and review of all project related documentation and reporting associated with both field efforts and laboratory analysis. The Data Manager will also be responsible for storage and safekeeping of these records for the duration of the project.

3.7. Field Contractor Project Manager (Field-PM)

The Field Contractor Project Manager (Field-PM) will be responsible for conduct and oversight of all field monitoring- and reporting-related activities, including completion of field datasheets, chain of custodies, and collection of field measurements and field samples, consistent with the monitoring methods and procedures in the SAP/QAPP. The Field-PM will also be responsible for ensuring that personnel conducting monitoring are qualified to perform their responsibilities and have received appropriate training. The Field-PM will be responsible for initial receipt and review of all project related documentation and reporting associated with both field efforts and laboratory analysis.

The Field-PM will also be responsible for receiving all samples collected opportunistically by participating municipalities, including all caulk/sealant samples, initial review of sample IDs to ensure there are no duplicate sample IDs, and shipping the samples under COC to the appropriate laboratory (CEH for the caulk/sealant samples; ALS for all other samples). Participating municipalities should ship all samples they collect to the Field PM at the following address:

Jon Toal
Kinnetic Laboratories, Inc.
307 Washington Street
Santa Cruz, CA 95060
Reference: BASMAA POC Monitoring Project
(831)457-3950

3.8. Laboratory Project Manager (Lab-PM)

The Laboratory Project Manager (Lab-PM) and chemists at each analytical laboratory will be responsible for ensuring that the laboratory's quality assurance program and standard operating procedures (SOPs) are consistent with this SAP/QAPP, and that laboratory analyses meet all applicable requirements or explain any deviations. Each Lab-PM will also be responsible for coordinating with the Field-PM and other staff (e.g., Consultant -PM, Data Manager, QA Officer) and facilitating communication between the Field-PM, the Consultant -PM, and analytical laboratory personnel, as required for the project.

The Center for Environmental Health (CEH) will provide chlorine content screening of all caulk/sealant samples collected using X-Ray Fluorescence (XRF) technology to assist in selection of samples for further laboratory analysis of PCBs. This XRF-screening will also provide additional information on the utility of XRF in prioritizing samples for chemical PCBs analyses.

All other laboratory analyses will be provided by ALS Environmental.

3.1. Report Preparer

The Report Preparer (RP) will be responsible for developing draft and final reports for each of the following components of the Monitoring Program: (1) Source identification; and (2) Management action effectiveness. All draft reports will be submitted to the PMT for review and input prior to submission for approval by the BASMAA Board of Directors (BOD).

4. Monitoring Program Description

4.1. Work Statement and Program Overview

The Monitoring Program consists of the following three major tasks, each of which has a field sampling component:

- **Task 1. Evaluate presence and possible concentrations of PCBs in roadway and storm drain infrastructure caulk and sealants**. This task involves analysis of 20 composite samples of caulk/sealant collected from public roadway and storm drain infrastructure throughout the permit area to investigate PCB concentrations. The goal of this task is to evaluate, at a limited screening level, whether and in what concentrations PCBs are present in public roadway and storm drain infrastructure caulk and sealants in the portions of the Bay Area under the jurisdiction of the Phase I Permittees identified in Table 3-1 (Bay Area).

- **Task 2. Evaluate Annual mass of PCBs and mercury captured in Hydrodynamic Separator (HDS) Unit sumps during maintenance.** This task involves collecting sediment samples from the sumps of public HDS unit during maintenance cleanouts to evaluate the mass of PCBs and mercury captured by these devices. The goal of this task is to provide data to better characterize the concentrations of POCs in HDS Unit sump sediment and improve estimates of the mass captured and removed from these units during current maintenance practices for appropriate TMDL load reduction crediting purposes.

- **Task 3. Bench-scale testing of the mercury and PCBs removal effectiveness of selected BSM mixtures enhanced with biochar.** This task involves collecting stormwater from the Bay Area that will then be used to conduct laboratory column tests designed to evaluate the mercury and PCBs treatment effectiveness of various biochar-amended BSM mixtures. Real stormwater will be used for the column tests to account for the effect of influent water quality on load removal. The goal of this task is to identify BSM mixtures amended with biochar that meet operational infiltration requirements and are effective for PCBs and mercury removal for future field testing.

All monitoring results and interpretations will be documented in BASMAA reports for submission to the Regional Water Board according to the schedule in the MRP.

4.2. Sampling Detail

The Monitoring Program includes three separate sampling tasks that involve collection and analysis of the following types of samples: caulk/sealants (Task 1); sediment from HDS units (Task 2); and stormwater collected and used for column tests in the lab (Task 3). Additional details specific to the sampling design for each task are provided below.

4.2.1. Task 1 - Caulk/Sealant samples

The PMT will recruit municipal partners from within each stormwater program to participate in this task. All caulk/sealant samples will be collected from locations within public roadway or storm drain infrastructure in the participating municipalities. Exact sample sites will be identified based on available information for each municipal partner, including: age of public infrastructure; records of infrastructure repair or rehabilitation (aiming for the late 1960s through the 1970s); and current municipal staff knowledge about locations that meet the site selection criteria identified in the study design (BASMAA, 2017a). Field crews led by the Field-PM and/or municipal staff will conduct field reconnaissance to further identify specific sampling locations and if feasible, will collect caulk/sealant samples during these initial field visits. Follow-up sampling events will be conducted for any sites that require additional planning or equipment for sample collection (e.g., confined space entry, parking controls, etc.). Sample locations will include any of the following public infrastructure where caulk/sealant are present: roadway or sidewalk surfaces, between expansion joints for roadways, parking garages, bridges, dams, or storm drain pipes, and/or in pavement joints (e.g., curb and gutter). Sampling will only occur during periods of dry weather when urban runoff flows through any structures that will be sampled are minimal, and do not present any safety hazards or other logistical issues during sample collection. Sample collection methods are described further in Section 9.

As opportunities arise, municipal staff will also collect samples following the methods and procedures described in this SAP/QAPP during ongoing capital projects that provide access to public infrastructure locations with caulk/sealant that meet the sample site criteria. All samples collected by participating municipal staff will be delivered to the Field PM under COC. The Field-PM will be responsible for storing all caulk/sealant samples and shipping the samples under COC to CEH for XRF screening analysis.

All caulk/sealant samples collected will be screened for chlorine content using XRF technology described in Section 9. Samples will be grouped for compositing purposes as described in the study design (BASMAA, 2017a). Up to three samples will be included per composite and a total of 20 composite caulk/sealant samples will be analyzed for the RMP 40 PCB congeners[1]. All compositing and PCBs analysis will be conducted blind to the location where each sample was collected. Laboratory analysis methods must be able to detect a minimum PCBs concentration of 200 parts per billion (ppb, or µg/Kg). Laboratory analytical methods are described further in Section 12. The range of PCB concentrations found in caulk based on this documented sampling design will be reported to the Regional Water Board within the Permittees' 2018 Annual Reports.

4.2.2. Task 2 - Sediment samples from HDS Units

The PMT will recruit municipal partners that maintain public HDS units to participate in this task. All sediment samples will be collected from the sump of selected HDS units during scheduled cleaning and maintenance. Selection of the HDS units for sampling will be opportunistic, based on the units that are scheduled for maintenance by participating municipalities during the project period. Field crews led by the Field-PM and municipal maintenance staff will coordinate sampling with scheduled maintenance events. As needed, municipal staff will dewater the HDS unit sumps prior to sample collection, and provide assistance to field crews with access to the sump sediment as needed (e.g., confined space entry, parking controls, etc.). All sump sediment samples will be collected following the methods and procedures described in this SAP/QAPP. Sampling will only occur during periods of dry weather when urban runoff flows into the HDS unit sumps are minimal, and do not present any safety hazards or other logistical issues during sample collection. Sample collection methods are described further in Section 9.

All sediment samples collected will be analyzed for the RMP 40 PCB congeners, total mercury, total organic carbon (TOC), particle size distribution (PSD), and bulk density. Laboratory analytical methods are described further in Section 12. The range of PCB and mercury concentrations observed in HDS Unit sump sediments and the annual pollutant masses removed during cleanouts will be reported to the Regional Water Board in March 2019.

4.2.3. Task 3 - Storm Water and Column Test Samples

This task will collect stormwater from Bay Area locations that will then be used as the influent for column tests of biochar-amended BSM. Bay Area stormwater samples will be collected from locations

[1] The 40 individual congeners routinely quantified by the Regional Monitoring Program (RMP) for Water Quality in the San Francisco Estuary include: PCBs 8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, l05, 110, 118, 128, 132, 138, 141, 149, l51, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203

within public roadway or storm drain infrastructure in participating municipalities. Field personnel lead by the Field PM will collect stormwater samples during three qualifying storm events and ensure all samples are delivered to the lab of OWP at CSUS within 24-hours of collection. Stormwater will be collected from one watershed that has a range of PCB concentrations and is considered representative of Bay Area watersheds (e.g. the West Oakland Ettie Street Pump Station watershed). Storms from the representative watershed should be targeted randomly without bias, thereby accounting for the effects of storm intensity and ensuring variability in contaminant concentration, proportion of dissolved contaminants, particle size, particle size distribution, and particle density. To achieve this, minimal mobilization criteria should be used to ensure predicted storm intensity and runoff volume are likely to yield the desired volume. Sample collection methods are described further in Section 9.

The stormwater collected will be used as the influent for column tests of various BSM mixtures amended with biochar. These tests will be implemented in three phases. First, hydraulic screening tests will be performed to ensure all amended BSM mixtures meet the MRP infiltration rate requirements of 12 in/h initial maximum infiltration or minimum 5 in/h long-term infiltration rate. Second, column tests will be performed using Bay Area stormwater to evaluate pollutant removal. Third, additional column tests will be performed using lower concentration (e.g., diluted) Bay Area stormwater to evaluate relative pollutant removal performance at lower concentrations. Further details about the column testing are provided in Section 9.3.

All influent and effluent water samples collected will be analyzed for the RMP 40 PCB congeners, total mercury, suspended sediment concentrations (SSC), TOC, and turbidity. Laboratory analytical methods are described further in Section 12. The range of PCB and mercury concentrations observed in influent and effluent water samples and the associated pollutant mass removal efficiencies for each BSM mixture tested will be reported to the Regional Water Board in March 2019.

4.3. Schedule

Caulk/sealant sampling (Task 1) will be conducted between July 2017 and December 2017. HDS Unit sampling (Task 2) will be conducted between July 2017 and May 2018. Stormwater sample collection and BSM column tests (Task 3) will occur between October 2017 – April 2018.

4.4. Geographical Setting

Field operations will be conducted across multiple Phase I cities in the San Francisco Bay region within the counties of San Mateo, Santa Clara, Alameda, and Contra Costa, and the City of Vallejo.

4.5. Constraints

Caulk/sealant sampling and HDS unit sampling will only be conducted during dry weather, when urban runoff flows through the sampled structures are minimal and do not present safety hazards or other logistical concerns. Caulk/sealant sampling will be limited to the caulk/sealant available and accessible at sites that meet the project site criteria (described in the Study Design, BASMAA 2017a). HDS unit sampling will be limited by the number of public HDS units that are available for maintenance during the project period. Extreme wet weather may pose a safety hazard to sampling personnel and may therefore impact wet season sampling.

5. Measurement Quality Objectives (MQO)

The quantitative measurements that estimate the true value or concentration of a physical or chemical property always involve some level of uncertainty. The uncertainty associated with a measurement generally results from one or more of several areas: (1) natural variability of a sample; (2) sample handling conditions and operations; (3) spatial and temporal variation; and (4) variations in collection or analytical procedures. Stringent Quality Assurance (QA) and Quality Control (QC) procedures are essential for obtaining unbiased, precise, and representative measurements and for maintaining the integrity of the sample during collection, handling, and analysis, as well and for measuring elements of variability that cannot be controlled. Stringent procedures also must be applied to data management to assure that accuracy of the data is maintained.

MQOs are established to ensure that data collected are sufficient and of adequate quality for the intended use. MQOs include both quantitative and qualitative assessment of the acceptability of data. The qualitative goals include representativeness and comparability, and the quantitative goals include completeness, sensitivity (detection and quantization limits), precision, accuracy, and contamination.

MQOs associated with representativeness, comparability, completeness, sensitivity, precision, accuracy, and contamination are presented below in narrative form.

5.1. Representativeness and Comparability

The representativeness of data is the ability of the sampling locations and the sampling procedures to adequately represent the true condition of the sample sites. The comparability of data is the degree to which the data can be compared directly between all samples collected under this SAP/QAPP. Field personnel, including municipal personnel that collect samples, will strictly adhere to the field sampling protocols identified in this SAP/QAPP to ensure the collection of representative, uncontaminated, comparable samples. The most important aspects of quality control associated with chemistry sample collection are as follows:

- Field personnel will be thoroughly trained in the proper use of sample collection equipment and will be able to distinguish acceptable versus unacceptable samples in accordance with pre-established criteria.
- Field personnel are trained to recognize and avoid potential sources of sample contamination (e.g., dirty hands, insufficient field cleaning).
- Samplers and utensils that come in direct contact with the sample will be made of non-contaminating materials, and will be thoroughly cleaned between sampling stations.
- Sample containers will be pre-cleaned and of the recommended type.
- All sampling sites will be selected according to the criteria identified in the project study design (BASMAA, 2017a)

Further, the methods for collecting and analyzing PCBs in infrastructure caulk and sealants will be comparable to other studies of PCBs in building material and infrastructure caulk (e.g., Klosterhaus et al., 2014). This SAP/QAPP was also developed to be comparable with the California Surface Water Ambient Monitoring Program (SWAMP) Quality Assurance Program Plan (QAPrP, SWAMP 2013). All sediment and water quality data collected during the Monitoring Program will be performed in a manner so that data are SWAMP comparable [2].

5.2. Completeness

Completeness is defined as the percentage of valid data collected and analyzed compared to the total expected to being obtained under normal operating conditions. Overall completeness accounts for both sampling (in the field) and analysis (in the laboratory). Valid samples include those for analytes in which the concentration is determined to be below detection limits.

Under ideal circumstances, the objective is to collect 100 percent of all field samples desired, with successful laboratory analyses on 100% of measurements (including QC samples). However, circumstances surrounding sample collections and subsequent laboratory analysis are influenced by numerous factors, including availability of infrastructure meeting the required sampling criteria (applies to both infrastructure caulk sampling and HDS Unit sampling), flow conditions, weather, shipping damage or delays, sampling crew or lab analyst error, and QC samples failing MQOs. An overall completeness of greater than 90% is considered acceptable for the Monitoring Program.

5.3. Sensitivity

Different indicators of the sensitivity of an analytical method to measure a target parameter are often used including instrument detection limits (IDLs), method detection limits (MDLs), and method reporting limits (MRLs). For the Monitoring Program, MRL is the measurement of primary interest, consistent with SWAMP Quality Assurance Project Plan (SWAMP 2013). Target MRLs for all analytes by analytical method provided in Section 13.

5.4. Precision

Precision is used to measure the degree of mutual agreement among individual measurements of the same property under prescribed similar conditions. Overall precision usually refers to the degree of agreement for the entire sampling, operational, and analysis system. It is derived from reanalysis of individual samples (laboratory replicates) or multiple collocated samples (field replicates) analyzed on equivalent instruments and expressed as the relative percent difference (RPD) or relative standard deviation (RSD). Analytical precision can be determined from duplicate analyses of field samples, laboratory matrix spikes/matrix spike duplicates (MS/MSD), laboratory control samples (LCS) and/or reference material samples. Analytical precision is expressed as the RPD for duplicate measurements:

$$RPD = ABS([X1 - X2] / [(X1 + X2) / 2])$$

Where: X1 = the first sample result
X2 = the duplicate sample result.

[2] SWAMP data templates and documentation are available online at http://waterboards.ca.gov/water_issues/programs/swamp/data_management_resources/templates_docs.shtml

Precision will be assessed during the Monitoring Program by calculating the RPD of laboratory replicate samples and/or MS/MSD samples, which will be run at a frequency of 1 per analytical batch for each analyte. Target RPDs for the Monitoring Program are identified in Section 13.

5.5. Accuracy

Accuracy describes the degree of agreement between a measurement (or the average of measurements of the same quantity) and its true environmental value, or an acceptable reference value. The "true" values of the POCs in the Monitoring Program are unknown and therefore "absolute" accuracy (and representativeness) cannot be assessed. However, the analytical accuracy can be assessed through the use of laboratory MS samples, and/or LCS. For MS samples, recovery is calculated from the original sample result, the expected value (EV = native + spike concentration), and the measured value with the spike (MV):

% Recovery = (MV-N) x 100% / (EV-N)

Where: MV = the measured value
EV = the true expected (reference) value
N = the native, unspiked result

For LCS, recovery is calculated from the concentration of the analyte recovered and the true value of the amount spiked:

% Recovery = (X/TV) x 100%

Where: X = concentration of the analyte recovered
TV = concentration of the true value of the amount spiked

Surrogate standards are also spiked into samples for some analytical methods (i.e., PCBs) and used to evaluate method and instrument performance. Although recoveries on surrogates are to be reported, control limits for surrogates are method and laboratory specific, and no project specific recovery targets for surrogates are specified, so long as overall recovery targets for accuracy (with matrix spikes) are achieved. Where surrogate recoveries are applicable, data will not be reported as surrogate-corrected values.

Analytical accuracy will be assessed during the Monitoring Program based on recovery of the compound of interest in matrix spike and matrix spike duplicates compared with the laboratory's expected value, at a frequency of 1 per analytical batch for each analyte. Recovery targets for the Monitoring Program are identified in Section 13.

5.6. Contamination

Collected samples may inadvertently be contaminated with target analytes at many points in the sampling and analytical process, from the materials shipped for field sampling, to the air supply in the analytical laboratory. When appropriate, blank samples evaluated at multiple points in the process chain help assure that compound of interest measured in samples actually originated from the target matrix in the sampled environment and are not artifacts of the collection or analytical process.

Method blanks (also called laboratory reagent blanks, extraction blanks, procedural blanks, or preparation blanks) are used by laboratory personnel to assess laboratory contamination during all stages of sample preparation and analysis. The method blank is processed through the entire analytical procedure in a manner identical to the samples. A method blank concentration should be less than the RL or should not exceed a concentration of 10% of the lowest reported sample concentration. A method blank concentration greater than 10% of the lowest reported sample concentration will require corrective action to identify and eliminate the source(s) of contamination before proceeding with sample analysis. If eliminating the blank contamination is not possible, all impacted analytes in the analytical batch shall be flagged. In addition, a detailed description of the likely contamination source(s) and the steps taken to eliminate/minimize the contaminants shall be included in narrative of the data report. If supporting data is presented demonstrating sufficient precision in blank measurement that the 99% confidence interval around the average blank value is less than the MDL or 10% of the lowest measured sample concentration, then the average blank value may be subtracted.

A field blank is collected to assess potential sample contamination levels that occur during field sampling activities. Field blanks are taken to the field, transferred to the appropriate container, preserved (if required by the method), and treated the same as the corresponding sample type during the course of a sampling event. The inclusion of field blanks is dependent on the requirements specified in the relevant MQO tables or in the sampling method.

6. Special Training Needs / Certification

All fieldwork will be performed by contractor staff that has appropriate levels of experience and expertise to conduct the work, and/or by municipal staff that have received the appropriate instruction on sample collection, as determined by the Field PM and/or the PMT. The Field-PM will ensure that all members of the field crew (including participating municipal staff) have received appropriate instructions based on methods described in this document (Section 9) for collecting and transporting samples. As appropriate, sampling personnel may be required to undergo or have undergone OSHA training / certification for confined space entry in order to undertake particular aspects of sampling within areas deemed as such.

Analytical laboratories are to be certified for the analyses conducted at each laboratory by ELAP, NELAP, or an equivalent accreditation program as approved by the PMT. All laboratory personal will follow methods described in Section 13 for analyzing samples.

7. Program Documentation and Reporting

The Consultant Team in consultation with the PMT will prepare draft and final reports of all monitoring data, including statistical analysis and interpretation of the data, as appropriate, which will be submitted to the BASMAA BOD for approval. Following approval by the BASMAA BOD, Final project reports will be available for submission with each stormwater program's Annual Report in 2018 (Task 1) or in the March 31, 2019 report to the Regional Water Board (Tasks 2 and 3). Procedures for overall management of project documents and records and report preparation are summarized below.

7.1. Field Documentation

All field data gathered for the project are to be recorded in field datasheets, and scanned or transcribed to electronic documents as needed to permit easy access by the PMT, the consultant team, and other appropriate parties.

7.1.1. Sampling Plans, COCs, and Sampling Reports

The Field-PM will be responsible for development and submission of field sampling reports to the Data Manager and Consultant-PM. Field crews will collect records for sample collection, and will be responsible for maintaining these records in an accessible manner. Samples sent to analytical laboratories will include standard Chain of Custody (COC) procedures and forms; field crews will maintain a copy of originating COCs at their individual headquarters. Analytical laboratories will collect records for sample receipt and storage, analyses, and reporting. All records, except lab records, generated by the Monitoring Program will be stored at the office of the Data Manager for the duration of the project, and provided to BASMAA at the end of the project.

7.1.2. Data Sheets

All field data gathered by the Monitoring Program will be recorded on standardized field data entry forms. The field data sheets that will be used for each sampling task are provided in Appendix A.

7.1.3. Photographic Documentation

Photographic documentation is an important part of sampling procedures. An associated photo log will be maintained documenting sites and subjects associated with photos. If an option, the date function on the camera shall be turned on. Field Personnel will be instructed to take care to avoid any land marks when taking photographs, such as street signs, names of buildings, road mile markers, etc. that could be used later to identify a specific location. A copy of all photographs should be provided at the conclusion of sampling efforts and maintained for project duration.

7.2. Laboratory Documentation

The Monitoring Program requires specific actions to be taken by contract laboratories, including requirements for data deliverables, quality control, and on-site archival of project-specific information. Each of these aspects is described below.

7.2.1. Data Reporting Format

Each laboratory will deliver data in electronic formats to the Field-PM, who will transfer the records to the Data Manager, who is responsible for storage and safekeeping of these records for the duration of the project. In addition, each laboratory will deliver narrative information to the QA Officer for use in data QA and for long-term storage.

The analytical laboratory will report the analytical data to the Field-PM via an analytical report consisting of, at a minimum:

1. Letter of transmittal
2. Chain of custody information
3. Analytical results for field and quality control samples (Electronic Data Deliverable, EDD)
4. Case narrative

5. Copies of all raw data.

The Field-PM will review the data deliverables provided by the laboratory for completeness and errors. The QA Officer will review the data deliverables provided by the laboratory for review of QA/QC. In addition to the laboratory's standard reporting format, all results meeting MQOs and results having satisfactory explanations for deviations from objectives shall be reported in tabular format on electronic media. SWAMP-formatted electronic data deliverable (EDD) templates are to be agreed upon by the Data Manager, QA Officer, and the Lab-PM prior to onset of any sampling activities related to that laboratory.

Documentation for analytical data is kept on file at the laboratories, or may be submitted with analytical results. These may be reviewed during external audits of the Monitoring Program, as needed. These records include the analyst's comments on the condition of the sample and progress of the analysis, raw data, and QC checks. Paper or electronic copies of all analytical data, field data forms and field notebooks, raw and condensed data for analysis performed on-site, and field instrument calibration notebooks are kept as part of the Monitoring Program archives for a minimum period of eight years.

7.2.2. Other Laboratory QA/QC Documentation

All laboratories will have the latest version of this Monitoring Program SAP/QAPP in electronic format. In addition, the following documents and information from the laboratories will be current, and they will be available to all laboratory personnel participating in the processing of samples:

1. Laboratory QA plan: Clearly defines policies and protocols specific to a particular laboratory, including personnel responsibilities, laboratory acceptance criteria, and corrective actions to be applied to the affected analytical batches, qualification of data, and procedures for determining the acceptability of results.

2. Laboratory Standard Operation Procedures (SOPs): Contain instructions for performing routine laboratory procedures, describing exactly how a method is implemented in the laboratory for a particular analytical procedure. Where published standard methods allow alternatives at various steps in the process, those approaches chosen by the laboratory in their implementation (either in general or in specific analytical batches) are to be noted in the data report, and any deviations from the standard method are to be noted and described.

3. Instrument performance information: Contains information on instrument baseline noise, calibration standard response, analytical precision and bias data, detection limits, scheduled maintenance, etc.

4. Control charts: Control charts are developed and maintained throughout the Program for all appropriate analyses and measurements for purposes of determining sources of an analytical problem or in monitoring an unstable process subject to drift. Control charts serve as internal evaluations of laboratory procedures and methodology and are helpful in identifying and correcting systematic error sources. Control limits for the laboratory quality control samples are ±3 standard deviations from the certified or theoretical concentration for any given analyte.

Records of all quality control data, maintained in a bound notebook at each workstation, are signed and dated by the analyst. Quality control data include documentation of standard calibrations, instrument maintenance and tests. Control charts of the data are generated by the analysts monthly or for analyses done infrequently, with each analysis batch. The laboratory quality assurance specialist will review all QA/QC records with each data submission, and will provide QA/QC reports to the Field-PM with each batch of submitted field sample data.

7.3. Program Management Documentation

The BASMAA-PM and Consultant-PM are responsible for managing key parts of the Monitoring Program's information management systems. These efforts are described below.

7.3.1. SAP/QAPP

All original SAP/QAPPs will be held by the Consultant-PM. This SAP/QAPP and its revisions will be distributed to all parties involved with the Monitoring Program. Copies will also be sent to the each participating analytical laboratory's contact for internal distribution, preferably via electronic distribution from a secure location.

Associated with each update to the SAP/QAPP, the Consultant-PM will notify the BASMAA-PM and the PMT of the updated SAP/QAPP, with a cover memo compiling changes made. After appropriate distributions are made to affected parties, these approved updates will be filed and maintained by the SAP/QAPP Preparers for the Monitoring Program. Upon revision, the replaced SAP/QAPPs will be discarded/deleted.

7.3.2. Program Information Archival

The Data Manager and Consultant-PM will oversee the actions of all personnel with records retention responsibilities, and will arbitrate any issues relative to records retention and any decisions to discard records. Each analytical laboratory will archive all analytical records generated for this Program. The Consultant-PM will be responsible for archiving all management-level records.

Persons responsible for maintaining records for this Program are shown in Table 7-1.

Table 7-1. Document and Record Retention, Archival, and Disposition

Type	Retention (years)	Archival	Disposition
Field Datasheets	8	Data Manager	Maintain indefinitely
Chain of Custody Forms	8	Data Manager	Maintain indefinitely
Raw Analytical Data	8	Laboratory	Recycling
Lab QC Records	8	Laboratory	Recycling
Electronic data deliverables	8	Data Manager	Maintain indefinitely
Reports	8	Consultant-PM	Maintain indefinitely

As discussed previously, the analytical laboratory will archive all analytical records generated for this Program. The Consultant-PM will be responsible for archiving all other records associated with implementation of the Monitoring Program.

All field operation records will be entered into electronic formats and maintained in a dedicated directory managed by the BASMAA-PM.

7.4. Reporting

The Consultant team will prepare draft and final reports for each component of the Monitoring Program. The PMT will provide review and input on draft reports and submit to the BASMAA BOD for approval. Once approved by the BASMAA BOD, the Monitoring Program reports will be available to each individual stormwater program for submission to the Regional Water Board according to the schedule outlined in the MRP and summarized in Table 7.2.

Table 7-2. Monitoring Program Final Reporting Due Dates.

Monitoring Program Component	Task	MRP Reporting Due Date
Source Identification	Task 1 - Evaluation of PCB concentrations in roadway and storm drain infrastructure caulk and sealants	September 30, 2018
Management Action Effectiveness	Task 2 - Evaluation of the annual mass of PCBs and mercury captured in HDS Unit sump sediment	March 31, 2019
	Task 3 - Bench-scale testing of the mercury and PCBs removal effectiveness of selected BSM mixtures.	

8. Sampling Process Design

All information generated through conduct of the Monitoring Program will be used to inform TMDL implementation efforts for mercury and PCBs in the San Francisco Bay region. The Monitoring Program will implement the following tasks: (1) evaluate the presence and concentrations of PCB in caulk and sealants from public roadway and stormdrain infrastructure; (2) evaluate mass of PCBs and mercury removed during HDS Unit maintenance; and (3) evaluate the mercury and PCBs treatment effectiveness of various BSM mixtures in laboratory column tests using stormwater collected from Bay Area locations. Sample locations and the timing of sample collection will be selected using the directed sampling design principle. This is a deterministic approach in which points are selected deliberately based on knowledge of their attributes of interest as related to the environmental site being monitored. This principle is also known as "judgmental," "authoritative," "targeted," or "knowledge-based." Individual monitoring aspects are summarized further under Field Methods (Section 9) and in the task-specific study designs (BASMAA 2017a,b).

8.1. Caulk/Sealant Sampling

Caulk/sealant sampling will support the Monitoring Program's Task 1 to evaluate PCBs in roadway and stormdrain infrastructure caulk/sealant, as described previously (see Section 4). Further detail on caulk/sealant sampling methods and procedures are provided under Field Methods (Section 9).

8.2. Sediment Quality Sampling

Sediment sampling will support the Monitoring Program's Task 2 to evaluate the mass of mercury and PCBs removed during HDS unit maintenance, as described previously (see Section 4). Further detail on sediment sampling methods and procedures are provided under Field Methods (Section 9).

8.3. Water Quality Sampling

Water sampling will support the Monitoring Program's Task 3 to evaluate the mercury and PCBs treatment effectiveness of various BSM mixtures, as described previously (see Section 4). Further detail on water sampling methods and procedures are provided under Field Methods (Section 9).

8.4. Sampling Uncertainty

There are multiple sources of potential sampling uncertainty associated with the Monitoring Program, including: (1) measurement error; (2) natural (inherent) variability; (3) undersampling (or poor representativeness); and (4) sampling bias (statistical meaning). Measures incorporated to address these areas of uncertainty are discussed below:

(1) Measurement error combines all sources of error related to the entire sampling and analysis process (i.e., to the measurement system). All aspects of dealing with uncertainty due to measurement error have been described elsewhere within this document.

(2) Natural (inherent) variability occurs in any environment monitored, and is often much wider than the measurement error. Prior work conducted by others in the field of stormwater management have demonstrated the high degree of variability in environmental media, which will be taken into consideration when interpreting results of the various lines of inquiry.

(3) Under- or unrepresentative sampling happens at the level of an individual sample or field measurement where an individual sample collected is a poor representative for overall conditions encountered given typical sources of variation. To address this situation, the Monitoring Program will be implementing a number of QA-related measures described elsewhere within this document, including methods refined through implementation of prior, related investigations.

(4) Sampling bias relates to the sampling design employed and whether the appropriate statistical design is employed to allow for appropriate understanding of environmental conditions. To a large degree, the sampling design required by the Monitoring Program is judgmental, which will therefore incorporate an unknown degree of sampling bias into the Project. There are small measures that have been built into the sampling design to combat this effect (e.g., homogenization of sediments for chemistry analyses), but overall this bias is a desired outcome designed to meet the goals of this Monitoring Program, and will be taken into consideration when interpreting results of the various investigations.

Further detail on measures implemented to reduce uncertainty through mobilization, sampling, sample handling, analysis, and reporting phases are provided throughout this document.

9. Sampling Methods

The Monitoring Program involves the collection of three types of samples: Caulk/sealants; sediment from HDS unit sumps; and water quality samples. Field collection will be conducted by field contractors or municipal staff using a variety of sampling protocols, depending on the media and parameter monitored. These methods are presented below. In addition, the Monitoring Program will utilize several field sampling SOPs previously developed by the BASMAA Regional Monitoring Coalition identified in Table 9-3 (RMC, BASMAA, 2016).

9.1. Caulk/Sealant Sampling (Task 1)

Procedures for collecting caulk and sealant samples are not well established. Minimal details on caulk or sealant sample collection methodologies are available in peer-reviewed publications. The caulk/sealant sampling procedures described here were adapted from a previous study examining PCBs in building materials conducted in the Bay Area (Klosterhaus et al., 2014). The methods described by Klosterhaus et al. (2014) were developed through consultation with many of the previous authors of caulk literature references therein, in addition to field experience gained during the Bay Area study. It is anticipated that lessons will also be learned during the current study.

9.1.1. Sample Site Selection

Once a structure has been identified as meeting the selection criteria and permission is granted to perform the testing or collection of sealant samples, an on-site survey of the structure will be used to identify sealant types and locations on the structure to be sampled. It is expected that sealants from a number of different locations on each structure may sampled; however, inconspicuous locations on the structure will be targeted.

9.1.2. Initial Equipment Cleaning

The sampling equipment that is pre-cleaned includes:

- Glass sample jars
- Utility knife, extra blades
- Stainless-steel forceps

Prior to sampling, all equipment will be thoroughly cleaned. Glass sample containers will be factory pre-cleaned (Quality Certified™, ESS Vial, Oakland, CA) and delivered to field team at least one week prior to the start of sample collection. Sample containers will be pre-labeled and kept in their original boxes, which will be transported in coolers. Utility knife blades, forceps, stainless steel spoons, and chisels will be pre-cleaned with Alconox, Liquinox, or similar detergent, and then rinsed with deionized water and methanol. The cleaned equipment will then be wrapped in methanol-rinsed aluminum foil and stored in clean Ziploc bags until used in the field.

9.1.3. Field Cleaning Protocol

Between each use the tool used (utility knife blade, spoon or chisel) and forceps will be rinsed with methanol and then deionized water, and inspected to ensure all visible sign of the previous sample have been removed. The clean tools, extra blades, and forceps will be kept in methanol-rinsed aluminum foil and stored in clean Ziploc bags when not in use.

9.1.4. Blind Sampling Procedures

The intention of this sampling is to better determine whether sealants in road and storm drain infrastructure contain PCBs at concentrations of concern, and to understand the relative importance of PCBs in this infrastructure among the other known sources of PCBs that can affect San Francisco Bay. At this phase of the project, we are not seeking to identify specific facilities requiring mitigation (if PCBs are identified, this could be a future phase). Therefore, in this initial round of sampling, we are not identifying sample locations, but instead implementing a blind sampling protocol, as follows:

- All samples will be collected without retaining any information that would identify structure locations. The information provided to the contractor on sampling locations will not be retained. Structure location information will not be recorded on any data sheets or in any data spreadsheets or other electronic computer files created for the Project. Physical sealant samples collected will be identified only by a sample identification (ID) designation (Section 4). Physical sealant sample labels will contain only the sample ID (see Section 4 and example label in Appendix A). Samples will be identified only by their sample ID on the COC forms.
- As an added precaution and if resources allow, oversampling will occur such that more samples will be collected than will be sent to the laboratory for compositing and analysis. In this case, the Project team would select a subset of samples for PCB analysis based on factors such as application type and/or chlorine content, but blind to the specific location where each sample was collected.
- Up to three individual sealant samples will be composited by the laboratory prior to analysis for PCBs, following instructions from the Consultant PM. This further ensures a blind sampling approach because samples collected at different locations will be analyzed together.

9.1.5.Caulk/Sealant Collection Procedures

At each sample location, the Field-PM, and/or municipal staff, will make a final selection of the most accessible sampling points at the time of sampling. From each point sampled, a one inch strip (aiming for about 10 g of material) of caulk or sealant will be removed from the structure using one of the following solvent-rinsed tools: a utility knife with a stainless-steel blade, stainless steel spoon to scrape off the material, or a stainless steel chisel. The Field-PM or municipal staff at the site will select the appropriate tool based on the conditions of the caulk/sealant at each sample point. Field personnel will wear nitrile gloves during sample collection to reduce potential sample contamination. The sample will then be placed in a labeled, factory-cleaned glass jar. For each caulk sample collected, field personnel will fill out a field data sheet at the time of sample collection, which includes the following information:

- Date and time of sample collection,
- sample identification designation,
- qualitative descriptions of relevant structure or caulk/sealant features, including use profile, color and consistency of material collected, surface coating (paint, oily film, masonry residues etc.)
- crack dimensions, the length and/or width of the caulk bead sampled, spacing of expansion joints in a particular type of application, and
- a description of any unusual occurrences associated with the sampling event (especially those that could affect sample or data quality).

Appendix A contains an example field data sheet. All samples will be kept in a chilled cooler in the field (i.e., at 4 ºC ± 2 ºC), and kept refrigerated pending delivery under COC to the Field PM at KLI. Further, the field data sheets will remain with the samples when they are shipped to KLI, and will then be maintained by the Field PM at KLI.

As needed, the procedure for replacement of the caulk/sealant will be coordinated with the appropriate municipal staff to help ensure that the sampling does not result in damage to the structure.

9.1.6. Sample ID Designation

Every sample must have a unique sample ID to ensure analytical results from each sample can be differentiated from every other sample. This information should follow the sample through the COC, analytical, and interpretation and reporting processes. For the infrastructure caulk/sealant samples, the sample ID must not contain information that can be used to identify where the sample was collected. The following 2-step process will be followed to assign sample IDs to the caulk/sealant samples.

1. Upon collection, the sample will be labeled according to the following naming convention:

   MMDDYYYY-TTTT-##

   Where:

MM	2 digit month of collection
DD	2 digit date of collection
YYYY	4 digit year of collection
TTTT	4 digit time of collection (military time)
##	Sequential 2-digit sample number (i.e., 01, 02, 03…etc.)

   For example, a sample collected on September 20, 2017 at 9 AM could be assigned the following sample ID: 09202017-0900-01.

2. This second step was added to avoid issues that could arise due to duplicate sample IDs, while maintaining the blind sampling approach. While the sample naming system identified above is unlikely to produce duplicate sample IDs, there is a chance that different groups may collect samples simultaneously. This second step will be implemented by the Field PM at KLI upon receipt of caulk/sealant samples from participating municipalities. The Field PM at KLI will review the sample IDs on the COC forms for all samples and compare the sample IDs to all caulk samples for this project already in storage at KLI. If any two samples have the same sample IDs, the Field PM will add a one-digit number to the end of one of the sample IDs, selected at random. This extra number will be added to the sample container label, the field data sheet, and the COC form for that sample.

9.2. HDS Unit Sampling Procedures (Task 2)

9.2.1. Sample Site Selection

Sample site selection will be opportunistic, based on the public HDS units that participating municipalities schedule for cleaning during the project. The project team will coordinate with participating municipalities to schedule sampling during HDS unit cleanouts.

9.2.2. Field Equipment and Cleaning

A list of potential sampling equipment for soil/sediment is presented in Table 5. The equipment list should be reviewed and tailored by field contractors to meet the needs of each individual sampling site. Appropriate sampling equipment is prepared in the laboratory a minimum of four days prior to sampling. Prior to sampling, all equipment will be thoroughly cleaned. Equipment is soaked (fully immersed) for three days in a solution of Alconox, Liquinox, or similar phosphate-free detergent and deionized water. Equipment is then rinsed three times with deionized water. Equipment is next rinsed with a dilute solution

(1-2%) of hydrochloric acid, followed by a rinse with reagent grade methanol, followed by another set of three rinses with deionized water. All equipment is then allowed to dry in a clean place. The cleaned equipment is then wrapped in aluminum foil or stored in clean Ziploc bags until used in the field.

Table 9-1 Field Equipment for HDS Unit Sampling.

Description of Equipment	Material (if applicable)
Sample scoops	Stainless steel or Kynar coated
Sample trowels	Stainless steel or Kynar coated
Compositing bucket	Stainless steel or Kynar coated
Ekman Dredge (as needed)	Stainless steel
Sample containers (with labels)	As coordinated with lab(s)
Methanol, Reagent grade (Teflon squeeze bottle with refill)	
Hydrochloric acid, 1-2%, Reagent grade (Teflon squeeze bottle)	
Liquinox detergent (diluted in DI within Teflon squeeze bottle)	
Deionized / reverse osmosis water	
Plastic scrub brushes	
Container for storage of sampling derived waste, dry	
Container for storage of sampling derived waste, wet	
Wet ice	
Coolers, as required	
Aluminum foil (heavy duty recommended)	
Protective packaging materials	Bubble / foam bags
Splash proof eye protection	
PPE for sampling personnel, including traffic mgmt as required	
Gloves for dry ice handling	Cotton, leather, etc.
Gloves for sample collection, reagent handling	Nitrile
Field datasheets	
COC forms	
Custody tape (as required)	
Shipping materials (as required)	
GPS	

9.2.3. Soil / Sediment Sample Collection

Field sampling personnel will collect sediment samples from HDS unit sumps using methods that minimize contamination, losses, and changes to the chemical form of the analytes of interest. The samples will be collected in the field into pre-cleaned sample containers of a material appropriate to the analysis to be conducted. Pre-cleaned sampling equipment is used for each site, whenever possible and/or when necessary. Appropriate sampling technique and measuring equipment may vary depending on the location, sample type, sampling objective, and weather. Additional safety measures may be necessary in some cases; for example, if traffic control or confined space entry is required to conduct the sampling.

Ideally and where a sufficient volume of soil/sediment allows, samples are collected into a composite container, where they are thoroughly homogenized, and then aliquoted into separate jars for chemical analysis. Sediment samples for metals and organics are submitted to the analytical laboratories in separate jars, which have been pre-cleaned according to laboratory protocol. It is anticipated that soil / solid media will be collected for laboratory analysis using one of two techniques: (1) Remote grab of submerged sediments within HDS unit sumps using Ekman dredge or similar; or (2) direct grab sampling of sediments after dewatering HDS unit sumps using individual scoops, push core sampling, or similar. Each of these techniques is described briefly below.

- Soil and Sediment Samples, Submerged. Wet soil and sediment samples may be collected from within HDS unit sumps. Sample crews must exercise judgment on whether submerged samples can be collected in a manner that does not substantially change the character of the soil/sediment collected for analysis (e.g., loss of fine materials). It is anticipated that presence of trash within the sumps may interfere with sample collection by preventing complete grab closure and loss of significant portion of the sample. Field crews will have the responsibility to determine the best method for collection of samples within each HDS Unit sump. If sampling personnel determine that sample integrity cannot be maintained throughout collection process, it is preferable to cancel sampling operations rather than collect samples with questionable integrity. This decision making process is more fully described in Section 11, Field Variances.

- Soil and Sediment Samples, Dry. Soils / sediments may be collected from within the HDS unit sump after dewatering. Field crews will have the responsibility to identify areas of sediment accumulation within areas targeted for sampling and analysis, and determine the best method for collection of samples with minimal disturbance to the sampling media.

After collection, all soil/sediment samples for PCBs and mercury analyses will be homogenized and transferred from the sample-dedicated homogenization pail into factory-supplied wide-mouth glass jars using a clean trowel or scoop. The samples will be transferred to coolers containing double-bagged wet ice and chilled to 6°C immediately upon collection.

For each sample collected, field personnel will fill out a field data sheet at the time of sample collection. Appendix A contains an example field data sheet. All samples will be kept in a chilled cooler in the field, and kept refrigerated pending delivery under COC to the field-PM. The Field PM will be responsible for sending the samples in a single batch to CEH for XRF analysis under COC. Following XRF analysis, CEH will deliver the samples under COC to the Consultant-PM. The Consultant-PM will be responsible for working with the project team to group samples for compositing, and sending those samples to the analytical laboratory under COC.

9.2.4.Sample ID Designation

Every sample must have a unique sample ID so that the analytical results from each sample can be differentiated from every other sample. This information should follow the sample through the COC, analytical, and interpretation and reporting processes. Each sediment/soil sample collected from HDS units will be labeled according to the following naming convention:

MMM-UUU-##

where:

MMM	Municipal Abbreviation (i.e., SJC=San Jose; OAK=Oakland; SUN=Sunnyvale).
UUU	HDS Unit Catchment ID; this is the number provided by the municipality for a specific HDS unit.
##	Sequential Sample Number (i.e., 01, 02, 03…etc.)

9.3. Water Quality Sampling and Column Testing Procedures (Task 3)

For this task, monitoring will be conducted during three storm events. The stormwater collected during these events will then be used as the influent for the laboratory column tests of amended BSM mixtures. Four influent samples (i.e., one sample of Bay Area stormwater from each of the three monitored storm events plus one diluted stormwater sample) and 20 effluent samples from the column tests that includes 3 tests for each of the six columns, plus one test with the diluted stormwater in two columns (one test column and one control column) will be collected and analyzed for pollutant concentrations.

9.3.1. Sample Site Selection

Two stormwater collection sites have been selected based on influent PCB concentrations measured during CW4CB (BASMAA, 2017c). Both sites are near tree wells located on Ettie Street in West Oakland. The first site is the influent to tree well #6 (station code = TW6). During CW4CB, influent stormwater concentrations at this location were average to high, ranging from 30 ng/L to 286 ng/L. Stormwater collected from this site will be used as the influent for one of the main column tests and some water will be reserved for the dilution series column tests. The amount of dilution will be determined after results are received from the lab from the first run. The second site is the influent to tree well #2 (station code=TW2). During CW4CB, influent stormwater concentrations at this location were low to average, ranging from 6 ng/L to 39 ng/L. Stormwater collected from this site will be used for the remaining two main column tests..

9.3.2. Field Equipment and Cleaning

Field sampling equipment includes:

1. Borosilicate glass carboys
2. Glass sample jars
3. Peristaltic pump tubing

Prior to sampling, all equipment will be thoroughly cleaned. Glass sample containers and peristaltic pump tubing will be factory pre-cleaned. Prior to first use and after each use, glass carboys (field carboys and effluent collection carboys) will be washed using phosphate-free laboratory detergent and scrubbed with a plastic brush. After washing the carboy will be rinsed with methylene chloride, then de-ionized water, then 2N nitric acid, then again with de-ionized water. Glass carboys will be cleaned after each sample run before they are returned to the Field PM for reuse in the field.

9.3.3. Water Sampling Procedures

During each storm event, stormwater will be collected in six, five-gallon glass carboys. To fill the carboys, the Field PM will create a backwater condition in the gutter before the drain inlet at each site and use a peristaltic pump to pump the water into glass carboys. Field personnel will wear nitrile gloves during sample collection to prevent contamination. Carboys will be stored and transported in coolers with either wet ice or blue ice, and will be delivered to OWP within 24 hours of collection.

9.3.4. Hydraulic Testing

Based on the literature review and availability, the best five biochars will be mixed with the standard BSM to create biochar amended BSMs. Initially, each biochar will be mixed with standard BSM at a rate of 25% biochar by volume (the same as that at the CW4CB Richmond PG&E Substation 1st and Cutting site). Hydraulic conductivity can be determined using the method stated in the BASMAA soil specification, method ASTM D2434.

1. Follow the directions for permeability testing in ASTM D2434 for the BSM.
2. Sieve enough of the sample biochar to collect at least 15 in^3 on a no. 200 sieve.
3. Mix the sieved biochar with standard BSM at a 1 to 4 ratio.
4. Thoroughly mix the soil.
5. Follow the directions for permeability testing in ASTM D2434.
6. If the soil mix is more than 1 in/hr different from the BSM, repeat steps 1-4 but on step 3, adjust the ratio as estimated to achieve the same permeability as the BSM.
7. Repeat steps 2-6 for each biochar.

9.3.5. Column Testing Procedures

Column Setup: Up to five biochar amended BSMs and one standard BSM will be tested (based on performance and availability of biochars). Six glass columns with a diameter of eight inches and a height of three feet will be mounted to the wall with sufficient height between the bottom of the columns and the floor to allow for effluent sample collection. Each column will be capped at the bottom and fitted with a spigot to facilitate sampling. Soil depth for all columns will be 18" after compaction, which is a standard depth used in bay area bioretention installations (see Figure 9-1 below). To retain soil the bottom of the soil layer will be contained by a layer of filter fabric on top of structural backing. Behind each column, a yardstick will be mounted to the wall so that the depth of water in the column can be monitored.

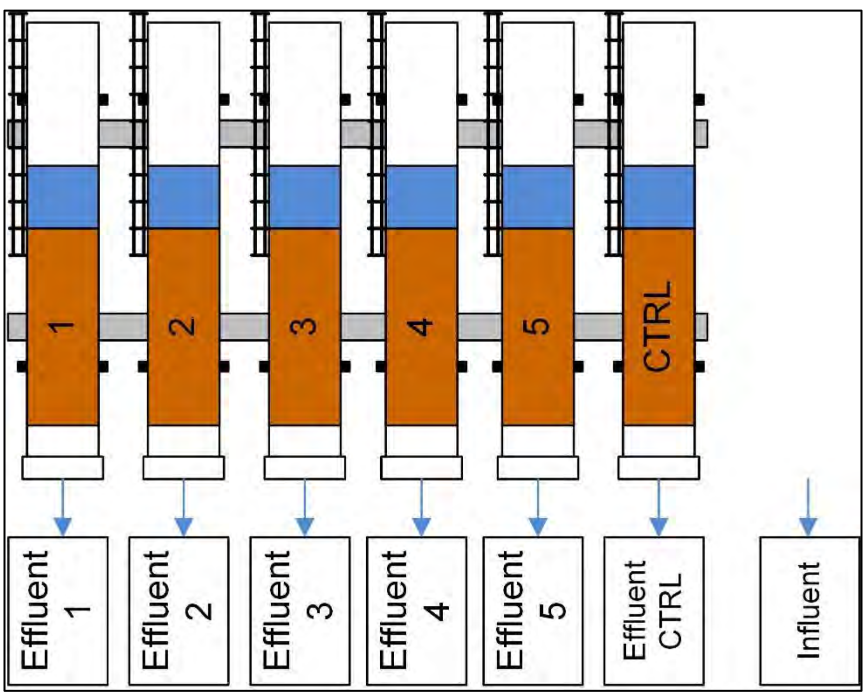

Figure 9-1. Column Test Setup

Dilution Run Column Setup: One of the existing biochar-amended BSM column and the standard BSM will be tested using diluted stormwater.

Testing procedure pre run setup: Before a sampling run begins a clean glass carboy will be placed under each soil column and labeled to match, this carboy will be sized to collect the full effluent volume of the sample run. A glass beaker will also be assigned and labeled for each column of sufficient volume to accurately measure a single influent dose equivalent to 1 inch of depth in the column. An additional beaker will be prepared and labeled influent.

Media conditioning: Within 24 to 72 hours prior to the first column test run, pre-wet each column with a stormwater matrix collected from the CSUS campus by filling each column from the invert until water ponds above the media. Drain the water after 3 hours.

Sampling run: When the six glass carboys are delivered:

1. Inspect each carboy and fill out the Sample Receiving worksheet.
2. The runs will begin within 72 hours of delivery.
3. Select one carboy at random and fully mix it using a portable lab mixer for five minutes.
4. Turn off and remove the mixer, allow the sample to rest for one minute to allow the largest particles to settle to the bottom.
5. Fill each of the six dosing beakers and the one influent sample jar.
6. Pour each aliquot beaker into its respective column; record the time and height of water in each column.
7. Repeat steps 3-6 for each of the remaining carboys until a total of 18 inches of water is applied to each column. Before pouring an aliquot record the height of water in each column and the time. Pour each successive aliquot from the carboy when all columns have less than three inches of water above the soil surface. The water level should never be above 6 inches in any column at any time (6 inches is a standard ponding depth used in the bay area). Pour all aliquots from a single carboy into the columns at the same time.
8. Collect turbidity samples from the effluent of each column at the beginning, middle, and end of the sampling run. Fill the cuvettes for turbidity measurement directly from the effluent stream of each column and dispose of them after testing.
9. Collect mercury samples from the effluent of each column at the middle of the sample run using pre-labeled sample containers provided by the lab for that purpose.
10. Fill a pre-labeled sample jar from each columns effluent. The jar will be obtained from the laboratory performing the PCB analysis.
11. Pack each jar in ice and complete the lab COCs.
12. Ship the samples to the lab for analysis.

9.3.6.Sample ID Designations

Every sample must have a unique sample identification to ensure analytical results from each sample can be differentiated from every other sample. This information should follow the sample through the COC, analytical, and interpretation and reporting processes. Each influent and effluent water quality sample will be labeled according to the following naming convention:

SSS-TT-MMDDYYYY-##

Where:	
SSS	Station code (see Table 9-2 for station codes)
TT	Sample Type (IN=influent; EF=Effluent)
MM	2 digit month of collection
DD	2 digit date of collection
YYYY	4 digit year of collection
##	Sequential 2-digit sample number (i.e., 01, 02, 03…etc.)

For example, a sample collected at the West Oakland Tree Well #2 site on October 20, 2017 and used for the influent sample for run #3 could be assigned the following sample ID: TW2-IN-09202017-03.

Table 9-2 Station Codes for Stormwater Influent Samples and Column Tests.

Station Code	Station Description
TW2	Stormwater sample collected from the West Oakland Tree Well #2
TW6	Stormwater sample collected from the West Oakland Tree Well #6
CO1	Effluent sample collected from column number 1
CO2	Effluent sample collected from column number 2
CO3	Effluent sample collected from column number 3
CO4	Effluent sample collected from column number 4
CO5	Effluent sample collected from column number 5
CO6	Effluent sample collected from column number 6

9.4. Collection of Samples for Archiving

Archive samples will not be collected for this Monitoring Program. The sample size collected will be enough to support additional analyses if QA/QC issues arise. Once quality assurance is certified by the QA Officer, the laboratory will be instructed to dispose of any leftover sample materials.

9.5. Waste Disposal

Proper disposal of all waste is an important component of field activities. At no time will any waste be disposed of improperly. The proper methods of waste disposal are outlined below:

9.5.1. Routine Garbage

Regular garbage (paper towels, paper cups, etc.) is collected by sampling personnel in garbage bags or similar. It can then be disposed of properly at appropriate intervals.

9.5.2. Detergent Washes

Any detergents used or detergent wash water should be collected in the field in a water-tight container and disposed of appropriately.

9.5.3. Chemicals

Methanol, if used, should be disposed of by following all appropriate regulations. It should always be collected when sampling and never be disposed in the field.

9.1. Responsibility and Corrective Actions

If monitoring equipment fails, sampling personnel will report the problem in the comments section of their field notes and will not record data values for the variables in question. Actions will be taken to replace or repair broken equipment prior to the next field use.

9.2. Standard Operating Procedures

SOPs associated with sampling and sample handling expected to be used as part of implementation of The Monitoring Program are identified in Table 9-3. Additional details on sample container information, required preservation, holding times, and sample volumes for all Monitoring Program analytes are listed in Table 10-1 of Section 10.

Table 9-3. List of BASMAA RMC SOPs Utilized by the Monitoring Program.

RMC SOP #	RMC SOP	Source
FS-2	Water Quality Sampling for Chemical Analysis, Pathogen Indicators, and Toxicity	BASMAA 2016
FS-3	Field Measurements, Manual	BASMAA 2016
FS-4	Field Measurements, Continuous General Water Quality	BASMAA 2016
FS-5	Temperature, Automated, Digital Logger	BASMAA 2016
FS-6	Collection of Bedded Sediment Samples for Chemical Analysis and Toxicity	BASMAA 2016
FS-7	Field Equipment Cleaning Procedures	BASMAA 2016
FS-8	Field Equipment Decontamination Procedures	BASMAA 2016
FS-9	Sample Container, Handling, and Chain of Custody Procedures	BASMAA 2016
FS-10	Completion and Processing of Field Datasheets	BASMAA 2016
FS-11	Site and Sample Naming Convention	BASMAA 2016

In addition, contractor-specific plans and procedures may be required for specific aspects of the Monitoring Program implementation (e.g., health and safety plans, dry ice shipping procedures).

10. Sample Handling and Custody

Sample handling and chain of custody procedures are described in detail in RMC SOP FS-9 (Table 9-3) (BASMAA 2016). The Field-PM or designated municipal staff on site during sample collection will be responsible for overall collection and custody of samples during field sampling. Field crews will keep a field log, which will consist of sampling forms for each sampling event. Sample collection methods described in this document and the study designs (BASMAA 2017a, b) will be followed for each sampling task. Field data sheets will be filled out for each sample collected during the project. Example field data sheets are provided in Appendix A, and described further in Section 9.

The field crews will have custody of samples during field sampling, and COC forms will accompany all samples from field collection until delivery to the analyzing laboratory. COC procedures require that possession of samples be traceable from the time the samples are collected until completion and submittal of analytical results. Each laboratory will follow sample custody procedures as outlined in its QA plans.

Information on sampling containers, preservation techniques, packaging and shipping, and hold times is described below and summarized in Table 10.1.

10.1. Sampling Containers

Collection of all sample types require the use of clean containers. Factory pre-cleaned sample containers of the appropriate type will be provided by the contracted laboratory and delivered to field team at least one week prior to the start of sample collection. Individual laboratories will be responsible for the integrity of containers provided. The number and type of sample containers required for all analytes by media type for each sampling task are provided in Table 10.1.

10.2. Sample Preservation

Field Crews will collect samples in the field in a way that neither contaminates, loses, or changes the chemical form of the analytes of interest. The samples will be collected in the field into pre-cleaned sample containers of a material appropriate to the analysis to be conducted. Pre-cleaned sampling equipment is used for each site, whenever possible and/or when necessary. Appropriate sampling technique and measurement equipment may vary depending on the location, sample type, sampling objective, and weather.

In general, all samples will be packed in sufficient wet ice or frozen ice packs during shipment, so that they will be kept between 2 and 4º C (Table 10.1). When used, wet ice will be double bagged in Zip-top bags to prevent contamination via melt water. Where appropriate, samples may be frozen to prevent degradation. If samples are to be shipped frozen on dry ice, then appropriate handling procedures will be followed, including ensuring use of appropriate packaging materials and appropriate training for shipping personnel.

10.3. Packaging and Shipping

All samples will be handled, prepared, transported, and stored in a manner so as to minimize bulk loss, analyte loss, contamination, or biological degradation. Sample containers will be clearly labeled with an indelible marker. All caps and lids will be checked for tightness prior to shipping. Ice chests will be sealed with packing tape before shipping. Samples will be placed in the ice chest with enough ice or frozen ice packs to maintain between 2 and 4º C. Additional packing material will be added as needed. COC forms will be placed in a zip-top bag and placed inside of the ice chest.

10.4. Commercial Vehicle Transport

If transport of samples to the contracted laboratories is to be by commercial carriers, pickup will be pre-arranged with the carrier and all required shipping forms will be completed prior to sample pickup by the commercial carrier.

10.5. Sample Hold Times

Sample hold times for each analyte by media type are presented in Table 10-1.

Table 10-1 Sample Handling for the Monitoring Program Analytes by media type.

Analyte	Sample Media	Sample Container	Minimum Sample / Container Size[a]	Preservative	Hold Time (at 6º C)
PCBs (40-RMP Congeners)	Caulk or sealant	Pre-cleaned 250-mL glass sample container (e.g., Quality Certified™, ESS Vial, Oakland, CA)	10 g	Cool to 6° C within 24 hours, then freeze to ≤-20° C	1 year at -20º C; Samples must be analyzed within 14 days of collection or thawing.
	Sediment	Pre-cleaned 250-mL I-Chem 200 Series amber glass jar with Teflon lid liner	500 mL (two jars)	Cool to 6° C within 24 hours, then freeze to ≤-20° C	1 year at -20º C; Samples must be analyzed within 14 days of collection or thawing.
	Water	1000-mL I-Chem 200-Series amber glass bottle, with Teflon lid-liner	1000 mL/per individual analyses	Cool to 6º C in the dark.	1 year until extraction, 1 year after extraction
Total Mercury	Sediment	Pre-cleaned 250-mL I-Chem 200 Series amber glass jar with Teflon lid liner	100 g	Cool to 6º C and in the dark	1 year at -20º C; Samples must be analyzed within 14 days of collection or thawing.
	Water	250-mL glass or acid-cleaned Teflon bottle	250 mL	Cool to 6º C in the dark and acidify to 0.5% with pre-tested HCl within 48 hours	6 months at room temperature following acidification
Bulk Density	Sediment	250-mL clear glass jar; pre-cleaned	250 mL	Cool to 6º C	7 days
Grain Size and TOC	Sediment	250-mL clear glass jar; pre-cleaned	250 mL	Cool to 6º C, in the dark up to 28 days[2]	28 days at ≤6 ◦C; 1 year at ≤-20 ◦C
SSC	Water	125-mL amber glass jar or Polyethylene Bottles	125 mL	Cool to 6º C and store in the dark	7 days
Turbidity	Water				
Total Solids	Water	1 L HDPE	1 L	Cool to ≤6 ◦C	7 days
TOC	Water	40-mL glass vial	40 mL	Cool to 6º C and store in the dark. If analysis is to occur more than two hours after sampling, acidify (pH < 2) with HCl or H_2SO_4.	28 days
Particle Size Distribution	Water	1 L HDPE	2 L	Cool to 6º C and store in the dark	7 days

[a]QC samples or other analytes require additional sample bottles.

11. Field Health and Safety Procedures

All field crews will be expected to abide by their employer's (i.e., the field contractor's) health and safety programs. Additionally, prior to the fieldwork, field contractors are required to develop site-specific Health and Safety plans that include the locations of the nearest emergency medical services.

Implementation of the Monitoring Program activities may require confined space entry (CSE) to accomplish sampling goals. Sampling personnel conducting any confined space entry activities will be expected to be certified for CSE and to abide by relevant regulations.

12. Laboratory Analytical Methods

12.1. Caulk/Sealant Samples (Task 1)

12.1.1. XRF Chlorine analysis

XRF technology will be used in a laboratory setting to rank samples for chlorine content before sending the samples to the project laboratory for chemical analysis. Procedures for testing caulk or sealants using X-Ray fluorescence (XRF) and collecting caulk and sealant samples are not well described, and minimal detail on caulk or sealant sample collection is available in peer-reviewed publications. Sealant sampling procedures were adapted from the previous study examining PCBs in building materials (Klosterhaus et al., 2014).

An XRF analyzer will be used at the Center for Environmental Health (CEH) as a screening tool to estimate the concentration of chlorine (Cl) in collected caulk and sealant samples from various structures. Settings for the analyzer will be 'standardized' using procedures developed/ recommended by CEH each time the instrument is turned on and prior to any measurement. European plastic pellet reference materials (EC680 and EC681) will be used as 'check' standards upon first use to verify analyzer performance. A 30 second measurement in 'soil' mode will be used. CEH personnel will inspect the caulk/sealant surfaces and use a stainless steel blade to scrape off any paint, concrete chips, or other visible surface residue. The caulk/sealant surface to be sampled will then be wiped with a laboratory tissue to remove any remaining debris that may potentially interfere with the XRF analysis. At least two XRF readings will be collected from each sample switching the orientation or position of the sample between readings. If Cl is detected, a minimum of four additional readings will be collected on the same material to determine analytical variability. Each individual Cl reading and its detection limit will be recorded on the data sheet. After XRF analysis, all samples will be returned to their original sample container. Results of the XRF analysis will be provided to the project team as a table of ranked Cl screening results for possible selection for chemical (PCBs) analysis.

12.1.2. Selection of Samples for PCB analysis and Compositing

Once samples have been ranked for their chlorine content, primarily samples with the highest Cl will preferentially be selected for chemical analysis. About 75% of samples to be analyzed should be selected from samples with the top quartile Cl content. The remaining 25% should be selected from samples with medium (25 to 75th percentile) Cl, as the previous study using XRF screening showed inconsistent correlation between total Cl and PCB. Although samples with very low Cl seldom had much PCBs, samples with medium Cl on occasion had higher PCBs than samples with high Cl, and within the high Cl group, Cl content was not a good predictor of their ranks of PCB concentration.

In addition to Cl content, other factors about each sample that were recorded on the field data sheets at the time of sample collection, including the color or consistency of the sample, the type and/or age of the structure that was sampled, or the type of caulk or sealant application will be considered in selecting the samples that will be sent to the laboratory for PCBs analysis, as well as how the samples will be grouped for compositing purposes. Those factors are described in more detail in the study design (BASMAA, 2017a).

The Consultant PM will work with the project team to identify up to three samples for inclusion in each composite. A common composite ID will then be assigned to each sample that will be composited together (i.e., all samples the lab should composite together will be identified by the common composite ID). The composite ID will consist of a single letter designation and will be identical for all samples (up to 3 total) that will be composited together. The Consultant PM will add the composite ID to each sample container label, to each sample ID on all COC forms, and to each field data sheet for all samples prior to sending the samples to the laboratory for PCBs analysis.

12.1.3. Sample Preparation

The project laboratory will composite the samples prior to extraction and PCBs analysis according to the groupings identified by the common composite ID. Sample preparation will include removal of any paint, concrete chips, or other surface debris, followed by homogenization of the caulk/sealant material and compositing up to three samples per composite. Each sample will have a composite ID that will be used to identify which samples should be composited together. Samples with the same composite ID will be combined into a single composite sample. For example, all samples with composite ID = “A” will be composited together; all samples with composite ID = “B” will be composited together, etc. Sample preparation and compositing will follow the procedures outlined in the laboratory SOPs (Appendix B). After compositing, each composite sample will be assigned a new sample ID using the following naming convention:

X-MMDDYYYY

Where:

X	the single letter Composite ID that is common to all samples included in a given composite.
MM	2 digit month of composite preparation
DD	2 digit date of composite preparation
YYYY	4 digit year of composite preparation

For example, if three samples with the composite ID= “A” are combined into a single composite sample on December 12, 2017, the new (composite) sample ID would be the following: A-12122017.

12.1.4. PCBs Analysis

All composite caulk/sealant samples will be extracted by Method 3540C, and analyzed for the RMP-40 PCB congeners[3] using a modified EPA Method 8270C (GC/MS-SIM), in order to obtain positive

[3] The 40 individual congeners routinely quantified by the Regional Monitoring Program (RMP) for Water Quality in the San Francisco Estuary include: PCBs 8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, l05, 110, 118, 128, 132, 138, 141, 149, l51, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203

identification and quantitation of PCBs. PCB content of these material covers an extremely wide range, so the subsampling of material should include sufficient material for quantification assuming that the concentration is likely to be around the median of previous results. There may be samples with much higher concentrations, which can be reanalyzed on dilution as needed. Method Reporting Limits (MRLs) for each of the RMP-40 PCB Congeners are 0.5 µg/Kg.

12.2. Sediment Samples Collected from HDS Units (Task 2)

All sediment samples collected from HDS units under Task 2 will be analyzed for TOC, grain size, bulk density, total mercury, and PCBs (RMP 40 Congeners1) by the methods identified in Table 12-1. All sediment samples (with the exception of grain size) will be sieved by the laboratory at 2 mm prior to analysis.

Table 12-1. Laboratory Analytical Methods for Analytes in Sediment

Analyte	Sampling Method	Recommended Analytical Method	Reporting Units
Total Organic Carbon (TOC)	Grab	EPA 415.1, 440.0, 9060, or ASTM D4129M	%
Grain Size	Grab	ASTM D422M/PSEP	%
Bulk Density	Grab	ASTM E1109-86	g/cm3
Mercury	Grab	EPA 7471A, 7473, or 1631	µg/kg
PCBs (RMP 40 Congeners)	Grab	EPA 1668	µg/kg

12.3. Water Samples – Stormwater and Column Tests (Task 3)

All water samples submitted to the laboratory will be analyzed for SSC, TOC, total mercury and PCBs (RMP-40 congeners) according to the methods identified in Table 12-2.

Table 12-2. Laboratory Analytical Methods for Analytes in Water

Analyte	Sampling Method	Recommended Analytical Method	Reporting Units
Suspended Sediment Concentration (SSC)	Grab	ASTM D3977-97 (Method C)	mg/L
Total Organic Carbon (TOC)	Grab	EPA 415.1 or SM 5310B	%
Mercury (Total)	Grab	EPA 1631	µg/L
PCBs (RMP 40 Congeners)	Grab	EPA 1668	ng/L

12.4. Method Failures

The QA Officer will be responsible for overseeing the laboratory implementing any corrective actions that may be needed in the event that methods fail to produce acceptable data. If a method fails to provide acceptable data for any reason, including analyte or matrix interferences, instrument failures, etc., then the involved samples will be analyzed again if possible. The laboratory in question's SOP for handling these types of problems will be followed. When a method fails to provide acceptable data, then the laboratory's

SOP for documenting method failures will be used to document the problem and what was done to rectify it.

Corrective actions for chemical data are taken when an analysis is deemed suspect for some reason. These reasons include exceeding accuracy or precision ranges and/or problems with sorting and identification. The corrective action will vary on a case-by-case basis, but at a minimum involves the following:

- A check of procedures.
- A review of documents and calculations to identify possible errors.
- Correction of errors based on discussions among analysts.
- A complete re-identification of the sample.

The field and laboratory coordinators shall have systems in place to document problems and make corrective actions. All corrective actions will be documented to the FTL and the QA Officer.

12.5. Sample Disposal

After analysis of the Monitoring Program samples has been completed by the laboratory and results have been accepted by QA Officer and the Field-PM, they will be disposed by laboratory staff in compliance with all federal, state, and local regulations. The laboratory has standard procedures for disposing of its waste, including left over sample materials

12.6. Laboratory Sample Processing

Field samples sent to the laboratories will be processed within their recommended hold time using methods agreed upon method between the Lab-PM and Field-PM. Each sample may be assigned unique laboratory sample ID numbers for tracking processing and analyses of samples within the laboratory. This laboratory sample ID (if differing from the field team sample ID) must be included in the data submission, within a lookup table linking the field sample ID to that assigned by the lab.

Samples arriving at the laboratory are to be stored under conditions appropriate for the planned analytical procedure(s), unless they are processed for analysis immediately upon receipt. Samples to be analyzed should only be removed from storage when laboratory staff are ready to proceed.

13. Quality Control

Each step in the field collection and analytical process is a potential source of contamination and must be consistently monitored to ensure that the final measurement is not adversely affected by any processing steps. Various aspects of the quality control procedures required by the Monitoring Program are summarized below.

13.1. Field Quality Control

Field QC results must meet the MQOs and frequency requirements specified in Tables 13-1 – 13-4 below.

13.1.1. Field Blanks

A field blank is collected to assess potential sample contamination levels that occur during field sampling activities. Field blanks are taken to the field, transferred to the appropriate container, preserved (if required by the method), and treated the same as the corresponding sample type during the course of a sampling event. The inclusion of field blanks is dependent on the requirements specified in the relevant MQO tables or in the sampling method or SOP.

Collection of caulk or sealant field blank samples has been deemed unnecessary due to the difficulty in collection and interpretation of representative blank samples and the use of precautions that minimize contamination of the samples. Additionally, PCBs have been reported to be present in percent concentrations when used in sealants; therefore any low level contamination (at ppb or even ppm level) due to sampling equipment and procedures is not expected to affect data quality because it would be many orders of magnitude lower than the concentrations deemed to be a positive PCB signal.

For stormwater samples, field blanks will be generated using lab supplied containers and clean matrices. Sampling containers will be opened as though actual samples were to be collected, and clean lab-supplied matrix (if any) will be transferred to sample containers for analysis.

13.1.2. Field Duplicates

Field samples collected in duplicate provide precision information as it pertains to the sampling process. The duplicate sample must be collected in the same manner and as close in time as possible to the original sample. This effort is to attempt to examine field homogeneity as well as sample handling, within the limits and constraints of the situation. These data are evaluated in the data analysis/assessment process for small-scale spatial variability.

Field duplicates will not be collected for caulk/sealant samples (Task 1), as assessment of within-structure variability of PCB concentrations in sealants is not a primary objective of the Project. Due to budget limitations, PCBs analysis of only one caulk/sealant sample per application will be targeted to maximize the number of Bay Area structures and structure types that may be analyzed in the Project. The selected laboratory will conduct a number of quality assurance analyses (see Section 13), including a limited number of sample duplicates, to evaluate laboratory and method performance as well as variability of PCB content within a sample.

For all sediment and water samples, 5% of field duplicates and/or column influent/effluent duplicates will be collected along with primary samples in order to evaluate small scale spatial or temporal variability in sample collection without specifically targeting any apparent or likely bias (e.g. different sides of a seemingly symmetrical unit, or offset locations in making a composite, or immediately following collection of a primary water sample would be acceptable, whereas collecting one composite near an inlet and another near the outlet, or intentionally collecting times with vastly different flow rates, would not be desirable).

13.1.3. Field Corrective Action

The Field PM is responsible for responding to failures in their sampling and field measurement systems. If monitoring equipment fails, personnel are to record the problem according to their documentation protocols. Failing equipment must be replaced or repaired prior to subsequent sampling events. It is the combined responsibility of all members of the field organization to determine if the performance requirements of the specific sampling method have been met, and to collect additional samples if necessary. Associated data is to be flagged accordingly. Specific field corrective actions are detailed in Table 13-8.

13.2. Laboratory Quality Control

Laboratories providing analytical support to the Monitoring Program will have the appropriate facilities to store, prepare, and process samples in an ultra-clean environment, and will have appropriate instrumentation and staff to perform analyses and provide data of the required quality within the time period dictated by the Monitoring Program. The laboratories are expected to satisfy the following:

1. Demonstrate capability through pertinent certification and satisfactory performance in inter-laboratory comparison exercises.
2. Provide qualification statements regarding their facility and personnel.
3. Maintain a program of scheduled maintenance of analytical balances, laboratory equipment and instrumentation.
4. Conduct routine checking of analytical balances using a set of standard reference weights (American Society of Testing and Materials Class 3, NIST Class S-1, or equivalents). Analytical balances are serviced at six-month intervals or when test weight values are not within the manufacturer's instrument specifications, whichever occurs first.
5. Conduct routine checking and recording the composition of fresh calibration standards against the previous lot. Acceptable comparisons are within 2% of the precious value.
6. Record all analytical data in bound (where possible) logbooks, with all entries in ink, or electronically.
7. Monitor and document the temperatures of cold storage areas and freezer units on a continuous basis.
8. Verify the efficiency of fume/exhaust hoods.
9. Have a source of reagent water meeting specifications described in Section 8.0 available in sufficient quantity to support analytical operations.
10. Label all containers used in the laboratory with date prepared, contents, initials of the individual who prepared the contents, and other information as appropriate.
11. Date and safely store all chemicals upon receipt. Proper disposal of chemicals when the expiration date has passed.
12. Have QAPP, SOPs, analytical methods manuals, and safety plans readily available to staff.
13. Have raw analytical data readily accessible so that they are available upon request.

In addition, laboratories involved in the Monitoring Program are required to demonstrate capability continuously through the following protocols:

1. Strict adherence to routine QA/QC procedures.
2. Regular participation in annual certification programs.
3. Satisfactory performance at least annually in the analysis of blind Performance Evaluation Samples and/or participation in inter-laboratory comparison exercises.

Laboratory QC samples must satisfy MQOs and frequency requirements. MQOs and frequency requirements are listed in Tables 13-1 – 13-3. Frequency requirements are provided on an analytical batch level. The Monitoring Program defines an analytical batch as 20 or fewer samples and associated quality control that are processed by the same instrument within a 24-hour period (unless otherwise specified by method). Target Method Reporting Limits are provided in Tables 13.4 – 13.8. Details regarding sample preparation are method- or laboratory SOP-specific, and may consist of extraction, digestion, or other techniques.

13.2.1. Calibration and Working Standards

All calibration standards must be traceable to a certified standard obtained from a recognized organization. If traceable standards are not available, procedures must be implemented to standardize the utilized calibration solutions (*e.g.*, comparison to a CRM – see below). Standardization of calibration solutions must be thoroughly documented, and is only acceptable when pre-certified standard solutions are not available. Working standards are dilutions of stock standards prepared for daily use in the laboratory. Working standards are used to calibrate instruments or prepare matrix spikes, and may be prepared at several different dilutions from a common stock standard. Working standards are diluted with solutions that ensure the stability of the target analyte. Preparation of the working standard must be thoroughly documented such that each working standard is traceable back to its original stock standard. Finally, the concentration of all working standards must be verified by analysis prior to use in the laboratory.

13.2.2. Instrument Calibration

Prior to sample analysis, utilized instruments must be calibrated following the procedures outlined in the relevant analytical method or laboratory SOP. Each method or SOP must specify acceptance criteria that demonstrate instrument stability and an acceptable calibration. If instrument calibration does not meet the specified acceptance criteria, the analytical process is not in control and must be halted. The instrument must be successfully recalibrated before samples may be analyzed.

Calibration curves will be established for each analyte covering the range of expected sample concentrations. Only data that result from quantification within the demonstrated working calibration range may be reported unflagged by the laboratory. Quantification based upon extrapolation is not acceptable; sample extracts above the calibration range should be diluted and rerun if possible. Data reported below the calibration range must be flagged as estimated values that are Detected not Quantified.

13.2.3. Initial Calibration Verification

The initial calibration verification (ICV) is a mid-level standard analyzed immediately following the calibration curve. The source of the standards used to calibrate the instrument and the source of the standard used to perform the ICV must be independent of one another. This is usually achieved by the purchase of standards from separate vendors. Since the standards are obtained from independent sources and both are traceable, analyses of the ICV functions as a check on the accuracy of the standards used to calibrate the instrument. The ICV is not a requirement of all SOPs or methods, particularly if other checks on analytical accuracy are present in the sample batch.

13.2.4. Continuing Calibration Verification

Continuing calibration verification (CCV) standards are mid-level standards analyzed at specified intervals during the course of the analytical run. CCVs are used to monitor sensitivity changes in the instrument during analysis. In order to properly assess these sensitivity changes, the standards used to perform CCVs must be from the same set of working standards used to calibrate the instrument. Use of a second source standard is not necessary for CCV standards, since other QC samples are designed to assess the accuracy of the calibration standards. Analysis of CCVs using the calibration standards limits this QC sample to assessing only instrument sensitivity changes. The acceptance criteria and required frequency for CCVs are detailed in Tables 13-1 through 13-3. If a CCV falls outside the acceptance limits, the analytical system is not in control, and immediate corrective action must be taken.

Data obtained while the instrument is out of control is not reportable, and all samples analyzed during this period must be reanalyzed. If reanalysis is not an option, the original data must be flagged with the appropriate qualifier and reported. A narrative must be submitted listing the results that were generated while the instrument was out of control, in addition to corrective actions that were applied.

13.2.5. Laboratory Blanks

Laboratory blanks (also called extraction blanks, procedural blanks, or method blanks) are used to assess the background level of a target analyte resulting from sample preparation and analysis. Laboratory blanks are carried through precisely the same procedures as the field samples. For both organic and inorganic analyses, a minimum of at least one laboratory blank must be prepared and analyzed in every analytical batch or per 20 samples, whichever is more frequent. Some methods may require more than one laboratory blank with each analytical run. Acceptance criteria for laboratory blanks are detailed in Tables 13-1 through 13-3. Blanks that are too high require corrective action to bring the concentrations down to acceptable levels. This may involve changing reagents, cleaning equipment, or even modifying the utilized methods or SOPs. Although acceptable laboratory blanks are important for obtaining results for low-level samples, improvements in analytical sensitivity have pushed detection limits down to the point where some amount of analyte will be detected in even the cleanest laboratory blanks. The magnitude of the blanks must be evaluated against the concentrations of the samples being analyzed and against project objectives.

13.2.6. Reference Materials and Demonstration of Laboratory Accuracy

Evaluation of the accuracy of laboratory procedures is achieved through the preparation and analysis of reference materials with each analytical batch. Ideally, the reference materials selected are similar in matrix and concentration range to the samples being prepared and analyzed. The acceptance criteria for reference materials are listed in Tables 13-1 – 13-3. The accuracy of an analytical method can be assessed using CRMs only when certified values are provided for the target analytes. When possible, reference materials that have certified values for the target analytes should be used. This is not always possible, and often times certified reference values are not available for all target analytes. Many reference materials have both certified and non-certified (or reference) values listed on the certificate of analysis. Certified reference values are clearly distinguished from the non-certified reference values on the certificate of analysis.

13.2.7. Reference Materials vs. Certified Reference Materials

The distinction between a reference material and a certified reference material does not involve how the two are prepared, rather with the way that the reference values were established. Certified values are determined through replicate analyses using two independent measurement techniques for verification. The certifying agency may also provide “non-certified or “reference” values for other target analytes. Such values are determined using a single measurement technique that may introduce bias. When available, it is preferable to use reference materials that have certified values for all target analytes. This is not always an option, and therefore it is acceptable to use materials that have reference values for these analytes. Note: Standard Reference Materials (SRMs) are essentially the same as CRMs. The term "Standard Reference Material" has been trademarked by the National Institute of Standards and Technology (NIST), and is therefore used only for reference materials distributed by NIST.

13.2.8. Laboratory Control Samples

While reference materials are not available for all analytes, a way of assessing the accuracy of an analytical method is still required. LCSs provide an alternate method of assessing accuracy. An LCS is a specimen of known composition prepared using contaminant-free reagent water or an inert solid spiked with the target analyte at the midpoint of the calibration curve or at the level of concern. The LCS must be analyzed using the same preparation, reagents, and analytical methods employed for regular samples. If an LCS needs to be substituted for a reference material, the acceptance criteria are the same as those for the analysis of reference materials..

13.2.9. Prioritizing Certified Reference Materials, Reference Materials, and Laboratory Control Samples

Certified reference materials, reference materials, and laboratory control samples all provide a method to assess the accuracy at the mid-range of the analytical process. However, this does not mean that they can be used interchangeably in all situations. When available, analysis of one certified reference material per analytical batch should be conducted. Certified values are not always available for all target analytes. If no certified reference material exists, reference values may be used. If no reference material exists for the target analyte, an LCS must be prepared and analyzed with the sample batch as a means of assessing accuracy. The hierarchy is as follows: analysis of a CRM is favored over the analysis of a reference material, and analysis of a reference material is preferable to the analysis of an LCS. Substitution of an LCS is not acceptable if a certified reference material or reference material is available, contact the Project Manager and QAO for approval before relying exclusively on an LCS as a measure of accuracy.

13.2.10.Matrix Spikes

A MS is prepared by adding a known concentration of the target analyte to a field sample, which is then subjected to the entire analytical procedure. The MS is analyzed in order to assess the magnitude of matrix interference and bias present. Because these spikes are often analyzed in pairs, the second spike is called the MSD. The MSD provides information regarding the precision of measurement and consistency of the matrix effects. Both the MS and MSD are split from the same original field sample. In order to properly assess the degree of matrix interference and potential bias, the spiking level should be approximately 2-5x the ambient concentration of the spiked sample. To establish spiking levels prior to sample analysis, if possible, laboratories should review any relevant historical data. In many instances, the laboratory will be spiking samples blind and will not meet a spiking level of 2-5x the ambient concentration. In addition to the recoveries, the relative percent difference (RPD) between the MS and MSD is calculated to evaluate how matrix affects precision. The MQO for the RPD between the MS and MSD is the same regardless of the method of calculation. These are detailed in Tables 13-1 – 13-3. Recovery data for matrix spikes provides a basis for determining the prevalence of matrix effects in the samples collected and analyzed. If the percent recovery for any analyte in the MS or MSD is outside of the limits specified in Tables 13-1 – 13-3, the chromatograms (in the case of trace organic analyses) and raw data quantitation reports should be reviewed. Data should be scrutinized for evidence of sensitivity shifts (indicated by the results of the CCVs) or other potential problems with the analytical process. If associated QC samples (reference materials or LCSs) are in control, matrix effects may be the source of the problem. If the standard used to spike the samples is different from the standard used to calibrate the instrument, it must be checked for accuracy prior to attributing poor recoveries to matrix effects.

13.2.11.Laboratory Duplicates

In order to evaluate the precision of an analytical process, a field sample is selected and prepared in duplicate. Specific requirements pertaining to the analysis of laboratory duplicates vary depending on the type of analysis. The acceptance criteria for laboratory duplicates are specified in Tables 13-1 – 13-3.

13.2.12.Laboratory Duplicates vs. Matrix Spike Duplicates

Although the laboratory duplicate and matrix spike duplicate both provide information regarding precision, they are unique measurements. Laboratory duplicates provide information regarding the precision of laboratory procedures at actual ambient concentrations. The matrix spike duplicate provides information regarding how the matrix of the sample affects both the precision and bias associated with the results. It also determines whether or not the matrix affects the results in a reproducible manner. MS/MSDs are often spiked at levels well above ambient concentrations, so thus are not representative of typical sample precision. Because the two concepts cannot be used interchangeably, it is unacceptable to analyze only an MS/MSD when a laboratory duplicate is required.

13.2.13.Replicate Analyses

The Monitoring Program will adopt the same terminology as SWAMP in defining replicate samples, wherein replicate analyses are distinguished from duplicate analyses based simply on the number of involved analyses. Duplicate analyses refer to two sample preparations, while replicate analyses refer to three or more. Analysis of replicate samples is not explicitly required.

13.2.14.Surrogates

Surrogate compounds accompany organic measurements in order to estimate target analyte losses or matrix effects during sample extraction and analysis. The selected surrogate compounds behave similarly to the target analytes, and therefore any loss of the surrogate compound during preparation and analysis is presumed to coincide with a similar loss of the target analyte. Surrogate compounds must be added to field and QC samples prior to extraction, or according to the utilized method or SOP. Surrogate recovery data are to be carefully monitored. If possible, isotopically labeled analogs of the analytes are to be used as surrogates.

13.2.15.Internal Standards

To optimize gas chromatography mass spectrometry (GC-MS) analysis, internal standards (also referred to as “injection internal standards”) may be added to field and QC sample extracts prior to injection. Use of internal standards is particularly important for analysis of complex extracts subject to retention time shifts relative to the analysis of standards. The internal standards can also be used to detect and correct for problems in the GC injection port or other parts of the instrument. The analyst must monitor internal standard retention times and recoveries to determine if instrument maintenance or repair or changes in analytical procedures are indicated. Corrective action is initiated based on the judgment of the analyst. Instrument problems that affect the data or result in reanalysis must be documented properly in logbooks and internal data reports, and used by the laboratory personnel to take appropriate corrective action. Performance criteria for internal standards are established by the method or laboratory SOP.

13.2.16.Dual-Column Confirmation

Due to the high probability of false positives from single-column analyses, dual column confirmation should be applied to all gas chromatography and liquid chromatography methods that do not provide definitive identifications. It should not be restricted to instruments with electron capture detection (ECD).

13.2.17.Dilution of Samples

Final reported results must be corrected for dilution carried out during the process of analysis. In order to evaluate the QC analyses associated with an analytical batch, corresponding batch QC samples must be analyzed at the same dilution factor. For example, the results used to calculate the results of matrix spikes must be derived from results for the native sample, matrix spike, and matrix spike duplicate analyzed at the same dilution. Results derived from samples analyzed at different dilution factors must not be used to calculate QC results.

13.2.18.Laboratory Corrective Action

Failures in laboratory measurement systems include, but are not limited to: instrument malfunction, calibration failure, sample container breakage, contamination, and QC sample failure. If the failure can be corrected, the analyst must document it and its associated corrective actions in the laboratory record and complete the analysis. If the failure is not resolved, it is conveyed to the respective supervisor who should determine if the analytical failure compromised associated results. The nature and disposition of the problem must be documented in the data report that is sent to the Consultant-PM. Suggested ccorrective actions are detailed in Table 13-9.

Table 13-1. Measurement Quality Objectives - PCBs.

Laboratory Quality Control	Frequency of Analysis	Measurement Quality Objective
Tuning[2]	Per analytical method	Per analytical method
Calibration	Initial method setup or when the calibration verification fails	• Correlation coefficient (r^2 >0.990) for linear and non-linear curves • If RSD<15%, average RF may be used to quantitate; otherwise use equation of the curve • First- or second-order curves only (not forced through the origin) • Refer to SW-846 methods for SPCC and CCC criteria[2] • Minimum of 5 points per curve (one of them at or below the RL)
Calibration Verification	Per 12 hours	• Expected response or expected concentration ±20% • RF for SPCCs=initial calibration[4]
Laboratory Blank	Per 20 samples or per analytical batch, whichever is more frequent	<RL for target analytes
Reference Material	Per 20 samples or per analytical batch	70-130% recovery if certified; otherwise, 50-150% recovery
Matrix Spike	Per 20 samples or per analytical batch, whichever is more frequent	50-150% or based on historical laboratory control limits (average±3SD)
Matrix Spike Duplicate	Per 20 samples or per analytical batch, whichever is more frequent	50-150% or based on historical laboratory control limits (average±3SD); RPD<25%
Surrogate	Included in all samples and all QC samples	Based on historical laboratory control limits (50-150% or better)
Internal Standard	Included in all samples and all QC samples (as available)	Per laboratory procedure
Field Quality Control	**Frequency of Analysis**	**Measurement Quality Objective**
Field Duplicate	5% of total Project sample count (sediment and water samples only)	RPD<25% (n/a if concentration of either sample<RL)
Field Blank	Not required for the Monitoring Program	<RL for target analytes

Table 13-2. Measurement Quality Objectives – Inorganic Analytes.

Laboratory Quality Control	Frequency of Analysis	Measurement Quality Objective
Calibration Standard	Per analytical method or manufacturer's specifications	Per analytical method or manufacturer's specifications
Continuing Calibration Verification	Per 10 analytical runs	80-120% recovery
Laboratory Blank	Per 20 samples or per analytical batch, whichever is more frequent	<RL for target analyte
Reference Material	Per 20 samples or per analytical batch, whichever is more frequent	75-125% recovery
Matrix Spike	Per 20 samples or per analytical batch, whichever is more frequent	75-125% recovery
Matrix Spike Duplicate	Per 20 samples or per analytical batch, whichever is more frequent	75-125% recovery ; RPD<25%
Laboratory Duplicate	Per 20 samples or per analytical batch, whichever is more frequent	RPD<25% (n/a if concentration of either sample<RL)
Internal Standard	Accompanying every analytical run when method appropriate	60-125% recovery
Field Quality Control	**Frequency of Analysis**	**Measurement Quality Objective**
Field Duplicate	5% of total Project sample count	RPD<25% (n/a if concentration of either sample<RL), unless otherwise specified by method
Field Blank, Equipment Field, Eqpt Blanks	Not required for the Monitoring Program	Blanks<RL for target analyte

Table 13-3. Measurement Quality Objectives – Conventional Analytes.

Laboratory Quality Control	Frequency of Analysis	Measurement Quality Objective
Calibration Standard	Per analytical method or manufacturer's specifications	Per analytical method or manufacturer's specifications
Laboratory Blank	Total organic carbon only: one per 20 samples or per analytical batch, whichever is more frequent (n/a for other parameters)	80-120% recovery
Reference Material	One per analytical batch	RPD<25% (n/a if native concentration of either sample<RL)
Laboratory Duplicate	(TOC only) one per 20 samples or per analytical batch, whichever is more frequent (n/a for other parameters)	80-120% recovery
Field Quality Control	**Frequency of Analysis**	**Measurement Quality Objective**
Field Duplicate	5% of total Project sample count	RPD<25% (n/a if concentration of either sample<RL)
Field Blank, Travel Blank, Field Blanks	Not required for the Monitoring Program analytes	NA

Consistent with SWAMP QAPP and as applicable, percent moisture should be reported with each batch of sediment samples. Sediment data must be reported on a dry weight basis.

Table 13-4. Target MRLs for Sediment Quality Parameters.

Analyte	MRL
Sediment Total Organic Carbon	0.01% OC
Bulk Density	n/a
%Moisture	n/a
%Lipids	n/a
Mercury	30 µg/kg

Table 13-5. Target MRLs for PCBs in Water, Sediment and Caulk

Congener	Water MRL (µg/L)	Sediment MRL (µg/kg)	Caulk/Sealant MRL (µg/kg)
PCB 8	0.002	0.2	0.5
PCB 18	0.002	0.2	0.5
PCB 28	0.002	0.2	0.5
PCB 31	0.002	0.2	0.5
PCB 33	0.002	0.2	0.5
PCB 44	0.002	0.2	0.5
PCB 49	0.002	0.2	0.5
PCB 52	0.002	0.2	0.5
PCB 56	0.002	0.2	0.5
PCB 60	0.002	0.2	0.5
PCB 66	0.002	0.2	0.5
PCB 70	0.002	0.2	0.5
PCB 74	0.002	0.2	0.5
PCB 87	0.002	0.2	0.5
PCB 95	0.002	0.2	0.5
PCB 97	0.002	0.2	0.5
PCB 99	0.002	0.2	0.5
PCB 101	0.002	0.2	0.5
PCB 105	0.002	0.2	0.5
PCB 110	0.002	0.2	0.5
PCB 118	0.002	0.2	0.5
PCB 128	0.002	0.2	0.5
PCB 132	0.002	0.2	0.5
PCB 138	0.002	0.2	0.5
PCB 141	0.002	0.2	0.5
PCB 149	0.002	0.2	0.5
PCB 151	0.002	0.2	0.5
PCB 153	0.002	0.2	0.5
PCB 156	0.002	0.2	0.5
PCB 158	0.002	0.2	0.5
PCB 170	0.002	0.2	0.5
PCB 174	0.002	0.2	0.5
PCB 177	0.002	0.2	0.5
PCB 180	0.002	0.2	0.5
PCB 183	0.002	0.2	0.5
PCB 187	0.002	0.2	0.5
PCB 194	0.002	0.2	0.5
PCB 195	0.002	0.2	0.5
PCB 201	0.002	0.2	0.5
PCB 203	0.002	0.2	0.5

Table 13-6. Size Distribution Categories for Grain Size in Sediment

Wentworth Size Category	Size	MRL
Clay	<0.0039 mm	1%
Silt	0.0039 mm to <0.0625 mm	1%
Sand, very fine	0.0625 mm to <0.125 mm	1%
Sand, fine	0.125 mm to <0.250 mm	1%
Sand, medium	0.250 mm to <0.5 mm	1%
Sand, coarse	0.5 mm to < 1.0 mm	1%
Sand, very coarse	1.0 mm to < 2 mm	1%
Gravel	2 mm and larger	1%

Table 13-7. Target MRLs for TOC, SSC, and Mercury in Water

Analyte	MRL
Total Organic Carbon	0.6 mg/L
Suspended Sediment Concentration	0.5 mg/L
Mercury	0.0002 µg/L

Table 13-8. Corrective Action – Laboratory and Field Quality Control

Laboratory Quality Control	Recommended Corrective Action
Calibration	Recalibrate the instrument. Affected samples and associated quality control must be reanalyzed following successful instrument recalibration.
Calibration Verification	Reanalyze the calibration verification to confirm the result. If the problem continues, halt analysis and investigate the source of the instrument drift. The analyst should determine if the instrument must be recalibrated before the analysis can continue. All of the samples not bracketed by acceptable calibration verification must be reanalyzed.
Laboratory Blank	Reanalyze the blank to confirm the result. Investigate the source of contamination. If the source of the contamination is isolated to the sample preparation, the entire batch of samples, along with the new laboratory blanks and associated QC samples, should be prepared and/or re-extracted and analyzed. If the source of contamination is isolated to the analysis procedures, reanalyze the entire batch of samples. If reanalysis is not possible, the associated sample results must be flagged to indicate the potential presence of the contamination.
Reference Material	Reanalyze the reference material to confirm the result. Compare this to the matrix spike/matrix spike duplicate recovery data. If adverse trends are noted, reprocess all of the samples associated with the batch.
Matrix Spike	The spiking level should be near the midrange of the calibration curve or at a level that does not require sample dilution. Reanalyze the matrix spike to confirm the result. Review the recovery obtained for the matrix spike duplicate. Review the results of the other QC samples (such as reference materials) to determine if other analytical problems are a potential source of the poor spike recovery.
Matrix Spike Duplicate	The spiking level should be near the midrange of the calibration curve or at a level that does not require sample dilution. Reanalyze the matrix spike duplicate to confirm the result. Review the recovery obtained for the matrix spike. Review the results of the other QC samples (such as reference materials) to determine if other analytical problems are a potential source of the poor spike recovery.
Internal Standard	Check the response of the internal standards. If the instrument continues to generate poor results, terminate the analytical run and investigate the cause of the instrument drift.
Surrogate	Analyze as appropriate for the utilized method. Troubleshoot as needed. If no instrument problem is found, samples should be re-extracted and reanalyzed if possible.
Field Quality Control	**Recommended Corrective Action**
Field Duplicate	Visually inspect the samples to determine if a high RPD between results could be attributed to sample heterogeneity. For duplicate results due to matrix heterogeneity, or where ambient concentrations are below the reporting limit, qualify the results and document the heterogeneity. All failures should be communicated to the project coordinator, who in turn will follow the process detailed in the method.
Field Blank	Investigate the source of contamination. Potential sources of contamination include sampling equipment, protocols, and handling. The laboratory should report evidence of field contamination as soon as possible so corrective actions can be implemented. Samples collected in the presence of field contamination should be flagged.

14. Inspection/Acceptance for Supplies and Consumables

Each sampling event conducted for the Monitoring Program will require use of appropriate consumables to reduce likelihood of sample contamination. The Field-PM will be responsible for ensuring that all supplies are appropriate prior to their use. Inspection requirements for sampling consumables and supplies are summarized in Table 14-1.

Table 14-1. Inspection / Acceptance Testing Requirements for Consumables and Supplies

Project-related Supplies	Inspection / Testing Specifications	Acceptance Criteria	Frequency	Responsible Person Sampling Containers
Sampling supplies	Visual	Appropriateness; no evident contamination or damage; within expiration date	Each purchase	Field Crew Leader

15. Non Direct Measurements, Existing Data

No data from external sources are planned to be used with this project.

16. Data Management

As previously discussed, the Monitoring Program data management will conform to protocols dictated by the study designs (BASMAA 2017a, b). A summary of specific data management aspects is provided below.

16.1. Field Data Management

All field data will be reviewed for legibility and errors as soon as possible after the conclusion of sampling. All field data that is entered electronically will be hand-checked at a rate of 10% of entries as a check on data entry. Any corrective actions required will be documented in correspondence to the QA Officer.

16.2. Laboratory Data Management

Record keeping of laboratory analytical data for the proposed project will employ standard record-keeping and tracking practices. All laboratory analytical data will be entered into electronic files by the instrumentation being used or, if data is manually recorded, then it will be entered by the analyst in charge of the analyses, per laboratory standard procedures.

Following the completion of internal laboratory quality control checks, analytical results will be forwarded electronically to the Field-PM. The analytical laboratories will provide data in electronic format, encompassing both a narrative and electronic data deliverable (EDD).

17. Assessments and Response Actions

17.1. Readiness Reviews

The Field-PM will review all field equipment, instruments, containers, and paperwork to ensure that everything is ready prior to each sampling event. All sampling personnel will be given a brief review of the goals and objectives of the sampling event and the sampling procedures and equipment that will be used to achieve them. It is important that all field equipment be clean and ready to use when it is needed. Therefore, prior to using all sampling and/or field measurement equipment, each piece of equipment will be checked to make sure that it is in proper working order. Equipment maintenance records will be checked to ensure that all field instruments have been properly maintained and that they are ready for use. Adequate supplies of all preservatives, bottles, labels, waterproof pens, etc. will be checked before each field event to make sure that there are sufficient supplies to successfully support each sampling event, and, as applicable, are within their expiration dates. It is important to make sure that all field activities and measurements are properly recorded in the field. Therefore, prior to starting each field event, necessary paperwork such as logbooks, chain of custody record forms, etc. will be checked to ensure that sufficient amounts are available during the field event. In the event that a problem is discovered during a readiness review it will be noted in the field log book and corrected before the field crew is deployed. The actions taken to correct the problem will also be documented with the problem in the field log book. This information will be communicated by the Field-PM prior to conducting relevant sampling. The Field-PM will track corrective actions taken.

17.2. Post Sampling Event Reviews

The Field-PM will be responsible for post sampling event reviews. Any problems that are noted will be documented along with recommendations for correcting the problem. Post sampling event reviews will be conducted following each sampling event in order to ensure that all information is complete and any deviations from planned methodologies are documented. Post sampling event reviews will include field sampling activities and field measurement documentation in order to help ensure that all information is complete. The reports for each post sampling event will be used to identify areas that may be improved prior to the next sampling event.

17.3. Laboratory Data Reviews

The Field-PM will be responsible for reviewing the laboratory's data for completeness and accuracy. The data will also be checked to make sure that the appropriate methods were used and that all required QC data was provided with the sample analytical results. Any laboratory data that is discovered to be incorrect or missing will immediately be reported to the both the laboratory and Consultant-PM. The laboratory's QA manual details the procedures that will be followed by laboratory personnel to correct any invalid or missing data. The Consultant-PM has the authority to request re-testing if a review of any of the laboratory data is found to be invalid or if it would compromise the quality of the data and resulting conclusions from the proposed project.

18. Instrument/Equipment Testing, Inspection and Maintenance

18.1. Field Equipment

Field measurement equipment will be checked for operation in accordance with manufacturer's specifications. All equipment will be inspected for damage when first employed and again when returned from use. Maintenance logs will be kept and each applicable piece of equipment will have its own log that documents the dates and description of any problems, the action(s) taken to correct problem(s), maintenance procedures, system checks, follow-up maintenance dates, and the person responsible for maintaining the equipment.

18.2. Laboratory Equipment

All laboratories providing analytical support for chemical or biological analyses will have the appropriate facilities to store, prepare, and process samples. Moreover, appropriate instrumentation and staff to provide data of the required quality within the schedule required by the program are also required. Laboratory operations must include the following procedures:

- A program of scheduled maintenance of analytical balances, microscopes, laboratory equipment, and instrumentation.
- Routine checking of analytical balances using a set of standard reference weights (American Society of Testing and Materials (ASTM) Class 3, NIST Class S-1, or equivalents).
- Checking and recording the composition of fresh calibration standards against the previous lot, wherever possible. Acceptable comparisons are < 2% of the previous value.
- Recording all analytical data in bound (where possible) logbooks, with all entries in ink, or electronic format.
- Monitoring and documenting the temperatures of cold storage areas and freezer units once per week.
- Verifying the efficiency of fume hoods.
- Having a source of reagent water meeting ASTM Type I specifications (ASTM, 1984) available in sufficient quantity to support analytical operations. The conductivity of the reagent water will not exceed 18 megaohms at 25°C. Alternately, the resistivity of the reagent water will exceed 10 mmhos/cm.
- Labeling all containers used in the laboratory with date prepared, contents, initials of the individual who prepared the contents, and other information, as appropriate.
- Dating and safely storing all chemicals upon receipt. Proper disposal of chemicals when the expiration date has passed.
- Having QAPP, SOPs, analytical methods manuals, and safety plans readily available to staff.
- Having raw analytical data, such as chromatograms, accessible so that they are available upon request.

Laboratories will maintain appropriate equipment per the requirements of individual laboratory SOPs and will be able to provide information documenting their ability to conduct the analyses with the required level of data quality. Such information might include results from interlaboratory comparison studies, control charts and summary data of internal QA/QC checks, and results from certified reference material analyses.

19. Instrument/Equipment Calibration and Frequency

19.1. Field Measurements

Any equipment used should be visually inspected during mobilization to identify problems that would result in loss of data. As appropriate, equipment-specific SOPs should be consulted for equipment calibration.

19.2. Laboratory Analyses

19.2.1. In-house Analysis – XRF Screening

A portable XRF analyzer will be used as a screening tool to estimate the chlorine concentration in each caulk sample. Since caulk often contains in excess of 1% PCBs and detection limits of portable XRF may be in the ppm range, the portable XRF may be able to detect chlorine within caulk containing PCBs down to about 0.1%. The analysis will be performed on the field samples using a test stand. The analyzer will be calibrated for chlorine using plastic pellet European reference materials (EC680 and EC681) upon first use, and standardized each time the instrument is turned on and prior to any caulk Cl analysis. The standardization procedure will entail a calibration analysis of the materials provided/recommended with the XRF analyzer. Analyses will be conducted in duplicate on each sample and notes kept. The mean will be used for comparison to GC–MS results.

19.2.2. Contract Laboratory Analyses

The procedures for and frequency of calibration will vary depending on the chemical parameters being determined. Equipment is maintained and checked according to the standard procedures specified in each laboratory's instrument operation instruction manual.

Upon initiation of an analytical run, after each major equipment disruption, and whenever on-going calibration checks do not meet recommended DQOs (see Section 13), analytical systems will be calibrated with a full range of analytical standards. Immediately after this procedure, the initial calibration must be verified through the analysis of a standard obtained from a different source than the standards used to calibrate the instrumentation and prepared in an independent manner and ideally having certified concentrations of target analytes of a CRM or certified solution. Frequently, calibration standards are included as part of an analytical run, interspersed with actual samples.

Calibration curves will be established for each analyte and batch analysis from a calibration blank and a minimum of three analytical standards of increasing concentration, covering the range of expected sample concentrations. Only those data resulting from quantification within the demonstrated working calibration range may be reported by the laboratory.

The calibration standards will be prepared from reference materials available from the EPA repository, or from available commercial sources. The source, lot number, identification, and purity of each reference material will be recorded. Neat compounds will be prepared weight/volume using a calibrated analytical balance and Class A volumetric flasks. Reference solutions will be diluted using Class A volumetric glassware. Individual stock standards for each analyte will be prepared. Combination working standards will be prepared by volumetric dilution of the stock standards. The calibration standards will be stored at -20º C. Newly prepared standards will be compared with existing standards prior to their use. All solvents used will be commercially available, distilled in glass, and judged suitable for analysis of selected chemicals. Stock standards and intermediate standards are prepared on an annual basis and working standards are prepared every three months.

Sampling and analytical logbooks will be kept to record inspections, calibrations, standard identification numbers, the results of calibrations, and corrective action taken. Equipment logs will document instrument usage, maintenance, repair and performance checks. Daily calibration data will be stored with the raw sample data

20. Data Review, Verification, and Validation

Defining data review, verification, and validation procedures helps to ensure that Monitoring Plan data will be reviewed in an objective and consistent manner. Data review is the in-house examination to ensure that the data have been recorded, transmitted, and processed correctly. The Field-PM will be responsible for initial data review for field forms and field measurements; QA Officer will be responsible for doing so for data reported by analytical laboratories. This includes checking that all technical criteria have been met, documenting any problems that are observed and, if possible, ensuring that deficiencies noted in the data are corrected.

In-house examination of the data produced from the proposed Monitoring Program will be conducted to check for typical types of errors. This includes checking to make sure that the data have been recorded, transmitted, and processed correctly. The kinds of checks that will be made will include checking for data entry errors, transcription errors, transformation errors, calculation errors, and errors of data omission.

Data generated by Program activities will be reviewed against MQOs that were developed and documented in Section 13. This will ensure that the data will be of acceptable quality and that it will be SWAMP-comparable with respect to minimum expected MQOs.

QA/QC requirements were developed and documented in Sections 13.1 and 13.2, and the data will be checked against this information. Checks will include evaluation of field and laboratory duplicate results, field and laboratory blank data, matrix spike recovery data, and laboratory control sample data pertinent to each method and analytical data set. This will ensure that the data will be SWAMP-comparable with respect to quality assurance and quality control procedures.

Field data consists of all information obtained during sample collection and field measurements, including that documented in field log books and/or recording equipment, photographs, and chain of custody forms. Checks of field data will be made to ensure that it is complete, consistent, and meets the data management requirements that were developed and documented in Section 13.1.

Lab data consists of all information obtained during sample analysis. Initial review of laboratory data will be performed by the laboratory QA/QC Officer in accordance with the lab's internal data review procedures. However, upon receipt of laboratory data, the Lab-PM will perform independent checks to ensure that it is complete, consistent, and meets the data management requirements that were developed and documented in Section 13.2. This review will include evaluation of field and laboratory QC data and also making sure that the data are reported in compliance with procedures developed and documented in Section 7.

Data verification is the process of evaluating the completeness, correctness, and conformance / compliance of a specific data set against the method, procedural, or contractual specifications. The Lab-PM and Data Manager will conduct data verification, as described in Section 13 on Quality Control, in order to ensure that it is SWAMP-comparable with respect to completeness, correctness, and conformance with minimum requirements.

Data will be separated into three categories for use with making decisions based upon it. These categories are: (1) data that meets all acceptance requirements, (2) data that has been determined to be unacceptable for use, and (3) data that may be conditionally used and that is flagged as per US EPA specifications.

21. Verification and Validation Methods

Defining the methods for data verification and validation helps to ensure that Program data are evaluated objectively and consistently. For the proposed Program many of these methods have been described in Section 20. Additional information is provided below.

All data records for the Monitoring Program will be checked visually and will be recorded as checked by the checker's initials as well as with the dates on which the records were checked. Consultant Team staff will perform an independent re-check of at least 10% of these records as the validation methodology.

All of the laboratory's data will be checked as part of the verification methodology process. Each contract laboratory's Project Analyst will conduct reviews of all laboratory data for verification of their accuracy.

Any data that is discovered to be incorrect or missing during the verification or validation process will immediately be reported to the Consultant-PM. If errors involve laboratory data then this information will also be reported to the laboratory's QA Officer. Each laboratory's QA manual details the procedures that will be followed by laboratory personnel to correct any invalid or missing data. The laboratory's QA Officer will be responsible for reporting and correcting any errors that are found in the data during the verification and validation process.

If there are any data quality problems identified, the QA Officer will try to identify whether the problem is a result of project design issues, sampling issues, analytical methodology issues, or QA/QC issues (from laboratory or non-laboratory sources). If the source of the problems can be traced to one or more of these basic activities then the person or people in charge of the areas where the issues lie will be contacted and efforts will be made to immediately resolve the problem. If the issues are too broad or severe to be easily corrected then the appropriate people involved will be assembled to discuss and try to resolve the issue(s) as a group. The QA Officer has the final authority to resolve any issues that may be identified during the verification and validation process.

22. Reconciliation with User Requirements

The purpose of the Monitoring Program is to comply with Provisions of the MRP and provide data that can be used to identify sources of PCBs to urban runoff, and to evaluate management action effectiveness in removing POCs from urban runoff in the Bay Area. The objectives of the Monitoring Program are to provide the following outcomes:

1. Satisfy MRP Provision C.8.f. requirements for POC monitoring for source identification;

2. Satisfy MRP Provision C.12.e.ii requirements to evaluate PCBs presence in caulks/sealants used in storm drain or roadway infrastructure in public ROWs;
3. Report the range of PCB concentrations observed in 20 composite samples of caulk/sealant collected from structures installed or rehabilitated during the 1970's;
4. Satisfy MRP Provision C.8.f. requirements for POC monitoring for management action effectiveness;
5. Quantify the annual mass of mercury and PCBs captured in HDS Unit sumps during maintenance; and
6. Identify BSM mixtures for future field testing that provide the most effective mercury and PCBs treatment in laboratory column tests.

Information from field data reports (including field activities, post sampling events, and corrective actions), laboratory data reviews (including errors involving data entry, transcriptions, omissions, and calculations and laboratory audit reports), reviews of data versus MQOs, reviews against QA/QC requirements, data verification reports, data validation reports, independent data checking reports, and error handling reports will be used to determine whether or not the Monitoring Program's objectives have been met. Descriptions of the data will be made with no extrapolation to more general cases.

Data from all monitoring measurements will be summarized in tables. Additional data may also be represented graphically when it is deemed helpful for interpretation purposes.

The above evaluations will provide a comprehensive assessment of how well the Program meets its objectives. The final project reports will reconcile results with project MQOs.

23. References

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BASMAA 2017a. The Evaluation of PCBs Presence in Public Roadway and Storm Drain Infrastructure Caulk and Sealants Study Design. Prepared by EOA Inc. and the San Francisco Estuary Institute (SFEI). June 2017.

BASMAA 2017b. POC Monitoring for Management Action Effectiveness Study Design. Prepared by the Office of Water Programs, Sacramento State, CA, EOA Inc., and the San Francisco Estuary Institute (SFEI). July 2017.

BASMAA, 2017c. Clean Watershed for a Clean Bay (CW4CB) Final Report. Prepared for Bay Area Stormwater Management Agencies Association. Prepared by Geosyntec and EOA, Inc., May 2017.

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Surface Water Ambient Monitoring Program Quality Assurance Team, 2013. *SWAMP Quality Assurance Project Plan.* Prepared for the California State Water Quality Control Board. 2013.

24. Appendix A: Field Documentation

Caulk/Sealant Sampling Field Data Sheet											
Caulk/Sealant Sampling Field Data Sheet			**Composite ID:**				Contractor:			Pg of Pgs	
Sample ID:			Date (mm/dd/yyyy):				Personnel:			Failure Reason	
Photos (Y / N)			ArrivalTime:		DepartureTime:						
Photo Log Identifier			**Land-Use at the Sample Location:**				Commercial (pre-1980; post 1980)			Open Space	
			Industrial (pre-1980; post-1980)				Residential (pre 1980; post 1980)			Other:	
Description of Structure: (Do not include any information on the location of the structure)								**Diagram of Structure (if needed) to identify where caulk/sealants were located in/on structure**			
Structure Type:	Storm Drain Catch Basin	Roadway Surface		Sidewalk	Curb/Gutter	Bridge					
	Other:										
Structure Material:	Concrete	Asphalt	Other:								
Condition of Structure:	Good	Fair	Poor	Other:							
Year of Strucutre Construction											
Year of Repair											
Description of Caulk or Sealant Sample Collected:											
Application or Usage	Caulk	caulk between adjoining surfaces of same material (e.g., concrete-concrete); Describe:									
		caulk between adjoining surfaces of different types of material (e.g., concrete-asphalt); Describe:									
		Other:									
	Sealant	Crack Repair (describe):									
		Other:									
Color											
Texture	Hard/brittle	Soft/pliable	Other:								
Condition	Good (intact/whole)		Poor (crumbling/disintegrating)	Other:							
Location	Surface	Between Joints		Submerged	Exposed	At street level	Below street level	Other:			
Amount of Caulk/Sealant observed on structure	Crack dimensions:					Spacing of expansion joints					
	Length&width of caulk bead sampled:						Other:				
Samples Taken											
COLLECTION DEVICE:				Equiptment type used:							
SITE/SAMPLING DESCRIPTION AND COMMENTS:											

HDS Unit Sampling Field Data Sheet (Sediment Chemistry)			Contractor:	Pg of Pgs
City:	Date (mm/dd/yyyy):	/ /	*Contractor:	
HDS Catchment ID:	ArrivalTime:	DepartureTime:	*SampleTime (1st sample):	Failure Reason
	Personnel:			

Photos (Y / N)	*GPS/DGPS	**Lat (dd.ddddd)**	**Long (ddd.ddddd)**	Address, Location, and Sketches (if needed)
Photo Log Identifier	**Target (if known):**			
	***Actual:**			
	GPS Device:			

Estimate of Volume of Sediment in the HDS unit sump prior to cleanout:	
Estimate of Volume of Sediment REMOVED from the HDS unit sump during the cleanout:	

Env. Conditions		WIND DIRECTION (from):	N W E S	
SITE ODOR:	None,Sulfides,Sewage,Petroleum,Smoke,Other_______			
SKY CODE:	Clear, Partly Cloudy, Overcast, Fog, Smoky, Hazy			
PRECIP:	None, Fog, Drizzle, Rain			
PRECIP (last 24 hrs):	Unknown, <1", >1", None			
SOILODOR:	None, Sulfides, Sewage, Petroleum, Mixed, Other_______________			
SOILCOLOR:	Colorless, Green, Yellow, Brown			
SOILCOMPOSITION:	Silt/Clay, Sand, Gravel, Cobble, Mixed, Debris			
SOILPOSITION	Submerged, Exposed			

Samples Taken (3 digit ID nos. of containers filled)	**Field Dup at Site? YES / NO:** (create separate datasheet for FDs, with unique IDs (i.e., blind samples)
COLLECTION DEVICE:	Equiptment type used: Scoop (SS / PC / PE), Core (SS / PC / PE), Grab (Van Veen / Eckman / Petite Ponar), Broom (nylon, natural fiber)

Sample ID (City-Catchment ID-Sample	DepthCollec (cm)	Composite / Grab (C / G)	Grain Size	PCBs	Hg	Bulk Density	TOC	OTHER		

SITE/SAMPLING DESCRIPTION AND COMMENTS:

Stormwater Field Data Sheet (Water Chemistry)		Entered in d-base (initial/date)	Pg of Pgs
***Station Code:**	*Date (mm/dd/yyyy): / /	*PurposeFailure:	*Agency:
Personnel:	ArrivalTime: DepartureTime:		*Protocol:

	*GPS/DGPS	**Lat (dd.ddddd)**	**Long (ddd.ddddd)**	OCCUPATION METHOD: Walk-in Bridge R/V __________ Other
GPS Device:	**Target:**		-	
Datum: NAD83 Accuracy (ft / m):	***Actual:**		-	Sampling Location (e.g., gutter at SW corner of 10th Street)

Habitat Observations (CollectionMethod = Habitat_generic)		WADEABILITY: Y / N / Unk	BEAUFORT SCALE (see attachment)
SITE ODOR:	None,Sulfides,Sewage,Petroleum,Smoke,Other____		
SKY CODE:	Clear, Partly Cloudy, Overcast, Fog, Smoky, Hazy	WIND DIRECTION (from):	N W E S
OTHER PRESENCE:	Vascular,Nonvascular,OilySheen,Foam,Trash,Other_		
DOMINANT SUBSTRATE:	Bedrock, Concrete, Cobble, Boulder, Gravel, Sand, Mud, Unk, Other_________		

PHOTOS (RB & LB assigned when facing downstream; RENAME to StationCode_yyyy_mm_dd_uniquecode):
1: (RB / LB / BB / US / DS / ##)
2: (RB / LB / BB / US / DS / ##)
3: (RB / LB / BB / US / DS / ##)

WATERCLARITY:	Clear (see bottom), Cloudy (>4" vis), Murky (<4" vis)	PRECIPITATION:	None, Fog, Drizzle, Rain, Snow
WATERODOR:	None, Sulfides, Sewage, Petroleum, Mixed, Other___	PRECIPITATION (last 24 hrs):	Unknown, <1", >1", None
WATERCOLOR:	Colorless, Green, Yellow, Brown		
OVERLAND RUNOFF (Last 24 hrs):	none, light, moderate / heavy, unknown		
OBSERVED FLOW:	NA, Dry Waterbody Bed, No Obs Flow, Isolated Pool, Trickle (<0.1cfs), 0.1-1cfs, 1-5cfs, 5-20cfs, 20-50cfs, 50-200cfs, >200cfs		

Field Samples (Record Time Sample Collected)

Carboy ID #	Start Sample Time	End Sample Time	Sample Type (Grab=G; Integrated = I)	Collection Depth (m)	Field Dup (Yes/No)	Indiv bottle (by hand, by pole, by bucket); Teflon tubing; Kemmer; Pole & Beaker; Other

COMMENTS:

Stormwater Influent Samples – Office of Water Programs

Sample Receiving								
Date (mm/dd/yy):		Time (24 hr) :			Team Member's Initial:			
Carboy	Temperature	pH	Observations					
1								
2								
3								
4								
5								
6								
7								

Stormwater Column Tests – Office of Water Programs

Sampling Run			
Date (mm/dd/yy):	Time (24 hr) :	Team Member's Initials:	Column ID:

During Test - Timed Measurements

Time	Water Depth	Media Condition	Other Observations

Grab Sample - Beginning of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Middle of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - End of Run

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

Grab Sample - Mercury

Time	Water Depth	Turbidity (NTU)	Temp	pH	Other Observations

25. Appendix B: Laboratory Standard Operating Procedures (SOPs)

APPENDIX C: QA SUMMARY REPORTS

QA Summary Report for ALS Analysis of PCBs in Sediment and Tissue HDS samples for the Pollutants of Concern Monitoring for Source Identification and Management Action Effectiveness Study, 2017-2018

Prepared By Don Yee, SFEI QA Officer, for BASMAA Regional Monitoring Coalition

November 12, 2018

QA Issues for Project Manager to Review
None.

Reporting Issues for Lab to Review
None.

Hold time review (especially desired by stormwater programs)
One sample was analyzed ~1week past the 1 year recommended hold times for PCBs, and flagged VH, but it is unlikely to affect results severely.

QA Review
Completeness
Data were reported for 8 field samples, 3 as sediment and 5 as tissue, analyzed for the RMP 40 PCBs with 38 unique analytes (including coeluters). 3 lab blanks, and 5 LCS samples were also reported, for the 38 target analyte individual congeners or coeluter groups.

Percent usable (non-reject) field data
98% of the data were reportable, with 2% of the data (one analyte) rejected for poor recovery issues.

Overall acceptability
Overall the data were acceptable, with one sample flagged for hold time about 1 week too long, and one analyte (PCB 183/185) with poor LCS recovery. Several other PCB congeners/groups were flagged for recovery deviations >35%, or for detection in blank samples, but none of them were severe enough to be censored.

MDLs sensitivity
Overall about 5% of the analyte results were non-detect, with another 3% flagged as estimated due to being under the reporting limit.

QB averages (procedural, field blank)
8 analytes/coeluting groups were detected in blanks. Field sample concentrations were always at least 3x higher, so no results were censored.

Average precision from replicate field sample
Precision was calculated using the LCS replicates, with only PCB 183/185 showing RSDs averaging 53%, which was flagged but not censored.

Accuracy (using a variety of SRMs or Matrix spike QRECs)

However, PCB 183/185 recovery averaged 75% error, so was censored for being over 2x outside the target range (>70%, with a target of 35% error). PCB 158 and 105 were also flagged for marginal recovery but not censored.

Comparison of dissolved and total phases

Not applicable.

Summary paragraph for report:

The HDS sediment/tissue dataset included 8 field samples, with 3 blanks, and 5 LCSs (some in duplicate), meeting the minimum number of QC samples required, reported for the RMP 40 PCB analytes (with their coeluters, yielding 38 unique analytes). All but 1 Sample was analyzed within the recommended hold time of 1 year (the last ~1 week late). 8 of the analytes were detected in blanks, but field sample concentrations were over 3x higher, so no results were censored. Two of the analytes had recovery with average >35% deviation from target values in the LCS, and one (PCB 183/185) had average error >70%, so was censored. PCB 183/185 was also flagged for poor precision (RSD 53%), but that analyte was already rejected for poor recovery, so the precision flag is largely moot.

QA Summary Report for ALS Analysis of Hg, TOC, TS and Density in HDS Sediment and Tissue samples for the Pollutants of Concern Monitoring for Source Identification and Management Action Effectiveness Study, 2017-2018

Prepared By Don Yee, SFEI QA Officer, for BASMAA Regional Monitoring Coalition

November 14, 2018

QA Issues for Project Manager to Review

None.

Reporting Issues for Lab to Review

Review with lab formatting convention for lab reps - increment lab replicate not replicate if using CEDEN conventions.

Hold time review (especially desired by stormwater programs)

Nearly all samples were past the 1 week QAPP listed hold times for density and total solids, and flagged VH. However, so long as initial masses were recorded well, it is unlikely to affect results severely.

QA Review

Completeness

Eight field samples were reported for density and Hg as 3 sediment and 5 tissue samples. TOC was reported for 7 samples, with 2 field replicates, and no result for SJC-604. Total solids was reported twice for all the sediment samples and once each for the tissue ones, and total volatile solids was reported for 4 of the tissue samples (skipping SJ-604). MS/D pairs were reported for 2 sites for TOC, and 2 for Hg. 9 lab blanks were reported for mercury, and 6 for TOC, meeting the 1 per batch requirement. 3 LCSs were also reported for TOC.

Percent usable (non-reject) field data

All of the data were reportable, with none rejected/censored.

Overall acceptability

Overall the data were acceptable, with all but 1 density and total solids samples flagged for hold time beyond the 1 week listed in the BASMAA POC QAPP. If initial sample weights are recorded well though, dessication in storage or other artifacts of extended storage can be corrected for/will be minor.

MDLs sensitivity

No results were non-detect.

QB averages (procedural, field blank)

Only Hg was occasionally detected in the blanks, but concentrations averaged <MDL so results were not flagged.

Average precision from replicate field sample

Precision on the field sample replicates for TOC and total solids, averaged <5% RPD. RPD on the MS/Ds for mercury averaged <10%, well within the target 25%, so no precision flags were added.

Accuracy (using a variety of SRMs or Matrix spike QRECs)
Recovery errors on MS/Ds averaged 2% for TOC and 15% for Hg, well within their respective ±20% and ±25% QAPP targets, so no recovery flags were added.

Comparison of dissolved and total phases
Not applicable.

Summary paragraph for report:

The HDS sediment/tissue dataset included 8 field samples reported for Hg, total solids, and density, but only 7 for TOC and 4 tissue ones for total volatile solids (missing SJC-604). MS/D pairs were reported for 2 sites for TOC, and Hg. 9 lab blanks were reported for mercury, and 6 for TOC, meeting the 1 per batch requirement. 3 LCSs were also reported for TOC. Nearly all density and total solids were analyzed past the 1 week QAPP listed hold times, and flagged VH, but so long as initial masses were recorded well, it is unlikely to affect results severely. Only Hg was occasionally detected in the blanks, but averaged <MDL so results were not flagged. Precision (<25% RPD) and recovery targets (±20% for conventional analytes and ±25% for Hg) were met for all QC samples, so no other flags were added.

QA Summary Report for ALS Analysis of Grain Size in Sediment HDS samples for the Pollutants of Concern Monitoring for Source Identification and Management Action Effectiveness Study, 2017-2018

Prepared By Don Yee, SFEI QA Officer, for BASMAA Regional Monitoring Coalition

November 19, 2018

QA Issues for Project Manager to Review

ALS Lab reported all grainsize by their usual convention relative to dw estimated from separate moisture measurement (rather than summed fraction weights of processed sample), yielding sums of fractions not 100%. Results were recalculated to normalize to a sum of 100%. The smaller size fractions approximately match the Wentworth cutoffs (powers of 2 below 31.3, 15.6, etc), but the next size fraction up is 75um rather than 62.5, and the coarser fractions are listed just by analytename (e.g. Sand, Very Fine) without any indication of size range, which could differ between Wentworth and ASTM scales.

Reporting Issues for Lab to Review

Review with lab formatting convention for lab reps - increment lab replicate not replicate if using CEDEN conventions.

Hold time review (especially desired by stormwater programs)

All samples were analyzed within the project QAPP specified 28 days.

QA Review

Completeness

Three field samples were reported analyzed in replicate for 14 grainsize fractions.

Percent usable (non-reject) field data

All of the data were reportable, with none rejected/censored.

Overall acceptability

Overall the data were acceptable. Many fractions are only a few percent of total mass, so comparing replicates based on RPD (relative percent difference) of a small percentage to start with is inappropriate. Replicates are thus compared on raw differences in reported percentage per fraction. Percent difference in replicates <5% for all fractions, so no results were qualified..

MDLs sensitivity

No results were non-detect.

QB averages (procedural, field blank)

No blanks were run, which is common for grainsize analysis.

Average precision from replicate field sample

Differences on the sample replicates for grainsize were all nominally <5%. so no precision flags were added. Many fractions are only a few percent of total mass, so comparing replicates based on RPD (relative percent difference) of a small percentage to start with would be inappropriate.

Accuracy (using a variety of SRMs or Matrix spike QRECs)
No recovery samples were run, which is common for grainsize analysis.

Comparison of dissolved and total phases
Not applicable.

Comparison to previous years
Not applicable

Ratio Checking Summary
Not applicable

Sums Summary
All grainsize fractions summed to 100% for each sample and within each lab replicate analysis (after normalization).

Summary paragraph for report:

The HDS sediment dataset included 3 field samples reported for grainsize, all analyzed in replicate. No blanks or recovery samples were reported, which is common for grainsize analysis. Fourteen size fractions were reported, with results normalized from the raw lab reported percentages to yield sums of 100% for each analysis. Nominal percent differences in lab replicates for any given sample were always <5%, so no qualifier flags were added.

APPENDIX D: PCBS CONGENERS CONCENTRATION DATA

HDS Site ID	Station Code	Sample Date	Collection Time	Matrix	PCB Congener(s)	PCB Concentration (ng/kg dw)
1	SUN-MatCDS1	3/8/2018	9:10 AM	Sediment + Organic Debris	PCB 008	566
					PCB 018/30	1,528
					PCB 020/28	3,736
					PCB 021/33	2,043
					PCB 031	2,791
					PCB 044/47/65	2,994
					PCB 049/69	1,902
					PCB 052	3,485
					PCB 056	1,681
					PCB 060	896
					PCB 066	3,472
					PCB 070/61/74/76	4,337
					PCB 083/99	963
					PCB 086/87/97/109/119/125	1,178
					PCB 090/101/113	1,552
					PCB 093/95/100	1,411
					PCB 105	632
					PCB 110/115	2,006
					PCB 118	1,190
					PCB 128/166	323
					PCB 129/138/163	2,883
					PCB 132	644
					PCB 135/151/154	767
					PCB 141	353
					PCB 147/149	1,564
					PCB 153/168	1,785
					PCB 156/157	249
					PCB 158	190
					PCB 170	442
					PCB 174	663
					PCB 177	340
					PCB 180/193	1,583
					PCB 183/185	554
					PCB 187	1,350
					PCB 194	491
					PCB 195	172
					PCB 201	156
					PCB 203	663

HDS Site ID	Station Code	Sample Date	Collection Time	Matrix	PCB Congener(s)	PCB Concentration (ng/kg dw)
2	SUN-MatCDS2	3/8/2018	9:45 AM	Sediment + Organic Debris	PCB 008	359
					PCB 018/30	583
					PCB 020/28	863
					PCB 021/33	249
					PCB 031	842
					PCB 044/47/65	1,331
					PCB 049/69	1,072
					PCB 052	2,662
					PCB 056	240
					PCB 060	142
					PCB 066	635
					PCB 070/61/74/76	1,043
					PCB 083/99	806
					PCB 086/87/97/109/119/125	971
					PCB 090/101/113	1,482
					PCB 093/95/100	1,353
					PCB 105	530
					PCB 110/115	1,691
					PCB 118	1,151
					PCB 128/166	396
					PCB 129/138/163	3,094
					PCB 132	748
					PCB 135/151/154	928
					PCB 141	417
					PCB 147/149	2,072
					PCB 153/168	2,266
					PCB 156/157	224
					PCB 158	201
					PCB 170	770
					PCB 174	1,410
					PCB 177	641
					PCB 180/193	3,683
					PCB 183/185	1,281
					PCB 187	3,007
					PCB 194	1,806
					PCB 195	528
					PCB 201	415
					PCB 203	2,000

HDS Site ID	Station Code	Sample Date	Collection Time	Matrix	PCB Congener(s)	PCB Concentration (ng/kg dw)
3	OAK-5-G	10/16/2017	10:20 AM	sediment	PCB 008	394
					PCB 018/30	710
					PCB 020/28	821
					PCB 021/33	161
					PCB 031	752
					PCB 044/47/65	1,500
					PCB 049/69	900
					PCB 052	2,480
					PCB 056	548
					PCB 060	ND
					PCB 066	26
					PCB 070/61/74/76	2,500
					PCB 083/99	3,060
					PCB 086/87/97/109/119/125	4,550
					PCB 090/101/113	5,890
					PCB 093/95/100	4,150
					PCB 105	3,830
					PCB 110/115	8,890
					PCB 118	8,680
					PCB 128/166	2,380
					PCB 129/138/163	13,000
					PCB 132	3,190
					PCB 135/151/154	2,610
					PCB 141	1,630
					PCB 147/149	4,940
					PCB 153/168	7,080
					PCB 156/157	1,720
					PCB 158	ND
					PCB 170	80
					PCB 174	1,330
					PCB 177	ND
					PCB 180/193	ND
					PCB 183/185	883
					PCB 187	1,560
					PCB 194	553
					PCB 195	211
					PCB 201	89
					PCB 203	535

HDS Site ID	Station Code	Sample Date	Collection Time	Matrix	PCB Congener(s)	PCB Concentration (ng/kg dw)
4	OAK-5-D	2/2/2018	10:55 AM	sediment	PCB 008	ND
					PCB 018/30	1,150
					PCB 020/28	2,010
					PCB 021/33	1,070
					PCB 031	1,660
					PCB 044/47/65	5,590
					PCB 049/69	2,900
					PCB 052	9,710
					PCB 056	2,810
					PCB 060	739
					PCB 066	1,940
					PCB 070/61/74/76	12,300
					PCB 083/99	13,500
					PCB 086/87/97/109/119/125	22,200
					PCB 090/101/113	28,000
					PCB 093/95/100	21,200
					PCB 105	13,700
					PCB 110/115	45,800
					PCB 118	25,600
					PCB 128/166	9,820
					PCB 129/138/163	54,500
					PCB 132	17,900
					PCB 135/151/154	16,000
					PCB 141	7,620
					PCB 147/149	28,600
					PCB 153/168	30,700
					PCB 156/157	5,760
					PCB 158	ND
					PCB 170	353
					PCB 174	ND
					PCB 177	6,470
					PCB 180/193	ND
					PCB 183/185	4,280
					PCB 187	7,300
					PCB 194	2,720
					PCB 195	1,060
					PCB 201	520
					PCB 203	2,740

HDS Site ID	Station Code	Sample Date	Collection Time	Matrix	PCB Congener(s)	PCB Concentration (ng/kg dw)
5	PAL-Meadow	10/25/2017	10:50 AM	Sediment + Organic Debris	PCB 008	139
					PCB 018/30	193
					PCB 020/28	321
					PCB 021/33	63
					PCB 031	335
					PCB 044/47/65	604
					PCB 049/69	513
					PCB 052	1,182
					PCB 056	98
					PCB 060	56
					PCB 066	287
					PCB 070/61/74/76	488
					PCB 083/99	431
					PCB 086/87/97/109/119/125	490
					PCB 090/101/113	682
					PCB 093/95/100	651
					PCB 105	307
					PCB 110/115	911
					PCB 118	656
					PCB 128/166	ND
					PCB 129/138/163	1,620
					PCB 132	339
					PCB 135/151/154	355
					PCB 141	168
					PCB 147/149	755
					PCB 153/168	953
					PCB 156/157	140
					PCB 158	113
					PCB 170	225
					PCB 174	264
					PCB 177	141
					PCB 180/193	672
					PCB 183/185	219
					PCB 187	516
					PCB 194	227
					PCB 195	56
					PCB 201	52
					PCB 203	214

HDS Site ID	Station Code	Sample Date	Collection Time	Matrix	PCB Congener(s)	PCB Concentration (ng/kg dw)
6	SJC-604	10/5/2017	10:35 AM	Sediment + Organic Debris	PCB 008	4,335
					PCB 018/30	5,822
					PCB 020/28	11,881
					PCB 021/33	3,990
					PCB 031	10,761
					PCB 044/47/65	12,893
					PCB 049/69	9,787
					PCB 052	18,317
					PCB 056	2,812
					PCB 060	1,726
					PCB 066	7,505
					PCB 070/61/74/76	12,475
					PCB 083/99	ND
					PCB 086/87/97/109/119/125	11,777
					PCB 090/101/113	15,545
					PCB 093/95/100	12,673
					PCB 105	7,492
					PCB 110/115	18,274
					PCB 118	16,142
					PCB 128/166	2,985
					PCB 129/138/163	27,208
					PCB 132	6,254
					PCB 135/151/154	7,046
					PCB 141	3,442
					PCB 147/149	15,838
					PCB 153/168	16,345
					PCB 156/157	2,366
					PCB 158	1,878
					PCB 170	3,446
					PCB 174	4,244
					PCB 177	2,518
					PCB 180/193	7,238
					PCB 183/185	3,149
					PCB 187	5,990
					PCB 194	2,327
					PCB 195	779
					PCB 201	284
					PCB 203	1,777

HDS Site ID	Station Code	Sample Date	Collection Time	Matrix	PCB Congener(s)	PCB Concentration (ng/kg dw)
7	SUN-27A	3/8/2018	11:15 AM	Sediment + Organic Debris	PCB 008	395
					PCB 018/30	401
					PCB 020/28	942
					PCB 021/33	149
					PCB 031	853
					PCB 044/47/65	1,410
					PCB 049/69	1,104
					PCB 052	2,578
					PCB 056	151
					PCB 060	78
					PCB 066	577
					PCB 070/61/74/76	989
					PCB 083/99	884
					PCB 086/87/97/109/119/125	898
					PCB 090/101/113	1,867
					PCB 093/95/100	1,458
					PCB 105	513
					PCB 110/115	1,795
					PCB 118	1,149
					PCB 128/166	517
					PCB 129/138/163	6,614
					PCB 132	1,434
					PCB 135/151/154	1,843
					PCB 141	970
					PCB 147/149	4,229
					PCB 153/168	4,807
					PCB 156/157	317
					PCB 158	445
					PCB 170	2,024
					PCB 174	2,675
					PCB 177	1,470
					PCB 180/193	5,952
					PCB 183/185	1,952
					PCB 187	3,494
					PCB 194	1,102
					PCB 195	458
					PCB 201	213
					PCB 203	951

HDS Site ID	Station Code	Sample Date	Collection Time	Matrix	PCB Congener(s)	PCB Concentration (ng/kg dw)
8	SJC-612-01	9/13/2017	1:53 PM	sediment	PCB 008	24
					PCB 018/30	36
					PCB 020/28	93
					PCB 021/33	42
					PCB 031	69
					PCB 044/47/65	175
					PCB 049/69	92
					PCB 052	295
					PCB 056	77
					PCB 060	42
					PCB 066	162
					PCB 070/61/74/76	444
					PCB 083/99	455
					PCB 086/87/97/109/119/125	683
					PCB 090/101/113	943
					PCB 093/95/100	729
					PCB 105	352
					PCB 110/115	1,270
					PCB 118	879
					PCB 128/166	204
					PCB 129/138/163	1,330
					PCB 132	410
					PCB 135/151/154	571
					PCB 141	217
					PCB 147/149	60
					PCB 153/168	843
					PCB 156/157	133
					PCB 158	125
					PCB 170	14
					PCB 174	ND
					PCB 177	328
					PCB 180/193	ND
					PCB 183/185	211
					PCB 187	432
					PCB 194	186
					PCB 195	68
					PCB 201	33
					PCB 203	179

FINAL REPORT: PILOT STORMWATER DIVERSION PROJECT

North Richmond Stormwater Pump Station
Contra Costa, California

Prepared for:

Contra Costa County
Martinez, California

Prepared by:

Amec Foster Wheeler Environment & Infrastructure, Inc.
180 Grand Avenue, Suite 1100
Oakland, California 94612

March 2016

Project No. 5025153001.01

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FINAL REPORT: PILOT STORMWATER DIVERSION PROJECT
North Richmond Stormwater Pump Station
Contra Costa County, California

1.0 EXECUTIVE SUMMARY

Normally, municipal staff would never consider deliberately diverting stormwater into their community's sanitary sewage treatment systems, but that is exactly what this award-winning pilot project accomplished. The motivation was a requirement established in the 2009 National Pollutant Discharge Elimination System (NPDES) Permit for Urban Stormwater Discharges issued to the Contra Costa Clean Water Program's (CCCWP) 21 permittees, along with all of the other municipal stormwater permittees in the San Francisco Bay Area. Order number R2-2009-0074, issued on October 14, 2009 and commonly known as "The Municipal Regional Permit" (MRP), was the first Bay Area municipal stormwater permit adopted after water quality plans for mercury and polychlorinated biphenyls (PCBs), known as "Total Maximum Daily Loads," or TMDLs, had been formally established for the Bay. Those TMDL plans call for substantial reduction of pollutant loads from urban stormwater discharges to the Bay – e.g., a 90 percent reduction in the total load of PCBs from all Bay Area stormwater discharges. The MRP issued in 2009 (known as MRP 1.0) required pilot projects to evaluate the feasibility of reducing PCB loads by various methods of treatment and source control. Provision C.12.f of the MRP required permittees to evaluate diversion of dry weather and wet weather urban runoff into sanitary sewage conveyance and treatment systems to determine if diversion to sanitary treatment is a useful tool for reducing PCB loads from urban runoff.

Contra Costa County Watersheds Program (County) led the pilot project for CCCWP. The County owns the North Richmond Stormwater Pump Station (NRSPS) and maintenance is shared through a Joint Exercise of Powers Agreement (JEPA) with the City of Richmond (both CCCWP permittees). The County partnered with the West County Wastewater District (WCWD), to provide conveyance capacity and treatment service. Converting the aging Pump Station facility to divert stormwater gave the County the opportunity to include facility improvements. Project funding came from the County and City and was supplemented with funds from the CCCWP (supported by all CCCWP permittees), as well as grant funds from the United States Environmental Protection Agency. In general, the County and City funds went to the Pump Station improvements and the EPA and CCCWP funds covered the added costs of planning, designing, implementing, monitoring, and reporting on the diversion pilot project.

The County completed construction of the diversion infrastructure in the fall of 2015. Pilot tests of dry and wet weather diversions of water from the pump station to WCWD were successfully completed by November 2015, and results formally reported to the County by January 2016. This final project report documents the project implementation and lessons learned for inclusion in the annual “Urban Creeks Monitoring Report”, a deliverable required in the MRP. Findings and recommendations are expected to guide actions during the next five year MRP.

The lessons learned from this pilot project include both good news and bad news.

The Good News:

- CCCWP permittees complied with provision C.12.f of MRP 1.0 by collaborating with several partners to complete a pump station stormwater diversion pilot with a permanent, “hard-piped” diversion system installed at the NRSPS.
- WCWD experienced no overflows, sewage treatment system upsets, or other disruptions to operations as a result of the pilot diversion project.
- In addition to rehabilitating existing infrastructure, the NRSPS diversion project offers new operational flexibility to the Pump Station owners.
- Project partners gained a new understanding of the incentives and opportunities that can potentially support co-management of urban runoff with water reclamation systems originally designed for sanitary sewage.
- There is now an established partnership and relationship between the County and WCWD, and with new infrastructure now in place and the pilot successfully completed, there is an opportunity to pursue grant funding to support stormwater harvest and use projects in the future.

The Bad News:

- The wet and dry diversion pilot tests accomplished miniscule load reductions: e.g., about one milligram (0.001 grams) of PCBs, against a required Baywide PCB load reduction of 18,000 grams by the year 2028.
- Conveyance limitations of the sanitary sewage system prohibit substantial scale-up of the pilot to larger diversion flows. The diversion pump installed pumps 200 to 250 gallons per minute into the WCWD collection system. Larger flow rates risk sanitary sewer overflows. The design of the pump station provides 135,000 gallons per minute of stormwater pumping capacity, about 600 times more volume than the diversion. That might be comparable to a person sipping water from a gushing fire hydrant.
- Even if all of the stormwater from the 339 acre catchment served by the NRSPS could be captured and treated – which would require a substantial capital project - the total PCB load reduction possible is on the order of one to ten grams at best, still a tiny fraction of the overall load reduction mandate for the Bay.
- The total project cost was over $1.4 million which included some necessary upgrades to the existing Pump Station infrastructure. The cost for a "stand-alone" stormwater diversion project would be approximately $1 million.

This is an example of opportunistically combining stormwater quality enhancement and municipal infrastructure restoration into one project. The project evolved and changed from its inception five years ago. Initially the project included substantial improvements to the Pump Station until the estimated costs approached $2 million. Then the project was changed to only include improvements to the extent needed to complete the stormwater diversion. The total final project cost was $1,440,000. The actual construction contract for the pump station project was $469,469. Design of the pump station project cost an additional $280,000. Both these design and construction costs reflected a project to divert stormwater plus some improvements to the Pump Station facilities. The remaining $690,531 of the project cost, over and above design and construction, comes from planning studies, monitoring, reporting, project management, and multi-agency coordination. A diversion project of this scale, implemented as a “stand-alone,” without including any infrastructure rehabilitation, would cost close to $1,000,000 for planning, construction, monitoring, project management, and reporting.

In summary, this project achieved the objective of installing and pilot testing urban runoff diversion infrastructure. Diversion of dry and wet weather urban runoff into the nearest water reclamation facility offers only incremental PCB load reduction benefits. Diversion is not a “silver bullet” that will make a significant difference to PCB loads; however, consideration of multiple water quality benefits, such as trash controls, water resource development, and reduction of bacteria, oil and grease, and other urban pollutants discharged to Wildcat Marsh and the Bay may motivate additional, expanded stormwater harvest and use projects in this watershed. Water resource needs may be the overall driver. The newly installed diversion infrastructure installed can harvest and re-use up to 50 million gallons per year of urban runoff, primarily as dry weather urban runoff, should WCWD choose to implement longer term diversions. Overall, the immediate benefit of extending the useful life of the NRSPS and having diversion capabilities, opens longer term planning opportunities that makes this project a success.

On February 25, 2016, the NRSPS Stormwater Diversion Project was awarded the honor of Environmental Project of the Year by the Northern California Chapter of the American Public Works Association (Appendix A). The award named CCCWP as “an essential partner in the development and construction of this innovative project.”

2.0 BACKGROUND

This section begins with a summary of the thought process that led to investigation of urban runoff diversions as a tool for implementing TMDLs for pollutants of concern in urban stormwater. The project partners are then described, followed by a description of the project setting.

2.1 ORIGINS OF THE STORMWATER DIVERSION CONCEPT

Completion of this pilot project culminates a thought process that has evolved in the Bay Area over the past fifteen years. Table 1 below documents some of the major milestones in this thought process. Details presented below help understand the regulatory and decision making context that led to this pilot project.

Table 1 Timeline of NRSPS Diversion Pilot Project Development

Time Frame	Milestone
2000 – 2002	Baywide investigation of PCBs in storm drain system sediment leads to discovery of 20 mg/kg PCBs at Ettie Street Pump Station
2006	Water Board accepts East Bay Municipal Utility District (EBMUD) monitoring at Ettie Street Pump Station diversion as a tSupplemental Environmental Project
2008	EPA Water Quality Improvement Fund grant awarded to support NRSPS diversion pilot
2009	MRP 1.0 Adopted
2010	EBMUD Report on Ettie Street Pump Station Diversion completed BASMAA Feasibility Evaluation Report submitted to Water Board
2010 – 2013	San Francisco Estuary Institute monitors water quality at NRSPS
2011 – 2013	CCCWP and the County negotiate agreement with WCWD to accept diversion flows
2013 – 2014	NRSPS rehabilitation and diversion design completed
2015	MRP 2.0 issued NRSPS stormwater diversion project constructed, diversion monitored for dry and wet weather event

Since the advent of the Clean Water Act in 1973, communities have generally tried to keep urban runoff separate from sewage treatment conveyance and infrastructure (sanitary sewage systems). Treating the volumes of runoff generated by storm flows would require development of sufficient treatment capacity that would be unused most of the time. Additionally, the very different compositions of sanitary sewage compared to urban runoff recommend different methods of treatment. Some older cities, such as San Francisco, Portland, and Seattle, have conveyance systems that were originally designed to combine sanitary sewage and storm flows. Those communities have to use much larger treatment systems compared to separate systems, and are continuously working to reduce incidents of combined system overflows of partially–treated water during large storm events. In more modern cities with separate systems, municipal workers implement programs to reduce inflow and infiltration (I & I) of stormwater into their sanitary sewage systems.

More recently, some beach communities in California have begun to implement dry weather diversions of urban runoff into their sanitary sewage systems. A review by the Bay Area Stormwater Management Agencies Association (BASMAA) documented case studies of voluntary diversions to sanitary sewers (BASMAA, 2010). In all cases examined, the motivation was to reduce impacts of bacteria from dry weather urban runoff on nearby beaches. The economic and human health benefits resulting from such dry weather diversions are clear – avoiding beach closures is important to any seaside community. Also, the diversion flows are generally small compared to the sanitary sewage conveyance and treatment capacity, so the risk of conveyance system overflows and/or treatment system disruption is less with dry weather diversions compared to wet weather diversions.

In all of the voluntary diversions reviewed by BASMAA (2010), diversions were designed and operated to shut down during wet weather events to protect the sanitary sewage systems. That is an important point that will inform the lessons learned and recommendations from this pilot project. Substantial equalization and storage capacity is needed for diversion to sanitary sewage systems to make a significant impact on stormwater pollutant loads.

In the Bay Area, the interest in management of stormwater by diversion to sanitary sewers began at the Ettie Street Pump Station (ESPS), located in West Oakland. In the 2000 – 2002 time frame, the discovery of sediments in the sump of the ESPS having PCB concentrations up to 20 mg/kg, well above thresholds of concern for stormwater discharges to the Bay, led staff of the San Francisco Bay Regional Water Quality Control Board (Water Board) to ask whether diversion from the pump station to the nearby East Bay Municipal Utility District (EBMUD) wastewater treatment plant was a reasonable approach to preventing PCB-contaminated sediments from reaching the Bay. EBMUD agreed to monitor a pilot diversion project at the Ettie Street pumping station (EBMUD, 2010). The pilot study was a Supplemental Environmental Project delivered by EBMUD in lieu of a penalty related to a prior incident (Water Board Order No. R2-2006-0028). The study demonstrated that small flows (up to 50 gallons per minute) could safely be diverted into the EBMUD wastewater collection system during a storm event, and that the loads reduced or avoided by the diversion were small in comparison to pollutant loads conveyed by the storm pumps at Ettie Street to the Bay. Interestingly, since the time that sediments with high PCB concentrations were removed from the Ettie Street pump station wet well, PCB concentrations in sediments exceeding 1 mg/kg have not been observed at that location.

During the time that the Ettie Street diversion pilot was being developed by EBMUD, the MRP was being developed by Water Board staff. MRP 1.0 (Order No. R2-2009-0074) included requirements for pilot projects to test diverting stormwater from pump stations into sanitary sewers. Provisions C.11.f (for mercury) and C.12.f (for PCBs) for MRP 1.0 state that:

- Task Description – The Permittees shall evaluate the reduced loads of mercury and PCBs from diversion of dry weather and first flush stormwater flows to sanitary sewers. The knowledge and experience gained through pilot implementation will be used to determine the implementation scope of urban runoff diversion in subsequent permit terms. The Permittees shall document the knowledge and experience gained through pilot implementation, and this documentation will provide a basis for determining the implementation scope of urban runoff diversion projects in subsequent permit terms.
- Implementation Level – The Permittees shall implement pilot projects to address the role of pump stations as a source of pollutants of concern (primarily PCBs and secondarily mercury). This work is in addition to Provisions C.2 and C.10 that address dissolved oxygen depletion and trash impacts in receiving waters. The objectives of this provision are: to implement five pilot projects for urban runoff diversion from stormwater pump stations to POTWs; evaluate the reduced loads of mercury and PCBs resulting from the diversion; and gather information to guide the

selection of additional diversion projects required in future permits. Collectively, the Permittees shall select five stormwater pump stations and five alternates by evaluating drainage characteristics and the feasibility of diverting flows to the sanitary sewer.

(1) The Permittees should work with the local POTW on a watershed, program, or regional level to evaluate feasibility and to establish cost sharing agreements. The feasibility evaluation shall include, but not be limited to, costs, benefits, and impacts on the stormwater and wastewater agencies and the receiving waters relevant to the diversion and treatment of the dry weather and first flush flows.

(2) From this feasibility evaluation, the Permittees shall select five pump stations and five alternates for pilot diversion studies. At least one urban runoff diversion pilot project shall be implemented in each of the five counties (San Mateo, Contra Costa, Alameda, Santa Clara, and Solano). The pilot and alternate locations should be located in industrially dominated catchments where elevated PCB and mercury concentrations are documented.

(3) The Permittees shall implement flow diversion to the sanitary sewer at the five pilot pump stations. As part of the pilot studies, they shall monitor and measure PCB and mercury load reduction.

The reporting requirements of this provision included a feasibility evaluation report for diversion opportunities throughout the Bay Area. That report was completed as a regional project by BASMAA (2010). The final report requirement for each diversion project stated that:

The March 15, 2014 Integrated Monitoring Report shall include:

- Evaluation of pilot program effectiveness.
- PCBs (and mercury) loads reduced.
- Updated feasibility evaluation procedures to guide future diversion project selection.

Following adoption of MRP 1.0 in 2009, the CCCWP selected the NRSPS for the pilot project and the County Public Works Department agreed to be the project lead. The San Francisco Estuary Institute (SFEI) monitored the NRSPS to characterize loads of PCBs and mercury from 2010 to 2013; SFEI's work was initially funded by the EPA Water Quality Improvement fund grant, and later by BASMAA as one of four monitoring projects implemented as a regional collaboration. Negotiation with WCWD to gain their acceptance of the pilot project took place between 2011 and 2013, including two meetings with the WCWD Board of Directors. The design of the project was completed in 2014, and construction was completed in 2015. Dry and wet weather diversion were monitored in the fall of 2015, concurrent with completion of the diversion infrastructure.

This report fulfills the final report requirement established by provisions C.11.f and C.12.f of MRP 1.0. It is included in the 2016 Urban Creeks Monitoring Report, two years later than the required submittal, because of unavoidable delays in the planning, design, and construction of the diversion infrastructure. Water Board staff were closely involved in the development of this project and have been kept informed in writing as to progress on completion of this requirement.

2.2 PROJECT PARTNERS

The success of this project results from collaboration among project partners listed in Table 2 below. Details of their roles in developing and implementing this project provided below help understand the institution complexity of this kind of project that spans several jurisdictions and affects many interested parties.

Table 2 Partners in the NRSPS Diversion Pilot Project

Partner	Role
Contra Costa County Department of Public Works	Owner of the NRSPS facility
City of Richmond	Responsible for a portion of the NRSPS maintenance
Contra Costa County Flood Control and Water Conservation District	Designs and builds flood protection facilities Restores and enhances natural resources in creeks
West County Wastewater District	Provides sanitary sewage treatment to its service area Operates NRSPS under and O&M agreement with the County (Appendix B) Permitted dry and wet weather diversions for treatment in this pilot study(Appendix C)
Contra Costa Clean Water Program (on behalf of 21 permittees)	Supports facilitation, planning, and monitoring through staff and consultant labor, and direct fiscal contributions
United States Environmental Protection Agency, Region 9	Awarded and Managed Water Quality Improvement Fund Grant
San Francisco Estuary Partnership	Contract Manager for Water Quality Improvement Fund Grant
San Francisco Estuary Institute	Monitoring contractor for grant and subsequent BASMAA-funded project at NRSPS
Bay Area Stormwater Management Agencies Association	Regional planning and coordination
San Francisco Bay Regional Water Quality Control Board	Regulatory incentives to implement project; supported application for EPA Water Quality Improvement Fund grant; participated in discussions with WCWD

During the development of MRP 1.0, County staff determined that needed rehabilitation of the NRSPS presented an opportunity to implement a pilot diversion project. The two original low-flow pumps at the NRSPS had failed. Replacement of the low flow pumps presented an opportunity to build a diversion connection to the West County Wastewater District, which has sanitary sewage conveyance located next to the NRSPS. The County sought and obtained grant funding administered by the San Francisco Estuary Project through U.S. EPA's San Francisco Bay Area Water Quality Improvement Fund. The project is one of several in the "Estuary 2100 Phase 2: Building Partnerships for Resilient Watersheds" program. The grant provided $496,649 in EPA funds, matched by $186,383 from the County to plan, design, construct, and monitor an engineered diversion into WCWD. This report also fulfills the final report deliverable requirement of that grant.

Grant funding was used for design, project management, and monitoring of the pilot diversion. Overall costs to complete the diversion exceeded the original grant fund and County match. Additional funds needed for design and construction of the rehabilitation were provided by the County and the City of Richmond. Additional funds needed for monitoring and reporting on the pilot project were provided by the CCCWP (which includes program contributions from the County and the City of Richmond as permittees). The CCCWP contribution was premised on the fact that project completion gained compliance with the MRP provision for all permittees.

The City of Richmond participated as a "silent partner" in this project. City of Richmond staff expressed concerns in the development of this project because of legal matters that the City is addressing. The City of Richmond shares a common outfall with WCWD to discharge treated sanitary sewage to the Bay. The NPDES permit for the common outfall provides joint liability for WCWD and Richmond, and so the City of Richmond's legal concerns over issues such as I&I also relate to WCWD, to some extent.

The WCWD engaged in discussions with County staff in order to prepare the Feasibility Study for the stormwater diversion. Concerns expressed by WCWD staff and Board members included the potential for spills, disruptions to the sewage treatment system, and incurring costs to rate payers that were unrelated to the service of sanitary sewage treatment. WCWD staff and Board members also acknowledged their role as environmental stewards and were willing to move forward with a diversion project, conditioned on their concerns being addressed. The participation of Water Board staff in these discussions was essential to achieving consensus. After a diversion concept plan had been proposed and refined to be responsive to WCWD concerns, an "agreement" in the form of a WCWD Waste Discharge Permit was developed to support the pilot project (Appendix C). Because of the limited scope of the pilot project, WCWD agreed to waive fees for the connection to their sanitary sewage conveyance system and for accepting/treating the discharge. Through its existing contract with the County to operate and maintain the NRSPS, WCWD did charge for the labor and expense of monitoring the discharge to verify it would not cause an upset of WCWD's activated sludge treatment system.

2.3 PROJECT SETTING

The community-wide North Richmond Storm Drain Project was built in the early 1970s and included construction of the NRSPS. The NRSPS is designed to manage the stormwater for a portion of the City of Richmond, San Pablo and the unincorporated County area of North Richmond (Figure 1). The project consists of a network of stormwater collection pipes which drain into the wet well of the pump station. The stormwater is then pumped into the discharge channel of the pump station which drains by gravity into a 78-inch discharge pipeline.

The project site is located in a watershed comprised mainly of industrial and residential land (Figure 1). The storm drain collection system delivers stormwater to the NRSPS located on the southwest corner of Gertrude Avenue and Richmond Parkway. The station's 78-inch discharge pipeline runs westward from the pump station along an easement on the Chevron Chemical Company property just south of Gertrude Avenue. At about 950 feet downstream of the pump station, the pipeline expands into an 8-foot by 4-foot box culvert which crosses Gertrude Avenue and runs into a trapezoidal earth channel that drains to Wildcat Creek.

The storm drain collection system consists of over 14,000 linear feet of reinforced concrete pipe in sizes ranging from 15 inches to 84 inches in diameter. The collection system drains an approximate 339 acres area west of 13th Street between Wildcat Creek to the north and Castro Street to the south.

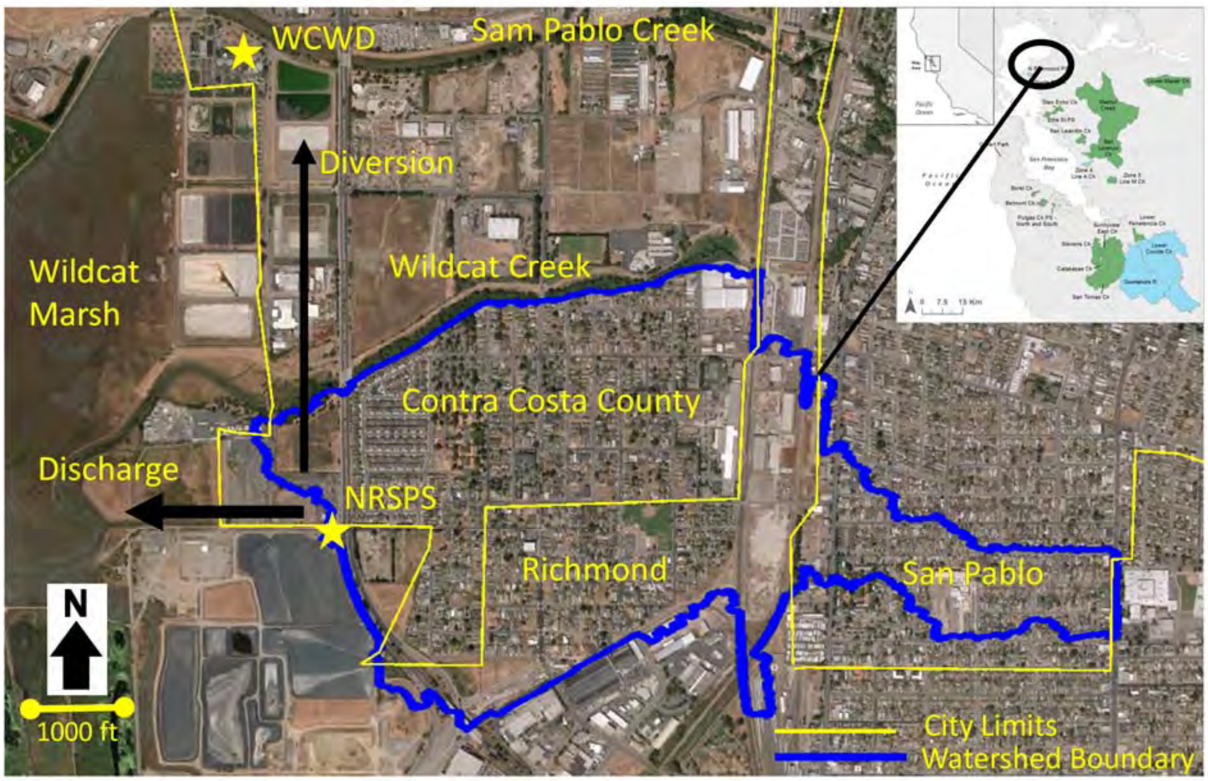


Figure 1 Watershed Setting of the NRSPS

The NRSPS's structure consists of a 3-level main structure and a discharge channel. The lowest level of the main structure, approximately 25 feet below ground, is the pump station wet well where stormwater from the collection system is received. Stormwater entering the station is routed to two compartments where it is lifted to the station's discharge channel by the stormwater pumps. The NRSPS is designed for a firm capacity of 135,000 gallons per minute (gpm). Four pumps, each capable of pumping 45,000 gpm of stormwater, are provided in the station. Three of these pumps provide for the firm capacity of the station while the fourth one serves as the standby unit.

The pumping station is designed to handle smaller dry-weather flows as well as storm flows. The original design had two pumps rated at 3,500 gpm each that were set to operate in lead-lag mode. Those low flow pumps were replaced during the rehabilitation with a smaller, 250 gpm pump used for diversion and a larger, 2,500 gpm pump which was connected directly to the discharge channel. The 250 gpm pump was selected because the nearest sewage system conveyance had a capacity restriction of 0.6 million gallons per day (mgd) to 1.4 mgd, or 400 to 1000 gpm (Figure 2). The design intention was to minimize the chance of surging the manhole as a result of the diversion.

A model of the NRSPS watershed was developed using EPA's Stormwater Management Model 5.0 (SWMM). The model was used to explore how increasing diversion volumes related to increased percentages of storm flow treated (Appendix D). Even though the pump station's rated capacity is 135,000 gpm, smaller diversion pumps (i.e., up to 1,900 gpm) can capture significant percentages of overall storm flow for the three events modeled (Table 3), because of the storage and equalization capacity in the stormwater conveyance system leading up to the NRSPS.

Table 3 SWMM Model Predictions for the Percent Stormwater Treated Under a Range of Theoretical Diversion Flows

Theoretical Diversion Flow (gpm)	Percent of stormwater treated for different storm events		
	April 4, 2013	September 21, 2013	February 2005-October 2013
500	3	2	2
1400	68	25	36
1900	84	44	44

Table 3 denotes <u>theoretical</u> outcomes of diversion scenarios. As noted above, actual diversion flows in this project were limited to 250 gpm for safety reasons. To achieve greater diversion flows, and therefore larger amounts of stormwater treated, either an alternative to WCWD treatment would be needed, or some means of storing and conveying water to WCWD other than the existing WCWD conveyance system would be needed. This is described in more detail in Section 7.0 below (conclusions and lessons learned).

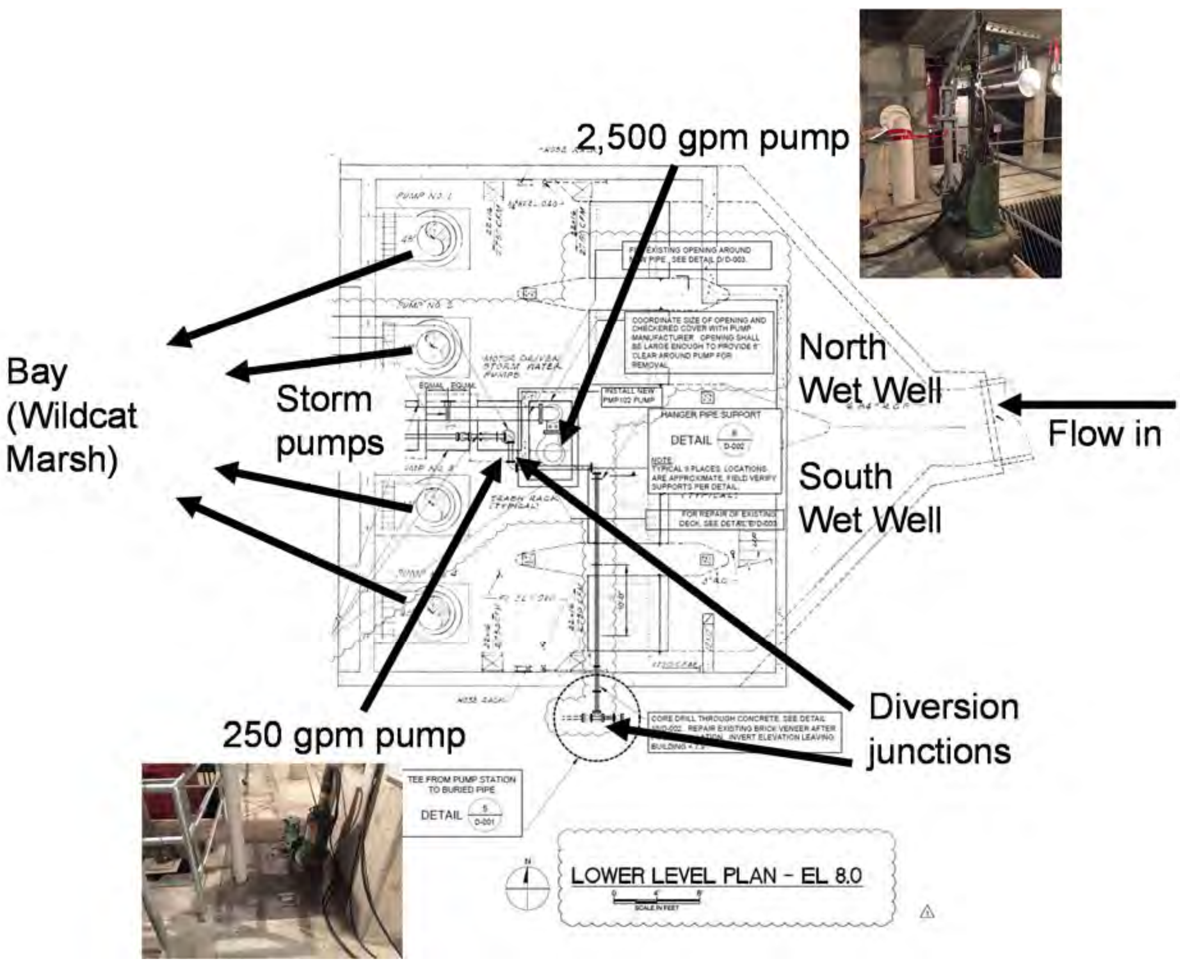
Figure and Data Provided by Ken Cook, District Engineer, WCWD on 10/9/2012

Figure 2 Sewage System Conveyance Capacity in Vicinity of NRSPS

4.0 DIVERSION INFRASTRUCTURE INSTALLED

On April 14, 2015, the Contra Costa County Board of Supervisors awarded a construction contract for the North Richmond Pump Station Stormwater Diversion Project to improve the pump station and provide the capability of diverting stormwater to the WCWD treatment plant for a short, specified period of time. As noted above, the diversion was a NPDES Permit requirement for the County, the Flood Control District, and all 19 cities and towns in the County. The approved construction contract amount was $469,369. The project was funded with grant funds from the Environmental Protection Agency, through the San Francisco Estuary Partnership, and with partnering funds from the CCCWP, City of Richmond, and County. Construction began on July 13, 2015 and was completed on November 24, 2015.

The project removed two 3500 gpm pumps that did not work and replaced them with two new pumps, one rated at 250 gpm and one rated at 2500 gpm (Figure 3). The new 2500 gpm pump is connected to a 14-inch discharge pipe that drains out to the Bay. The new 250 gpm pump is hooked up to a discharge pipe to the Bay as well, but also to a 4-inch discharge pipe from the pump to the outside of the pump station building. Diversion junctions inside the building and outside the building allow flexibility in routing flows from the 4 inch diversion pipe to the Bay, to WCWD, or to alternative treatment and storage should such facilities become available in the future.



Base figure as provided by the County from design drawings completed by Brown and Caldwell as a subcontractor to LCA Architects

Figure 3 Summary of Key NRSPS Improvements Related to the Diversion Project

Details showing the construction and operation of the valved diversion junctions are shown in Figure 4 below. The design goal for allowing two pathways for diverted water is to provide flexibility for NRSPS owners to explore alternative or supplemental options to treatment with sanitary sewage systems located nearby.

A temporary discharge pipe was installed from the pump station building to an existing Wastewater District manhole in Gertrude Avenue. The temporary discharge pipe was linked to a permanent manhole connection installed as part of this project (Figure 5). The manhole connection included a temporary float switch sensor that would automatically shut down the diversion pump if the manhole surged.

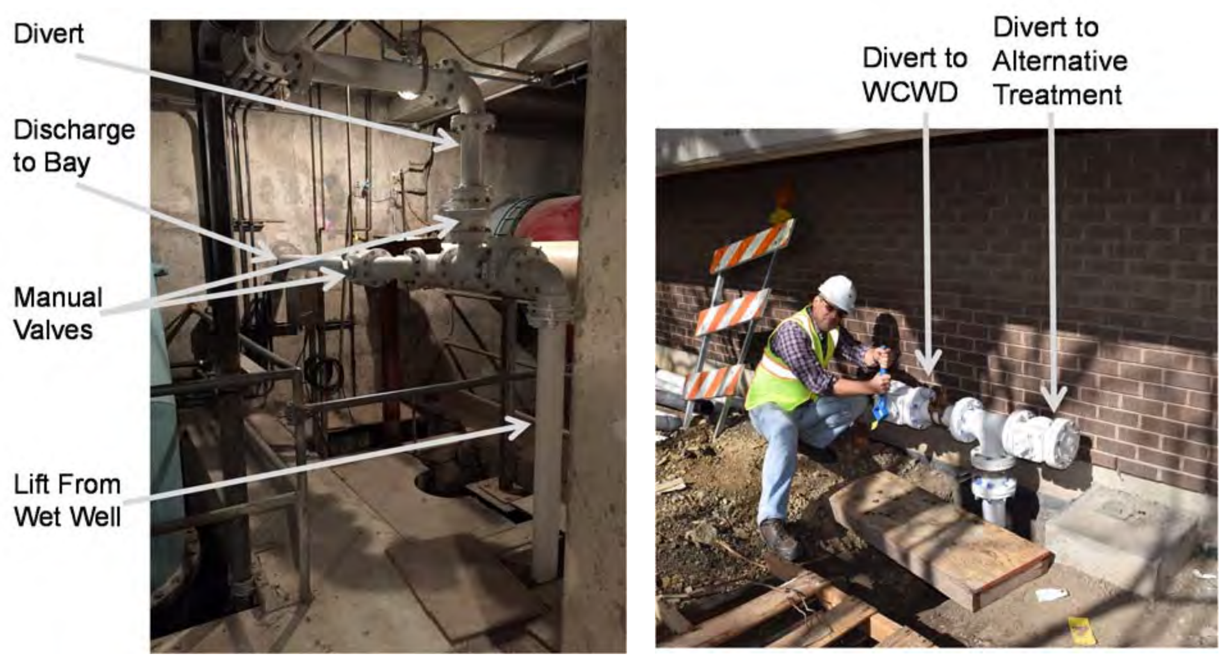


Figure 4 Valved Diversion Junctions Inside and Outside Building Provide Operational Flexibility

Figure 5 Permanent Manhole Connection to WCWD Linked to the NRSPS via a Temporary Pipe Aligned Along West Gertrude Avenue

Comparison of the size of pipes conveying diversion flows, low flows, and storm flows helps appreciate the size of the diversion in relation to the conveyance capacity of the NRSPS (Figure 6). The 250 gpm diversion flow pipe is 4 inches in diameter, about the size of an adult's hand. The newly installed 2,500 gpm low flow pump feeds a pipe, connected only to the Bay, which is 14 inches in diameter, about the length of an adult's forearm. Storm flows are forced to the Bay by three existing 45,000 gpm pumps, each one discharging through a 48 inch pipe, about an adult's chest height. The small volume of diversion flows in relation to storm flows helps manage expectations in regards to the pollutant loads reduced by the diversion pilot project described in Section 5.0 below.

Figure 6 **Comparison of the Pipe Sizes Conveying 250 gpm Diversion Flow, 2,500 gpm Low Flows, and 35,000 gpm storm flows**

Other needed repair and rehabilitation work at the NRSPS was completed in addition to restoring a low flow pump and installing a diversion pump, valves and pipes. The two non-functioning pumps and the old sensor equipment was demolished and removed. The old motor control panel could not be modified to accommodate the new set of pumps, so a separate control panel was installed along with new level sensors. Overall, the project helps extend the useful life of the NRSPS in addition to adding stormwater diversion capability. The description of project costs in Section 6.0 parses out costs of the diversion pilot from those for the necessary repair and rehabilitation at the NRSPS to help understand the cost of infrastructure enhancements addressing only water quality improvement.

5.0 WET AND DRY WEATHER PILOT TESTS

During the completion of construction of the diversion, dry weather and wet weather pilot diversions to WCWD were tested. A temporary pump and discharge pipe was linked to the permanent manhole connection located on Gertrude Avenue. The temporary pump provided around 200 gpm of flow to the WCWD collection system; however, dry weather flows are around 100 gpm, therefore the dry weather diversion did not operate continuously. For the dry weather diversion, an average diversion flow rate of 100 gpm was assumed, accounting for pump down time between diversion runs. A temporary pump was necessary because the diversion pilot needed to be conducted before the project was completed. The County was concerned that opportunities for rain events would be lost if the pilot was postponed until installation and testing of the permanent diversion pump had been completed.

The dry weather pilot diversion was completed on September 23, 2015 (Appendix E). The wet weather diversion was completed on November 2, 2015 (Appendix F). Table 4 below summarizes key data from the reports on the diversion pilots. The diversion flow volumes listed in Column A of Table 4 are multiplied by average pollutant concentrations listed in Column B to calculate pollutant loads diverted as shown in Column C. Column D shows ratios of pollutant concentrations to suspended sediment concentrations (SSC), effectively the pollutant concentration in suspended sediments. It is assumed that all sediment is removed from the diverted stormwater at the WCWD treatment plant, along with all pollutants attached to the sediment particles such as PCBs and Mercury.

Table 4 Monitoring Results from Wet and Dry Weather Diversion Pilots at NRSPS

(A) Diversion Information		(B) Average Pollutant Concentration				(C) Pollutant Load Diverted				(D) Pollutant Concentration in Suspended Sediments		
		mg/L	ng/L			kg	mg			ng/g		
Type and Date	Flow Diverted (gal)[1]	SSC	Hg	MeHg	PCB	SSC	Hg	MeHg	PCB	Hg SSC	MeHg SSC	PCB SSC
Dry 9/10/2015 to 9/23/2015	456,000	34	9.1	0.06	0.37	59	16	0.10	0.64	270	2	11
Wet 11/2/2015	32,000	52	36	0.49	7.0	6	4	0.06	0.84	690	9	134

1. Flow for the dry weather event was estimated based on 100 gpm x 60 minutes / hr x 8 hrs per day x 9.5 working days

The flow volume was more than ten-fold larger for the dry weather diversion because it went on for nine and a half working days, as compared to a half a working day for the brief wet weather event sampled on November 2. Despite the much larger flow volume diverted, the PCB loads diverted to WCWD are comparable for the wet and dry pilot tests. This is because the SSC concentration was higher during wet weather (52 mg/L compared to 34 mg/L), and the monitored PCB concentrations in the suspended sediments conveyed by the wet weather event were more than ten-fold higher compared to the dry weather event (134 ng/g compared to 11 ng/g). The same was true for methylmercury (MeHg). Mercury (Hg) concentrations in wet weather suspended sediments were only around three-fold higher compared to dry weather (690 vs 270 ng/g), and so the mercury loads diverted by the dry weather diversion ended up being four-fold greater than the wet weather diversion. The total PCBs removed by treatment during the pilot period was almost one and a half milligrams (1.48 mg) and total Mercury removed was 20 milligrams.

These pollutant concentrations in suspended sediments are consistent with regional trends. Stormwater from a pilot test at 1st Street and Cutting Blvd. in Richmond were recently shown to have mercury / SSC ratios of approximately 1 (Contra Costa Clean Water Program, 2015). PCB The average PCB to suspended sediment ratio of 134 at the NRSPS is typical of older urban areas along the Bay (Contra Costa Clean Water Program, 2013), and consistent with previous monitoring conducted by the San Francisco Estuary Institute (BASMAA, 2014).

6.0 PROJECT COSTS

The overall cost of executing this pilot project was $1,440,000. The actual construction contract for the pump station rehabilitation was $469,469; that cost included the construction and contractor labor related to the diversion pilot. Design of the pump station project cost an additional $280,000. Both design and construction reflected a project to divert storm water plus some improvements to the pump station facilities. The remaining project costs, over and above design and construction, comes from planning study, monitoring, reporting, project management, and multi-agency coordination that results from implementing a grant funded pilot project involving multiple jurisdictions with the goal of fulfilling a regulatory mandate.

The following subsections provide a more detailed analysis of costs provided by Contra Costa County to help parse out the base cost of the rehabilitation of the NRSPS from the cost of enhancements needed to accomplish the goal of diverting urban runoff to WCWD. Though the multiple project partners and funders necessitated extensive parsing out of the project costs, the important cost information for most readers is the estimate to replicate this project as a standalone stormwater diversion project, rather than an add-on to a rehabilitation.

6.1 FACILITY IMPROVEMENT

Stormwater flowing to the NRSPS comes from the City of Richmond, the unincorporated community of North Richmond, and, to a small extent, the City of San Pablo. The City of Richmond and County share the cost of maintaining, improving, and operating the pump station. Even though the purpose of the project was to divert stormwater to the Wastewater District, some work resulted in improvements to the existing pump station facilities. To divide the project costs amongst the funding partners, costs associated with improvements to the facilities needed to be separated from the costs associated solely with stormwater diversion. Those project costs that improved the pump station facilities had a long-term benefit to the pump station operations. Those project costs associated solely with the temporary stormwater diversion did not help improve pump station operations. The new 2,500 gpm pump is used for lifting low storm flows in the pump station and will save the large 45,000 gpm pumps from being used to evacuate the wet wells during low flow events. The new 250 gpm pump was used for the temporary diversion of stormwater to the WCWD treatment plant, but can also be used to lift dry weather flows in the pump station and extend the service life of both the 2,500 gpm pump and the large 45,000 gpm pumps. The four 45,000 gpm storm pumps (Figure 3) are the primary workhorses of the NRSPS and the most valuable asset and most expensive component. Anything that extends their service life is a benefit to the County and City.

6.2 STORMWATER DIVERSION COMPONENTS

That portion of the project that related solely to the temporary diversion of stormwater consists of a permanent discharge pipe installed from the 250 gpm pump to a connection point on the outside of the building. In addition, a temporary discharge hose was installed from the connection point outside the pump station building to the WCWD manhole in Gertrude Avenue. A sensor conduit was also installed from the building to the manhole. Lastly, a permanent discharge pipe was installed into the manhole from the edge of the pavement on Gertrude Avenue to connect with the temporary discharge pipe from the pump station, and a sensor conduit was installed into the manhole. A temporary sensor was placed in the manhole to measure the flow and elevation of the flows within the WCWD manhole to make sure diversion flows did not exceed the capacity of the sewer line.

6.3 CONSTRUCTION COST SPLIT

The contractor bid the project on a lump sum basis, but provided a breakdown of costs for all elements of the project. Those elements of the project that constitute the temporary stormwater diversion and facility improvements are shown in Table 5 below.

Table 5 North Richmond Pump Station Rehabilitation and Diversion Construction Costs

Task No.	Description	Stormwater Diversion	Facility Improvements	Totals
1	Temporary Diversion Pipes (4-inch)	$31,000		$31,000
2	Temporary Diversion electrical work (50%)	$32,500		$32,500
3	Facility electrical improvement work (50%)		$32,500	$32,500
4	Facility pump improvement work		$183,100	$183,100
5	Facility demolition/preparation work		$34,000	$34,000
6	Water control during construction		$22,400	$22,400
7	Miscellaneous Costs	$5,267	$22,602	$27,869
8	Mobilization and Overhead	$20,034	$85,966	$106,000
	Total Construction Cost	**$88,801**	**$380,568**	**$469,369**

1. Miscellaneous Costs, and Mobilization and Overhead are soft costs that are split between Stormwater Diversion and Facility Improvements in proportion to the hard costs for each one (18.9%/81.1%).
2. The cost split for electrical work between the temporary diversion component and the facility improvements component (50%/50%) was provided by the contractor, Valentine Corporation.
3. Total construction cost based on the construction contract awarded to Valentine Corporation on April 1, 2015.
4. Cost breakdown for each task provided by the contractor, Valentine Corporation.

6.4 MOST LIKELY PUMP STATION STORMWATER DIVERSION PROJECT COSTS

How does this project compare to other likely stormwater diversion projects in the Bay Area? In some ways the North Richmond Pump Station is different from other pump stations in the Bay Area. These differences need to be examined in order to determine the cost estimate for the most likely pump station diversion project, a project applicable to the average pump station in the Bay Area.

6.4.1 Pump Replacement

The NRSPS has suffered from decades of deferred maintenance. As result, the two original smaller 3500 gpm pumps had not been working for years. In addition, the original dry weather flows were based on agricultural land-uses. Today's land-uses, and the land-uses reflected in the General Plan, are more residential and produce less dry weather flows. The combination of a lower demand and two nonfunctioning pumps resulted in a design to install the new diversion project pumps in place of the nonfunctioning pumps. The average pump station will likely have all of its pumps maintained and operating, and may not be able to remove an operational pump for a small stormwater diversion pump. The size of the stormwater diversion pump is based on the limiting capacity of the wastewater district facility accepting the stormwater flows, however, it is likely a much smaller pump size than that needed for pump station operations. Finding a new spot to place a stormwater diversion pump in an existing pump station may or may not present a problem.

6.4.2 Agency Coordination

In some cases, the pump station and wastewater district accepting the stormwater is owned by the same agency. In this case, the NRSPS is owned by Contra Costa County and the wastewater treatment plant is owned by the West County Wastewater District. The WCWD, though supportive of the project, was naturally concerned about the potential impact the diversion of stormwater might have on their treatment plant. As result, two years of stormwater sampling and analysis was conducted to determine the constituents in the stormwater. A Feasibility Study was prepared to determine the feasibility of diverting stormwater from the pump station to the treatment plant from an engineering perspective and, given the pollutants and pollutant loading in the stormwater, determine if there were any impacts on the wastewater treatment train. The WCWD expressed some additional concerns that prompted a second Technical Study which addressed those concerns. This initial planning effort, from initiating the stormwater sampling to the WCWD accepting the project design concept, took over3 years.

6.4.3 Facility Improvement

Due to the extensive deferred maintenance of the NRSPS, a portion of the stormwater diversion project resulted in improvements to the pump station facilities. Some of the costs that would be part of a stand-alone stormwater diversion project were identified as a facility improvement in the NRSPS project. However, in a typical stormwater diversion project many of those costs would be a project cost. For example, the cost of water control during construction was identified as a facility improvement in the NRSPS project, whereas a stand-alone stormwater diversion project would have to account for that type of cost.

6.4.4 Stormwater Diversion Project Costs

For the NRSPS project, the contract items were divided between those needed for the stormwater diversion and those that resulted in improvements to the existing pump station facility. However, the costs assigned to the stormwater diversion part of the project are not representative of a stand-alone stormwater diversion project. Using the construction contract for the NRSPS project and assigning costs to project elements for a more likely stormwater diversion project results and a more realistic cost estimate for a stand-alone stormwater diversion project. Table 5 above shows the cost split between stormwater diversion elements and facility improvement elements for the NRSPS Stormwater Diversion Project. Table 6 shows the contract costs associated with a more likely stand-alone stormwater diversion project. This estimated construction cost is based on the construction contract for the NRSPS Stormwater Diversion Project plus change orders associated with the stormwater diversion component of the project. The estimated construction contract cost (approximately $160,000) from Table 6 can be used to build a total project cost estimate for a stormwater diversion project using the costs of the project elements for the NRSPS Stormwater Diversion Project and adjusting them accordingly. For example, the $280,000 design cost for the full project was adjusted, proportionally, to $95,000 for a smaller stand-alone stormwater diversion project. The final project cost estimate for a stand-alone stormwater diversion project is shown on Table 7.

Table 6 Most Likely Stormwater Diversion Construction Costs

Task	Description	Stormwater Costs	Diversion
1	Diversion pipes within building	$31,000	
2	Diversion pipes outside building	$10,000	
3	Electrical work	$32,500	
4	250 GPM pump	$15,410	
5	Water control	$22,400	
6	Miscellaneous	$8,918	
8	Mobilization and Overhead	$33,920	
9	Change Orders	$4,519	
	Total Construction Cost	**$158,667**	

Table 7 North Richmond Stormwater Diversion Project Final Cost Estimate for Stormwater Diversion Only

Task No.	Task Description	Notes	Cost Estimate
1	Project Management	1	$268,000.00
2	Pre-project lab work	2	$137,000
3	Monitoring	3	$150,000
4	Diversion staff costs	4	$12,000
5	Feasibility Report	5	$76,000
6	Technical Report	6	$59,000
7	Final Report	7	$10,000
8	Design	8	$95,000
9	Construction Contract	9	$160,000
10	Construction Management	10	$16,000
		TOTAL	**$983,000**

1. Project Management costs include pre-project work with SFEI and Wastewater District
2. Advance fieldwork and lab analysis performed by SFEI funded primarily with grants
3. Additional two years of monitoring funded by BASMAA
4. Estimated by the Wastewater District and includes $2000 County staff time
5. Feasibility Study completed on November 7, 2012
6. Technical Report completed on November 20, 2013
7. Final Report identifies how project objective was met and lessons learned
8. Design includes CEQA, permitting, right-of-way, and engineering and architectural work
9. Construction cost estimate taken from Table 1
10. Estimated to be 10% of construction contract amount

7.0 CONCLUSIONS AND LESSONS LEARNED

The magnitude of the diverted pollutant loads in this pilot test compared to regulatory mandates is sobering. Diverting almost a milligram of PCBs during a prolonged (9.5 days) diversion or a single (0.5 day) storm event achieves almost nothing compared to the current Baywide mandate of reducing 18,000 grams of PCBs (18 million milligrams) from all stormwater sources each year. This pilot test achieved a tiny fraction - about 0.00001 percent - of the 18 kg load reduction goal established by the TMDL for PCBs in San Francisco Bay.

Scaling the pilot up to the maximum diversion capacity, 250 gpm operated year-round, 24 hours a day seven days a week, would not extend the PCB load reductions by an appreciable amount. Note from Table 3 above that a theoretical wet weather diversion of 500 gpm captures only two to three percent of the storm flows modeled. It would take much larger diversion flows – i.e. thousands of gallons per minute – to capture appreciable amounts of storm flows. Diversions of that scale would require either separate offline high rate treatment, or offline storage and equalization so that WCWD could treat and use the water when it is needed by recycled water customers. Any such approach is a much more substantial and costly engineering endeavor than what has been achieved at the NRSPS through this pilot project.

Overall, stormwater diversion to sanitary does not appear to be a tool that will provide substantive progress towards meeting PCB load reduction goals established by the TMDL.

Monitoring at the NRSPS shows that the estimated watershed PCB load is no more than approximately 10 grams per year generated in that drainage (BASMAA, 2014; Hunt et al., 2012). Even with an impressive capture and use project that harvested nearly all stormwater from the NRSPS service area, 10 grams per year is a very small step towards attaining a load reduction goal of 18,000 grams per year.

From a cost perspective, a diversion project of this scale, implemented as a "stand-alone," without including any infrastructure rehabilitation, would cost close to $1,000,000 for planning, design, construction, monitoring, project management, and reporting.

In summary, this project achieved the objective of installing and pilot testing urban runoff diversion infrastructure. Diversion of dry and wet weather urban runoff into the nearest water reclamation facility offers only incremental PCB load reduction benefits. Diversion is not a "silver bullet" that will make a significant difference to PCB loads; however, consideration of multiple water quality benefits, such as trash controls, water resource development, and reduction of bacteria, oil and grease, and other urban pollutants discharged to Wildcat Marsh and the Bay may motivate additional, expanded stormwater harvest and use projects in this watershed.

Water resource needs may be the overall driver. The newly installed diversion infrastructure can harvest and re-use approximately 50 million gallons[1] per year of urban runoff, primarily as dry weather urban runoff, should WCWD desire to use the infrastructure to implement longer term diversions. Overall, the immediate benefit of extending the useful life of the NRSPS and having diversion capabilities, opens longer term planning opportunities that makes this project a success.

On February 25, 2016, the NRSPS Stormwater Diversion Project was awarded the honor of Environmental Project of the Year by the Northern California Chapter of the American Public Works Association (Appendix A). The award named CCCWP as "an essential partner in the development and construction of this innovative project."

8.0 REFERENCES

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[1] This figure is based on an assumed 100 gpm of dry weather flow year-round, diverted 365 days per year, 24 hours a day, with 10 percent down time for storms and maintenance.

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APPENDIX A

Award - Environmental Project of the Year by the Northern California Chapter of the American Public Works Association (February 25, 2016)

AMERICAN PUBLIC WORKS ASSOCIATION
APWA
NORTHERN CALIFORNIA CHAPTER

Northern California Chapter
Proudly Proclaims the

NORTH RICHMOND PUMP STATION STORMWATER DIVERSION PROJECT

as the

2016
ENVIRONMENT PROJECT OF THE YEAR

and Recognizes the

Contra Costa Clean Water Program

As an Essential Partner in the Development and Construction of this Innovative Project

Brian Balbas
2016 Chapter President
February 25, 2016

APPENDIX B

Joint Exercise of Powers Agreement between Contra Costa County and the West County Wastewater District for Maintenance of the NRSPS (August 11, 1981)

Stand - Maintenance

In the Board of Supervisors
of
Contra Costa County, State of California

August 11, 19 81

In the Matter of

Approving and Authorizing Joint Exercise of Powers Agreement with West Contra Costa Sanitary District for Maintenance of the North Richmond Storm Drain Pump Station.
0330-6S7331

RECEIVED
AUG 26 1981
WEST CONTRA COSTA SANITARY DISTRICT

The Public Works Director having recommended that the Board of Supervisors approve and authorize its Chairman to execute the revised Joint Exercise of Powers Agreement with the West Contra Costa Sanitary District (formerly the San Pablo Sanitary District) for the District to maintain the North Richmond Storm Drain Pump Station on behalf of the County; and

The Public Works Director having reported that this revised Agreement reflects changes in accounting and billing procedures and supersedes the original Agreement entered between the County and San Pablo Sanitary District on April 16, 1974;

IT IS BY THE BOARD ORDERED that the recommendation of the Public Works Director is APPROVED and the Chairman is AUTHORIZED to execute the Agreement.

PASSED by the Board on August 11, 1981 by the following vote:

AYES: Supervisors Fahden, Schroder, McPeak, Torlakson, Powers
NOES: None
ABSENT: None

I hereby certify that the foregoing is a true and correct copy of an order entered on the minutes of said Board of Supervisors on the date aforesaid.

Witness my hand and the Seal of the Board of Supervisors
affixed this 11th day of August, 19 81

J. R. OLSSON, Clerk

By Linda L. Page, Deputy Clerk
Linda L. Page

Originator: Public Works Dept.
Maintenance Division

cc: County Administrator
Auditor-Controller
Public Works Director
Accounting Division
Maintenance
West Contra Costa Sanitary via Maintenance

AGREEMENT

(JOINT EXERCISE OF POWERS - NORTH RICHMOND
STORM DRAIN PUMP STATION - MAINTENANCE)

1. PARTIES & DATE. Effective on August 11, 1981 the WEST CONTRA COSTA SANITARY DISTRICT, a political subdivision of the State of California, hereinafter referred to as "DISTRICT," and the COUNTY OF CONTRA COSTA, a political subdivision of the State of California, hereinafter referred to as "COUNTY," pursuant to Government Code Sections 6500 et seq., do mutually promise and agree as hereinafter set forth.

2. PURPOSE & SCOPE. This agreement supersedes the agreement entered into by SAN PABLO SANITARY DISTRICT and COUNTY OF CONTRA COSTA on April 16, 1974. COUNTY has constructed a storm drain system including a pumping station, in the unincorporated area of North Richmond on West Gertrude Avenue directly across from Deal Auto Wrecking at 400 West Gertrude, and has need to provide for the maintenance and operation of said pumping station, which DISTRICT is willing to provide.

3. MUTUAL PROMISES. DISTRICT shall be responsible for the maintenance and operation of said pumping station, in accordance with Paragraphs 4 and 5, below. COUNTY shall bear the cost of said maintenance and operation, including the cost of all utilities serving the pump station, such as electrical, telephone, water, sewers, natural gas, propane gas and telemetering. COUNTY also agrees to bear all costs associated with property ownership, such as frontage improvement costs and special assessments, which might be applicable.

4. DEFINITIONS.

a. "Maintenance" includes replacement and/or repair of all elements and components of the pumping station and appurtenances, including but not limited to the pumping units, engines, motors, structures, fuel storage, electrical panels, and piping, and routine maintenance such as cleaning, painting, lubrication, and maintenance of landscaping.

b. "Operation" includes operation of the pumping units and auxiliary facilities.

5. STANDARD. All operation and maintenance work shall be performed in accordance with good engineering practice and shall initially follow the Operation and Maintenance Manual to be prepared by County's consultant and furnished by COUNTY.

6. METHOD. DISTRICT will bill COUNTY every six months for actual direct labor costs, including reasonable overhead costs, the cost of supplies, and cost of services by others. DISTRICT will be allowed to add a surcharge which equals 5% of the total cost to cover the administrative and interest costs for funds advanced by DISTRICT. DISTRICT grants to the COUNTY the right to install monitoring

devices in DISTRICT'S treatment plant at locations designated by DISTRICT for the purpose of receiving monitoring signals originating at COUNTY'S pumping station. Except for emergency work, no single maintenance or operational task for which the estimated cost exceeds TWO THOUSAND FIVE HUNDRED DOLLARS ($2,500.00) shall be performed without first obtaining written approval from the appropriate COUNTY authority. In the event of emergency, DISTRICT shall notify COUNTY immediately of its repair work.

7. PAYMENT. COUNTY, upon being billed by DISTRICT for operation and maintenance costs, will reimburse DISTRICT within 30 days of receipt of invoice. DISTRICT annually will submit, no later than February 1 of each year, its estimate of annual operation and maintenance costs for COUNTY budgetary purposes. It is understood that the actual operation and maintenance costs from year to year may be greater or less than the estimated annual cost. The frequency of billing periods may be adjusted by mutual agreement of COUNTY and DISTRICT. There will be strict accountability of all DISTRICT costs and expenditures for operation and maintenance of the pump station. COUNTY reserves the right to review the financial books and records of DISTRICT with respect to charges invoiced to COUNTY.

8. INDEMNIFICATION. COUNTY, insofar as it may legally do so, shall indemnify and hold harmless DISTRICT, its officers, agents and employees from any and all liability, claims or losses resulting from, or associated with, DISTRICT'S maintenance of the pump station except where claim or damage results from negligence or willful misconduct on the part of DISTRICT, its officers, agents and employees. DISTRICT assumes responsibility for Workers' Compensation coverage and DISTRICT shall defend and indemnify COUNTY for and hold it harmless from any claims or losses on the part of DISTRICT'S employees which are governed by Workmens' Compensation. All other insurance coverage shall be furnished by COUNTY. DISTRICT shall not be liable for damage resulting from acts beyond its control, including labor strikes or stoppages, power outages, inability to procure fuel, and vandalism.

9. TERMINATION. This agreement will continue in full force and effect from year to year until rescinded or terminated. The agreement may be terminated at the end of any fiscal year by either party submitting written notification of termination to the other party on or before April 1 of the final year.

COUNTY OF CONTRA COSTA

By ______________________
Chairman, Board of Supervisors

ATTEST: J.R. Olsson
County Clerk

By ______________________
Deputy

Approved as to Form:
John B. Clausen, County Counsel

By ______________________

WEST CONTRA COSTA SANITARY DISTRICT

By ______________________
President

By ______________________
Secretary

Approved as to Form:
Robert W. Pelletreau, Board Attorney

By ______________________

APPENDIX C

Waste Water Discharge Permit No. SD-019 (September 16, 2015)

West County Wastewater District

WASTEWATER DISCHARGE PERMIT

PERMIT No. SD-019

In accordance with the West County Wastewater District (District) Wastewater Discharge Ordinance, No. 11-7-00 (Ordinance):

Contra Costa Public Works Department
North Richmond Pump Station
Richmond Parkway at W. Gertrude Avenue
Richmond, CA 94801

Is hereby authorized to discharge water from the North Richmond Pump Station into the District sewer system in accordance with the conditions set forth in this permit. Compliance with the Local Limits outlined in the Ordinance must be maintained for all discharges to the District's collection system and treatment plant. Compliance with this permit does not relieve the Contra Costa County Public Works Department (permittee) of its obligation to comply with any or all applicable pretreatment regulations, standards or requirements under local, State, and Federal laws, including any such regulations, standards, requirements, or laws that may become effective during the term of this permit.

Non-compliance with any term or condition of this permit shall constitute a violation of the District's Ordinance. Any person who violates permit conditions is subject to civil and criminal penalties and enforcement as outlined in the Ordinance and Federal pretreatment standards.

This permit shall become effective on **September 16, 2015** and shall expire at midnight on **September 15, 2018.** If the permittee wishes to continue to discharge wastestreams that are covered by the District's Ordinance, an application must be filed for renewal on or before February 28, 2018 (a minimum of 90 days before the permit expires).

Wastewater Discharge Permits are not transferable. The permittee shall notify the District prior to any change in ownership or operation, provide the succeeding owner or operator with a copy of this permit and notify them that an application for renewal of the permit may be required.

Brian E. Hill

Brian Hill
Water Pollution Control Plant Superintendant

PART 1 – EFFLUENT LIMITATIONS

A. Description of Discharge(s)

The permittee is authorized to discharge water from the connection listed below.

Outfall #	Description
1	Runoff from the stormwater collection system at the North Richmond Pump Station into a manhole on W. Gertrude Avenue

B. Discharge Limits

During the term of this permit all water generated and discharged from the facility shall comply with the District's Ordinance and shall not exceed the District's Specific Discharge Limitations:

Local Limits			
Total Metals	**Daily Maximum mg/L**	**Additional Parameters**	**Daily Maximum mg/L**
Arsenic (As)	0.37	Cyanide (CN^-)*	0.4
Cadmium (Cd)	0.5	Phenolic Compounds	8.0
Chrome (Cr)	2.0	Chloroform	3.34
Copper (Cu)	3.0	Methylene Chloride	0.18
Lead (Pb)	2.0	Tetrachloroethylene	14.26
Mercury (Hg)	0.02	Tributyltin	0.19
Nickel (Ni)	0.8		
Selenium	1.0	pH	6.0 – 12.0 units
Silver (Ag)	0.3	Temperature	< 130^{o} F
Zinc (Zn)	5.0		

The permittee shall not discharge any wastewater that is prohibited under Section 2 of the District's Ordinance during the term of this permit.

The maximum flow of stormwater regulated by flow restrictor or pump capacity shall at no time exceed **400 gallons per minute** unless previous written authorization is provided by the District.

PART 2 – MONITORING REQUIREMENTS

The permittee shall monitor this outfall for the following:

Weekly and Monthly Monitoring Requirements

Sample Parameter(s)	Frequency	Sampling Period(s)	Sampling Method
pH[1]	1x/week	October – December	Single Grab
Flow[2]	Continuous	October- December	Metered

Arsenic (As)(T)	1x/week	October- December	Single Grab
Cadmium (Cd)(T)	1x/week	October – December	Single Grab
Chromium (Cr)(T)	1x/week	October – December	Single Grab
Copper (Cu)(T)	1x/week	October – December	Single Grab
Lead (Pb)(T)	1x/week	October- December	Single Grab
Mercury (Hg)(T)	1x/week	October- December	Single Grab
Nickel (Ni)(T)	1x/week	October- December	Single Grab
Selenium (Se)(T)	1x/week	October – December	Single Grab
Silver (Ag)(T)	1x/week	October – December	Single Grab
Zinc (Zn)(T)	1x/week	October – December	Single Grab

(T) = Total

Quarterly Monitoring Requirements

Sample Parameter(s)	Frequency	Sampling Period(s)	Sampling Method
EPA Method 608	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
EPA Method 624	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
EPA Method 625	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Arsenic (As)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Cadmium (Cd)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Chromium (Cr)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Copper (Cu)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Lead (Pb)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Mercury (Hg)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Nickel (Ni)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Selenium (Se)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Silver (Ag)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]
Zinc (Zn)(T)	Quarterly[3]	Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec	Composite[4]

1. pH shall be measured in the field using a properly maintained and calibrated pH meter.

2. **Flow** - The permittee shall quantify the volume of water that is generated from regulated process operations, and is discharged to the sewer, using meters and/or totalizers, where feasible. Meter must be non-resettable; the total volume shall be recorded daily and record(s) submitted monthly.

3. Results from quarterly sampling may also be used to comply with the weekly sampling requirements for the week measurements are taken; only required for quarters when discharge occurs.

4. Composite grab sampling techniques shall be used and be representative of the total flow over a 24 hour discharge period.

Sampling & Analyses - All sampling and analyses required by the permit shall be performed in accordance with the techniques described in 40 CFR Part 136 and amendments thereto, using validated analytical methods approved by the EPA [40 CFR 403.12(g)] or by methods specified in the permit. Analyses shall use only wastewater methods.

The permittee shall maintain all equipment so that accurate and reliable readings are provided. Calibration of equipment shall be performed at a minimum of once per year and more often if/when necessary.

The permittee is responsible for monitoring discharge. The District will periodically monitor for compliance with the parameters outlined above and District's local limits.

PART 3 – REPORTING REQUIREMENTS

All self-monitoring reports shall contain the following certification signed by a duly authorized representative using these words:

"I certify under penalty of law that this document and all attachments were prepared under my direction or supervision and in accordance with the system designed to insure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person(s) who manage the system, or those directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate and complete. I am aware that there are significant penalties for knowingly submitting false information, including the possibility of fine and imprisonment for knowing violations."

Unless otherwise stated all information and reports required by the District shall be submitted as follows:

Information/Report for:	Due Before 5:00 p.m.
January	February 28th
February	March 30th
March	April 30th
April	May 30th
May	June 30th
June	July 30th
July	August 30th
August	September 30th
September	October 30th
October	November 30th
November	December 30th
December	January 30th

1. **Flow Report** - submit monthly a report outlining daily flow meter readings, gallons discharged per day, the total volume discharged each month, and a summary of the results of monthly and weekly monitoring requirements.

2. **Flow Meter Calibration & Report** – A minimum of once every calendar year (January 1st – December 31st), the flow meter (and any associated monitoring and/or recording equipment) shall be calibrated by a qualified, independent third party and certified that they are operating within specifications. The calibration report shall be submitted before the 15th of the month following the month the calibration(s) are performed.

3. **pH Meter Calibration(s) & Report** – portable pH meter(s) should be calibrated prior to each use. Meters shall be calibrated according to equipment specifications and using buffers appropriate for proper measurement of the waste stream(s) being monitored. Logs shall be kept to verify: date of calibration, the initials and name of the technician performing the calibration(s), buffers used, the before & after pH readings, and any problems noted and/or maintenance, etc. Logs shall be kept onsite and available for review upon request.

   Failure to provide the required reports within 30 days after the due date will be considered as significant noncompliance as outlined in the District's Sewer User Ordinance [Section 1.2 (45) (f)]. Reports need to be submitted by mail, fax, or in-person. If the report is submitted electronically, the permittee must also submit by mail or fax a certification statement as is outlined in 40 CFR 403.6 (a) (2) (ii) and to be signed by an authorized representative of the facility.

4. **Sampling & Analyses:**

   - Representative Sampling - Samples and measurements taken as required herein shall be representative of the volume and nature of the monitored discharge. All samples shall be taken at the monitoring points specified in the permit. All equipment used for sampling and analysis must be routinely calibrated, inspected and maintained to ensure its accuracy. Monitoring points shall not be changed without notification to and written approval by the District.

- Increased Sampling/Monitoring - In addition to any monitoring requirements of this permit, if the permittee monitors any pollutant at the point(s) of compliance more frequently than required by the permit, using test procedures prescribed in 40 CFR Part 136 and amendments thereto, or otherwise approved by EPA or as specified in the permit, the results of such monitoring shall be included in any calculations of the daily maximum and monthly averages. Pollutant discharge results shall be summarized and reported to the District; such increased monitoring frequency shall also be indicated in the report.

- Permit Violations and Automatic Re-sampling - If the results of analyses of the permittee's discharge indicate that a violation of the permit has occurred, the permittee, according to 40 CFR 403.12(g) must:

  a) Inform the District of the violation within 24 Hours of becoming aware of the violation and;
  b) The permittee shall also repeat the sampling and analysis and submit the results of the repeat analysis within 30 days after becoming aware of the violation.

  Exceptions to the requirement of repeat sampling and analysis are if the District samples the facility at least once per month, and/or, if the District performs sampling at the facility between the time the initial sample was collected (that indicated there was a violation) and when the results of that sample event were received.

- Record Contents - Facilities shall maintain records of all information resulting from any monitoring activities, including documentation associated with Best Management Practices. Copies of records shall be submitted to the District and originals shall be kept by the permittee; records of sampling and analysis shall include:

  a) The date, the exact place(s), time(s), and methods of sampling or measurements, and sample preservation techniques or procedures;
  b) Who performed the sampling or measurement (name and company);
  c) The date(s) analyses were performed;
  d) The person(s) who performed the analysis;
  e) The analytical technique(s)/method(s) used;
  f) The results of such analyses;
  g) Laboratory Quality Assurance and Quality Control reports (QA/QC);
  h) A record of sample possession from the time the sample was collected to the time the report of analysis was completed (Chain of Custody).

5. **Changes**

The facility is required to notify the District, in writing, of any significant changes to the User's operations or system which might alter the nature, quality, or volume of its discharge at least 90 days before the change. The facility is required to submit such information as may be deemed necessary to evaluate the changed condition, including submission of an updated wastewater discharge application. The District may modify this permit in response to changed conditions or anticipated changes in conditions.

6. **Retention of Records** – The facility shall maintain records of all information resulting from any monitoring activities, including documentation associated with Best Management Practices. Copies of records shall be submitted to the District and originals shall be kept by the permittee; records of sampling and analysis shall include:

   i) The date, the exact place(s), time(s), and methods of sampling or measurements, and sample preservation techniques or procedures;
   j) Who performed the sampling or measurement (name and company);
   k) The date(s) analyses were performed;
   l) The person(s) who performed the analysis;
   m) The analytical technique(s)/method(s) used;
   n) The results of such analyses;
   o) Laboratory Quality Assurance and Quality Control reports (QA/QC);
   p) A record of sample possession from the time the sample was collected to the time the report of analysis was completed (Chain of Custody).

7. **Waste Disposal** - The permittee shall maintain records to verify that any hazardous materials and/or wastes that are prohibited from discharge to the sanitary were disposed of properly. Wastes must be handled, stored, and disposed of according to applicable local, state, and federal regulations. Records of disposal and/or recycling of such wastes must be retained by the permittee for a period of three years. These records shall include the amount of waste generated and the method of final disposal (including appropriate waste manifests).

PART 4 – NOTIFICATION OF SLUG DISCHARGE AND BYPASS

The permittee shall notify the District immediately of any changes at the facility affecting the potential for a slug discharge and bypass.

The permittee shall notify the District immediately upon the occurrence of an accidental discharge of substances prohibited by Section 2 of the District's Ordinance or any slug loads or spills that may enter the sewer.

1. Bypass – the intentional diversion of wastestreams from any portion of an Industrial User's treatment facility [40 CFR 403.17 (a)].

2. Slug Discharge(s) - any discharge of a non-routine, episodic nature, including but not limited to an accidental spill or a non-customary batch Discharge, which has a reasonable potential to cause Interference or Pass Through, or in any other way violate the POTW's regulations, local limits or permit conditions. The results of such activities shall be available to the District upon request.

The permittee is required to notify the District immediately of any changes at the facility affecting the potential for a slug discharge, and if the District determines a plan is required, the permittee shall develop a plan that contains, at a minimum, the following:

a) Description of discharge practices, including non-routine batch Discharges;
b) Description of stored chemicals;
c) Procedures for immediately notifying the POTW of Slug Discharges, including any Discharge that would violate a prohibition under 40 CFR Part§ 403.5(b) with procedures for follow-up written notification within five days;
d) If necessary, procedures to prevent adverse impact from accidental spills, including inspection and maintenance of storage areas, handling and transfer of materials, loading and unloading operations, control of plant site run-off, worker training, building of containment structures or equipment, measures for containing toxic organic pollutants (including solvents), and/or measures and equipment for emergency response.

PART 5 – STANDARD CONDITIONS

The permittee shall comply with all requirements of this permit, all conditions specified in the District's Wastewater Discharge Ordinance (11-7-00).

PART 6 – CIVIL AND CRIMINAL PENALTIES

The facility is subject to civil and criminal penalties for violation(s) of Pretreatment Standards and requirements, and any applicable compliance schedule(s); reference Section 5 of the District's Wastewater Discharge Ordinance.

PART 7 - PERMIT EXTENSION

The District reserves the right to extend the permit if necessary. The District must provide a written notice to the permittee at least 90 days before the permit expires. The permit cannot be extended beyond the maximum of five years permit limit [40 CFR 403.8 (f1) (iii) (A)].

End of Permit

amec foster wheeler

APPENDIX D

SWMM Modeling for North Richmond Pump Station, Options for Minimizing Stormwater Discharge into the Bay (March 4, 2016)

Memo

To: Mitch Avalon
Contra Costa County
Project Manager of the
NRSPS Diversion Pilot

From: Sandy Chang
Dr. Khalil E.P. Abusaba

Tel: (510) 663-4100

Project: 5025153001.01

Fax: (510) 663-4141

cc: Cece Sellgren, Contra Costa County Watershed Program

Rob Carson, Contra Costa Clean Water Program

Date: March 4, 2016

Subject: SWMM Modeling for North Richmond Pump Station, Options for Minimizing Stormwater Discharge into the Bay

1.0 EXECUTIVE SUMMARY

The estimated dry weather flow rate for the NRSPS ranges from 80 gpm to 140 gpm. The percentage of stormwater that could be treated by using diversion pumps of varying size to provide onsite or offsite treatment is summarized in Table 1 below.

Table 1. Percent of stormwater that could be treated at the NRSPS under various assumed treatment capacities.

Treatment capacity (gpm)	% stormwater treated		
	April 4, 2013	September 21, 2013	February 2005-October 2013
500	3	2	2
1400	68	25	36
1900	84	44	44

Amec Foster Wheeler Environment & Infrastructure, Inc.
180 Grand Avenue, Suite 1100
Oakland, California 94612-3066
USA
Tel (510) 663-4100
Fax (510) 663-4141
amecfw.com

2.0 INTRODUCTION

The purpose of this memorandum is to document the approach and findings of flow modeling applied to the sub-watershed that drains into the North Richmond Pump Station (NRPS) (Fig. 1). This work is being done to assist Contra Costa County, as one of the NRSPS co-owners, who is taking the lead on a pilot project with the consent of the other co-owner, the City of Richmond. This modeling work has been done to support the design of a pilot project to divert stormwater from the NRSPS into the nearby West County Wastewater District (WCWD) sewage treatment plant (CCCWP, 2012).

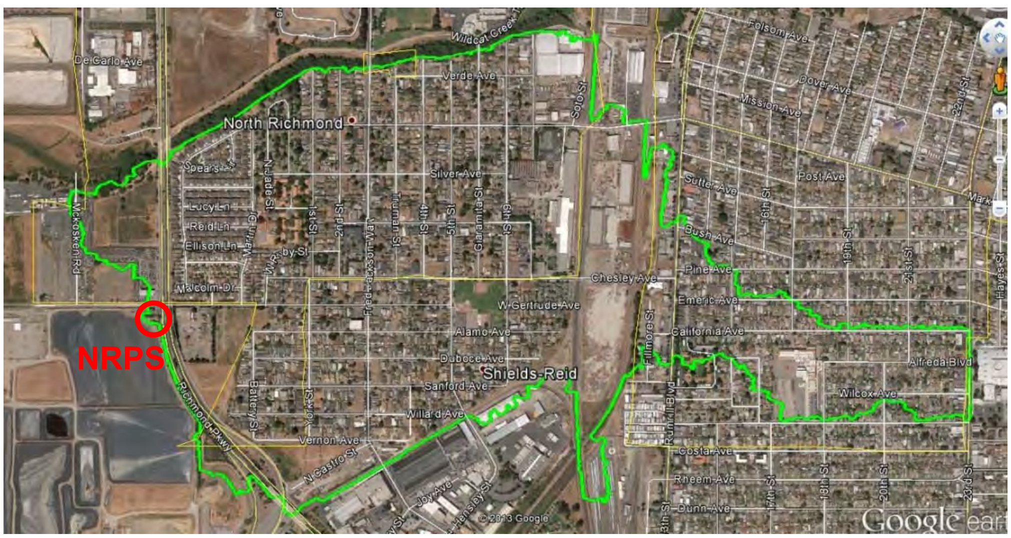

Figure 1: Delineation of sub-catchment drainage into NRPS (Contra Costa County).

The pilot diversion project is one of several pollutant reduction pilot projects required by the San Francisco Bay Regional Water Quality Control Board (SFRWQCB) through the Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit (Order No. R2-2009-0074, a.k.a. “the MRP”). The goal of pollutant reduction pilot projects required under the MRP is to evaluate the feasibility, costs, and benefits of different approaches to reducing stormwater loads of polychlorinated biphenyls (PCBs) and mercury discharged into the Bay. This pilot project evaluates the circumstances under which it may be feasible and cost effective to co-manage stormwater discharges from the NRSPS with municipal sanitary sewage using treatment capacity available at WCWD.

The NRPS was originally designed with four high flow pumps, each with a rated capacity of 45,000 gpm. Three of the pumps are duty pumps, one is a standby, giving the NRSPS a capacity of 135,000 gpm. The original design also included two smaller pumps for lower flows, each rated at 3500 gpm. Currently, only the three high flow pumps are functional. During periods of low flows, including both light rainfall events and prolonged periods of dry weather urban runoff that occur in the summer, the collection system upstream of the NRSPS are filled and emptied every one to two days by the high flow pumps operating in short bursts lasting no more than a few minutes. The current mode of operation is less than ideal, because of excessive use of the high flow pumps in a manner different from the design intent, and because of potential problems caused by accumulation of standing, stagnant water in the collection system.

As part of implementing this pilot project, low flow pumping capacity will be restored. Dry weather flow rates were likely higher in the early 1970s, when the NRSPS was designed, compared to current dry weather flow rates. Present-day dry weather inflow rates were estimated using modeling to support design of the diversion. In addition to estimating dry weather inflow rates, modeling is used to forecast how much stormwater can be diverted to either WCWD and/or an onsite stormwater that may be constructed in the future.

This study modeled five scenarios:

Scenario 1: The current system (with no low flow pumps operational). This scenario was used to estimate current dry weather inflow rates.

Scenario 2: The current system with 400 gpm low flow pumping capacity. This scenario was used to model dry weather and first flush diversions to WCWD.

Scenario 3: 400 gpm diversion to WCWD along with onsite treatment capacity of 100 gpm

Scenario 4: 400 gpm diversion to WCWD along with onsite treatment capacity of 1000 gpm

Scenario 5: 400 gpm diversion to WCWD along with onsite treatment capacity of 1500 gpm

These five scenarios address two key questions that need to be answered prior to proceeding with design of the pilot diversion project:

What is the current dry weather flow rate into the NRSPS?

How much stormwater can be treated, either onsite or by WCWD, under different design scenarios?

3.0 APPROACH

The NRPS was modeled using the EPA Storm Water Management Model (SWMM 5.0), a dynamic rainfall-runoff simulation model specifically adapted for designs related to urban storm water runoff, sanitary sewers, and other drainage systems. SWMM 5.0 has the capability to include pollutant loading and other water quality parameters, climate inputs such as precipitation and evaporation, groundwater interactions, as well as hydraulic mass balancing. The scope of this work was limited to analysis of water quantities.

Model design relied on specifications as outlined in the North Richmond Storm Drain Project Storm Drain System & Outfall Channel as-built[1] (Fig. 2) and the Pump Station and Discharge System design plans[2]. Using these drawings for guidance, a detailed model domain was created (Fig. 3) to mimic the stormwater conveyance system. Additional model inputs include the sub-watershed delineation as provided by Contra Costa County (Fig. 1) and rainfall data from the Richmond City Hall rain gauge[3] operated by the County.

Continuous water level monitoring data from the time period September 27, 2012 to May 21, 2013 were provided by the San Francisco Estuary Institute (SFEI), who has been monitoring flow and water quality at the NRSPS since 2010. Water level variation was used in Scenario 1 (existing conditions) to estimate dry weather inflow rates. Model dry weather inflow rates were varied until the timing of the rise and fall of water levels most closely matched the frequency of pump operation based on the continuous monitoring observations made by SFEI staff.

The three operational pumps were modeled as a single pump that varies between 7000 gpm (ramp up speed) and 135,000 gpm to match the inflow rates. This is not an exact replica of actual pump operations; the pumps turn on and off and ramp up and down their operating speeds in response to changing water levels. As a result, actual operations involve a certain lag time for the discharge pumps to match water inflow rates. In the model, the pumps respond to changing water levels instantaneously. This approximation is not thought to be a significant factor affecting the findings presented in this memorandum.

In the model, dry weather diversions and wet weather diversions (to WCWD) were assigned unique pumps. This was simply a modeling convenience to tabulate separately the volumes of stormwater vs. dry weather flows diverted – in the actual design of the pilot project, the same pump would be used to divert low flows as would be used to divert storm flows.

The models for each scenario are provided in a companion thumb drive to this memorandum.

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[1] Contra Costa County Flood Control & Water Conservation District, 1972. Contra Costa county North Richmond Storm Drain Project, Project No. W.S.-Calif.-436, Storm Drain System & Outfall Channel, November 21.

[2] Brown and Caldwell, 1972. Contra Costa County, North Richmond Storm Drain Project HUD Project No. W.W.-Calif.-436, Pump Station and Discharge System. November.

[3] The Richmond City Hall (RHL) rain gauge data, operated by Contra Costa County with website maintained by the California Department of Water Resources, is available at: http://cdec.water.ca.gov/cgi-progs/selectQuery?station_id=RHL&sensor_num=16&dur_code=E&start_date=&end_date=now

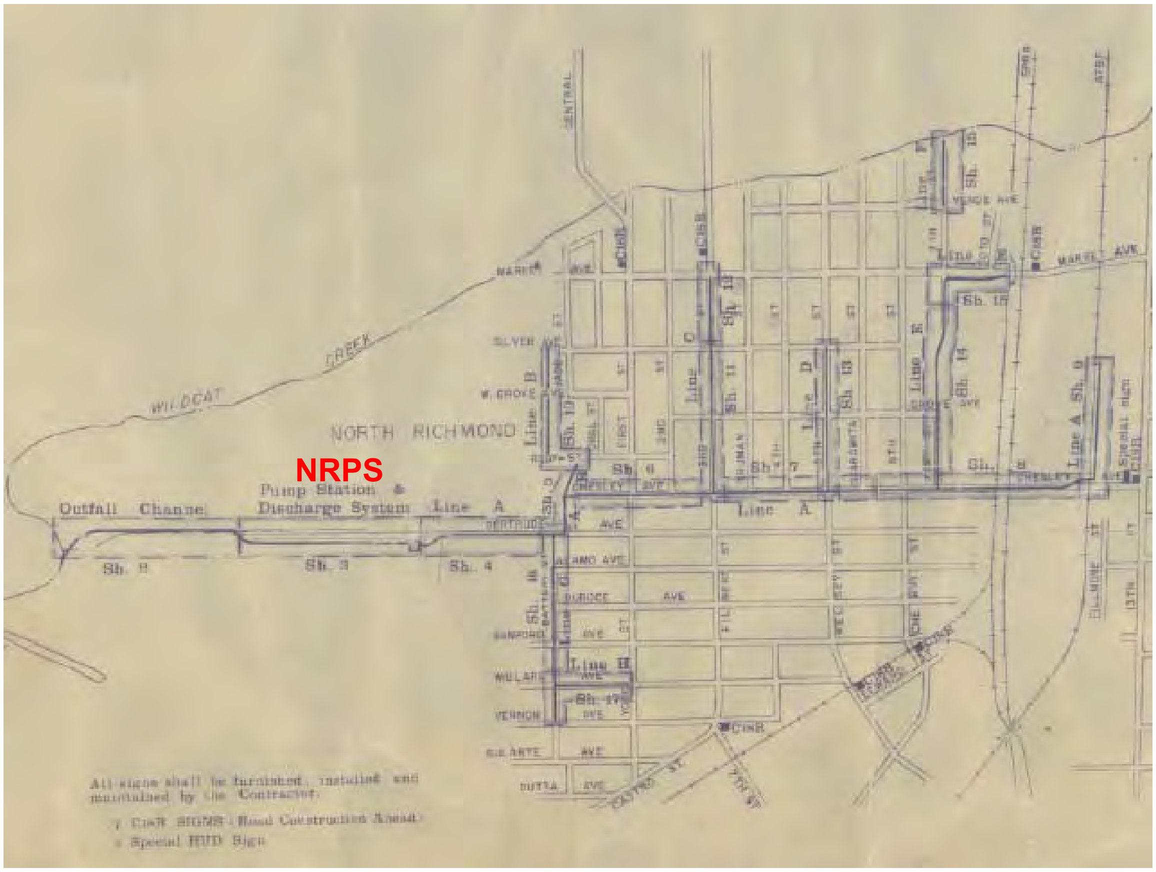

Figure 2: Storm Drain System of North Richmond Storm Drain Project (1972).

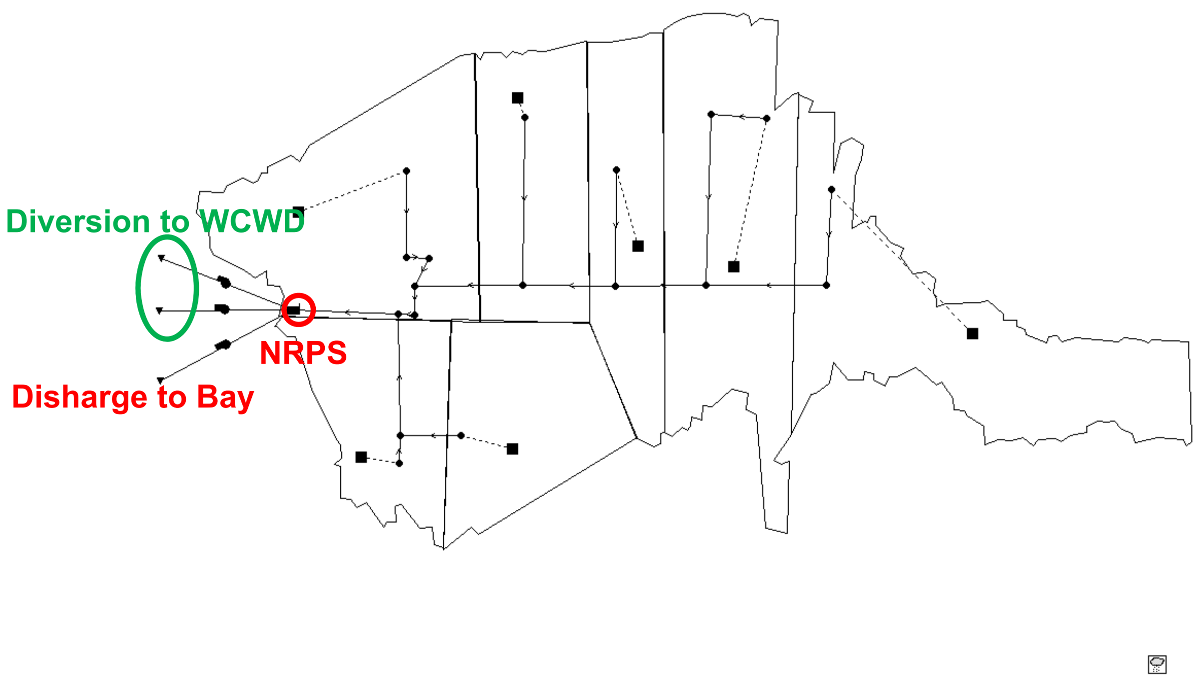

Figure 3: Watershed model with drainage system and diversion.

4.0 RESULTS

4.1 Scenario 1: Existing Conditions

The purpose of this base case is to estimate the dry weather inflow rate. Important calibrating observations include measurements made by San Francisco Estuary Institute (SFEI). Dry weather flow rates can be estimated with the following approaches:

1) The storage volume of the system when full and after pumps turn off can be calculated form geometry, and the dry weather inflow rate estimated based on the change in storage volume over time.
2) Alternatively, dry weather flow rates can be varied in the SWMM 5.0 model to find the closest match in model performance to the observed water level oscillations.
3) The volume pumped out on any particular pump run can be estimated based on pump run times and estimates or measurements of pump run speeds (rpm) and wet well

levels. This latter approach was piloted by SFEI in the 2012 -2013 through their monitoring on behalf of the San Francisco Bay Regional Monitoring Program.

Results from first two approaches are compared below. Comparisons to the third approach, using pump run times and speeds in conjunction with water level data, are deferred until completion of the annual monitoring reports for NRPS monitoring by SFEI.

The NRPS design plans show that when water elevation reaches -9.46 ft, water backs up into the upstream conveyance system – in other words, the conveyance system is design to provide storage buffer. Considering the volume of the pipe that is below elevation -2.83 ft (when the storm pumps are configured to turn on according to the NRPS manual), the system has an estimated storage capacity of 412,500 gal, including the pump station, when the conveyance system is full. The pumps are configured to switch off at elevation -5.58 ft. The storage volume in the system that is below elevation -5.58 feet is 205,300 gal. By difference, the amount of water pumped out each time the pumps switch on during dry weather flows is approximately 207,000 gal.

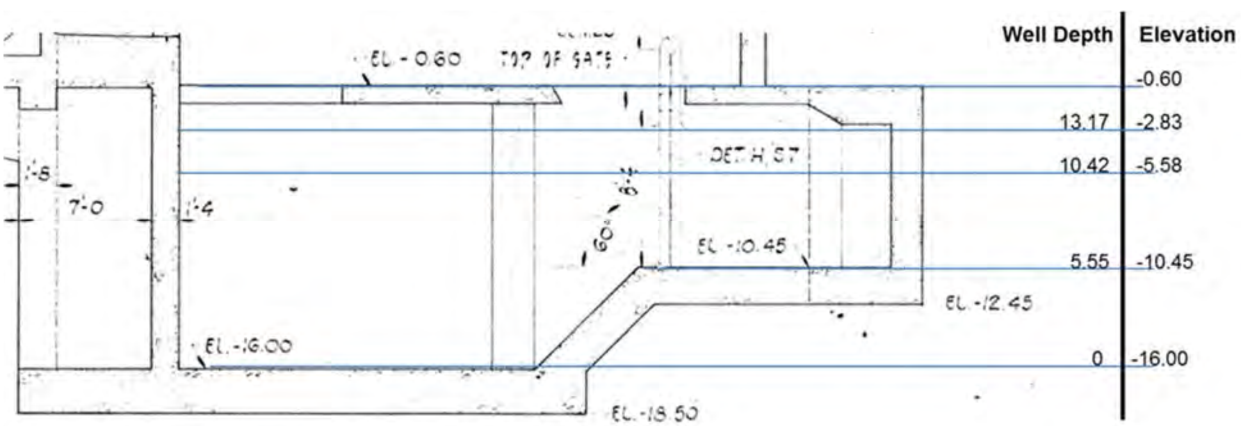

Figure 4: Cross-sectional view of wet well (Brown and Caldwell, 1972).

Based on SFEI's well level data from September 27, 2012 to October 10, 2013, before the first storm event, the pump turned on at an average interval of 1.52 days, ranging between 1.39 days to 1.80 days during the dry season (i.e., between seven weeks after the last rain event of the season to the first rain event of the next season). This corresponds to an estimated dry weather inflow rate of 95 gpm, with a likely range from 80 gpm to 100 gpm.

For comparison, the modeled dry weather flow that predicts a pump cycling frequency of 1.52 days is 130 gpm. Modeling dry weather flows ranging from 110 gpm to 140 gpm predicts pump cycling frequencies of 1.80 days to 1.39 days. One key difference is that according to SFEI, their depth gage was located on the elevated platform of the wet well, at elevation -10.45 (Fig. 5). If that is the case, the pump start up and shut off depths would appear to be at depths 12.5 ft and 9 ft, respectively, in contrast to 13.17 ft and 10.42 ft according to the NRPS manual. To replicate the SFEI data, the pump trigger depths were adjusted accordingly to the observed depth for comparison (Fig.6).The modeled water level variations closely match observed water level oscillations as reported by SFEI during both dry and wet weather conditions, as seen in Figure 5 and 6 for October 3-23, 2012.

In summary, the estimated dry weather inflow rate to the NRSPS is at least 80 gpm and could be as much as 140 gpm.

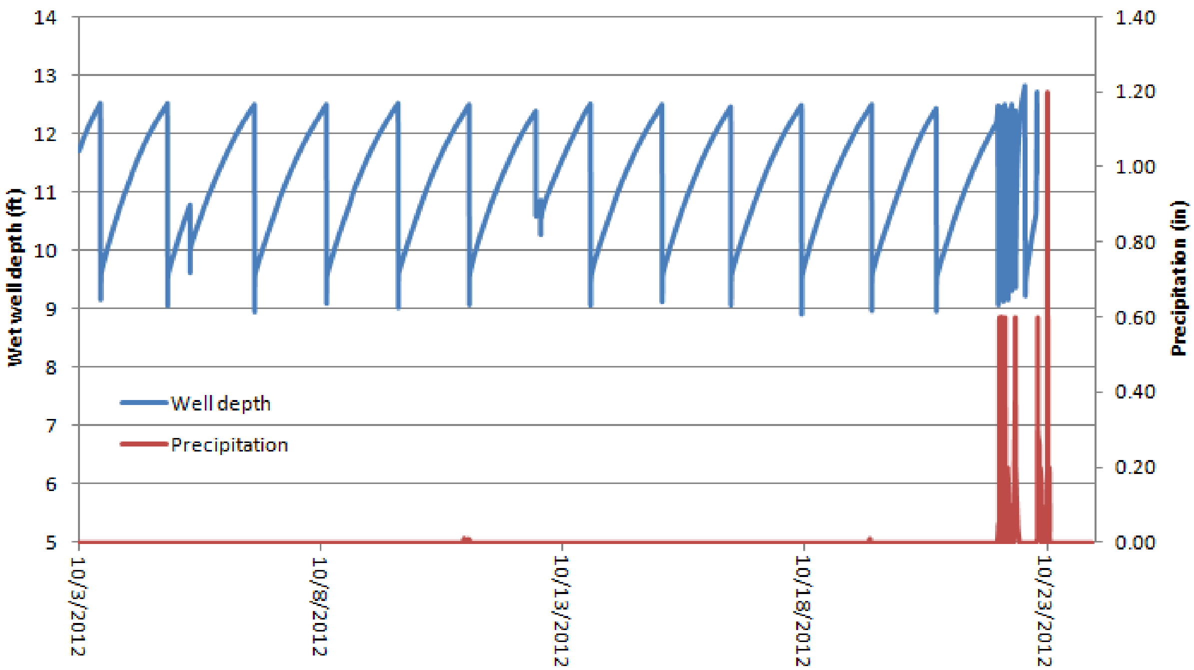

Figure 5: Wet well depth as observed by SFEI and rainfall as recorded by the Richmond City Hall rain gauge.

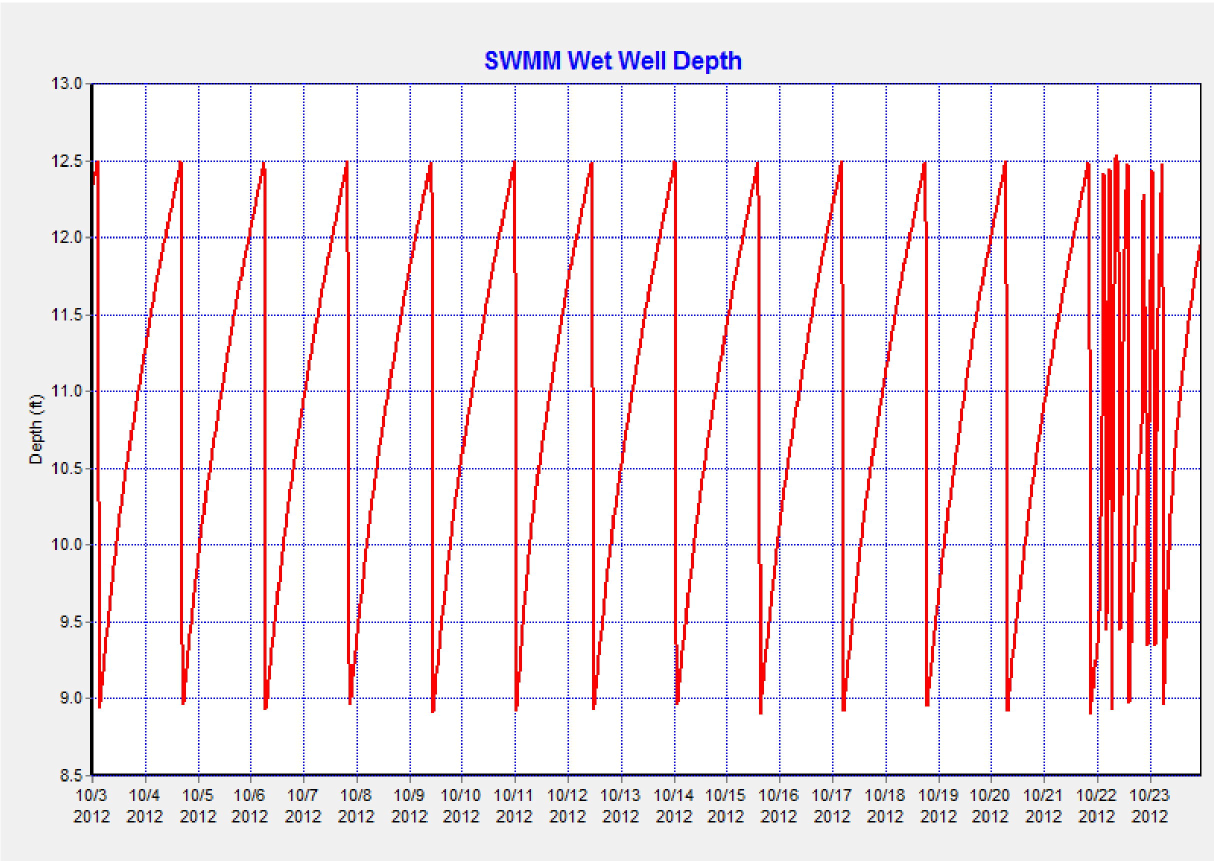

Figure 6: Wet well depth as modeled by SWMM using dry weather flow of 130 gpm and start up and shut off depth of 12.5 ft and 9 ft, respectively.

While there are some differences between the two dry weather flow estimates, with volume estimation method resulting in 80 gpm to 104 gpm while the model method resulting in 110 gpm to 140 gpm, there were several approximations that may lead to this discrepancy. One that is readily observed in figure 5 is the inconsistency of the pump in terms of shut off of the pump, which makes replicating the pump action difficult. Additionally, the range in estimated dry weather flow rates reflects the fact that dry weather flow rates are not expected to be constant. Furthermore, estimation of very low (i.e., three digit) dry weather flow rates based on variations of relatively large (i.e., six digit) storage volumes in an irregularly shaped conveyance system will have limited precision and accuracy. If more precise and accurate estimates of dry weather flow rate are desired, direct measurement in the conveyance channel using weirs or flumes would be necessary.

4.2 Scenario 2: Current System with Diversion to WCWD

This scenario evaluates a pilot project to divert up to 400 gpm dry weather flows and stormwater into WCWD. A diversion pump with a capacity of 400 gpm[4] was added to the model in Scenario 1, using the start up and shut off depths as specified in the original manual. The pump was programmed in the model to turn on at a water elevation of –4.5 ft and turn off at a water elevation of –5.58 ft. Considering the geometry of the collection system, this corresponds to a volume interval of 81,000 gallons. The recent September 21, 2013 rain event was examined as an example of how a pilot diversion during dry weather prior to an early season storm might operate.

When the model assumed a dry weather flow rate of 130 gpm, the storm pump is only on approximately 30 minutes every two days, equivalent to 0.89% utilization. This means that if the maximum diversion flow rate permitted is 400 gpm, then the time needed to drain the collection system to the shut off level each day in dry weather conditions is 13.3 hrs. Diversion capacity will be overwhelmed when inflow to NRPS exceed 260 gpm.

This would be the case for the most recent storm event on September 21, 2013. Unlike rain events most common in the Bay Area, the rain intensity was very high over a short period of time, with 0.66 in of rain over 2.5 hours (Fig. 7). This resulted in a spike in the wet well since the drainage system did not have the time to absorb and equilibrate the additional water (Fig. 8). Prior to this event, there had been no rainfall for three months. The steady oscillation of the wet well water elevation as seen in Figure 8 represents the accumulating and dry weather flow and subsequent draining of the well via the 400 gpm diversion pump, without any contribution from the storm pump.

At the onset of the rain event, the WCWD “wet” pump was activated due to the increased inflow into the well (Fig. 9). Sustained in the first hour of the rain event, the “wet” diversion pump only turns off when the storm pump turned on to prevent the wet well from flooding. This is also reflected in the depth of the wet well with the steep elevation drop after the initial peak in Figure 8. Since the diversion pump was not able to keep ahead of the storm, a single pulse was discharged into the Bay (Fig. 10). If total outflow from the rain event is defined as the combined discharge to the Bay and the wet weather diversion to WCWD, this set up was able to treat **32%** of the stormwater for this particular event, equivalent to the fuchsia portion of Figure 10.

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[4] 400 gpm was selected based on the capacity of the nearby 36 inch sanitary sewage conveyance to WCWD. WCWD has provided information showing that during a five year, 24 storm event, the available capacity is 0.6 to 1.4 mgd. This corresponds to available capacity of approximately 400 to 1,100 gpm.

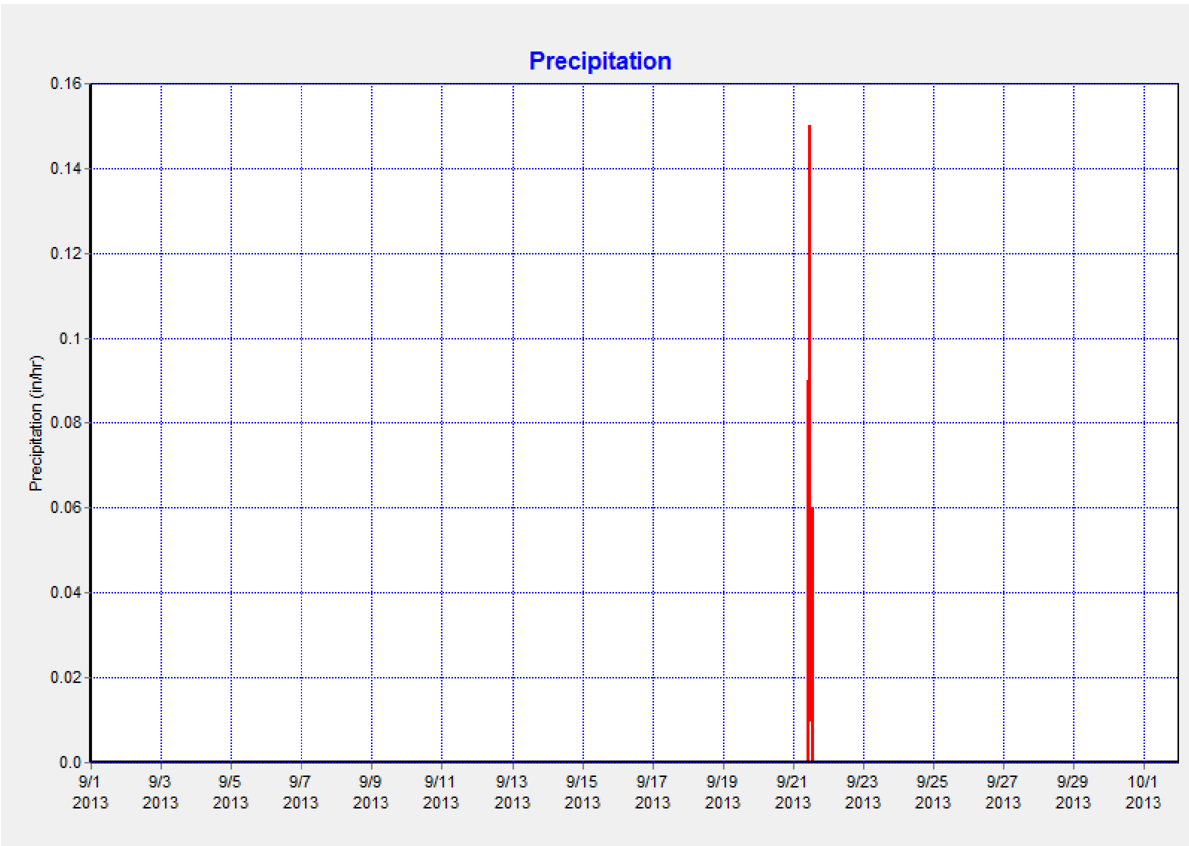


Figure 7: Precipitation as measured by Richmond City Hall rain gauge for September 2013.

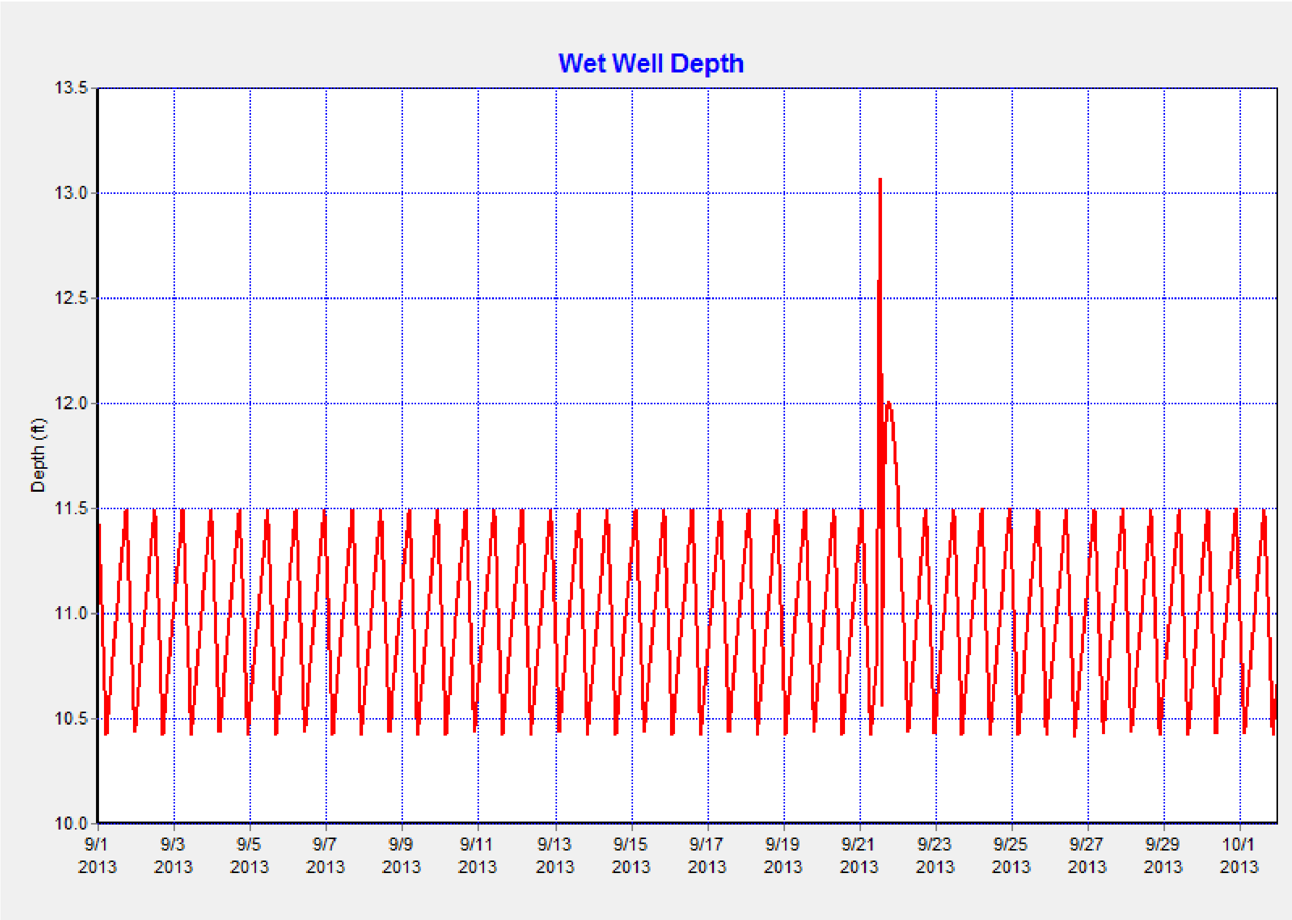


Figure 8: Depth of wet well for September 2013.

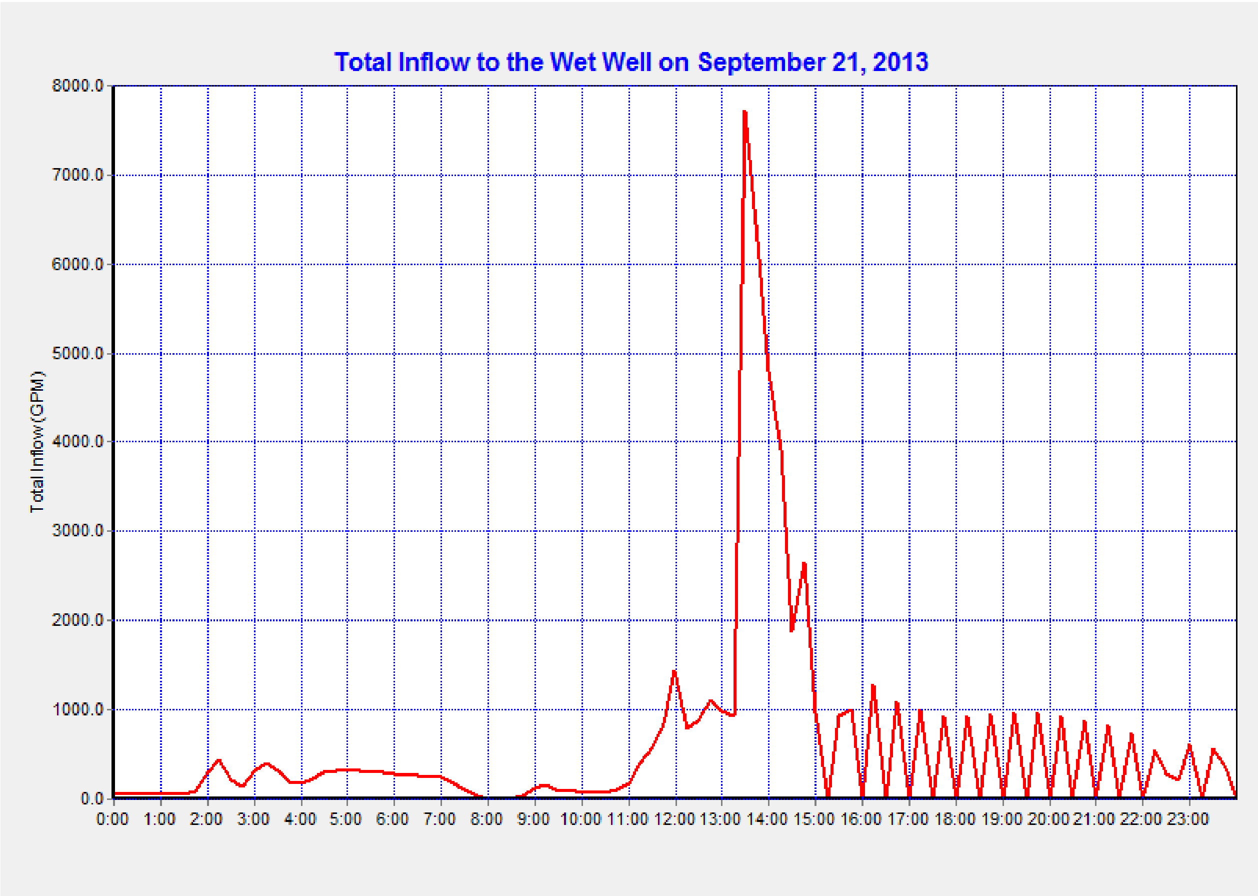
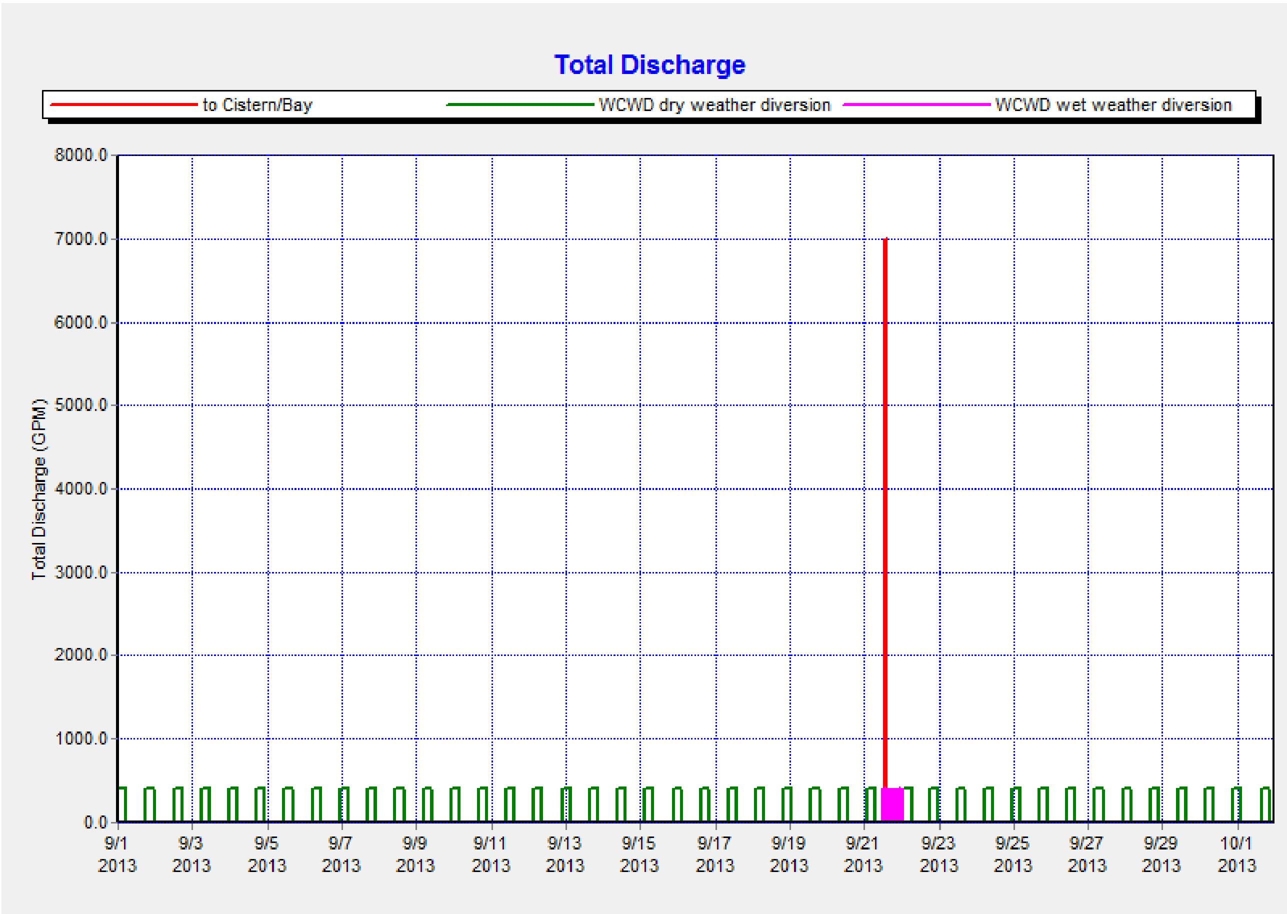


Figure 9: Flow into the wet well


Total Discharge
to Cistern/Bay
WCWD dry weather diversion
WCWD wet weather diversion
Total Discharge (GPM)
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
0.0
9/1 2013
9/3 2013
9/5 2013
9/7 2013
9/9 2013
9/11 2013
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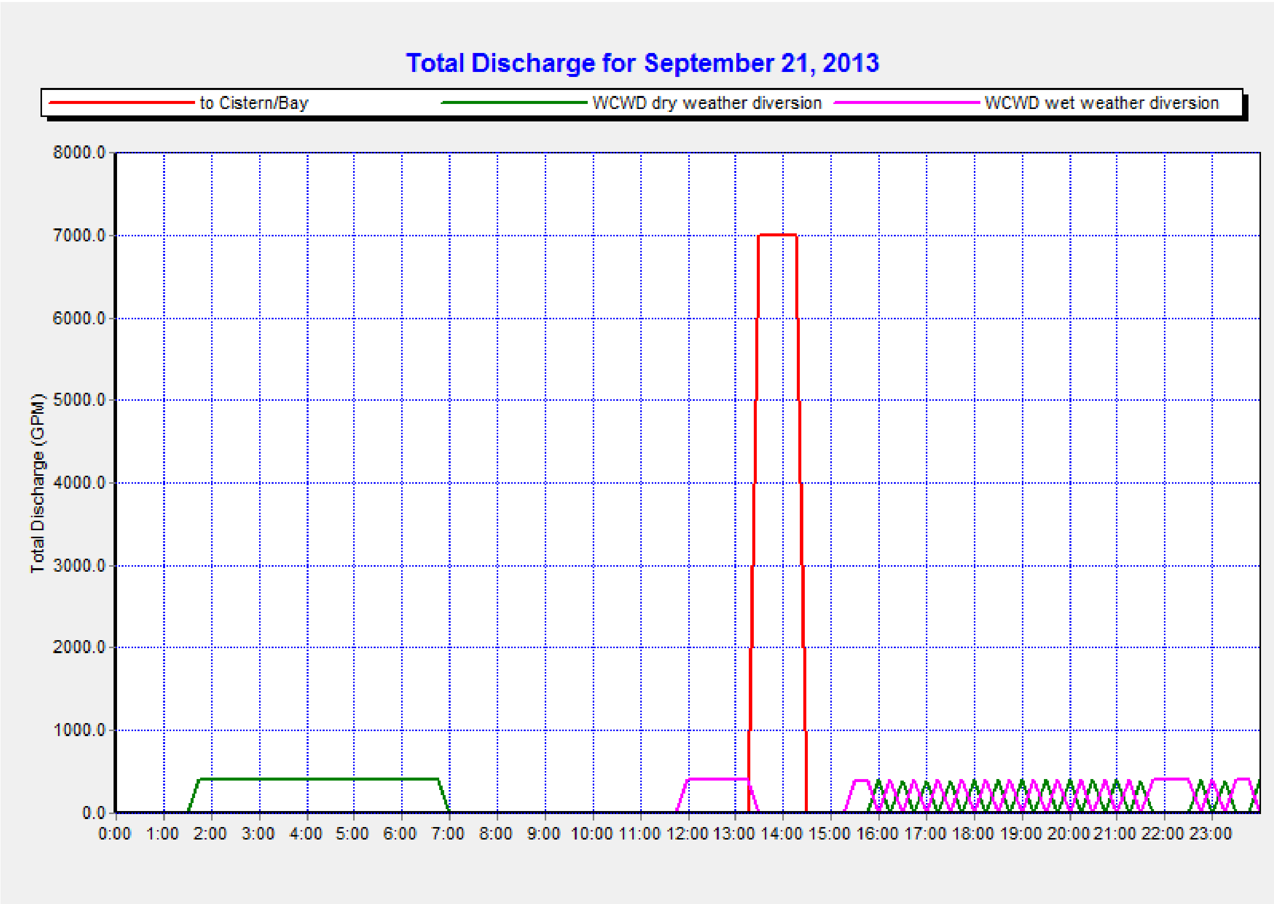

Figure 10: Discharge distribution for September 2013, first flush event for the entire month (top) and zoomed in to the rain event (bottom).

Note the switching between the “dry” and “wet” pumps in the bottom figure of Figure 10. This is due to the significant oscillation in the modeled inflow, as seen in Figure 6. This is likely a modeling artifact, resulting from the fact that modeled pumps do not have ramp-up or ramp down times, and that their flow rates do not vary with dynamic head, as they do in the real world. This could be improved with a more detailed modeling approach, but the presented simple approximation is sufficient to understand how a pump sized small enough to avoid overwhelming WCWD conveyance capacity would function during an early season storm.

From February 1, 2005 to October 1, 2013, having a continuously running 400gpm diversion pump would result in diverting **51% of total inflow** (combined wet and dry weather). If only the wet weather flow and the storm pump outflow were considered, **30% of storm flow** was diverted to WCWD in the model.

4.3 Scenario 3: Current System with Diversion and 100 gpm Onsite Treatment Capacity

An onsite treatment system was added to Scenario 3 by replacing the “wet” diversion pump with a small pump with a rated capacity of 100 gpm and startup depth of 12.5 ft. In this scenario, the onsite treatment was only active after the diversion pump shut off, though it was still the first line of defense during the wet season and served the important role of peak shaving. For the period between February 1, 2005 and October 1, 2013, **62% of total flow was diverted**, and approximately **2% of storm water was treated** onsite.

The storm on September 21, 2013 is examined as a point of comparison to Scenario 2. Recalling it was a high intensity storm where 0.66 inches of rain was produced over 2 hours (Fig. 11), the storm pumps had to turn on to mitigate the rainfall. Because the onsite pump as specified here is very small, only **2%** of the rain event was captured and treated onsite for this storm (Fig. 12).

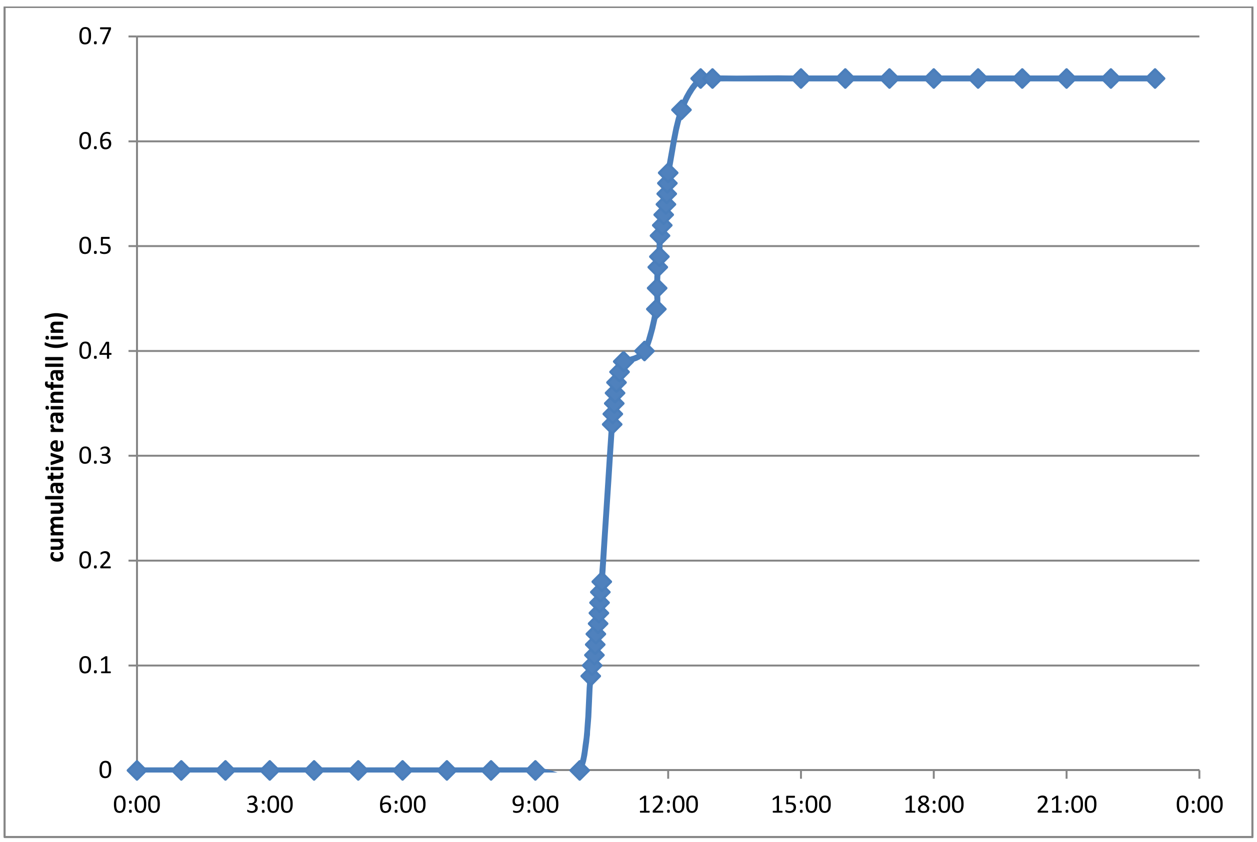

Figure 11: Cumulative rainfall as measured at Richmond City Hall for September 21, 2013.

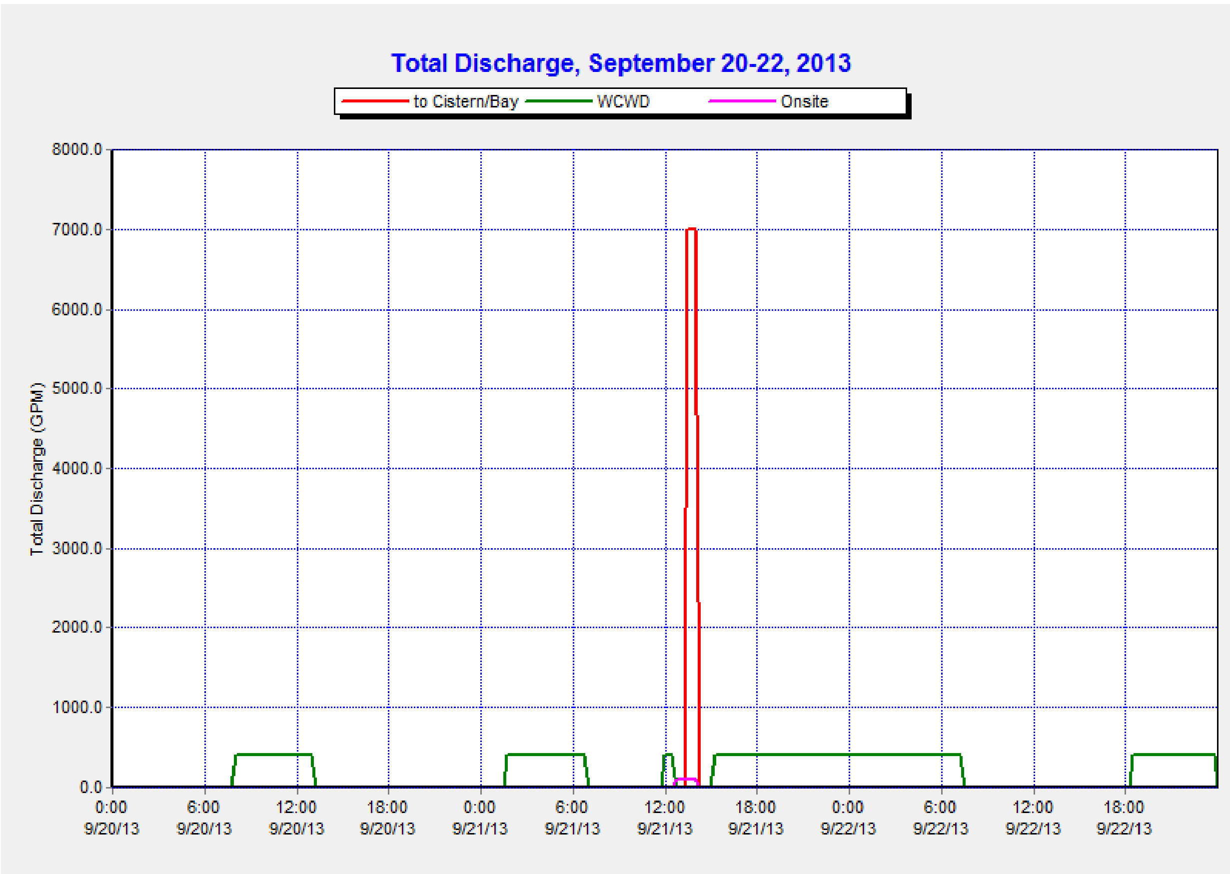

Figure 12: September 21, 2013 storm event outflow for 100 gpm onsite treatment.

In contrast to the September 21 flashy storm event, the April 4, 2013 storm event was more representative of typical storms in the Bay Area, with lower intensity over a longer duration (Fig. 13). In this case, 0.62 inches of rain fell over 11 hours. Because of the lower rain intensity, the diversion pump to WCWD would still turn on during the rain event because of the low inflow into the wet well. When the inflow rate exceeds typical dry flow rate, the onsite system cannot keep up with wet well elevation rise and the storm pump must turn on accordingly (Fig. 14). In this event, the **3%** of storm water treated onsite.

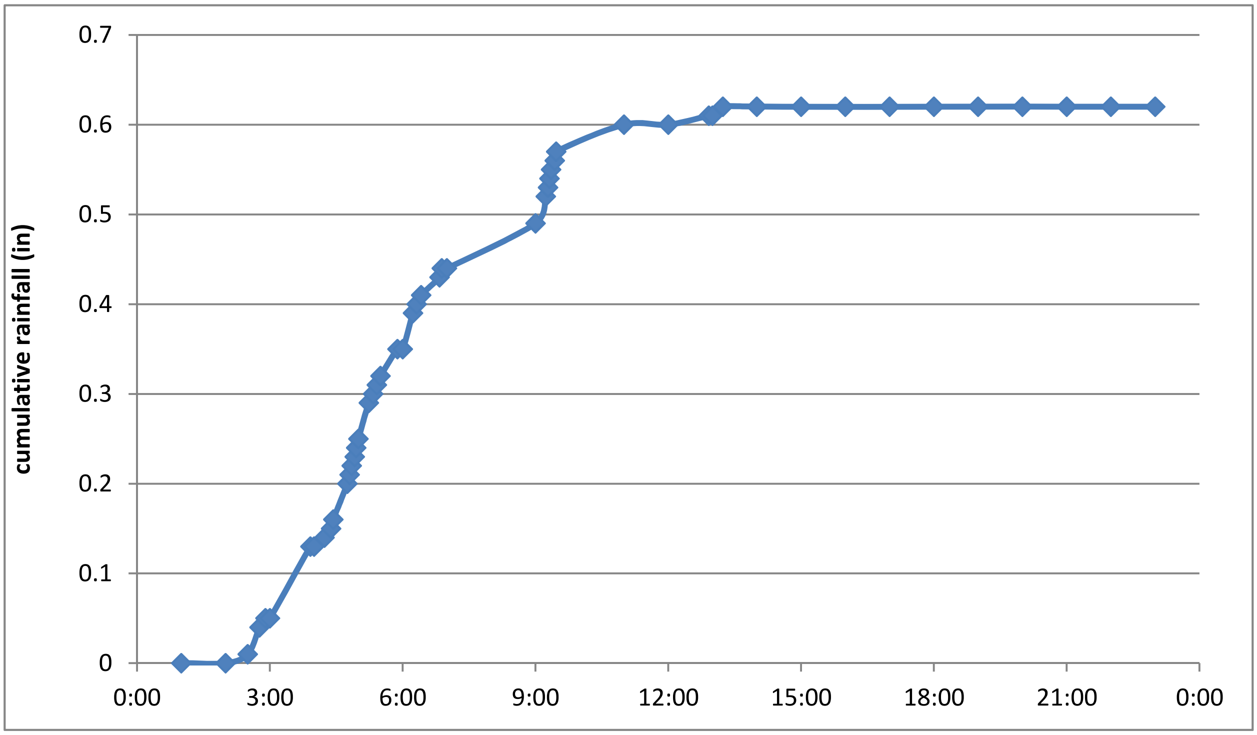

Figure 13: Cumulative rainfall as measured at Richmond City Hall for April 4, 2013.

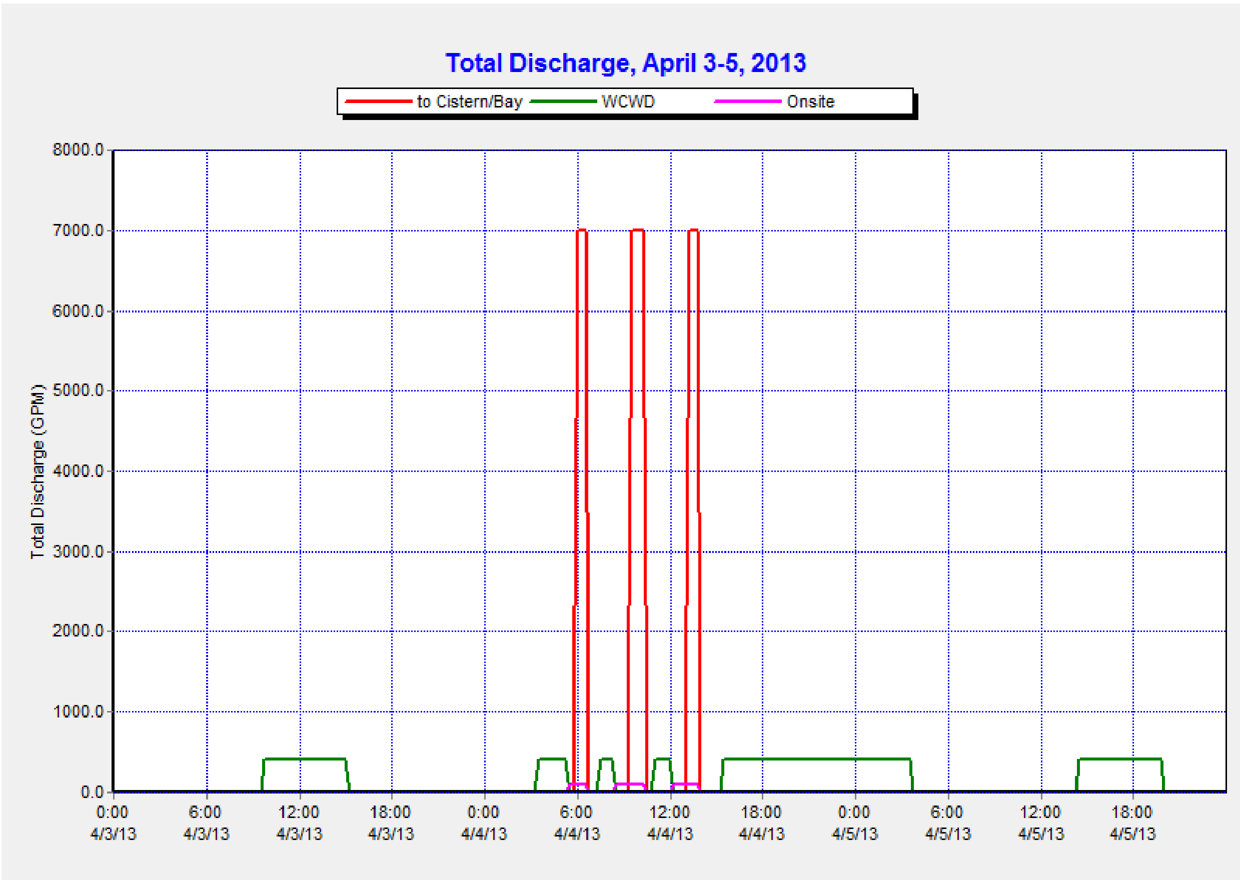

Figure 14: April 4, 2013 storm event outflow for 100 gpm onsite treatment.

4.4 Scenario 4: Current System with Diversion and 1000 gpm Onsite Treatment Capacity

In this Scenario, the onsite treatment capacity was increased to 1000 gpm. The diversion pump was designed such that it shuts off if either the onsite or storm pump was on, or if the flow into the well was greater than the dry weather flow rate. For the period between February 1, 2005 and October 1, 2013, **59% of total flow was diverted**, and approximately **36% of storm water was treated** onsite. Note that in Scenario 3, a slightly higher amount of flow was diverted in comparison to this scenario. This is because the diversion would take up some of the rainfall after rain event or during rain events when the rainfall intensity is low, as seen in the April storm.

The discharge distribution from the September and April storms from this scenario was to compared to the 100 gpm onsite treatment option. Once again, because of the high intensity of the September rain event, the 1000 gpm onsite pump was not able to capture the inflow and the storm pump had to turn on for support (Fig. 15). As a consequence, the outflow profile looked similar to that of the 100 gpm onsite treatment except with a shorter duration diversion to WCWD following the rain event, resulting in **25%** treatment. In contrast, the 1000 gpm pump was able to capture enough flow in the April event to decrease the number of storm pump activations from three to two (Fig. 16), resulting in **68%** treatment. Note that the onsite pump remained on for a long enough duration such that when the diversion pump turned back on, it returned to its normal duration, rather than elongated to accommodate the residual rainfall that subsequently infiltrated into the sub catchment system.

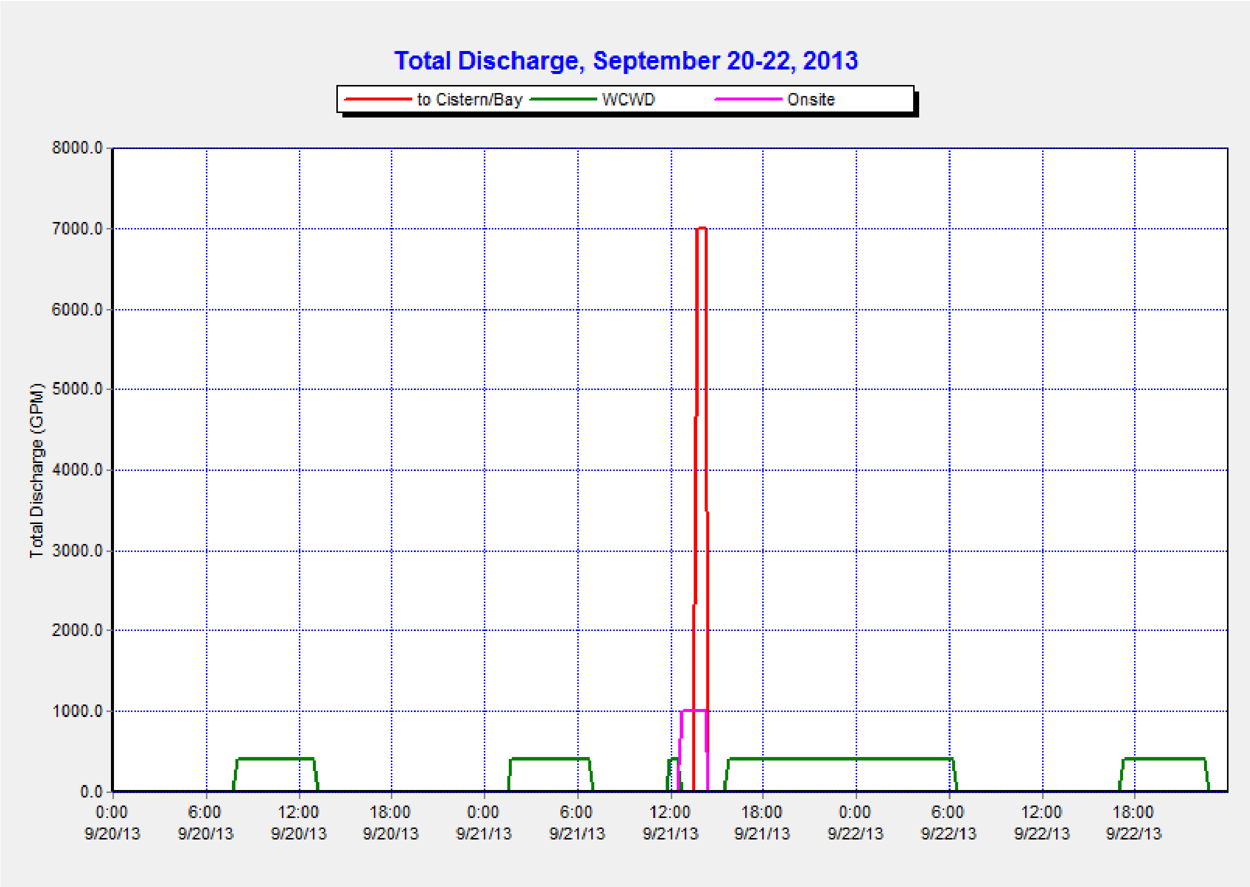

Figure 15: September 21, 2013 storm event outflow for 1000 gpm onsite treatment.

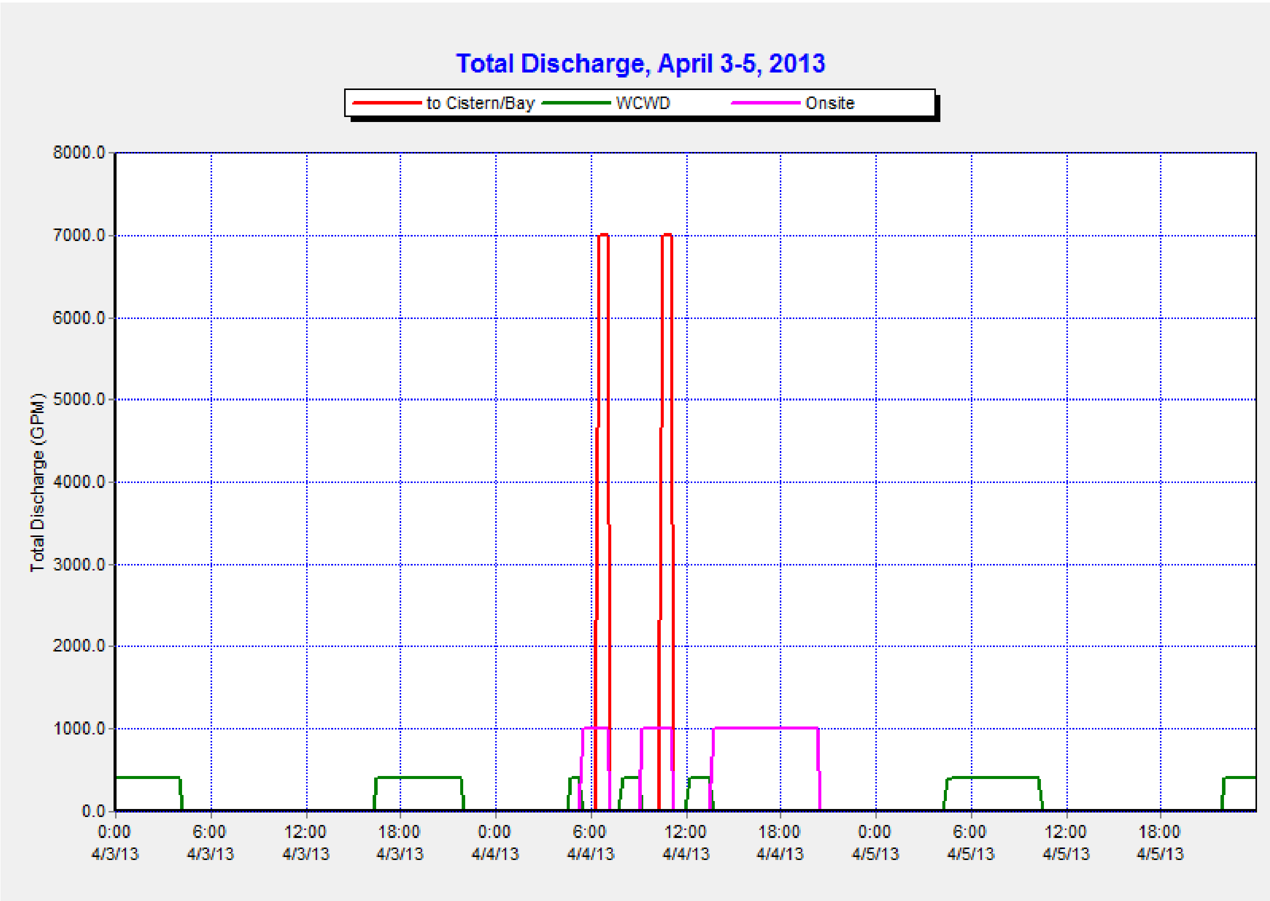

Figure 16: April 4, 2013 storm event outflow for 1000 gpm onsite treatment.

4.5 Scenario 5: Current System with Diversion and 1500 gpm Onsite Treatment Capacity

In this Scenario, the onsite treatment capacity was increased to 1500 gpm. The diversion pump was designed such that it shuts off if either the onsite or storm pump was on, or if the flow into the well was greater than the dry weather flow rate. For the period between February 1, 2005 and October 1, 2013, **60% of total flow was diverted**, and approximately **44% of storm water was treated** onsite. While the September rain event did not change much with this upgrade (Fig. 17), with **44%** of the stormwater was treated. The change in pump capacity resulted in only one storm pump start up during the April event (Fig. 18) and **84%** treatment, as well as less diversion to WCWD during the period.

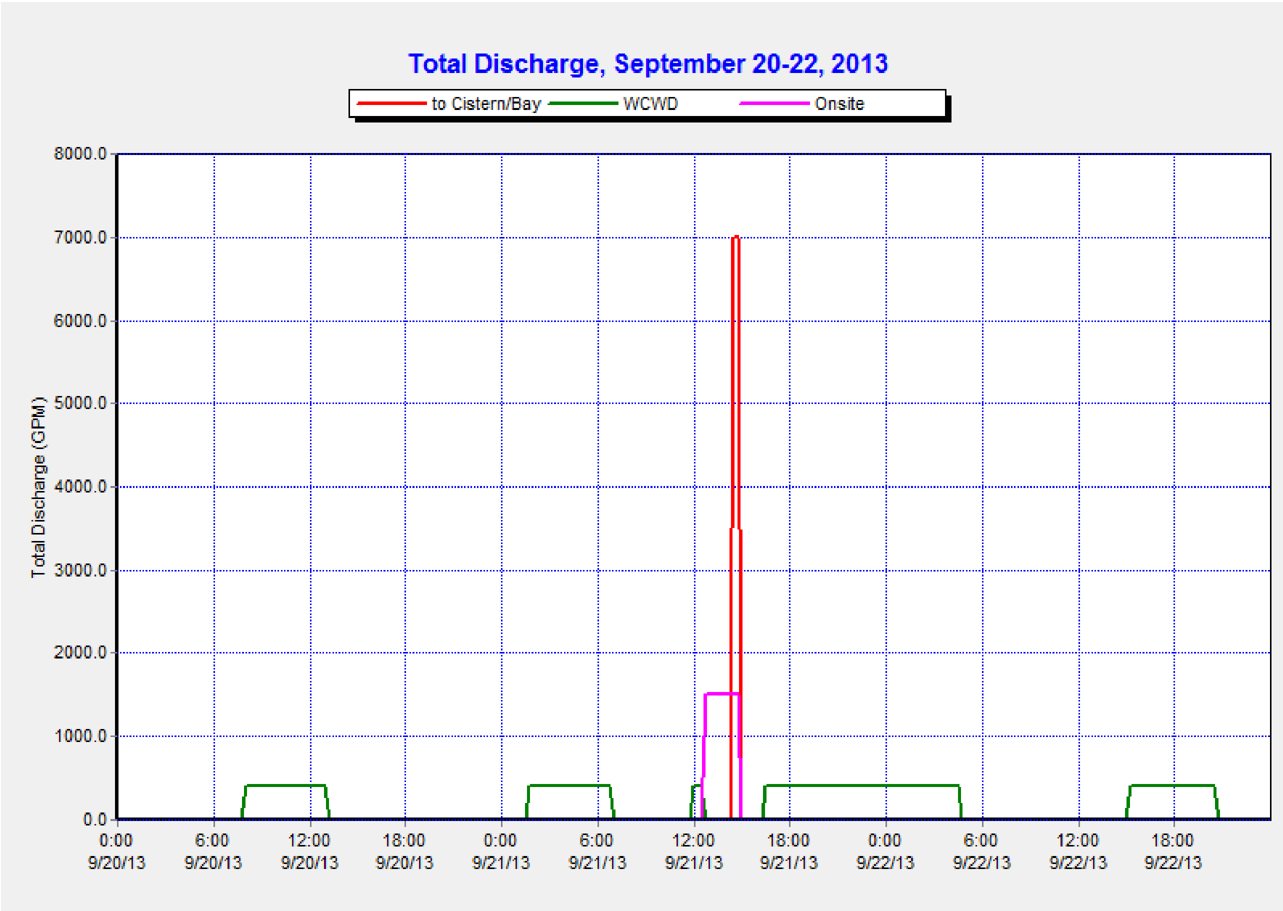

Figure 17: September 21, 2013 storm event outflow for 1500 gpm onsite treatment

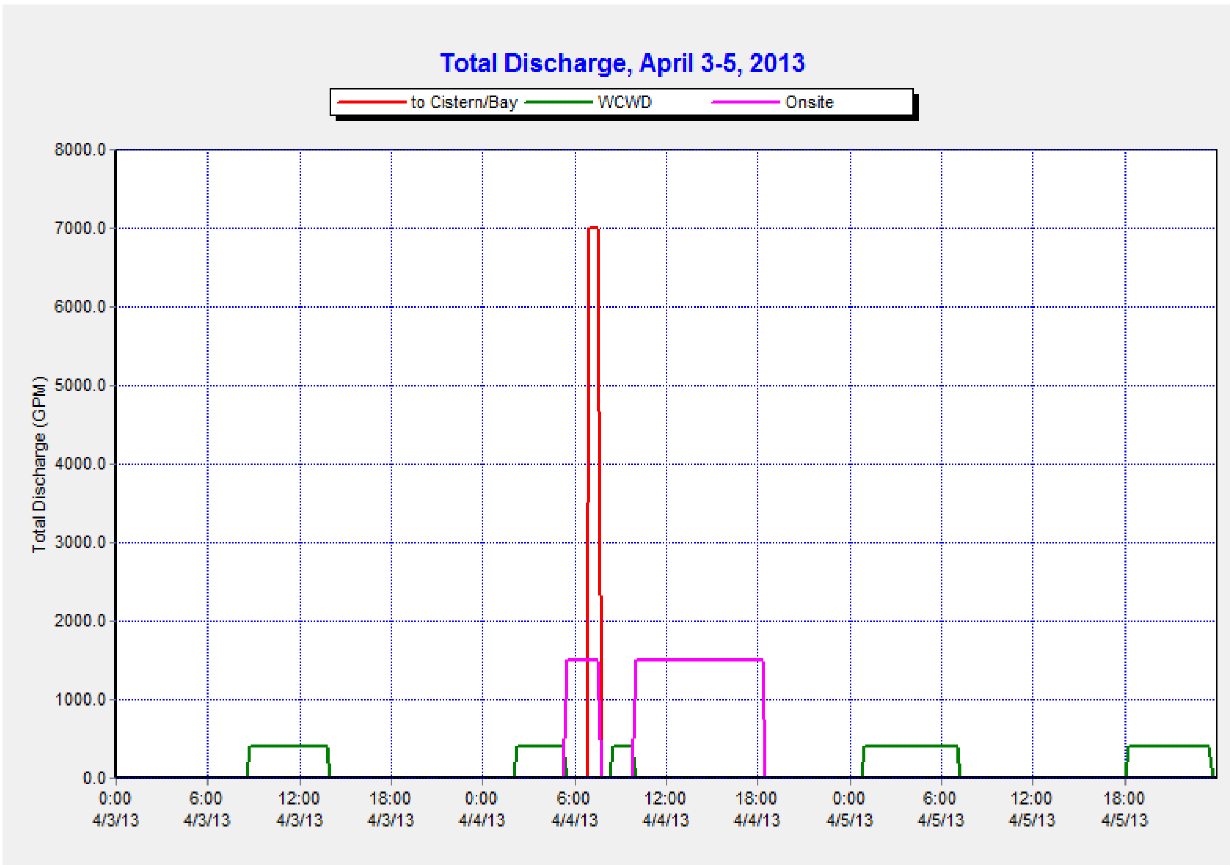

Figure 18: April 4, 2013 storm event outflow for 1500 gpm onsite treatment.

To capture the September event, the onsite treatment had to increase incrementally only to 1550 gpm, which resulted in **100%** treatment for that event (Fig. 19). This is possible because the event is short, even though the intensity was high.

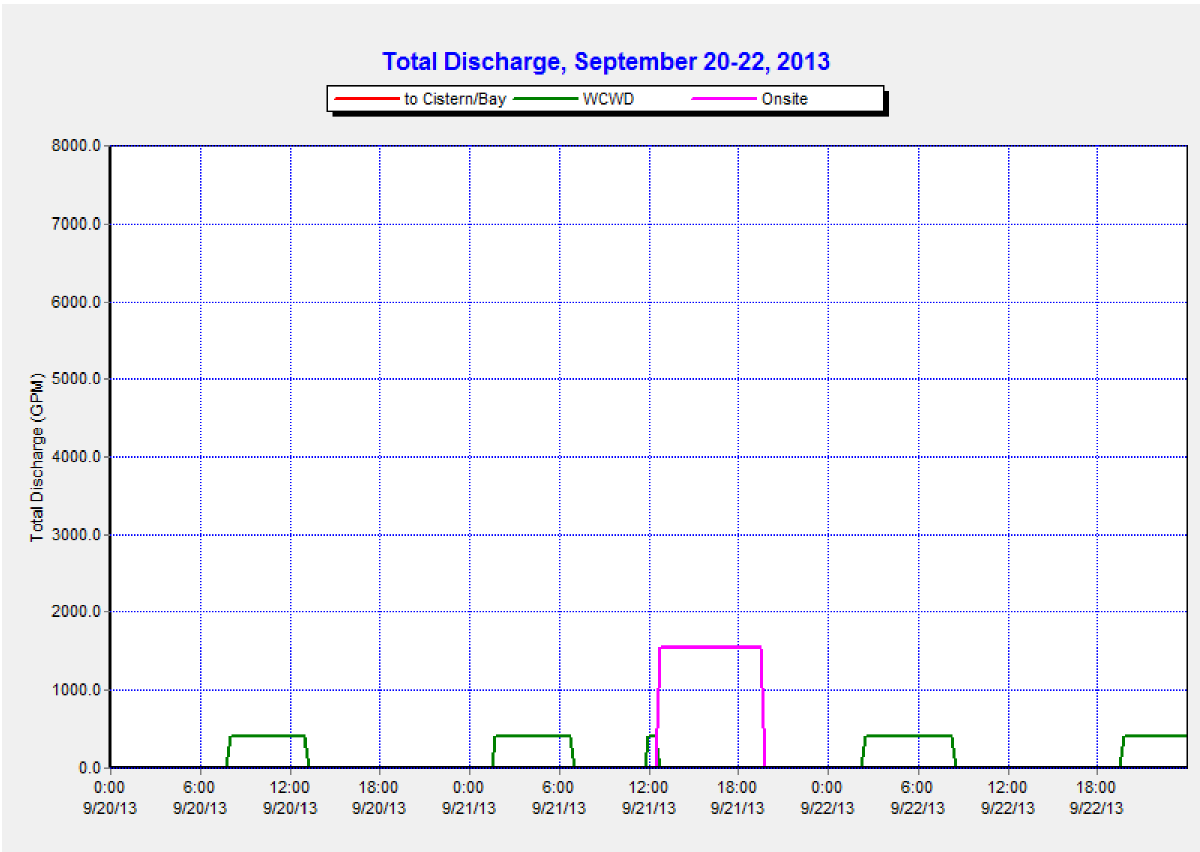

Figure 19: September 21, 2013 storm event outflow for 1550 gpm onsite treatment

5.0 SUMMARY

The estimated dry weather flow rate for the NRSPS ranges from 80 gpm to 140 gpm. The percentage of stormwater that could be treated by using diversion pumps of varying size to provide onsite or offsite treatment is summarized in Table 1 below.

Table 1. Percent of stormwater that could be treated at the NRSPS under various assumed treatment capacities.

Treatment capacity (gpm)	% stormwater treated		
	April 4, 2013	September 21, 2013	February 2005-October 2013
500	3	2	2
1400	68	25	36
1900	84	44	44

APPENDIX E

Field Sampling Report, North Richmond Pump Station Dry Weather Diversion, Water Quality Monitoring (December 1, 2015)

Field Sampling Report

North Richmond Pump Station Dry Weather Diversion, Water Quality Monitoring

December 1, 2015

Submitted to:

Ms. Cece Sellgren
Stormwater Manager
Contra Costa County Watershed Program

Submitted by:

APPLIED marine SCIENCES

4749 Bennett Drive, Suite L
Livermore, CA 94551
925-373-7142

1. Introduction

This report details activities associated with implementation of dry weather diversion water quality monitoring component of the North Richmond Pump Station (NRPS) Stormwater Diversion Project – Low Flow Sediment and Stormwater Sampling and Analysis. All sampling was conducted by Applied Marine Sciences, Inc. (AMS) personnel between September 10, 2015 and September 23, 2015.

2. Field Sampling Report

2.1. Objectives

The objectives of the sampling effort were as follows:

1. Collect up to ten water quality samples for analysis of PCB congeners, total mercury (Hg), total methyl-mercury (meHg) total organic carbon (TOC), and suspended sediment concentration (SSC) by ALS Group (ALS).
2. Collect required quality assurance (QA) samples consistent with California Surface Water Ambient Monitoring Program (SWAMP) Measurement Quality Objectives (MQOs) methods and frequencies.
3. Assess laboratory data quality using relevant SWAMP MQOs (SWAMP 2008).

2.2. Sampling Activities

Sampling activities for the NRPS dry diversion water quality monitoring study are summarized in Table 1. In total, AMS monitored nine of the ten possible diversion days; one day was intentionally skipped to be consistent with the original scope of work, which called for monitoring up to seven days of the target ten diversion days. Upon receiving direction to sample beyond the original seven days contracted, AMS then monitored each of the remaining diversion dates.

All field samples were collected from the diversion pipe exiting the NRPS. Field personnel filled sample containers using a new hose (25’ drinking water quality) attached to a spigot in the PVC diversion pipe that was installed by the construction contractor for monitoring purposes (Figure 1). Sampling personnel flushed the hose for a minimum of one minute prior to sample collection and used standard “clean hands / dirty hands” protocols for sample collection.

Field monitoring incorporated two types of field blanks in order to assess possible effects of the sampling protocols on the analytical results: (1) a bottle blank for which laboratory-provided blank water was transferred at the NRPS from its container of origin to a field sample container in order to assess effect of environmental conditions present and “clean hands / dirty hands” sampling, and (2) an equipment blank for which blank water was rinsed through a sampling hose in a laboratory setting in order to assess any contamination associated with the equipment used and “clean hands / dirty hands” sampling protocol.

Table 1. Sampling Activities for NRPS Dry Weather Diversion Water Quality Monitoring Study.

Sampling Event	Sample Date	Sample Time	Field Samples	Field Blanks	Field Dup	Comments
NRP-D-01	10/Sep/2015	10:30	X			
NRP-D-02	11/Sep/2015	08:15	X			
NRP-D-03	14/Sep/2015	08:30	X			
NRP-D-04	15/Sep/2015	NA				No samples collected
NRP-D-05	16/Sep/2015	08:45	X	X		Bottle blank
NRP-D-06	17/Sep/2015	08:15	X		X	
NRP-D-07	18/Sep/2015	08:40	X			
NRP-D-08	21/Sep/2015	08:45	X	X		Equipment blank
NRP-D-09	22/Sep/2015	08:35	X			
NRP-D-10	23/Sep/2015	08:35	X			

Figure 1. Monitoring Spigot at Diversion Pipe

2.3. Sample Labeling

The sample ID labeling system used for water quality samples is as follows:

WWW- E-DD

Where:

WWW	=	Watershed / site identifier (i.e., NRP)
E	=	Event type (i.e., D for dry diversion)
DD	=	Diversion day # (e.g., 10 for the 10th day of the diversion)

Field duplicate samples were indicated by use of a "5" in the tens place of the diversion date (e.g., NRP-D-56 indicates a field duplicate sample collected on the 6th diversion day). Field blank samples were labeled by the laboratory prior to delivery to AMS.

2.4. Results

Analyte concentrations reported by ALS are summarized in Table 2. As is typical for laboratory analytical reports, especially those associated with analysis of organic pollutants, some proportion of analytical results are flagged with qualifiers to be used in association with data interpretation. For that reason, the user should reference the spreadsheet Electronic Data Deliverable (EDD) for concentration data to be used in higher-level analyses and interpretation.

It should be noted that the laboratory reported PCB concentration data for individual congeners only. The summaries presented below were calculated by AMS and make use of a substitution of ½ of the method detection limit (MDL) for any congeners or other analytes (i.e., SSC) reported as non-detects (NDs). Any data reported between the MDL and Reporting Limit (RL) were quantified as reported by the lab for calculation of totals and basic statistics. Also any data that are qualified but not rejected outright are included in calculation of the total PCBs.

Table 2. Summary of NRPS Dry Weather Diversion Analytical Results.

Sampling Event	Hg (ng/L)	meHg (ng/L)	PCBs (pg/L)	SSC (mg/L)	Comments
NRP-D-01	6.65	0.08	191	91.5	
NRP-D-02	7.96	0.07	431	93.8	
NRP-D-03	8.07	0.07	174	90.4	
NRP-D-05	6.90	0.06	271	<1.8	Non-detect on SSC
NRP-D-06	8.85	0.06	415	3.1	
NRP-D-07	11.60	0.05	218	<1.9	Non-detect on SSC
NRP-D-08	12.50	0.06	509	16.7	
NRP-D-09	10.00	0.04	596	5.3	
NRP-D-10	9.65	0.03	548	1.9	
Avg.	9.1	0.06	373	34	
Min.	6.65	0.03	174	<1.8	
Max.	12.50	0.08	596	93.8	

3. Quality Assurance

All monitoring results were checked against SWAMP MQOs and qualified, as required, consistent with applicable California Environmental Data Exchange Network (CEDEN) QA codes.[1] A brief summary of data quality review follows by analyte type:

3.1.1. Inorganics (meHg and Hg)

In general, all measurements for Hg and meHg met SWAMP MQOs. The main exception to this is in the case of field blanks collected for analysis of meHg. For both Hg and meHg analyses, both of the field blanks collected resulted in concentrations exceeding laboratory RLs, resulting in a qualifier of “VIP” being applied to the affected field blank data. In the case of Hg, blank concentrations were relatively low compared with all field sample data (i.e., < 5x the concentration of the field samples). In the case of meHg, however, the highest concentration reported for all Project data is associated with the equipment blank field blank collected on Sept 21; for this reason both the affected field blank and field sample data are qualified with “VIP.” All other field sample and field blank data was reported below laboratory RLs, suggesting that the detectable presence of meHg at low concentrations in field samples may be an artifact of sampling protocols.

The Hg field sample / field duplicate pair collected on September 17th was slightly outside of SWAMP MQO control limits (CLs) for precision, with a calculated relative percent difference (RPD) of 26% vs. the CL of 25%. Both the field sample and field duplicate of this pair were flagged with a “VFDP” qualifier to indicate this, but this outcome is not expected to greatly alter the interpretation of the data.

3.1.2. Synthetic Organics (PCBs)

For several of the PCB congeners analyzed, minor blank contamination was identified associated with analysis of field blank or lab blank samples. QA samples reported at concentrations greater than RLs, as well as associated field sample data for which concentrations were reported as less than five times (5x) greater than associated blank concentrations, were flagged with a “VIP” qualifier, indicating a possible high bias. As the sums of the concentration of qualified blank data (approx 40 pg/L for lab blank samples and approx 30 pg/L for field blank samples) were relatively low compared to sum of the individual PCB congeners in the field samples (Table 2), this issue does not appear to provide much of a high bias to the calculated sums of PCBs.

There were also a small number of PCB congeners for which the field duplicate samples did not meet the typically-used SWAMP MQO for precision (RPD <25%). Affected congener data, both within the field sample and field duplicate, were flagged with a “VFDP” qualifier in these situations. Similar to the case for Hg discussed above, this outcome is not expected to greatly alter the interpretation of the data. It should be noted that the sum of PCBs reported for the field sample / field duplicate pair showed consistency, with an associated RPD of 1.5%.

As is typical for analysis of organic compounds, a small number of surrogate analyses fell outside of SWAMP MQO recommended control limits. These QA samples were flagged with a “VGN” qualifier to indicate this, but it is again not expected to affect the interpretation of data.

[1] http://ceden.waterboards.ca.gov/Metadata/ControlledVocab.php

3.1.3. Conventional Parameters (SSC)

All SSC data met recommended SWAMP MQOs.

4. Discussion

AMS field personnel coordinated with CCCWP and construction contractor to arrange sampling access at the pump station. Due to the uncertain duration of diversion activities, AMS targeted sample collection activities to coincide with the initiation of the diversion process each monitoring day. It is unknown how long contractors continued pumping each day before there was insufficient water to continue diversions, but there was sufficient flow each day to support sampling activities.

There was minimal rainfall reported and no observable runoff during the monitoring period. Between 9pm and 11pm on September 16, 2015, 0.02" of rainfall was reported at Weather Underground monitoring station KCARICHM24[2], which is located approximately 0.5 mi to the northeast of the NRPS.

5. References

SWAMP 2008. Surface Water Ambient Monitoring Program Quality Assurance Project Plan, Version 1.0. Prepared for the California State Water Quality Control Board by the SWAMP Quality Assurance Team. September 1, 2008.

[2] http://www.wunderground.com/personal-weather-station/dashboard?ID=KCARICHM24#history/s20150916/e20150916/mdaily

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APPENDIX F

Field Sampling Report, Diversion – Wet Weather Monitoring.
North Richmond Pump Station, Contra Costa County, California (January, 2016)

FIELD SAMPLING REPORT
DIVERSION – WET WEATHER MONITORING

North Richmond Pump Station
Contra Costa County, California

Prepared for:

Contra Costa County Watershed Program
Martinez, California

Prepared by:

Amec Foster Wheeler Environment & Infrastructure, Inc.
180 Grand Avenue, Suite 1100
Oakland, California 94612

January 2016

Project No. 5025153002.04

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DIVERSION – WET WEATHER MONITORING
North Richmond Pump Station
Contra Costa County, California

1.0 INTRODUCTION

This report summarizes the activities and results of monitoring a wet weather stormwater diversion from the North Richmond Stormwater Pump Station ("NRPS"), to the West County Wastewater District (WCWD) conducted by Amec Foster Wheeler Environment & Infrastructure, Inc. ("Amec Foster Wheeler") on November 2, 2015. The diversion was a pilot project required under provision C.11.f and C.12.f of the Municipal Regional Stormwater NPDES Permit issued to the 18 permittees of the Contra Costa Clean Water Program (Clean Water Program). The Contra Costa County Watersheds Program, a permittee of the Clean Water Program, carried out this diversion pilot on behalf of all permittees of the Clean Water Program, in fulfillment of commitments made under a United States Environmental Protection Agency Water Quality Improvement Fund grant.

The NRPS has been renovated with new low-flow pumps and other improvements by the Valentine Corporation (Valentine), a general engineering contractor. Valentine provided Amec Foster Wheeler access to the NRPS during this stormwater diversion pilot; Valentine also installed an operated a temporary sump pump that was used for the pilot diversion. Amec Foster Wheeler sampled diverted stormwater and submitted samples for analysis of total mercury, methylmercury, polychlorinated biphenyls (PCBs), and suspended sediment concentrations (SSC).

2.0 FIELD SAMPLING REPORT

This section summarizes the field effort. The objectives, activities, and quality assurance / quality control measures implemented in the field are described in the subsections below.

2.1 OBJECTIVES

The objectives of the sampling program were:

- Collect up to ten samples at different times intervals spaced roughly across the hydrograph of the storm event.
- Collect one time interval sample in duplicate and up to three field blanks.
- Sample analysis for PCB, total mercury, total methylmercury and SSC by McCambell Analytical, Inc. of Pittsburg, CA (Table 1).

2.2 SAMPLING ACTIVITIES

A suitable storm event for the diversion monitoring program began at approximately 11:00 pm on Sunday, November 1st. The Richmond City Hall station recorded 0.62 inch of rain by the end of the event at approximately 5:00 pm November 2nd (California Department of Water Resources, 2015). Figure 1 plots rainfall measured at the Richmond City Hall for the storm event. Most of the rain fell between 4 and 8 am on the morning of November 2nd. Watershed Program staff contacted Amec Foster Wheeler at about 6 AM to initiate sampling.

After testing for toxicity to activated sludge bacteria and finding no impairment of respiratory activity by the water in the pump station wet well, WCWD approved diversion of stormwater at approximately 9:00 am on November 2, 2015, and Valentine began pumping stormwater from the NRPS wet well to the sanitary sewer system via a system of PVC pipes. The initial stormwater diversion flow from the wet well was “choppy” due to debris such as leaves clogging the screen protecting the diversion intake pipes. After adjusting the height of the intake, a steady pumped flow rate of approximately 212 gallons per minute (gpm) was recorded after 9:30 am and maintained for the duration of the diversion. The large 45,000 gpm wet weather pumps did not turn on during the diversion sampling event. According to onsite Valentine staff, the large diversion pumps did operate several times during the storm event prior to diversion, so this was not a true “first flush” diversion pilot.

Amec Foster Wheeler staff completed field sampling of diverted stormwater between 9:30 and 11:30 am. Nine samples were collected: five stormwater samples, one field duplicate, and three field blanks (Table 2). To facilitate collection of stormwater diversion monitoring samples, Valentine installed a gate valve and spigot in the piping. A hose was attached to the spigot and flushed with diverted stormwater prior to collecting each sample. Stormwater samples were collected directly into sampling bottles from the hose. Field blanks used laboratory-provided blank water to fill the sample bottles. The field blank bottles were filled at the same location as the stormwater samples after the flow was turned off.

All samples were analyzed for total mercury, methylmercury and total PCB concentrations. Suspended sediment concentrations were measured in all samples except the field blanks.

2.3 QUALITY ASSURANCE

Monitoring results were checked against SWAMP MQOs. In general, all measurements met SWAMP MQOs with a few exceptions.

The calculation of the relative percent difference (RPD) for the field sample/ field duplicate pair were less than the SWAMP MQO control limits for precision of 25%, for all parameters including individual PCB congeners, except methylmercury. The methylmercury RPD was 31% versus the control limit of 25%. However, given the narrow range of data, this result is not expected to greatly alter the interpretation of the data.

The field blanks returned non-detectable concentrations of mercury, methylmercury and PCBs.

2.4 RESULTS

Analyte concentrations reported by McCambell Analytical are summarized in Table 3. Complete results, including any flagged or qualified results, are included as Appendix A. Total PCB concentrations were calculated from individual congeners. Congener concentrations reported as non-detects were replaced with one half of the method detection limit. This is consistent with the NRSPS Dry Weather Diversion Field Sampling report (Applied Marine Sciences, 2015), and reporting procedures established by the Bay Area Stormwater Management Agencies Association Regional Monitoring Coalition.

Measured concentrations of SSC, total Hg, methylmercury, and PCBs showed low variability across the 2.5 hour diversion monitoring event. Total mercury concentrations ranged from a minimum of 31 ng/L to a maximum of 42 ng/L. Methylmercury concentrations ranged from 0.4 ng/L to 0.51 ng/L. Total PCB concentrations ranged from a minimum of 4,671 pg/L to a maximum of 8,562 pg/L. Suspended sediment concentrations ranged from 49.3 mg/L to 53.9 mg/L.

Figures 2 through 4 show total mercury, methylmercury, and PCB concentrations plotted against SSC. As these parameters are generally associated with fine particulate matter in stormwater the small range of SSC in diverted stormwater is reflected in the small range of total mercury, methylmercury and PCB concentrations. The correlation between SSC and total Hg and PCB is not statistically significant for the sample size (critical correlation coefficient = 0.81 for $n = 6$ at $\alpha = 0.05$). There was a significant correlation between SSC and methylmercury. For all correlation analyses, poor correlations with SSC are expected because the range of SSC measurements in the data set is small – i.e., less than 10 percent variation from the lowest SSC measurement to the highest SSC measurement. Robust correlations of pollutants with SSC are best derived when the measured SSC varies between less than 10 mg/L up to 100 mg / L or greater, with several intermediate samples of differing SSC concentrations.

The purpose of regression analysis vs. SSC is to estimate the ratio of pollutants to suspended sediments based on the slope of the regression line. An alternative approach is to calculate individual pollutant to SSC ratios for each sample, and then determine the average ratio, as shown in Table 3. The mercury / SSC ratio of suspended sediments at the NRSPS wet weather event averaged 0.7 +/- 0.07 µg/g (ppm). For context, this is consistent with the expected concentration of mercury in urban sediments; stormwater from the 1st and Cutting area in Richmond were recently shown to have mercury / SSC ratios of approximately 1 (Contra Costa Clean Water Program, 2015). Suspended sediments in the NRSPS had approximately 9 +/- 2 ng/g (ppb) methylmercury; this is approximately ten time greater than watershed background methylmercury to suspended sediment concentrations recently measured by the Contra Costa Clean Water Program (2015). PCB to suspended sediment ratios at the NRSPS average 135 +/- 26 ng/g (ppb); this is typical of older urban areas of the Bay (Contra Costa Clean Water Program, 2013).

3.0 DIVERSION VOLUME AND MASS

As noted above, diversion of stormwater was approved by WCWD staff at approximately 9 am. A steady state pumping rate of 212 gpm was reached at about 9:30 am. An estimate of the total volume of stormwater diverted to the WCWD and the associated mass load of SSC, total mercury and PCB is presented in Table 4. Assuming a constant pumping rate, and that each stormwater sample was representative of the water quality for a given time interval, it is possible to calculate the mass diverted for each parameter by multiplying the flow rate times the elapsed time between samples, and the concentration. Based on this calculation approximately 32,012 gallons of stormwater, 4.2 mg of Hg, 0.05 mg of methylmercury, 0.80 mg of PCBs, and 6.2 kg of suspended sediment were diverted into the WCWD sewer system during the wet weather diversion monitoring program (Table 4).

4.0 DISCUSSION

Amec Foster Wheeler completed a wet weather diversion monitoring program at the NRSPS on November 2, 2015. Nine samples were collected and analyzed for SSC, total and methylmercury, and 40 PCB congeners. Analytical results showed that there was little variability across time for the diversion monitoring program for SSC, total mercury and PCBs. No methylmercury was detected in any stormwater sample.

Results of the diversion monitoring indicate that approximately 32,012 gallons of stormwater, 4.2 mg of Hg, 0.05 mg of methylmercury, 0.80 mg of PCBs, and 6.2 kg of suspended sediment were diverted into the WCWD sewer system between 9 and 11:30 am on November 2, 2015.

5.0 REFERENCES

Applied Marine Sciences, 2015. Field Sampling Report, North Richmond Pump Station Dry Weather Diversion, Water Quality Monitoring, December 1, 2015.

California Department of Water Resources. Retrieved January 3, 2016, from http://cdec.water.ca.gov/cgiprogs/selectQuery?station_id=RHL&sensor_num=16&dur_code=E&start_date=2015-11-01&end_date=2015-11-03&geom

Contra Costa Clean Water Program, 2014. Integrated Monitoring Report, Part C: Pollutants of Concern Implementation Plan. Submitted to the San Francisco Bay Regional Water Quality Control Board April 1, 2014.

Contra Costa Clean Water Program, 2015. Delta Methylmercury Control Study Preliminary Data Report. Submitted to the Central Valley Regional Water Quality Control Board, October 15, 2015.

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TABLES

TABLE 1

ANALYTICAL METHODS

North Richmond Pump Station
Contra Costa County, California

Analyte	Method	Reporting Limit	Units
Mercury	EPA E1631E	0.5	ng/L
Methyl Mercury	EPA 1630/FGS-070	0.05	ng/L
Total PCBs	EPA E1668C	Variable	pg/L
Suspended Sediment Concentration	ASTM D3977-B	1	mg/L

<u>Abbreviations</u>

ASTM = American Society for Testing and Materials
EPA = Environmental Protection Agency
mg/L = milligrams per liter
NA = not analyzed
ng/L = nanograms per liter
PCB = polychlorinated biphenyl
pg/L = picograms per liter

TABLE 2

SAMPLES AND ANALYTICAL METHODS
North Richmond Pump Station
Contra Costa County, California

Sample ID	Sample Type	Analyte and Method			
		Mercury by EPA E1631E	**Methyl Mercury by EPA 1630/FGS-070**	**PCBs by EPA E1668C**	**Suspended Sediment Concentration by ASTM D3977-B**
NRPS15-001	Stormwater	X	X	X	X
NRPS15-002	Stormwater	X	X	X	X
NRPS15-003	Field Duplicate	X	X	X	X
NRPS15-004	Field Blank	X	X	X	NA
NRPS15-005	Stormwater	X	X	X	X
NRPS15-006	Stormwater	X	X	X	X
NRPS15-007	Field Blank	X	X	X	NA
NRPS15-008	Stormwater	X	X	X	X
NRPS15-009	Field Blank	X	X	X	NA

<u>Abbreviations</u>
ASTM = American Society for Testing and Materials
EPA = Environmental Protection Agency
NA = not analyzed
PCB = polychlorinated biphenyl

TABLE 3

SUMMARY ANALYTICAL RESULTS

North Richmond Pump Station
Contra Costa County, California

Sample ID	Type	Time	Parameters: Mercury (ng/L)	Parameters: Methyl Mercury (ng/L)	Parameters: Total PCBs (pg/L)	Parameters: SSC (mg/L)	Ratios: Hg/SSC (µg/g)	Ratios: MeHg/SSC (ng/g)	Ratios: PCB/SSC (ng/g)
NRPS15-001	Stormwater	9:37	37	0.51	8293	54	1	9	154
NRPS15-002	Stormwater	9:52	36	0.51	7763	54	1	9	145
NRPS15-003	Field Duplicate	9:56	42	0.70	8342	53	1	13	158
NRPS15-004	Field Blank	10:10	ND	ND	68 *	NA	NA	NA	NA
NRPS15-005	Stormwater	10:28	37	0.40	6371	50	1	8	129
NRPS15-006	Stormwater	10:56	31	0.42	6664	49	1	8	135
NRPS15-007	Field Blank	11:00	ND	ND	68 *	NA	NA	NA	NA
NRPS15-008	Stormwater	11:31	32	0.42	4418	50	1	8	88
NRPS15-009	Field Blank	11:24	ND	ND	68 *	NA	NA	NA	NA
		Average	36	0.49	4673	52	0.69	9	135
		Standard Deviation	4.0	0.11	3651	2.1	0.07	2	26

Notes

* Calculation of total PCBs used 1/2 the method detection limit for ND congeners

Abbreviations:

mg/L = miligrams per liter
NA = not analyzed
ND = not detected
ng/L = nanograms per liter
PCB = polychlorinated biphenyl
pg/L = picograms per liter
SSC = suspended sediment concentration

TABLE 4

VOLUME AND MASS ESTIMATES
North Richmond Pump Station
Contra Costa County, California

Sample ID	Time	Elapsed Time (min)	Volume Diverted (gallons) [1]	Concentration				Mass							
				Hg (ng/L)	MeHg (ng/L)	PCBs (pg/L)	SSC (mg/L)	Hg ng	MeHg ng	PCBs pg	SSC mg	Hg mg	MeHg mg	PCBs mg	SSC kg
Start Diversion	9:00	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NRPS15-001	9:37	37	7844	37	0.506	8292.55	53.9	1,098,623	15,024	246,226,541	1,600,426	1.10	0.02	0.25	1.60
NRPS15-002	9:52	15	3180	36	0.507	7763.25	53.5	433,350	6,103	93,450,122	644,006	0.43	0.01	0.09	0.64
NRPS15-005	10:28	36	7632	37	0.401	6371.3	49.5	1,068,930	11,585	184,066,857	1,430,055	1.07	0.01	0.18	1.43
NRPS15-006	10:56	28	5936	31	0.417	6663.75	49.3	696,570	9,370	149,734,463	1,107,771	0.70	0.01	0.15	1.11
NRPS15-008	11:31	35	7420	32	0.415	4418.1	50.4	898,800	11,656	124,093,384	1,415,610	0.90	0.01	0.12	1.42
TOTALS			**32,012**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**4.20**	**0.05**	**0.80**	**6.20**

Notes:
1. 212 gpm steady state flow rate from diversion pump.

Abbreviations:
-- = not applicable
kg = kilograms
MeHg = methyl mercury
mg = miligrams
mg/L = miligrams per liter
min = minutes
ng = nanograms
ng/L = nanograms per liter
PCB = polychlorinated biphenyl
pg = picograms
pg/L = picograms per liter
SSC = suspended sediment concentration

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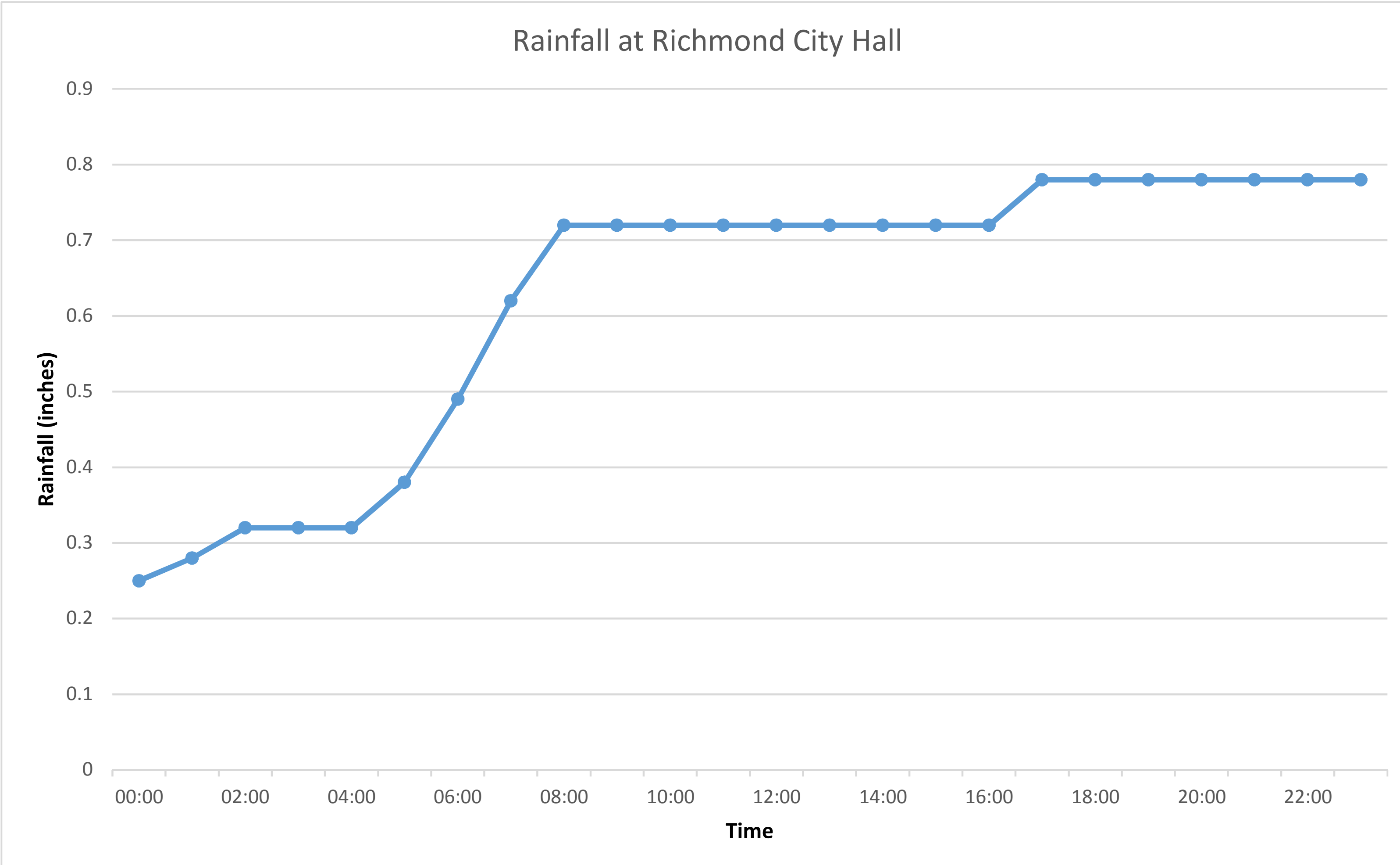
FIGURES



RAINFALL MEASURED AT RICHMOND CITY HALL, NOVEMBER 2, 2015 North Richmond Pump Station Contra Costa County, California			amec foster wheeler
Date: 1/12/16	Project No.	5025153002.04	Figure **1**

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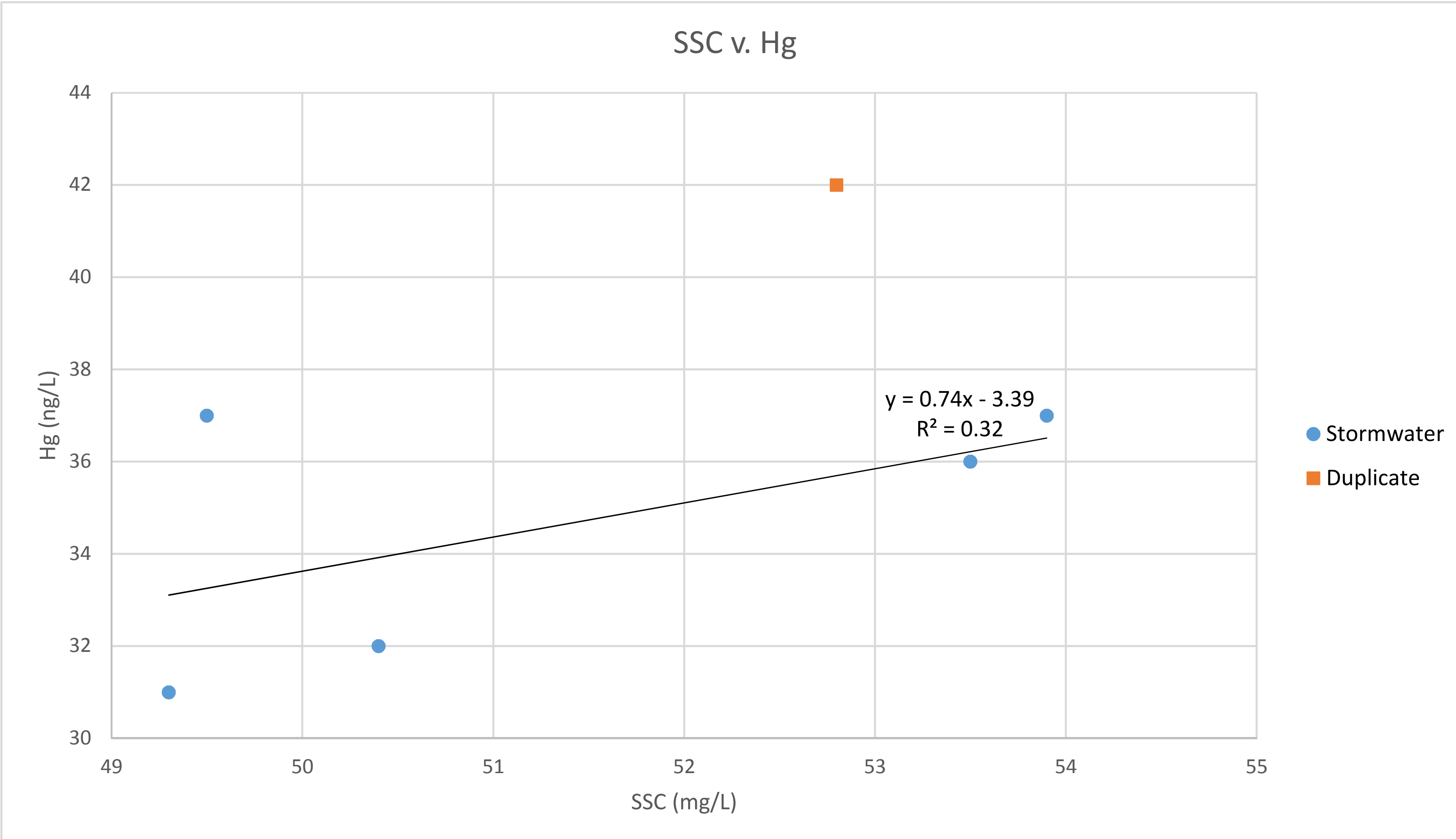

SCATTER PLOT OF SSC
AND TOTAL MERCURY
North Richmond Pump Station
Contra Costa County, California

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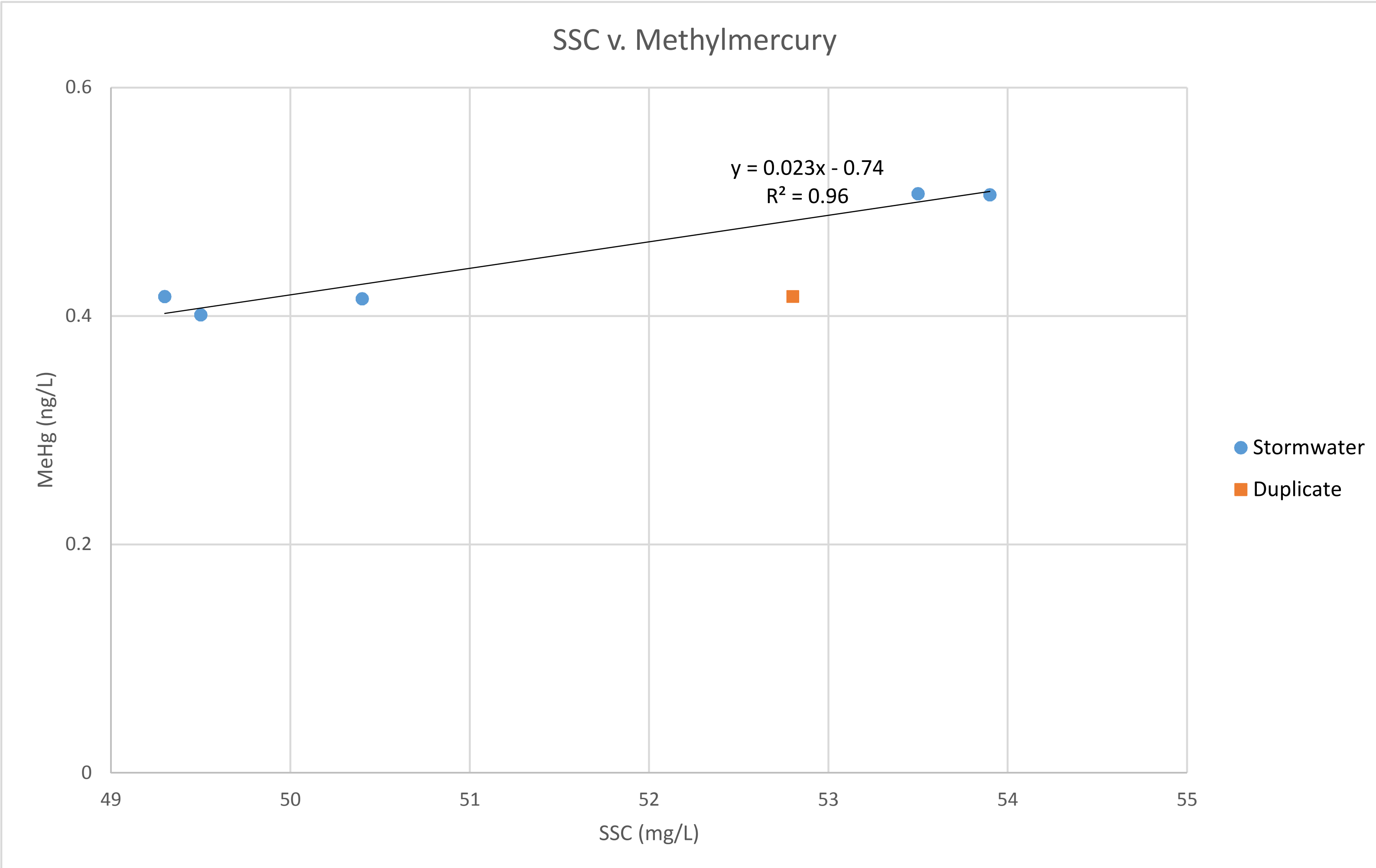
Figure 2

Date: 1/12/16	Project No.	5025153002.04



SCATTER PLOT OF SSC AND METHYLMERCURY
North Richmond Pump Station
Contra Costa County, California

Date: 1/12/16	Project No.	5025153002.04	Figure 3

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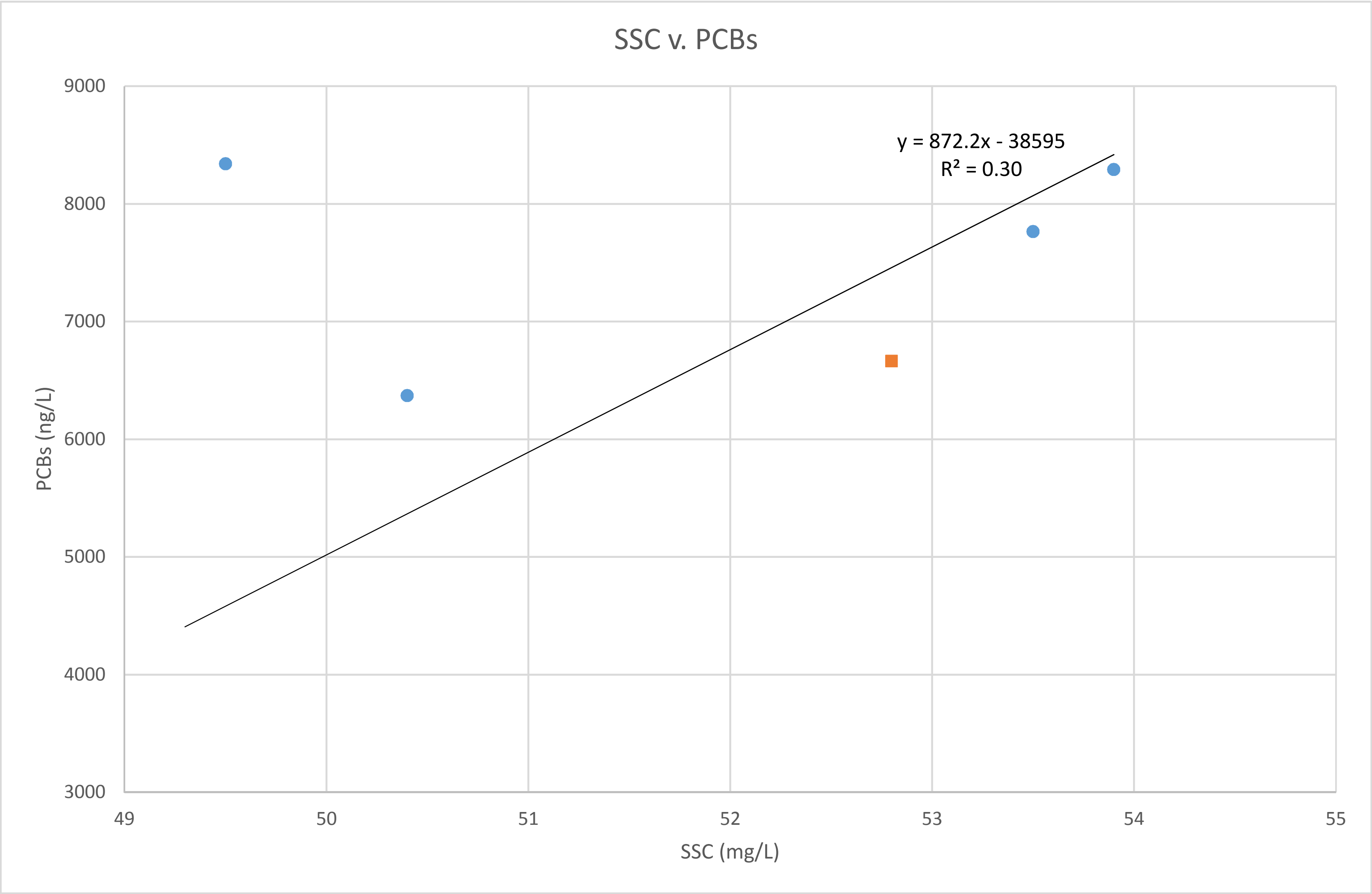

SCATTER PLOT OF SSC AND TOTAL PCBs North Richmond Pump Station Contra Costa County, California		
Date: 1/12/16	Project No.	5025153002.04

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Figure **4**

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APPENDIX A

Laboratory Certificates

11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

19 November 2015

Rosa Venegas
McCampbell Analytical, Inc
1534 Willow Pass Rd
Pittsburg, CA 94565

RE: MMHg

Enclosed are the analytical results for samples received by Eurofins Frontier Global Sciences. All quality control measurements are within established control limits and there were no analytical difficulties encountered with the exception of those listed in the case narrative section of this report.

If you have any questions concerning this report, please feel free to contact me.

Sincerely,

Amy Goodall
Project Manager

eurofins | Frontier Global Sciences

11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

ANALYTICAL REPORT FOR SAMPLES

Sample ID	Laboratory ID	Matrix	Date Sampled	Date Received
1511071-001C NRPSIS-001	1511087-01	Water	02-Nov-15 09:37	04-Nov-15 09:30
1511071-002C NRPSIS-002	1511087-02	Water	02-Nov-15 09:52	04-Nov-15 09:30
1511071-003C NRPSIS-003	1511087-03	Water	02-Nov-15 09:56	04-Nov-15 09:30
1511071-004C NRPSIS-004	1511087-04	Water	02-Nov-15 10:10	04-Nov-15 09:30
1511071-005C NRPSIS-005	1511087-05	Water	02-Nov-15 10:28	04-Nov-15 09:30
1511071-006C NRPSIS-006	1511087-06	Water	02-Nov-15 10:56	04-Nov-15 09:30
1511071-007C NRPSIS-007	1511087-07	Water	02-Nov-15 11:00	04-Nov-15 09:30
1511071-008C NRPSIS-008	1511087-08	Water	02-Nov-15 11:31	04-Nov-15 09:30
1511071-009C NRPSIS-009	1511087-09	Water	02-Nov-15 11:24	04-Nov-15 09:30

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SAMPLE RECEIPT

Samples were received at Eurofins Frontier Global Sciences (EFGS) on 11/4/2015 9:30:00 AM . The samples were received intact, on-ice within a sealed cooler at 1.4 degrees Celsius.

SAMPLE PREPARATION AND ANALYSIS

Samples were prepared and analyzed for methyl mercury by cold vapor gas chromatography atomic fluorescence spectrometry (CV-GC-AFS) in accordance with EPA 1630 (EFGS-070).

ANALYTICAL AND QUALITY CONTROL ISSUES

Method blanks were prepared for every preparation to assess possible blank contribution from the sample preparation procedure. The method blanks were carried through the entire analytical procedure. All blanks fell within the established acceptance criteria with the exception of any items narrated above or flagged and described in the notes and definitions section of the report.

Liquid spikes, certified reference material (CRM) or a quality control samples (QCS) were prepared for every preparation as a measure of accuracy. All liquid spikes, CRMs and/or QCS samples fell within the established acceptance criteria with the exception of any items narrated above or flagged and described in the notes and definitions section of the report.

As an additional measure of the accuracy of the methods used and to check for matrix interference, matrix spikes (MS) and matrix spike duplicates (MSD) were digested and analyzed. All of the matrix spike recoveries fell within the established acceptance criteria with the exception of any items flagged and described in the notes and definitions section of the report.

A reasonable measure of the precision of the analytical methods is the relative percent difference (RPD) between a matrix spike recovery and a matrix spike duplicate recovery and between laboratory control sample recovery and laboratory control sample duplicate recoveries. All of the relative percent differences established acceptance criteria with the exception of any items flagged and described in the notes and definitions section of the report.

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Sample Receipt Checklist

EFGS Work Order: 1511087

Client: McCampbell Analytical

Date & Time Received: 11/4/15 10:00

Date Labeled: 11/4/15 Labeled By: [illegible]

Project: ______

Received By: LM

Label Verified By: CMK

\# of Coolers Received: 1

Samples Arrived By: ✓ Shipping Service ____ Courier ____ Hand ____ Other (Specify: ______)

Coolant: ☐ None/Ambient ☑ Loose Ice ☐ Gel Ice ☐ Dry Ice Coolant Required: (Y)/N Temp Blank Used: Y/(N) for Cooler(s): ______

Notify Project Manager if packages/coolers are received without coolant or with thawed coolant and at a temperature in excess of 6°C. PM notified: Y/N

Cooler Information:	Y/N/NA	Comments
The coolers do not appear to be tampered with:	✓	
Custody Seals are present and intact:	N	
Custody seals signed:	N	

TID: 43/50	CF: -0.3 °C	Date/time: 11/4/15 10:00	By: LM
Cooler 1: 1.7 °C	w/ CF: 1.4 °C	Cooler 4: °C	w/ CF: °C
Cooler 2: °C	w/ CF: °C	Cooler 5: °C	w/ CF: °C
Cooler 3: °C	w/ CF: °C	Cooler 6: °C	w/ CF: °C

Chain of Custody:	Y/N/NA	Comments
Sample ID/Description:	Y	
Date and time of collection:	Y	
Sampled by:	N	
Preservation type:	N	
Requested analyses:	Y	
Required signatures:	Y	
Internal COC required:	N	

Sample Condition/Integrity:	Y/N/NA	Comments
Sample containers intact/present:	Y	
Sample labels are present and legible:	Y	
Sample ID on container/bag matches COC:	Y	
Correct sample containers used:	Y	
Samples received within holding times:	Y	
Sample volume sufficient for requested analyses:	Y	
Correct preservative used for requested analyses:	Y	

Anomalies/Non-conformances (attach additional pages if needed):

1511087

McCampbell Analytical, Inc.

1534 Willow Pass Rd
Pittsburg, CA 94565-1701
Phone: (925) 252-9262
Fax: (925) 252-9269

SUB CHAIN-OF-CUSTODY RECORD

WorkOrder: 1511071 **ClientCode: AMEC** **EDF: NO**

Subcontractor:

Eurofins Frontier Global Sciences
11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011

TEL: (425) 686-1996
FAX: (425) 686-3096
ProjectNo: North Richmond Pump Station
Acct #:

Subcontractor Standard TAT:

Date Received: **11/02/2015**

Lab ID	Client ID	Matrix	Collection Date	TAT	Requested Tests: E1630				
1511071-001C	NRPSIS-001	Water	11/2/2015 9:37	5 day(s)	1				
1511071-002C	NRPSIS-002	Water	11/2/2015 9:52	5 day(s)	1				
1511071-003C	NRPSIS-003	Water	11/2/2015 9:56	5 day(s)	1				
1511071-004C	NRPSIS-004	Water	11/2/2015 10:10	5 day(s)	1				
1511071-005C	NRPSIS-005	Water	11/2/2015 10:28	5 day(s)	1				
1511071-006C	NRPSIS-006	Water	11/2/2015 10:56	5 day(s)	1				
1511071-007C	NRPSIS-007	Water	11/2/2015 11:00	5 day(s)	1				
1511071-008C	NRPSIS-008	Water	11/2/2015 11:31	5 day(s)	1				
1511071-009C	NRPSIS-009	Water	11/2/2015 11:24	5 day(s)	1				

Comments: **PLEASE USE 'CLIENT ID' AS THE SAMPLE ID AND EMAIL ASAP!**

Please email results to Maria Venegas at subdata@mccampbell.com upon completion.

		Date/Time			Date/Time
Relinquished by:	[signature]	11/3	**Received by:**	[signature] Lars Moffet	11/4/15 10:00
Relinquished by:			**Received by:**	EFGS	

No Seal
UPS
1.4°C
12 885 54E 01 ~~444~~ 4460 4789
11/4/15 4pm

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11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

1511071-001C NRPSIS-001

1511087-01

Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Batch	Prepared	Sequence	Analyzed	Method	Notes
Sample Preparation: EFGS-013 Methyl Hg Distillation for Water											
Methyl Mercury (as Mercury)	**0.506**	0.026	0.050	ng/L	1.25	F511180	13-Nov-15	5K16026	14-Nov-15	EPA 1630/FGS-070	

Eurofins Frontier Global Sciences, Inc.

The results in this report only apply to the samples analyzed in accordance with the chain of custody document. This analytical report must be reproduced in its entirety.

Amy Goodall, Project Manager

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11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

1511071-002C NRPSIS-002

1511087-02

Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Batch	Prepared	Sequence	Analyzed	Method	Notes
Sample Preparation: EFGS-013 Methyl Hg Distillation for Water											
Methyl Mercury (as Mercury)	**0.507**	0.026	0.050	ng/L	1.25	F511180	13-Nov-15	5K16026	14-Nov-15	EPA 1630/FGS-070	

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11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

1511071-003C NRPSIS-003

1511087-03

Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Batch	Prepared	Sequence	Analyzed	Method	Notes
Sample Preparation: EFGS-013 Methyl Hg Distillation for Water											
Methyl Mercury (as Mercury)	**0.696**	0.026	0.050	ng/L	1.25	F511180	13-Nov-15	5K16026	14-Nov-15	EPA 1630/FGS-070	

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Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

1511071-004C NRPSIS-004

1511087-04

Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Batch	Prepared	Sequence	Analyzed	Method	Notes
Sample Preparation: EFGS-013 Methyl Hg Distillation for Water											
Methyl Mercury (as Mercury)	ND	0.026	0.050	ng/L	1.25	F511180	13-Nov-15	5K16026	14-Nov-15	EPA 1630/FGS-070	U

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Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

1511071-005C NRPSIS-005

1511087-05

Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Batch	Prepared	Sequence	Analyzed	Method	Notes
Sample Preparation: EFGS-013 Methyl Hg Distillation for Water											
Methyl Mercury (as Mercury)	**0.401**	0.026	0.050	ng/L	1.25	F511180	13-Nov-15	5K16026	14-Nov-15	EPA 1630/FGS-070	

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Amy Goodall, Project Manager

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11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

1511071-006C NRPSIS-006

1511087-06

Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Batch	Prepared	Sequence	Analyzed	Method	Notes
Sample Preparation: EFGS-013 Methyl Hg Distillation for Water											
Methyl Mercury (as Mercury)	**0.417**	0.026	0.050	ng/L	1.25	F511180	13-Nov-15	5K16026	14-Nov-15	EPA 1630/FGS-070	

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11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

1511071-007C NRPSIS-007

1511087-07

Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Batch	Prepared	Sequence	Analyzed	Method	Notes
Sample Preparation: EFGS-013 Methyl Hg Distillation for Water											
Methyl Mercury (as Mercury)	ND	0.026	0.050	ng/L	1.25	F511180	13-Nov-15	5K16026	14-Nov-15	EPA 1630/FGS-070	U

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11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

1511071-008C NRPSIS-008

1511087-08

Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Batch	Prepared	Sequence	Analyzed	Method	Notes
Sample Preparation: EFGS-013 Methyl Hg Distillation for Water											
Methyl Mercury (as Mercury)	**0.415**	0.026	0.050	ng/L	1.25	F511180	13-Nov-15	5K16026	14-Nov-15	EPA 1630/FGS-070	

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11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

1511071-009C NRPSIS-009

1511087-09

Analyte	Result	Detection Limit	Reporting Limit	Units	Dilution	Batch	Prepared	Sequence	Analyzed	Method	Notes
Sample Preparation: EFGS-013 Methyl Hg Distillation for Water											
Methyl Mercury (as Mercury)	ND	0.026	0.050	ng/L	1.25	F511180	13-Nov-15	5K16026	14-Nov-15	EPA 1630/FGS-070	U

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11720 Northcreek Pkwy N, Suite 400
Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

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1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

Quality Control Data

Analyte	Result	Detection Limit	Reporting Limit	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Notes
Batch F511180 - EFGS-013 Methyl Hg Distillation for Water											
Blank (F511180-BLK1)					Prepared & Analyzed: 13-Nov-15						
Methyl Mercury (as Mercury)	0.032	0.026	0.050	ng/L							J
Blank (F511180-BLK2)					Prepared: 13-Nov-15 Analyzed: 14-Nov-15						
Methyl Mercury (as Mercury)	ND	0.026	0.050	ng/L							U
Blank (F511180-BLK3)					Prepared: 13-Nov-15 Analyzed: 14-Nov-15						
Methyl Mercury (as Mercury)	ND	0.026	0.050	ng/L							U
LCS (F511180-BS1)					Prepared & Analyzed: 13-Nov-15						
Methyl Mercury (as Mercury)	1.168	0.026	0.050	ng/L	1.0010		117	70-130			
LCS Dup (F511180-BSD1)					Prepared & Analyzed: 13-Nov-15						
Methyl Mercury (as Mercury)	1.168	0.026	0.050	ng/L	1.0010		117	70-130	0.0104	25	
Duplicate (F511180-DUP1)		**Source: 1510485-02RE1**			Prepared: 13-Nov-15 Analyzed: 14-Nov-15						
Methyl Mercury (as Mercury)	0.319	0.026	0.050	ng/L		0.317			0.703	35	
Matrix Spike (F511180-MS1)		**Source: 1510485-05RE1**			Prepared: 13-Nov-15 Analyzed: 14-Nov-15						
Methyl Mercury (as Mercury)	1.922	0.026	0.050	ng/L	1.0010	0.423	150	65-130			QM-07
Matrix Spike (F511180-MS2)		**Source: 1511087-02RE1**			Prepared: 13-Nov-15 Analyzed: 14-Nov-15						
Methyl Mercury (as Mercury)	1.915	0.026	0.050	ng/L	1.0010	0.507	141	65-130			QM-07
Matrix Spike Dup (F511180-MSD1)		**Source: 1510485-05RE1**			Prepared: 13-Nov-15 Analyzed: 14-Nov-15						
Methyl Mercury (as Mercury)	1.917	0.026	0.050	ng/L	1.0010	0.423	149	65-130	0.271	35	QM-07
Matrix Spike Dup (F511180-MSD2)		**Source: 1511087-02RE1**			Prepared: 13-Nov-15 Analyzed: 14-Nov-15						
Methyl Mercury (as Mercury)	1.973	0.026	0.050	ng/L	1.0010	0.507	146	65-130	2.95	35	QM-07

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Bothell, WA 98011
425.686.1996 Phone
425.686.3096 Fax

McCampbell Analytical, Inc	Project: MMHg	
1534 Willow Pass Rd	Project Number: North Richmond Pump Station	**Reported:**
Pittsburg CA, 94565	Project Manager: Rosa Venegas	19-Nov-15 15:09

Notes and Definitions

U	Analyte was not detected and is reported as less than the LOD or as defined by the client. The LOD has been adjusted for any dilution or concentration of the sample.
QM-07	The spike recovery was outside control limits for the MS and/or MSD. The batch was accepted based on LCS and LCSD recoveries within control limits and, when analysis permits, acceptable AS/ASD.
J	The result is an estimated concentration.
DET	Analyte DETECTED
ND	Analyte NOT DETECTED at or above the reporting limit
NR	Not Reported
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference

McCampbell Analytical, Inc.

"When Quality Counts"

Analytical Report

WorkOrder: 1511071 **Amended:** 01/06/2016

Report Created for: AMEC

2101 Webster Street, 12th Floor
Oakland, CA 94612

Project Contact: Emily Sportsman
Project P.O.:
Project Name: North Richmond Pump Station

Project Received: 11/02/2015

Analytical Report reviewed & approved for release on 11/10/2015 by:

Angela Rydelius,
Laboratory Manager

The report shall not be reproduced except in full, without the written approval of the laboratory. The analytical results relate only to the items tested. Results reported conform to the most current NELAP standards, where applicable, unless otherwise stated in the case narrative.

1534 Willow Pass Road, Pittsburg, CA 94565-1701
Toll Free Telephone: (877) 252-9262 / Fax: (925) 252-9269
http://www.mccampbell.com / E-mail: main@mccampbell.com

Glossary of Terms & Qualifier Definitions

Client: AMEC
Project: North Richmond Pump Station
WorkOrder: 1511071

Glossary Abbreviation

95% Interval	95% Confident Interval
DF	Dilution Factor
DI WET	(DISTLC) Waste Extraction Test using DI water
DISS	Dissolved (direct analysis of 0.45 μm filtered and acidified water sample)
DLT	Dilution Test
DUP	Duplicate
EDL	Estimated Detection Limit
ITEF	International Toxicity Equivalence Factor
LCS	Laboratory Control Sample
MB	Method Blank
MB % Rec	% Recovery of Surrogate in Method Blank, if applicable
MDL	Method Detection Limit
ML	Minimum Level of Quantitation
MS	Matrix Spike
MSD	Matrix Spike Duplicate
N/A	Not Applicable
ND	Not detected at or above the indicated MDL or RL
NR	Data Not Reported due to matrix interference or insufficient sample amount.
PDS	Post Digestion Spike
PDSD	Post Digestion Spike Duplicate
PF	Prep Factor
RD	Relative Difference
RL	Reporting Limit (The RL is the lowest calibration standard in a multipoint calibration.)
RPD	Relative Percent Deviation
RRT	Relative Retention Time
SPK Val	Spike Value
SPKRef Val	Spike Reference Value
SPLP	Synthetic Precipitation Leachate Procedure
TCLP	Toxicity Characteristic Leachate Procedure
TEQ	Toxicity Equivalents
WET (STLC)	Waste Extraction Test (Soluble Threshold Limit Concentration)

Analytical Qualifiers

B	analyte detected in the associated Method Blank and in the sample
J	Result is less than the RL/ML but greater than the MDL. The reported concentration is an estimated value.
S	spike recovery outside accepted recovery limits
M	Estimated Maximum Possible Concentration

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-001	**1511071-001A**	**Water**	**11/02/2015 09:37**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 008		ND		4.0	50	1				11/18/2015 13:14
PCB 018/030		**62**		3.2	50	1	1.12	0.92		11/18/2015 13:14
PCB 020/028		**110**		3.7	50	1	1.02	0.85		11/18/2015 13:14
PCB 031		**95**		2.2	50	1	1.01	0.82		11/18/2015 13:14
PCB 033		ND		2.4	50	1				11/18/2015 13:14
PCB 044/047/065		**120**		9.9	100	1	0.77	1.01		11/18/2015 13:14
PCB 049/069		**58**	J	4.4	100	1	0.81	0.96		11/18/2015 13:14
PCB 052		**170**		3.2	50	1	0.8	1		11/18/2015 13:14
PCB 056		**60**		3.3	50	1	0.78	0.92		11/18/2015 13:14
PCB 060		**31**	J	3.3	50	1	0.73	0.94		11/18/2015 13:14
PCB 066		**110**		2.5	50	1	0.70	0.87		11/18/2015 13:14
PCB 070/074/076		**230**		8.2	200	1	0.75	0.84		11/18/2015 13:14
PCB 086/097/109/119		**94**	J	5.6	200	1	1.58	0.94		11/18/2015 13:14
PCB 087/125		ND		5.7	200	1				11/18/2015 13:14
PCB 090/101/113		**370**		5.4	200	1	1.59	1		11/18/2015 13:14
PCB 095		**300**		2.4	200	1	1.59	1.19		11/18/2015 13:14
PCB 099		**150**		2.5	100	1	1.57	1.05		11/18/2015 13:14
PCB 105	0.00003	**180**		2.6	50	1	1.54	1	0.0054	11/18/2015 13:14
PCB 110/115		**520**		4.5	100	1	1.61	1		11/18/2015 13:14
PCB 118	0.00003	**390**		2.6	100	1	1.58	1	0.0117	11/18/2015 13:14
PCB 128/166		**130**		3.3	100	1	1.22	1.05		11/18/2015 13:14
PCB 129/138/163		**890**		5.7	200	1	1.23	1		11/18/2015 13:14
PCB 132		**230**		2.5	50	1	1.21	1.01		11/18/2015 13:14
PCB 135/151		**250**		3.9	100	1	1.26	1.02		11/18/2015 13:14
PCB 141		**160**		2.4	50	1	1.21	0.96		11/18/2015 13:14
PCB 147/149		**550**		2.8	100	1	1.25	0.97		11/18/2015 13:14
PCB 153/168		**650**		4.3	100	1	1.24	0.96		11/18/2015 13:14
PCB 156/157	0.00003	**100**		4.9	100	1	1.3	1	0.003	11/18/2015 13:14
PCB 158		**97**		1.9	50	1	1.21	1.02		11/18/2015 13:14
PCB 170		**270**		1.5	50	1	1.07	0.99		11/18/2015 13:14
PCB 174		**390**		3.4	50	1	1.05	0.97		11/18/2015 13:14
PCB 177		**230**		1.7	50	1	1.09	0.99		11/18/2015 13:14
PCB 180/193		**660**		4.1	100	1	1.07	0.97		11/18/2015 13:14
PCB 183/185		**250**		3.5	100	1	1.06	0.97		11/18/2015 13:14
PCB 187		**400**		2.1	50	1	1.05	1.06		11/18/2015 13:14

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-001	**1511071-001A**	**Water**	**11/02/2015 09:37**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 194		**89**		1.6	50	1	0.99	1		11/18/2015 13:14
PCB 195		**36**	J	1.8	50	1	0.93	0.97		11/18/2015 13:14
PCB 201		**21**	J	1.9	50	1	0.89	1.04		11/18/2015 13:14
PCB 203		**65**		1.7	50	1	0.92	0.96		11/18/2015 13:14
								Total TEQ:	0.0201	

Isotope Dilution	REC (%)	Limits	
13C-PCB 028	99	5-145	11/18/2015 13:14
13C-PCB 111	77	10-145	11/18/2015 13:14
13C-PCB 178	74	10-145	11/18/2015 13:14
Surrogate			
13C-PCB 001	12	5-145	11/18/2015 13:14
13C-PCB 003	30	5-145	11/18/2015 13:14
13C-PCB 004	30	5-145	11/18/2015 13:14
13C-PCB 015	53	5-145	11/18/2015 13:14
13C-PCB 019	33	5-145	11/18/2015 13:14
13C-PCB 037	74	5-145	11/18/2015 13:14
13C-PCB 054	46	5-145	11/18/2015 13:14
13C-PCB 077	67	10-145	11/18/2015 13:14
13C-PCB 081	70	10-145	11/18/2015 13:14
13C-PCB 104	59	10-145	11/18/2015 13:14
13C-PCB 105	62	10-145	11/18/2015 13:14
13C-PCB 114	60	10-145	11/18/2015 13:14
13C-PCB 118	64	10-145	11/18/2015 13:14
13C-PCB 123	66	10-145	11/18/2015 13:14
13C-PCB 126	68	10-145	11/18/2015 13:14
13C-PCB 155	65	10-145	11/18/2015 13:14
13C-PCB 156/157	60	10-145	11/18/2015 13:14
13C-PCB 167	77	10-145	11/18/2015 13:14
13C-PCB 169	44	10-145	11/18/2015 13:14
13C-PCB 188	99	10-145	11/18/2015 13:14
13C-PCB 189	68	10-145	11/18/2015 13:14
13C-PCB 202	111	10-145	11/18/2015 13:14
13C-PCB 205	49	10-145	11/18/2015 13:14
13C-PCB 206	42	10-145	11/18/2015 13:14
13C-PCB 208	52	10-145	11/18/2015 13:14
13C-PCB 209	37	10-145	11/18/2015 13:14

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-001	**1511071-001A**	**Water**	**11/02/2015 09:37**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed

Analyst(s): MG

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Angela Rydelius, Lab Manager

McCampbell Analytical, Inc.
"When Quality Counts"
1534 Willow Pass Road, Pittsburg, CA 94565-1701
Toll Free Telephone: (877) 252-9262 / Fax: (925) 252-9269
http://www.mccampbell.com / E-mail: main@mccampbell.com

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-002	**1511071-002A**	**Water**	**11/02/2015 09:52**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 008		ND		4.0	50	1				11/18/2015 14:22
PCB 018/030		**47**	J	3.2	50	1	1.07	0.92		11/18/2015 14:22
PCB 020/028		**92**		3.7	50	1	1.07	0.85		11/18/2015 14:22
PCB 031		**74**		2.2	50	1	1.01	0.82		11/18/2015 14:22
PCB 033		ND		2.4	50	1				11/18/2015 14:22
PCB 044/047/065		**100**		9.9	100	1	0.8	1.01		11/18/2015 14:22
PCB 049/069		**46**	J	4.4	100	1	0.8	0.96		11/18/2015 14:22
PCB 052		**130**		3.2	50	1	0.78	1		11/18/2015 14:22
PCB 056		**54**		3.3	50	1	0.79	0.92		11/18/2015 14:22
PCB 060		**25**	J	3.3	50	1	0.77	0.94		11/18/2015 14:22
PCB 066		**91**		2.5	50	1	0.75	0.87		11/18/2015 14:22
PCB 070/074/076		**200**	J	8.3	200	1	0.76	0.84		11/18/2015 14:22
PCB 086/097/109/119		**79**	J	5.7	200	1	1.75	0.94		11/18/2015 14:22
PCB 087/125		ND		5.8	200	1				11/18/2015 14:22
PCB 090/101/113		**370**		5.4	200	1	1.63	1		11/18/2015 14:22
PCB 095		**260**		2.4	200	1	1.62	1.19		11/18/2015 14:22
PCB 099		**130**		2.5	100	1	1.64	1.05		11/18/2015 14:22
PCB 105	0.00003	**170**		2.6	50	1	1.49	1	0.0051	11/18/2015 14:22
PCB 110/115		**470**		4.5	100	1	1.64	1		11/18/2015 14:22
PCB 118	0.00003	**360**		2.6	100	1	1.55	1	0.0108	11/18/2015 14:22
PCB 128/166		**120**		3.3	100	1	1.22	1.05		11/18/2015 14:22
PCB 129/138/163		**870**		5.8	200	1	1.22	1		11/18/2015 14:22
PCB 132		**220**		2.5	50	1	1.24	1.01		11/18/2015 14:22
PCB 135/151		**240**		3.9	100	1	1.23	1.02		11/18/2015 14:22
PCB 141		**160**		2.4	50	1	1.27	0.96		11/18/2015 14:22
PCB 147/149		**540**		2.8	100	1	1.23	0.97		11/18/2015 14:22
PCB 153/168		**630**		4.3	100	1	1.26	0.96		11/18/2015 14:22
PCB 156/157	0.00003	**100**		4.9	100	1	1.28	1	0.003	11/18/2015 14:22
PCB 158		**86**		1.9	50	1	1.25	1.02		11/18/2015 14:22
PCB 170		**280**		1.5	50	1	1.01	0.99		11/18/2015 14:22
PCB 174		**420**		3.5	50	1	1.06	0.97		11/18/2015 14:22
PCB 177		**240**		1.7	50	1	1.07	0.99		11/18/2015 14:22
PCB 180/193		**700**		4.1	100	1	1.07	0.97		11/18/2015 14:22
PCB 183/185		**260**		3.6	100	1	1.07	0.97		11/18/2015 14:22
PCB 187		**410**		2.1	50	1	1.03	1.06		11/18/2015 14:22

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-002	**1511071-002A**	**Water**	**11/02/2015 09:52**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 194		**96**		1.6	50	1	0.9	1		11/18/2015 14:22
PCB 195		**40**	J	1.8	50	1	0.89	0.97		11/18/2015 14:22
PCB 201		**20**	J	1.9	50	1	0.84	1.04		11/18/2015 14:22
PCB 203		**70**		1.7	50	1	0.90	0.96		11/18/2015 14:22
							Total TEQ:		0.0189	

Isotope Dilution	REC (%)	Limits	Date Analyzed
13C-PCB 028	109	5-145	11/18/2015 14:22
13C-PCB 111	75	10-145	11/18/2015 14:22
13C-PCB 178	77	10-145	11/18/2015 14:22
Surrogate			
13C-PCB 001	9	5-145	11/18/2015 14:22
13C-PCB 003	30	5-145	11/18/2015 14:22
13C-PCB 004	30	5-145	11/18/2015 14:22
13C-PCB 015	60	5-145	11/18/2015 14:22
13C-PCB 019	38	5-145	11/18/2015 14:22
13C-PCB 037	85	5-145	11/18/2015 14:22
13C-PCB 054	55	5-145	11/18/2015 14:22
13C-PCB 077	76	10-145	11/18/2015 14:22
13C-PCB 081	80	10-145	11/18/2015 14:22
13C-PCB 104	57	10-145	11/18/2015 14:22
13C-PCB 105	62	10-145	11/18/2015 14:22
13C-PCB 114	61	10-145	11/18/2015 14:22
13C-PCB 118	65	10-145	11/18/2015 14:22
13C-PCB 123	67	10-145	11/18/2015 14:22
13C-PCB 126	69	10-145	11/18/2015 14:22
13C-PCB 155	65	10-145	11/18/2015 14:22
13C-PCB 156/157	67	10-145	11/18/2015 14:22
13C-PCB 167	85	10-145	11/18/2015 14:22
13C-PCB 169	50	10-145	11/18/2015 14:22
13C-PCB 188	100	10-145	11/18/2015 14:22
13C-PCB 189	75	10-145	11/18/2015 14:22
13C-PCB 202	117	10-145	11/18/2015 14:22
13C-PCB 205	54	10-145	11/18/2015 14:22
13C-PCB 206	45	10-145	11/18/2015 14:22
13C-PCB 208	54	10-145	11/18/2015 14:22
13C-PCB 209	37	10-145	11/18/2015 14:22

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-002	**1511071-002A**	**Water**	**11/02/2015 09:52**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed

Analyst(s): MG

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-003	**1511071-003A**	**Water**	**11/02/2015 09:56**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 008		ND		4.0	50	1				11/18/2015 15:28
PCB 018/030		**59**		3.2	50	1	1.04	0.92		11/18/2015 15:28
PCB 020/028		**110**		3.7	50	1	1.03	0.85		11/18/2015 15:28
PCB 031		**90**		2.2	50	1	1.08	0.82		11/18/2015 15:28
PCB 033		ND		2.4	50	1				11/18/2015 15:28
PCB 044/047/065		**120**		9.9	100	1	0.81	1.01		11/18/2015 15:28
PCB 049/069		**55**	J	4.4	100	1	0.74	0.96		11/18/2015 15:28
PCB 052		**150**		3.2	50	1	0.77	1		11/18/2015 15:28
PCB 056		**57**		3.3	50	1	0.78	0.92		11/18/2015 15:28
PCB 060		**29**	J	3.3	50	1	0.73	0.94		11/18/2015 15:28
PCB 066		**110**		2.5	50	1	0.77	0.87		11/18/2015 15:28
PCB 070/074/076		**220**		8.2	200	1	0.75	0.84		11/18/2015 15:28
PCB 086/097/109/119		**100**	J	5.7	200	1	1.51	0.94		11/18/2015 15:28
PCB 087/125		ND		5.7	200	1				11/18/2015 15:28
PCB 090/101/113		**400**		5.4	200	1	1.57	1		11/18/2015 15:28
PCB 095		**280**		2.4	200	1	1.58	1.19		11/18/2015 15:28
PCB 099		**140**		2.5	100	1	1.58	1.05		11/18/2015 15:28
PCB 105	0.00003	**180**		2.6	50	1	1.51	1	0.0054	11/18/2015 15:28
PCB 110/115		**520**		4.5	100	1	1.63	1		11/18/2015 15:28
PCB 118	0.00003	**400**		2.6	100	1	1.51	1	0.012	11/18/2015 15:28
PCB 128/166		**130**		3.3	100	1	1.27	1.05		11/18/2015 15:28
PCB 129/138/163		**920**		5.7	200	1	1.24	1		11/18/2015 15:28
PCB 132		**230**		2.5	50	1	1.23	1.01		11/18/2015 15:28
PCB 135/151		**240**		3.9	100	1	1.28	1.02		11/18/2015 15:28
PCB 141		**160**		2.4	50	1	1.24	0.96		11/18/2015 15:28
PCB 147/149		**560**		2.8	100	1	1.31	0.97		11/18/2015 15:28
PCB 153/168		**640**		4.3	100	1	1.26	0.96		11/18/2015 15:28
PCB 156/157	0.00003	**100**		4.9	100	1	1.21	1	0.003	11/18/2015 15:28
PCB 158		**100**		1.9	50	1	1.18	1.02		11/18/2015 15:28
PCB 170		**290**		1.5	50	1	1.03	0.99		11/18/2015 15:28
PCB 174		**390**		3.4	50	1	1.03	0.97		11/18/2015 15:28
PCB 177		**230**		1.7	50	1	1.03	0.99		11/18/2015 15:28
PCB 180/193		**700**		4.1	100	1	1.04	0.97		11/18/2015 15:28
PCB 183/185		**250**		3.5	100	1	1.05	0.96		11/18/2015 15:28
PCB 187		**380**		2.1	50	1	1.05	1.06		11/18/2015 15:28

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Toll Free Telephone: (877) 252-9262 / Fax: (925) 252-9269
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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-003	**1511071-003A**	**Water**	**11/02/2015 09:56**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 194		**100**		1.6	50	1	0.91	1		11/18/2015 15:28
PCB 195		**42**	J	1.8	50	1	0.89	0.97		11/18/2015 15:28
PCB 201		**21**	J	1.9	50	1	0.83	1.04		11/18/2015 15:28
PCB 203		**71**		1.7	50	1	0.83	0.96		11/18/2015 15:28
							Total TEQ:		0.0204	

Isotope Dilution	REC (%)	Limits	Date Analyzed
13C-PCB 028	97	5-145	11/18/2015 15:28
13C-PCB 111	70	10-145	11/18/2015 15:28
13C-PCB 178	68	10-145	11/18/2015 15:28
Surrogate			
13C-PCB 001	13	5-145	11/18/2015 15:28
13C-PCB 003	21	5-145	11/18/2015 15:28
13C-PCB 004	20	5-145	11/18/2015 15:28
13C-PCB 015	31	5-145	11/18/2015 15:28
13C-PCB 019	20	5-145	11/18/2015 15:28
13C-PCB 037	45	5-145	11/18/2015 15:28
13C-PCB 054	26	5-145	11/18/2015 15:28
13C-PCB 077	44	10-145	11/18/2015 15:28
13C-PCB 081	44	10-145	11/18/2015 15:28
13C-PCB 104	26	10-145	11/18/2015 15:28
13C-PCB 105	34	10-145	11/18/2015 15:28
13C-PCB 114	34	10-145	11/18/2015 15:28
13C-PCB 118	35	10-145	11/18/2015 15:28
13C-PCB 123	36	10-145	11/18/2015 15:28
13C-PCB 126	37	10-145	11/18/2015 15:28
13C-PCB 155	31	10-145	11/18/2015 15:28
13C-PCB 156/157	35	10-145	11/18/2015 15:28
13C-PCB 167	42	10-145	11/18/2015 15:28
13C-PCB 169	28	10-145	11/18/2015 15:28
13C-PCB 188	40	10-145	11/18/2015 15:28
13C-PCB 189	37	10-145	11/18/2015 15:28
13C-PCB 202	46	10-145	11/18/2015 15:28
13C-PCB 205	27	10-145	11/18/2015 15:28
13C-PCB 206	22	10-145	11/18/2015 15:28
13C-PCB 208	25	10-145	11/18/2015 15:28
13C-PCB 209	20	10-145	11/18/2015 15:28

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-003	**1511071-003A**	**Water**	**11/02/2015 09:56**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed

Analyst(s): MG

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-004	**1511071-004A**	**Water**	**11/02/2015 10:10**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 008		ND		4.1	50	1				11/18/2015 16:32
PCB 018/030		ND		3.2	50	1				11/18/2015 16:32
PCB 020/028		ND		3.8	50	1				11/18/2015 16:32
PCB 031		**3.9**	J	2.2	50	1	1.14	0.83		11/18/2015 16:32
PCB 033		ND		2.4	50	1				11/18/2015 16:32
PCB 044/047/065		ND		10	100	1				11/18/2015 16:32
PCB 049/069		ND		4.5	100	1				11/18/2015 16:32
PCB 052		**3.9**	J	3.2	50	1	0.74	1		11/18/2015 16:32
PCB 056		ND		3.3	50	1				11/18/2015 16:32
PCB 060		ND		3.3	50	1				11/18/2015 16:32
PCB 066		ND		2.5	50	1				11/18/2015 16:32
PCB 070/074/076		ND		8.3	200	1				11/18/2015 16:32
PCB 086/097/109/119		ND		5.7	200	1				11/18/2015 16:32
PCB 087/125		ND		5.8	200	1				11/18/2015 16:32
PCB 090/101/113		**7.0**	J	5.4	200	1	1.46	1		11/18/2015 16:32
PCB 095		**4.5**	J	2.4	200	1	1.33	1.19		11/18/2015 16:32
PCB 099		ND		2.5	100	1				11/18/2015 16:32
PCB 105	0.00003	**3.5**	JM	2.6	50	1	2.71	1	0.000105	11/18/2015 16:32
PCB 110/115		**9.3**	J	4.6	100	1	1.42	1		11/18/2015 16:32
PCB 118	0.00003	**7.4**	J	2.6	100	1	1.44	1	0.000222	11/18/2015 16:32
PCB 128/166		ND		3.3	100	1				11/18/2015 16:32
PCB 129/138/163		**17**	J	5.8	200	1	1.1	1		11/18/2015 16:32
PCB 132		**3.9**	J	2.5	50	1	1.2	1.02		11/18/2015 16:32
PCB 135/151		ND		4.0	100	1				11/18/2015 16:32
PCB 141		**3.5**	J	2.4	50	1	1.09	0.96		11/18/2015 16:32
PCB 147/149		**8.7**	J	2.8	100	1	1.34	0.97		11/18/2015 16:32
PCB 153/168		**11**	J	4.4	100	1	1.1	0.96		11/18/2015 16:32
PCB 156/157		ND		4.9	100	1				11/18/2015 16:32
PCB 158		ND		1.9	50	1				11/18/2015 16:32
PCB 170		**6.0**	JM	1.5	50	1	1.4	0.99		11/18/2015 16:32
PCB 174		**7.0**	J	3.5	50	1	1.08	0.97		11/18/2015 16:32
PCB 177		**2.7**	JM	1.7	50	1	0.28	0.99		11/18/2015 16:32
PCB 180/193		**14**	J	4.2	100	1	1.00	0.97		11/18/2015 16:32
PCB 183/185		ND		3.6	100	1				11/18/2015 16:32
PCB 187		**6.2**	J	2.1	50	1	1.15	1.06		11/18/2015 16:32

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McCampbell Analytical, Inc.
"When Quality Counts"
1534 Willow Pass Road, Pittsburg, CA 94565-1701
Toll Free Telephone: (877) 252-9262 / Fax: (925) 252-9269
http://www.mccampbell.com / E-mail: main@mccampbell.com

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-004	**1511071-004A**	**Water**	**11/02/2015 10:10**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 194		**2.7**	JM	1.6	50	1	1.07	1		11/18/2015 16:32
PCB 195		ND		1.8	50	1				11/18/2015 16:32
PCB 201		ND		1.9	50	1				11/18/2015 16:32
PCB 203		**2.1**	JM	1.7	50	1	0.63	0.96		11/18/2015 16:32
								Total TEQ:	0.000327	

Isotope Dilution	REC (%)	Limits	
13C-PCB 028	81	5-145	11/18/2015 16:32
13C-PCB 111	70	10-145	11/18/2015 16:32
13C-PCB 178	59	10-145	11/18/2015 16:32
Surrogate			
13C-PCB 001	31	5-145	11/18/2015 16:32
13C-PCB 003	34	5-145	11/18/2015 16:32
13C-PCB 004	30	5-145	11/18/2015 16:32
13C-PCB 015	35	5-145	11/18/2015 16:32
13C-PCB 019	28	5-145	11/18/2015 16:32
13C-PCB 037	46	5-145	11/18/2015 16:32
13C-PCB 054	32	5-145	11/18/2015 16:32
13C-PCB 077	59	10-145	11/18/2015 16:32
13C-PCB 081	57	10-145	11/18/2015 16:32
13C-PCB 104	30	10-145	11/18/2015 16:32
13C-PCB 105	54	10-145	11/18/2015 16:32
13C-PCB 114	52	10-145	11/18/2015 16:32
13C-PCB 118	52	10-145	11/18/2015 16:32
13C-PCB 123	52	10-145	11/18/2015 16:32
13C-PCB 126	58	10-145	11/18/2015 16:32
13C-PCB 155	28	10-145	11/18/2015 16:32
13C-PCB 156/157	48	10-145	11/18/2015 16:32
13C-PCB 167	50	10-145	11/18/2015 16:32
13C-PCB 169	47	10-145	11/18/2015 16:32
13C-PCB 188	35	10-145	11/18/2015 16:32
13C-PCB 189	47	10-145	11/18/2015 16:32
13C-PCB 202	42	10-145	11/18/2015 16:32
13C-PCB 205	37	10-145	11/18/2015 16:32
13C-PCB 206	29	10-145	11/18/2015 16:32
13C-PCB 208	30	10-145	11/18/2015 16:32
13C-PCB 209	26	10-145	11/18/2015 16:32

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-004	**1511071-004A**	**Water**	**11/02/2015 10:10**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed

Analyst(s): MG

(Cont.)

CDPH ELAP 1644 ♦ NELAP 4033ORELAP

Angela Rydelius, Lab Manager

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-005	**1511071-005A**	**Water**	**11/02/2015 10:28**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 008		ND		4.0	50	1				11/18/2015 17:37
PCB 018/030		**38**	J	3.2	50	1	1.02	0.92		11/18/2015 17:37
PCB 020/028		**82**		3.7	50	1	0.99	0.85		11/18/2015 17:37
PCB 031		**66**		2.2	50	1	1.05	0.82		11/18/2015 17:37
PCB 033		ND		2.4	50	1				11/18/2015 17:37
PCB 044/047/065		**86**	J	9.9	100	1	0.76	1.01		11/18/2015 17:37
PCB 049/069		**40**	J	4.4	100	1	0.82	0.96		11/18/2015 17:37
PCB 052		**110**		3.2	50	1	0.8	1		11/18/2015 17:37
PCB 056		**47**	J	3.3	50	1	0.76	0.93		11/18/2015 17:37
PCB 060		**23**	J	3.3	50	1	0.73	0.94		11/18/2015 17:37
PCB 066		**88**		2.5	50	1	0.73	0.87		11/18/2015 17:37
PCB 070/074/076		**180**	J	8.2	200	1	0.78	0.84		11/18/2015 17:37
PCB 086/097/109/119		**77**	J	5.7	200	1	1.56	0.94		11/18/2015 17:37
PCB 087/125		ND		5.7	200	1				11/18/2015 17:37
PCB 090/101/113		**320**		5.4	200	1	1.61	1		11/18/2015 17:37
PCB 095		**220**		2.4	200	1	1.6	1.19		11/18/2015 17:37
PCB 099		**120**		2.5	100	1	1.66	1.05		11/18/2015 17:37
PCB 105	0.00003	**150**		2.6	50	1	1.56	1	0.0045	11/18/2015 17:37
PCB 110/115		**410**		4.5	100	1	1.61	1		11/18/2015 17:37
PCB 118	0.00003	**320**		2.6	100	1	1.52	1	0.0096	11/18/2015 17:37
PCB 128/166		**100**		3.3	100	1	1.29	1.05		11/18/2015 17:37
PCB 129/138/163		**740**		5.7	200	1	1.24	1		11/18/2015 17:37
PCB 132		**180**		2.5	50	1	1.28	1.01		11/18/2015 17:37
PCB 135/151		**190**		3.9	100	1	1.23	1.02		11/18/2015 17:37
PCB 141		**130**		2.4	50	1	1.24	0.96		11/18/2015 17:37
PCB 147/149		**450**		2.8	100	1	1.25	0.97		11/18/2015 17:37
PCB 153/168		**530**		4.3	100	1	1.22	0.96		11/18/2015 17:37
PCB 156/157	0.00003	**86**	J	4.9	100	1	1.28	1	0.00258	11/18/2015 17:37
PCB 158		**76**		1.9	50	1	1.26	1.02		11/18/2015 17:37
PCB 170		**240**		1.5	50	1	1.03	0.99		11/18/2015 17:37
PCB 174		**330**		3.4	50	1	1.08	0.97		11/18/2015 17:37
PCB 177		**200**		1.7	50	1	1.1	0.99		11/18/2015 17:37
PCB 180/193		**600**		4.1	100	1	1.06	0.97		11/18/2015 17:37
PCB 183/185		**210**		3.5	100	1	1.04	0.97		11/18/2015 17:37
PCB 187		**330**		2.1	50	1	1.07	1.06		11/18/2015 17:37

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Analytical Report

Client: AMEC
Date Received: 11/2/15 20:38
Date Prepared: 11/18/15-11/23/15
Project: North Richmond Pump Station
WorkOrder: 1511071
Extraction Method: E1668C
Analytical Method: E1668C
Unit: pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-005	1511071-005A	Water	11/02/2015 10:28	GC36	113093

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 194		**89**		1.6	50	1	0.81	1		11/18/2015 17:37
PCB 195		**33**	J	1.8	50	1	0.85	0.97		11/18/2015 17:37
PCB 201		**20**	J	1.9	50	1	0.77	1.04		11/18/2015 17:37
PCB 203		**61**		1.7	50	1	0.88	0.96		11/18/2015 17:37
							Total TEQ:		0.0167	

Isotope Dilution	REC (%)	Limits	
13C-PCB 028	93	5-145	11/18/2015 17:37
13C-PCB 111	66	10-145	11/18/2015 17:37
13C-PCB 178	68	10-145	11/18/2015 17:37
Surrogate			
13C-PCB 001	9	5-145	11/18/2015 17:37
13C-PCB 003	21	5-145	11/18/2015 17:37
13C-PCB 004	20	5-145	11/18/2015 17:37
13C-PCB 015	39	5-145	11/18/2015 17:37
13C-PCB 019	24	5-145	11/18/2015 17:37
13C-PCB 037	54	5-145	11/18/2015 17:37
13C-PCB 054	31	5-145	11/18/2015 17:37
13C-PCB 077	53	10-145	11/18/2015 17:37
13C-PCB 081	55	10-145	11/18/2015 17:37
13C-PCB 104	32	10-145	11/18/2015 17:37
13C-PCB 105	41	10-145	11/18/2015 17:37
13C-PCB 114	39	10-145	11/18/2015 17:37
13C-PCB 118	41	10-145	11/18/2015 17:37
13C-PCB 123	42	10-145	11/18/2015 17:37
13C-PCB 126	45	10-145	11/18/2015 17:37
13C-PCB 155	39	10-145	11/18/2015 17:37
13C-PCB 156/157	42	10-145	11/18/2015 17:37
13C-PCB 167	53	10-145	11/18/2015 17:37
13C-PCB 169	32	10-145	11/18/2015 17:37
13C-PCB 188	55	10-145	11/18/2015 17:37
13C-PCB 189	46	10-145	11/18/2015 17:37
13C-PCB 202	64	10-145	11/18/2015 17:37
13C-PCB 205	33	10-145	11/18/2015 17:37
13C-PCB 206	26	10-145	11/18/2015 17:37
13C-PCB 208	31	10-145	11/18/2015 17:37
13C-PCB 209	21	10-145	11/18/2015 17:37

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1534 Willow Pass Road, Pittsburg, CA 94565-1701
Toll Free Telephone: (877) 252-9262 / Fax: (925) 252-9269
http://www.mccampbell.com / E-mail: main@mccampbell.com

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-005	**1511071-005A**	**Water**	**11/02/2015 10:28**	**GC36**	**113093**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed

Analyst(s): MG

(Cont.)

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-006	**1511071-006A**	**Water**	**11/02/2015 10:56**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 008		ND		4.1	50	1				11/22/2015 23:46
PCB 018/030		**38**	JB	3.2	50	1	1.16	0.92		11/22/2015 23:46
PCB 020/028		**72**		3.8	50	1	1.04	0.85		11/22/2015 23:46
PCB 031		**50**	JB	2.2	50	1	1.01	0.83		11/22/2015 23:46
PCB 033		ND		2.4	50	1				11/22/2015 23:46
PCB 044/047/065		**70**	J	9.9	100	1	0.83	1.01		11/22/2015 23:46
PCB 049/069		**31**	JM	4.4	100	1	0.99	0.96		11/22/2015 23:46
PCB 052		**94**		3.2	50	1	0.85	1		11/22/2015 23:46
PCB 056		**43**	J	3.3	50	1	0.80	0.92		11/22/2015 23:46
PCB 060		**18**	J	3.3	50	1	0.85	0.94		11/22/2015 23:46
PCB 066		**56**		2.5	50	1	0.75	0.87		11/22/2015 23:46
PCB 070/074/076		**130**	J	8.3	200	1	0.87	0.84		11/22/2015 23:46
PCB 086/097/109/119		**75**	J	5.7	200	1	1.53	0.94		11/22/2015 23:46
PCB 087/125		ND		5.8	200	1				11/22/2015 23:46
PCB 090/101/113		**260**		5.4	200	1	1.66	1		11/22/2015 23:46
PCB 095		**240**		2.4	200	1	1.45	1.19		11/22/2015 23:46
PCB 099		**89**	J	2.5	100	1	1.7	1.05		11/22/2015 23:46
PCB 105	0.00003	**150**		2.6	50	1	1.75	1	0.0045	11/22/2015 23:46
PCB 110/115		**480**		4.5	100	1	1.59	1		11/22/2015 23:46
PCB 118	0.00003	**340**		2.6	100	1	1.59	1	0.0102	11/22/2015 23:46
PCB 128/166		**130**		3.3	100	1	1.19	1.05		11/22/2015 23:46
PCB 129/138/163		**860**		5.8	200	1	1.25	1		11/22/2015 23:46
PCB 132		**300**		2.5	50	1	1.24	1.02		11/22/2015 23:46
PCB 135/151		**230**		4.0	100	1	1.37	1.02		11/22/2015 23:46
PCB 141		**160**		2.4	50	1	1.27	0.96		11/22/2015 23:46
PCB 147/149		**530**		2.8	100	1	1.31	0.97		11/22/2015 23:46
PCB 153/168		**480**		4.3	100	1	1.21	0.96		11/22/2015 23:46
PCB 156/157	0.00003	**86**	J	4.9	100	1	1.33	1	0.00258	11/22/2015 23:46
PCB 158		**93**		1.9	50	1	1.19	1.02		11/22/2015 23:46
PCB 170		**320**		1.5	50	1	1.14	0.99		11/22/2015 23:46
PCB 174		**330**		3.5	50	1	1.07	0.97		11/22/2015 23:46
PCB 177		**200**		1.7	50	1	1.02	0.99		11/22/2015 23:46
PCB 180/193		**580**		4.2	100	1	1.06	0.97		11/22/2015 23:46
PCB 183/185		**180**		3.6	100	1	1.16	0.96		11/22/2015 23:46
PCB 187		**300**		2.1	50	1	1.13	1.06		11/22/2015 23:46

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-006	**1511071-006A**	**Water**	**11/02/2015 10:56**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 194		**120**		1.6	50	1	0.77	1		11/22/2015 23:46
PCB 195		**53**		1.8	50	1	0.9	0.97		11/22/2015 23:46
PCB 201		ND		1.9	50	1				11/22/2015 23:46
PCB 203		**75**		1.7	50	1	0.82	0.96		11/22/2015 23:46
								Total TEQ:	0.0173	

Isotope Dilution	REC (%)	Limits	
13C-PCB 028	109	5-145	11/22/2015 23:46
13C-PCB 111	65	10-145	11/22/2015 23:46
13C-PCB 178	65	10-145	11/22/2015 23:46
Surrogate			
13C-PCB 001	63	5-145	11/22/2015 23:46
13C-PCB 003	80	5-145	11/22/2015 23:46
13C-PCB 004	73	5-145	11/22/2015 23:46
13C-PCB 015	90	5-145	11/22/2015 23:46
13C-PCB 019	82	5-145	11/22/2015 23:46
13C-PCB 037	99	5-145	11/22/2015 23:46
13C-PCB 054	81	5-145	11/22/2015 23:46
13C-PCB 077	101	10-145	11/22/2015 23:46
13C-PCB 081	87	10-145	11/22/2015 23:46
13C-PCB 104	67	10-145	11/22/2015 23:46
13C-PCB 105	106	10-145	11/22/2015 23:46
13C-PCB 114	84	10-145	11/22/2015 23:46
13C-PCB 118	85	10-145	11/22/2015 23:46
13C-PCB 123	77	10-145	11/22/2015 23:46
13C-PCB 126	101	10-145	11/22/2015 23:46
13C-PCB 155	46	10-145	11/22/2015 23:46
13C-PCB 156/157	84	10-145	11/22/2015 23:46
13C-PCB 167	72	10-145	11/22/2015 23:46
13C-PCB 169	85	10-145	11/22/2015 23:46
13C-PCB 188	64	10-145	11/22/2015 23:46
13C-PCB 189	95	10-145	11/22/2015 23:46
13C-PCB 202	70	10-145	11/22/2015 23:46
13C-PCB 205	75	10-145	11/22/2015 23:46
13C-PCB 206	47	10-145	11/22/2015 23:46
13C-PCB 208	45	10-145	11/22/2015 23:46
13C-PCB 209	26	10-145	11/22/2015 23:46

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-006	**1511071-006A**	**Water**	**11/02/2015 10:56**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed

Analyst(s): MG

(Cont.)

1534 Willow Pass Road, Pittsburg, CA 94565-1701
Toll Free Telephone: (877) 252-9262 / Fax: (925) 252-9269
http://www.mccampbell.com / E-mail: main@mccampbell.com

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-007	**1511071-007A**	**Water**	**11/02/2015 11:00**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 008		ND		4.1	50	1				11/22/2015 20:33
PCB 018/030		ND		3.2	50	1				11/22/2015 20:33
PCB 020/028		**4.9**	JB	3.8	50	1	0.95	0.85		11/22/2015 20:33
PCB 031		ND		2.3	50	1				11/22/2015 20:33
PCB 033		ND		2.5	50	1				11/22/2015 20:33
PCB 044/047/065		ND		10	100	1				11/22/2015 20:33
PCB 049/069		ND		4.5	100	1				11/22/2015 20:33
PCB 052		ND		3.2	50	1				11/22/2015 20:33
PCB 056		ND		3.3	50	1				11/22/2015 20:33
PCB 060		ND		3.3	50	1				11/22/2015 20:33
PCB 066		ND		2.6	50	1				11/22/2015 20:33
PCB 070/074/076		ND		8.5	200	1				11/22/2015 20:33
PCB 086/097/109/119		ND		5.8	200	1				11/22/2015 20:33
PCB 087/125		ND		5.9	200	1				11/22/2015 20:33
PCB 090/101/113		ND		5.5	200	1				11/22/2015 20:33
PCB 095		ND		2.5	200	1				11/22/2015 20:33
PCB 099		ND		2.6	100	1				11/22/2015 20:33
PCB 105		ND		2.7	50	1				11/22/2015 20:33
PCB 110/115		ND		4.6	100	1				11/22/2015 20:33
PCB 118	0.00003	**3.3**	J	2.7	100	1	1.40	1	0.000099	11/22/2015 20:33
PCB 128/166		ND		3.3	100	1				11/22/2015 20:33
PCB 129/138/163		ND		5.9	200	1				11/22/2015 20:33
PCB 132		ND		2.6	50	1				11/22/2015 20:33
PCB 135/151		ND		4.0	100	1				11/22/2015 20:33
PCB 141		ND		2.5	50	1				11/22/2015 20:33
PCB 147/149		ND		2.9	100	1				11/22/2015 20:33
PCB 153/168		ND		4.4	100	1				11/22/2015 20:33
PCB 156/157		ND		5.0	100	1				11/22/2015 20:33
PCB 158		ND		2.0	50	1				11/22/2015 20:33
PCB 170		ND		1.6	50	1				11/22/2015 20:33
PCB 174		ND		3.5	50	1				11/22/2015 20:33
PCB 177		ND		1.8	50	1				11/22/2015 20:33
PCB 180/193		ND		4.2	100	1				11/22/2015 20:33
PCB 183/185		ND		3.6	100	1				11/22/2015 20:33
PCB 187		ND		2.2	50	1				11/22/2015 20:33

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-007	**1511071-007A**	**Water**	**11/02/2015 11:00**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 194		ND		1.7	50	1				11/22/2015 20:33
PCB 195		ND		1.9	50	1				11/22/2015 20:33
PCB 201		ND		2.0	50	1				11/22/2015 20:33
PCB 203		ND		1.8	50	1				11/22/2015 20:33
							Total TEQ:		0.0000990	

Isotope Dilution	REC (%)	Limits	Date Analyzed
13C-PCB 028	114	5-145	11/22/2015 20:33
13C-PCB 111	92	10-145	11/22/2015 20:33
13C-PCB 178	81	10-145	11/22/2015 20:33
Surrogate			
13C-PCB 001	70	5-145	11/22/2015 20:33
13C-PCB 003	72	5-145	11/22/2015 20:33
13C-PCB 004	59	5-145	11/22/2015 20:33
13C-PCB 015	83	5-145	11/22/2015 20:33
13C-PCB 019	62	5-145	11/22/2015 20:33
13C-PCB 037	102	5-145	11/22/2015 20:33
13C-PCB 054	62	5-145	11/22/2015 20:33
13C-PCB 077	112	10-145	11/22/2015 20:33
13C-PCB 081	108	10-145	11/22/2015 20:33
13C-PCB 104	56	10-145	11/22/2015 20:33
13C-PCB 105	91	10-145	11/22/2015 20:33
13C-PCB 114	89	10-145	11/22/2015 20:33
13C-PCB 118	90	10-145	11/22/2015 20:33
13C-PCB 123	92	10-145	11/22/2015 20:33
13C-PCB 126	95	10-145	11/22/2015 20:33
13C-PCB 155	67	10-145	11/22/2015 20:33
13C-PCB 156/157	89	10-145	11/22/2015 20:33
13C-PCB 167	91	10-145	11/22/2015 20:33
13C-PCB 169	98	10-145	11/22/2015 20:33
13C-PCB 188	52	10-145	11/22/2015 20:33
13C-PCB 189	84	10-145	11/22/2015 20:33
13C-PCB 202	56	10-145	11/22/2015 20:33
13C-PCB 205	73	10-145	11/22/2015 20:33
13C-PCB 206	60	10-145	11/22/2015 20:33
13C-PCB 208	54	10-145	11/22/2015 20:33
13C-PCB 209	55	10-145	11/22/2015 20:33

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Analytical Report

Client: AMEC
Date Received: 11/2/15 20:38
Date Prepared: 11/18/15-11/23/15
Project: North Richmond Pump Station

WorkOrder: 1511071
Extraction Method: E1668C
Analytical Method: E1668C
Unit: pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-007	**1511071-007A**	**Water**	**11/02/2015 11:00**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed

Analyst(s): MG

(Cont.)

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-008	**1511071-008A**	**Water**	**11/02/2015 11:31**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 008		ND		4.1	50	1				11/22/2015 22:41
PCB 018/030		**50**	JB	3.2	50	1	1.09	0.92		11/22/2015 22:41
PCB 020/028		**130**		3.8	50	1	1.03	0.85		11/22/2015 22:41
PCB 031		**38**	JB	2.2	50	1	1.03	0.82		11/22/2015 22:41
PCB 033		ND		2.4	50	1				11/22/2015 22:41
PCB 044/047/065		**110**		10	100	1	0.78	1.01		11/22/2015 22:41
PCB 049/069		**24**	J	4.5	100	1	0.79	0.96		11/22/2015 22:41
PCB 052		**130**		3.2	50	1	0.76	1		11/22/2015 22:41
PCB 056		**33**	J	3.3	50	1	0.82	0.92		11/22/2015 22:41
PCB 060		**16**	J	3.3	50	1	0.76	0.94		11/22/2015 22:41
PCB 066		**57**		2.5	50	1	0.82	0.87		11/22/2015 22:41
PCB 070/074/076		**190**	J	8.3	200	1	0.8	0.84		11/22/2015 22:41
PCB 086/097/109/119		**55**	J	5.7	200	1	1.50	0.94		11/22/2015 22:41
PCB 087/125		ND		5.8	200	1				11/22/2015 22:41
PCB 090/101/113		**190**	J	5.4	200	1	1.60	1		11/22/2015 22:41
PCB 095		**120**	J	2.4	200	1	1.57	1.19		11/22/2015 22:41
PCB 099		**72**	J	2.5	100	1	1.56	1.05		11/22/2015 22:41
PCB 105	0.00003	**110**		2.6	50	1	1.55	1	0.0033	11/22/2015 22:41
PCB 110/115		**350**		4.5	100	1	1.57	1		11/22/2015 22:41
PCB 118	0.00003	**300**		2.6	100	1	1.56	1	0.009	11/22/2015 22:41
PCB 128/166		**74**	J	3.3	100	1	1.18	1.05		11/22/2015 22:41
PCB 129/138/163		**580**		5.8	200	1	1.23	1		11/22/2015 22:41
PCB 132		**130**		2.5	50	1	1.22	1.01		11/22/2015 22:41
PCB 135/151		**140**		4.0	100	1	1.26	1.02		11/22/2015 22:41
PCB 141		**93**		2.4	50	1	1.25	0.96		11/22/2015 22:41
PCB 147/149		**360**		2.8	100	1	1.26	0.97		11/22/2015 22:41
PCB 153/168		**430**		4.4	100	1	1.24	0.96		11/22/2015 22:41
PCB 156/157	0.00003	**61**	J	4.9	100	1	1.26	1	0.00183	11/22/2015 22:41
PCB 158		**60**		1.9	50	1	1.21	1.02		11/22/2015 22:41
PCB 170		**180**		1.5	50	1	1.05	0.99		11/22/2015 22:41
PCB 174		**220**		3.5	50	1	1.04	0.97		11/22/2015 22:41
PCB 177		**130**		1.7	50	1	1.03	0.99		11/22/2015 22:41
PCB 180/193		**450**		4.2	100	1	1.05	0.97		11/22/2015 22:41
PCB 183/185		**140**		3.6	100	1	1.04	0.97		11/22/2015 22:41
PCB 187		**220**		2.1	50	1	1.07	1.06		11/22/2015 22:41

(Cont.)

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-008	**1511071-008A**	**Water**	**11/02/2015 11:31**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 194		**65**		1.6	50	1	0.89	1		11/22/2015 22:41
PCB 195		**28**	J	1.8	50	1	0.87	0.97		11/22/2015 22:41
PCB 201		**12**	J	1.9	50	1	0.86	1.04		11/22/2015 22:41
PCB 203		**44**	J	1.7	50	1	0.93	0.96		11/22/2015 22:41
							Total TEQ:		0.0141	

Isotope Dilution	REC (%)	Limits	
13C-PCB 028	113	5-145	11/22/2015 22:41
13C-PCB 111	93	10-145	11/22/2015 22:41
13C-PCB 178	80	10-145	11/22/2015 22:41
Surrogate			
13C-PCB 001	51	5-145	11/22/2015 22:41
13C-PCB 003	61	5-145	11/22/2015 22:41
13C-PCB 004	49	5-145	11/22/2015 22:41
13C-PCB 015	74	5-145	11/22/2015 22:41
13C-PCB 019	51	5-145	11/22/2015 22:41
13C-PCB 037	93	5-145	11/22/2015 22:41
13C-PCB 054	52	5-145	11/22/2015 22:41
13C-PCB 077	96	10-145	11/22/2015 22:41
13C-PCB 081	97	10-145	11/22/2015 22:41
13C-PCB 104	55	10-145	11/22/2015 22:41
13C-PCB 105	83	10-145	11/22/2015 22:41
13C-PCB 114	81	10-145	11/22/2015 22:41
13C-PCB 118	82	10-145	11/22/2015 22:41
13C-PCB 123	84	10-145	11/22/2015 22:41
13C-PCB 126	88	10-145	11/22/2015 22:41
13C-PCB 155	60	10-145	11/22/2015 22:41
13C-PCB 156/157	79	10-145	11/22/2015 22:41
13C-PCB 167	88	10-145	11/22/2015 22:41
13C-PCB 169	64	10-145	11/22/2015 22:41
13C-PCB 188	89	10-145	11/22/2015 22:41
13C-PCB 189	81	10-145	11/22/2015 22:41
13C-PCB 202	98	10-145	11/22/2015 22:41
13C-PCB 205	59	10-145	11/22/2015 22:41
13C-PCB 206	48	10-145	11/22/2015 22:41
13C-PCB 208	58	10-145	11/22/2015 22:41
13C-PCB 209	40	10-145	11/22/2015 22:41

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-008	**1511071-008A**	**Water**	**11/02/2015 11:31**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	Qualifiers	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed

Analyst(s): MG

(Cont.)

CDPH ELAP 1644 ♦ NELAP 4033ORELAP

Angela Rydelius, Lab Manager

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-009	**1511071-009A**	**Water**	**11/02/2015 11:24**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 008		ND	4.3	50	1				11/22/2015 21:37
PCB 018/030		ND	3.4	50	1				11/22/2015 21:37
PCB 020/028		ND	4.0	50	1				11/22/2015 21:37
PCB 031		ND	2.4	50	1				11/22/2015 21:37
PCB 033		ND	2.6	50	1				11/22/2015 21:37
PCB 044/047/065		ND	11	100	1				11/22/2015 21:37
PCB 049/069		ND	4.7	100	1				11/22/2015 21:37
PCB 052		ND	3.4	50	1				11/22/2015 21:37
PCB 056		ND	3.5	50	1				11/22/2015 21:37
PCB 060		ND	3.5	50	1				11/22/2015 21:37
PCB 066		ND	2.7	50	1				11/22/2015 21:37
PCB 070/074/076		ND	8.8	200	1				11/22/2015 21:37
PCB 086/097/109/119		ND	6.1	200	1				11/22/2015 21:37
PCB 087/125		ND	6.2	200	1				11/22/2015 21:37
PCB 090/101/113		ND	5.8	200	1				11/22/2015 21:37
PCB 095		ND	2.6	200	1				11/22/2015 21:37
PCB 099		ND	2.7	100	1				11/22/2015 21:37
PCB 105		ND	2.8	50	1				11/22/2015 21:37
PCB 110/115		ND	4.8	100	1				11/22/2015 21:37
PCB 118		ND	2.8	100	1				11/22/2015 21:37
PCB 128/166		ND	3.5	100	1				11/22/2015 21:37
PCB 129/138/163		ND	6.2	200	1				11/22/2015 21:37
PCB 132		ND	2.7	50	1				11/22/2015 21:37
PCB 135/151		ND	4.2	100	1				11/22/2015 21:37
PCB 141		ND	2.6	50	1				11/22/2015 21:37
PCB 147/149		ND	3.0	100	1				11/22/2015 21:37
PCB 153/168		ND	4.6	100	1				11/22/2015 21:37
PCB 156/157		ND	5.2	100	1				11/22/2015 21:37
PCB 158		ND	2.1	50	1				11/22/2015 21:37
PCB 170		ND	1.6	50	1				11/22/2015 21:37
PCB 174		ND	3.7	50	1				11/22/2015 21:37
PCB 177		ND	1.8	50	1				11/22/2015 21:37
PCB 180/193		ND	4.4	100	1				11/22/2015 21:37
PCB 183/185		ND	3.8	100	1				11/22/2015 21:37
PCB 187		ND	2.3	50	1				11/22/2015 21:37

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-009	**1511071-009A**	**Water**	**11/02/2015 11:24**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed
PCB 194		ND	1.7	50	1				11/22/2015 21:37
PCB 195		ND	2.0	50	1				11/22/2015 21:37
PCB 201		ND	2.1	50	1				11/22/2015 21:37
PCB 203		ND	1.8	50	1				11/22/2015 21:37

Total TEQ: 0

Isotope Dilution	REC (%)	Limits	
13C-PCB 028	114	5-145	11/22/2015 21:37
13C-PCB 111	91	10-145	11/22/2015 21:37
13C-PCB 178	80	10-145	11/22/2015 21:37
Surrogate			
13C-PCB 001	75	5-145	11/22/2015 21:37
13C-PCB 003	77	5-145	11/22/2015 21:37
13C-PCB 004	62	5-145	11/22/2015 21:37
13C-PCB 015	88	5-145	11/22/2015 21:37
13C-PCB 019	64	5-145	11/22/2015 21:37
13C-PCB 037	106	5-145	11/22/2015 21:37
13C-PCB 054	61	5-145	11/22/2015 21:37
13C-PCB 077	117	10-145	11/22/2015 21:37
13C-PCB 081	115	10-145	11/22/2015 21:37
13C-PCB 104	58	10-145	11/22/2015 21:37
13C-PCB 105	97	10-145	11/22/2015 21:37
13C-PCB 114	94	10-145	11/22/2015 21:37
13C-PCB 118	94	10-145	11/22/2015 21:37
13C-PCB 123	96	10-145	11/22/2015 21:37
13C-PCB 126	102	10-145	11/22/2015 21:37
13C-PCB 155	69	10-145	11/22/2015 21:37
13C-PCB 156/157	96	10-145	11/22/2015 21:37
13C-PCB 167	98	10-145	11/22/2015 21:37
13C-PCB 169	109	10-145	11/22/2015 21:37
13C-PCB 188	51	10-145	11/22/2015 21:37
13C-PCB 189	90	10-145	11/22/2015 21:37
13C-PCB 202	55	10-145	11/22/2015 21:37
13C-PCB 205	76	10-145	11/22/2015 21:37
13C-PCB 206	63	10-145	11/22/2015 21:37
13C-PCB 208	54	10-145	11/22/2015 21:37
13C-PCB 209	56	10-145	11/22/2015 21:37

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1668C
Date Prepared:	11/18/15-11/23/15	**Analytical Method:**	E1668C
Project:	North Richmond Pump Station	**Unit:**	pg/L

40 PCB Congeners

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-009	**1511071-009A**	**Water**	**11/02/2015 11:24**	**GC36**	**113278**

Analytes	TEF WHO '05	Result	MDL	ML	DF	Ion Ratio	RRT	TEQ	Date Analyzed

Analyst(s): MG

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1631E
Date Prepared:	11/9/15	**Analytical Method:**	E1631E
Project:	North Richmond Pump Station	**Unit:**	ng/L

Mercury by CVAF

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-001	**1511071-001B**	**Water**	**11/02/2015 09:37**	**PSA2**	**112506**

Analytes	Result	RL	DF	Date Analyzed
Mercury	**37**	2.5	5	11/10/2015 11:57

Analyst(s): BBO

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-002	**1511071-002B**	**Water**	**11/02/2015 09:52**	**PSA2**	**112506**

Analytes	Result	RL	DF	Date Analyzed
Mercury	**36**	2.5	5	11/10/2015 12:22

Analyst(s): BBO

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-003	**1511071-003B**	**Water**	**11/02/2015 09:56**	**PSA2**	**112506**

Analytes	Result	RL	DF	Date Analyzed
Mercury	**42**	2.5	5	11/10/2015 12:27

Analyst(s): BBO

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-004	**1511071-004B**	**Water**	**11/02/2015 10:10**	**PSA2**	**112506**

Analytes	Result	RL	DF	Date Analyzed
Mercury	ND	0.50	1	11/10/2015 11:42

Analyst(s): BBO

(Cont.)

1534 Willow Pass Road, Pittsburg, CA 94565-1701
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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1631E
Date Prepared:	11/9/15	**Analytical Method:**	E1631E
Project:	North Richmond Pump Station	**Unit:**	ng/L

Mercury by CVAF

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-005	**1511071-005B**	**Water**	**11/02/2015 10:28**	**PSA2**	**112506**

Analytes	Result	RL	DF	Date Analyzed
Mercury	**37**	2.5	5	11/10/2015 12:47

Analyst(s): BBO

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-006	**1511071-006B**	**Water**	**11/02/2015 10:56**	**PSA2**	**112506**

Analytes	Result	RL	DF	Date Analyzed
Mercury	**31**	2.5	5	11/10/2015 12:32

Analyst(s): BBO

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-007	**1511071-007B**	**Water**	**11/02/2015 11:00**	**PSA2**	**112506**

Analytes	Result	RL	DF	Date Analyzed
Mercury	ND	0.50	1	11/10/2015 11:47

Analyst(s): BBO

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-008	**1511071-008B**	**Water**	**11/02/2015 11:31**	**PSA2**	**112506**

Analytes	Result	RL	DF	Date Analyzed
Mercury	**32**	2.5	5	11/10/2015 12:36

Analyst(s): BBO

(Cont.)

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	E1631E
Date Prepared:	11/9/15	**Analytical Method:**	E1631E
Project:	North Richmond Pump Station	**Unit:**	ng/L

Mercury by CVAF

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-009	**1511071-009B**	**Water**	**11/02/2015 11:24**	**PSA2**	**112506**

Analytes	Result	RL	DF	Date Analyzed
Mercury	ND	0.50	1	11/10/2015 11:52

Analyst(s): BBO

Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	ASTM D3977-B
Date Prepared:	11/6/15	**Analytical Method:**	ASTM D3977-B
Project:	North Richmond Pump Station	**Unit:**	mg/L

Suspended Sediment Concentration (SSC) in Water

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-001	**1511071-001D**	**Water**	**11/02/2015 09:37**	**WetChem**	**112590**

Analytes	Result	RL	DF	Date Analyzed
Suspended Sediment Concentration	**53.9**	1.00	1	11/06/2015 15:15

Analyst(s): AL

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-002	**1511071-002D**	**Water**	**11/02/2015 09:52**	**WetChem**	**112590**

Analytes	Result	RL	DF	Date Analyzed
Suspended Sediment Concentration	**53.5**	10.0	1	11/06/2015 15:20

Analyst(s): AL

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-003	**1511071-003D**	**Water**	**11/02/2015 09:56**	**WetChem**	**112590**

Analytes	Result	RL	DF	Date Analyzed
Suspended Sediment Concentration	**52.8**	1.00	1	11/06/2015 15:25

Analyst(s): AL

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-005	**1511071-005D**	**Water**	**11/02/2015 10:28**	**WetChem**	**112590**

Analytes	Result	RL	DF	Date Analyzed
Suspended Sediment Concentration	**49.5**	1.00	1	11/06/2015 15:30

Analyst(s): AL

(Cont.)

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Analytical Report

Client:	AMEC	**WorkOrder:**	1511071
Date Received:	11/2/15 20:38	**Extraction Method:**	ASTM D3977-B
Date Prepared:	11/6/15	**Analytical Method:**	ASTM D3977-B
Project:	North Richmond Pump Station	**Unit:**	mg/L

Suspended Sediment Concentration (SSC) in Water

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-006	1511071-006D	Water	11/02/2015 10:56	WetChem	112590

Analytes	Result	RL	DF	Date Analyzed
Suspended Sediment Concentration	**49.3**	1.00	1	11/06/2015 15:35

Analyst(s): AL

Client ID	Lab ID	Matrix	Date Collected	Instrument	Batch ID
NRPSIS-008	1511071-008D	Water	11/02/2015 11:31	WetChem	112590

Analytes	Result	RL	DF	Date Analyzed
Suspended Sediment Concentration	**50.4**	1.00	1	11/06/2015 15:40

Analyst(s): AL

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113093

SampleID **MB-113093** TestCode: **1668_PCB40_W** Units: **pg/L** Prep Date: **11/18/2015**
Batch ID: **113093** TestNo: **E1668C** Run ID: **GC36_151123A** Analysis Date: **11/18/2015**

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
PCB 001	ND	9.9	20				-				
PCB 003	ND	7.1	50				-				
PCB 004	ND	2.3	50				-				
PCB 008	ND	4.2	50				-				
PCB 015	ND	1.9	20				-				
PCB 018/030	ND	3.3	50				-				
PCB 019	ND	2.1	20				-				
PCB 020/028	ND	3.9	50				-				
PCB 031	ND	2.3	50				-				
PCB 033	ND	2.5	50				-				
PCB 037	2.20	1.8	20				-				JM
PCB 044/047/065	ND	10	100				-				
PCB 049/069	ND	4.6	100				-				
PCB 052	ND	3.3	50				-				
PCB 054	ND	2.6	50				-				
PCB 056	ND	3.4	50				-				
PCB 060	ND	3.4	50				-				
PCB 066	ND	2.6	50				-				
PCB 070/074/076	ND	8.6	200				-				
PCB 077	ND	2.6	50				-				
PCB 081	ND	2.2	50				-				
PCB 086/097/109/119	ND	5.9	200				-				
PCB 087/125	ND	6.0	200				-				
PCB 090/101/113	ND	5.6	200				-				
PCB 095	ND	2.5	200				-				
PCB 099	ND	2.6	100				-				
PCB 104	ND	2.7	50				-				
PCB 105	ND	2.7	50				-				
PCB 106	ND	5.3	50				-				
PCB 110/115	ND	4.7	100				-				
PCB 114	ND	3.0	50				-				
PCB 118	ND	2.7	100				-				
PCB 123	ND	3.4	50				-				
PCB 126	ND	5.5	50				-				
PCB 128/166	ND	3.4	100				-				
PCB 129/138/163	ND	6.0	200				-				
PCB 132	ND	2.6	50				-				
PCB 135/151	ND	4.1	100				-				
PCB 141	ND	2.5	50				-				
PCB 147/149	ND	2.9	100				-				
PCB 153/168	ND	4.5	100				-				
PCB 155	ND	1.9	50				-				
PCB 156/157	ND	5.1	100				-				
PCB 158	ND	2.0	50				-				
PCB 167	ND	3.7	50				-				
PCB 169	ND	2.8	50				-				

Angela Rydelius, Lab Manager

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113093

SampleID **MB-113093** TestCode: **1668_PCB40_W** Units: **pg/L** Prep Date: **11/18/2015**
Batch ID: **113093** TestNo: **E1668C** Run ID: **GC36_151123A** Analysis Date: **11/18/2015**

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
PCB 170	ND	1.6	50				-				
PCB 174	ND	3.6	50				-				
PCB 177	ND	1.8	50				-				
PCB 180/193	ND	4.3	100				-				
PCB 183/185	ND	3.7	100				-				
PCB 187	ND	2.2	50				-				
PCB 188	ND	2.0	50				-				
PCB 189	ND	4.4	50				-				
PCB 194	ND	1.7	50				-				
PCB 195	ND	1.9	50				-				
PCB 201	ND	2.0	50				-				
PCB 202	ND	4.0	100				-				
PCB 203	ND	1.8	50				-				
PCB 205	ND	5.1	50				-				
PCB 206	ND	3.9	50				-				
PCB 208	ND	4.8	50				-				
PCB 209	ND	3.7	50				-				
Isotope Dilution											
13C-PCB 028	1830			2000		91	5 - 145				
13C-PCB 111	1570			2000		78	10 - 145				
13C-PCB 178	1540			2000		77	10 - 145				
Surrogate											
13C-PCB 001	882			2000		44	5 - 145				
13C-PCB 003	860			2000		43	5 - 145				
13C-PCB 004	858			2000		43	5 - 145				
13C-PCB 015	956			2000		48	5 - 145				
13C-PCB 019	860			2000		43	5 - 145				
13C-PCB 037	1250			2000		62	5 - 145				
13C-PCB 052	2070			2000		103	5 - 145				
13C-PCB 054	956			2000		48	5 - 145				
13C-PCB 077	1400			2000		70	10 - 145				
13C-PCB 081	1400			2000		70	10 - 145				
13C-PCB 104	1080			2000		54	10 - 145				
13C-PCB 105	1410			2000		70	10 - 145				
13C-PCB 114	1400			2000		70	10 - 145				
13C-PCB 118	1400			2000		70	10 - 145				
13C-PCB 123	1410			2000		71	10 - 145				
13C-PCB 126	1390			2000		69	10 - 145				
13C-PCB 155	1300			2000		65	10 - 145				
13C-PCB 156/157	2950			4000		74	10 - 145				
13C-PCB 167	1540			2000		77	10 - 145				
13C-PCB 169	1640			2000		82	10 - 145				
13C-PCB 188	949			2000		47	10 - 145				
13C-PCB 189	1470			2000		74	10 - 145				
13C-PCB 194	2290			2000		115	10 - 145				
13C-PCB 202	951			2000		48	10 - 145				
13C-PCB 205	1300			2000		65	10 - 145				

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113093

SampleID **MB-113093** TestCode: **1668_PCB40_W** Units: **pg/L** Prep Date: **11/18/2015**
Batch ID: **113093** TestNo: **E1668C** Run ID: **GC36_151123A** Analysis Date: **11/18/2015**

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
13C-PCB 206	1020			2000		51	10 - 145				
13C-PCB 208	925			2000		46	10 - 145				
13C-PCB 209	1020			2000		51	10 - 145				

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113093

SampleID **LCS-113093** TestCode: **1668_PCB40_W** Units: **pg/L** Prep Date: **11/18/2015**
Batch ID: **113093** TestNo: **E1668C** Run ID: **GC36_151123B** Analysis Date: **11/18/2015**

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
PCB 001	1050	9.9	20	1000	0	105	60 - 135				
PCB 003	1040	7.1	50	1000	0	104	60 - 135				
PCB 004	1010	2.3	50	1000	0	101	60 - 135				
PCB 015	975	1.9	20	1000	0	98	60 - 135				
PCB 019	1000	2.1	20	1000	0	100	60 - 135				
PCB 037	1030	1.8	20	1000	0	103	60 - 135				
PCB 054	1020	2.6	50	1000	0	102	60 - 135				
PCB 077	1030	2.6	50	1000	0	103	60 - 135				
PCB 081	1030	2.2	50	1000	0	103	60 - 135				
PCB 104	1030	2.7	50	1000	0	103	60 - 135				
PCB 105	1000	2.7	50	1000	0	100	60 - 135				
PCB 114	992	3.0	50	1000	0	99	60 - 135				
PCB 118	1030	2.7	100	1000	0	103	60 - 135				
PCB 123	968	3.4	50	1000	0	97	60 - 135				
PCB 126	995	5.5	50	1000	0	100	60 - 135				
PCB 155	1010	1.9	50	1000	0	101	60 - 135				
PCB 156/157	2040	5.1	100	2000	0	102	60 - 135				
PCB 167	963	3.7	50	1000	0	96	60 - 135				
PCB 169	993	2.8	50	1000	0	99	60 - 135				
PCB 188	984	2.0	50	1000	0	98	60 - 135				
PCB 189	1000	4.4	50	1000	0	100	60 - 135				
PCB 202	995	4.0	100	1000	0	100	60 - 135				
PCB 205	1050	5.1	50	1000	0	105	60 - 135				
PCB 206	981	3.9	50	1000	0	98	60 - 135				
PCB 208	1030	4.8	50	1000	0	103	60 - 135				
PCB 209	1020	3.7	50	1000	0	103	60 - 135				
Isotope Dilution											
13C-PCB 028	1920			2000		96	15 - 145				
13C-PCB 111	1630			2000		81	40 - 145				
13C-PCB 178	1660			2000		83	40 - 145				
Surrogate											
13C-PCB 001	1860			2000		93	15 - 145				
13C-PCB 003	1680			2000		84	15 - 145				
13C-PCB 004	1650			2000		82	15 - 145				
13C-PCB 015	1630			2000		81	15 - 145				
13C-PCB 019	1600			2000		80	15 - 145				
13C-PCB 037	1660			2000		83	15 - 145				
13C-PCB 054	1610			2000		81	15 - 145				
13C-PCB 077	1640			2000		82	40 - 145				
13C-PCB 081	1710			2000		86	40 - 145				
13C-PCB 104	1730			2000		87	40 - 145				
13C-PCB 105	1740			2000		87	40 - 145				
13C-PCB 114	1740			2000		87	40 - 145				
13C-PCB 118	1760			2000		88	40 - 145				
13C-PCB 123	1790			2000		90	40 - 145				
13C-PCB 126	1540			2000		77	40 - 145				
13C-PCB 155	1980			2000		99	40 - 145				

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113093

SampleID **LCS-113093** TestCode: **1668_PCB40_W** Units: **pg/L** Prep Date: **11/18/2015**
Batch ID: **113093** TestNo: **E1668C** Run ID: **GC36_151123B** Analysis Date: **11/18/2015**

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
13C-PCB 156/157	3580			4000		90	40 - 145				
13C-PCB 167	1870			2000		94	40 - 145				
13C-PCB 169	1640			2000		82	40 - 145				
13C-PCB 188	1740			2000		87	40 - 145				
13C-PCB 189	1840			2000		92	40 - 145				
13C-PCB 202	1600			2000		80	40 - 145				
13C-PCB 205	1640			2000		82	40 - 145				
13C-PCB 206	1450			2000		73	40 - 145				
13C-PCB 208	1340			2000		67	40 - 145				
13C-PCB 209	1460			2000		73	40 - 145				

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Angela Rydelius, Lab Manager

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113278

SampleID **MB-113278** TestCode: **1668_PCB40_W** Units: **pg/L** Prep Date: **11/23/2015**
Batch ID: **113278** TestNo: **E1668C** Run ID: **GC36_151123C** Analysis Date: **11/22/2015**

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
PCB 001	ND	9.9	20				-				
PCB 003	ND	7.1	50				-				
PCB 004	ND	2.3	50				-				
PCB 008	ND	4.2	50				-				
PCB 015	ND	1.9	20				-				
PCB 018/030	3.60	3.3	50				-				J
PCB 019	ND	2.1	20				-				
PCB 020/028	6.20	3.9	50				-				J
PCB 031	3.80	2.3	50				-				JM
PCB 033	ND	2.5	50				-				
PCB 037	ND	1.8	20				-				
PCB 044/047/065	ND	10	100				-				
PCB 049/069	ND	4.6	100				-				
PCB 052	ND	3.3	50				-				
PCB 054	ND	2.6	50				-				
PCB 056	ND	3.4	50				-				
PCB 060	ND	3.4	50				-				
PCB 066	ND	2.6	50				-				
PCB 070/074/076	ND	8.6	200				-				
PCB 077	ND	2.6	50				-				
PCB 081	ND	2.2	50				-				
PCB 086/097/109/119	ND	5.9	200				-				
PCB 087/125	ND	6.0	200				-				
PCB 090/101/113	ND	5.6	200				-				
PCB 095	ND	2.5	200				-				
PCB 099	ND	2.6	100				-				
PCB 104	ND	2.7	50				-				
PCB 105	ND	2.7	50				-				
PCB 106	ND	5.3	50				-				
PCB 110/115	ND	4.7	100				-				
PCB 114	ND	3.0	50				-				
PCB 118	ND	2.7	100				-				
PCB 123	ND	3.4	50				-				
PCB 126	ND	5.5	50				-				
PCB 128/166	ND	3.4	100				-				
PCB 129/138/163	ND	6.0	200				-				
PCB 132	ND	2.6	50				-				
PCB 135/151	ND	4.1	100				-				
PCB 141	ND	2.5	50				-				
PCB 147/149	ND	2.9	100				-				
PCB 153/168	ND	4.5	100				-				
PCB 155	ND	1.9	50				-				
PCB 156/157	ND	5.1	100				-				
PCB 158	ND	2.0	50				-				
PCB 167	ND	3.7	50				-				
PCB 169	ND	2.8	50				-				
PCB 170	ND	1.6	50				-				

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113278

SampleID MB-113278	TestCode: 1668_PCB40_W	Units: pg/L	Prep Date: 11/23/2015
Batch ID: 113278	TestNo: E1668C	Run ID: GC36_151123C	Analysis Date: 11/22/2015

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
PCB 174	ND	3.6	50				-				
PCB 177	ND	1.8	50				-				
PCB 180/193	ND	4.3	100				-				
PCB 183/185	ND	3.7	100				-				
PCB 187	ND	2.2	50				-				
PCB 188	ND	2.0	50				-				
PCB 189	ND	4.4	50				-				
PCB 194	ND	1.7	50				-				
PCB 195	ND	1.9	50				-				
PCB 201	ND	2.0	50				-				
PCB 202	ND	4.0	100				-				
PCB 203	ND	1.8	50				-				
PCB 205	ND	5.1	50				-				
PCB 206	ND	3.9	50				-				
PCB 208	ND	4.8	50				-				
PCB 209	ND	3.7	50				-				
Isotope Dilution											
13C-PCB 028	2140			2000		107	5 - 145				
13C-PCB 111	1760			2000		88	10 - 145				
13C-PCB 178	1570			2000		79	10 - 145				
Surrogate											
13C-PCB 001	1100			2000		55	5 - 145				
13C-PCB 003	1150			2000		58	5 - 145				
13C-PCB 004	956			2000		48	5 - 145				
13C-PCB 015	1450			2000		73	5 - 145				
13C-PCB 019	1080			2000		54	5 - 145				
13C-PCB 037	1840			2000		92	5 - 145				
13C-PCB 052	1820			2000		91	5 - 145				
13C-PCB 054	1060			2000		53	5 - 145				
13C-PCB 077	2140			2000		107	10 - 145				
13C-PCB 081	2090			2000		105	10 - 145				
13C-PCB 104	1060			2000		53	10 - 145				
13C-PCB 105	1800			2000		90	10 - 145				
13C-PCB 114	1740			2000		87	10 - 145				
13C-PCB 118	1780			2000		89	10 - 145				
13C-PCB 123	1780			2000		89	10 - 145				
13C-PCB 126	1820			2000		91	10 - 145				
13C-PCB 155	1340			2000		67	10 - 145				
13C-PCB 156/157	3580			4000		89	10 - 145				
13C-PCB 167	1830			2000		91	10 - 145				
13C-PCB 169	1940			2000		97	10 - 145				
13C-PCB 188	1070			2000		53	10 - 145				
13C-PCB 189	1680			2000		84	10 - 145				
13C-PCB 194	2200			2000		110	10 - 145				
13C-PCB 202	1160			2000		58	10 - 145				
13C-PCB 205	1470			2000		73	10 - 145				
13C-PCB 206	1270			2000		64	10 - 145				

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113278

SampleID **MB-113278**	TestCode: **1668_PCB40_W**	Units: **pg/L**	Prep Date: **11/23/2015**
Batch ID: **113278**	TestNo: **E1668C**	Run ID: **GC36_151123C**	Analysis Date: **11/22/2015**

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
13C-PCB 208	1080			2000		54	10 - 145				
13C-PCB 209	1140			2000		57	10 - 145				

CDPH ELAP 1644 ♦ NELAP 4033ORELAP

Angela Rydelius, Lab Manager

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113278

SampleID **LCS-113278** TestCode: **1668_PCB40_W** Units: **pg/L** Prep Date: **11/23/2015**
Batch ID: **113278** TestNo: **E1668C** Run ID: **GC36_151123D** Analysis Date: **11/22/2015**

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
PCB 001	1080	9.9	20	1000	0	107	60 - 135				
PCB 003	1060	7.1	50	1000	0	106	60 - 135				
PCB 004	1030	2.3	50	1000	0	103	60 - 135				
PCB 015	1040	1.9	20	1000	0	104	60 - 135				
PCB 019	1040	2.1	20	1000	0	104	60 - 135				
PCB 037	1050	1.8	20	1000	0	105	60 - 135				
PCB 054	1050	2.6	50	1000	0	105	60 - 135				
PCB 077	1010	2.6	50	1000	0	101	60 - 135				
PCB 081	1040	2.2	50	1000	0	104	60 - 135				
PCB 104	1040	2.7	50	1000	0	104	60 - 135				
PCB 105	1010	2.7	50	1000	0	101	60 - 135				
PCB 114	1000	3.0	50	1000	0	100	60 - 135				
PCB 118	1030	2.7	100	1000	0	103	60 - 135				
PCB 123	992	3.4	50	1000	0	99	60 - 135				
PCB 126	995	5.5	50	1000	0	100	60 - 135				
PCB 155	1020	1.9	50	1000	0	103	60 - 135				
PCB 156/157	2000	5.1	100	2000	0	100	60 - 135				
PCB 167	967	3.7	50	1000	0	97	60 - 135				
PCB 169	965	2.8	50	1000	0	97	60 - 135				
PCB 188	1030	2.0	50	1000	0	103	60 - 135				
PCB 189	1000	4.4	50	1000	0	100	60 - 135				
PCB 202	1020	4.0	100	1000	0	101	60 - 135				
PCB 205	1020	5.1	50	1000	0	102	60 - 135				
PCB 206	993	3.9	50	1000	0	99	60 - 135				
PCB 208	1000	4.8	50	1000	0	100	60 - 135				
PCB 209	1020	3.7	50	1000	0	102	60 - 135				
Isotope Dilution											
13C-PCB 028	2020			2000		101	15 - 145				
13C-PCB 111	1460			2000		73	40 - 145				
13C-PCB 178	1370			2000		69	40 - 145				
Surrogate											
13C-PCB 001	972			2000		49	15 - 145				
13C-PCB 003	1030			2000		51	15 - 145				
13C-PCB 004	874			2000		44	15 - 145				
13C-PCB 015	1170			2000		59	15 - 145				
13C-PCB 019	894			2000		45	15 - 145				
13C-PCB 037	1400			2000		70	15 - 145				
13C-PCB 054	903			2000		45	15 - 145				
13C-PCB 077	1390			2000		69	40 - 145				
13C-PCB 081	1380			2000		69	40 - 145				
13C-PCB 104	880			2000		44	40 - 145				
13C-PCB 105	1100			2000		55	40 - 145				
13C-PCB 114	1110			2000		55	40 - 145				
13C-PCB 118	1140			2000		57	40 - 145				
13C-PCB 123	1150			2000		58	40 - 145				
13C-PCB 126	1060			2000		53	40 - 145				
13C-PCB 155	1380			2000		69	40 - 145				

CLIENT: AMEC
Work Order: 1511071
Project: North Richmond Pump Station

ANALYTICAL QC SUMMARY REPORT

BatchID: 113278

SampleID **LCS-113278**	TestCode: **1668_PCB40_W**	Units: **pg/L**	Prep Date: **11/23/2015**
Batch ID: **113278**	TestNo: **E1668C**	Run ID: **GC36_151123D**	Analysis Date: **11/22/2015**

Analyte	Result	MDL	ML	SPKValue	SPKRefVal	%REC	Limits	RPDRefVal	%RPD	RPDLimit	Qual
13C-PCB 156/157	2230			4000		56	40 - 145				
13C-PCB 167	1160			2000		58	40 - 145				
13C-PCB 169	1160			2000		58	40 - 145				
13C-PCB 188	963			2000		48	40 - 145				
13C-PCB 189	1210			2000		60	40 - 145				
13C-PCB 202	773			2000		39	40 - 145				S
13C-PCB 205	1100			2000		55	40 - 145				
13C-PCB 206	964			2000		48	40 - 145				
13C-PCB 208	759			2000		38	40 - 145				S
13C-PCB 209	914			2000		46	40 - 145				

Quality Control Report

Client:	AMEC	**WorkOrder:**	1511071
Date Prepared:	11/9/15	**BatchID:**	112506
Date Analyzed:	11/10/15	**Extraction Method:**	E1631E
Instrument:	PSA2	**Analytical Method:**	E1631E
Matrix:	Water	**Unit:**	ng/L
Project:	North Richmond Pump Station	**Sample ID:**	MB/LCS-112506 1511071-001BMS/MSD

QC Summary Report for Mercury by CVAF

Analyte	MB Result	LCS Result	RL	SPK Val	MB SS %REC	LCS %REC	LCS Limits
Mercury	ND	2.45	0.50	2.5	-	98	80-120

Analyte	MS Result	MSD Result	SPK Val	SPKRef Val	MS %REC	MSD %REC	MS/MSD Limits	RPD	RPD Limit
Mercury	132	138	100	36.65	95	101	80-120	4.45	20

McCampbell Analytical, Inc.
1534 Willow Pass Rd
Pittsburg, CA 94565-1701
(925) 252-9262

CHAIN-OF-CUSTODY RECORD

WorkOrder: 1511071 **ClientCode: AMEC**

☐ WaterTrax ☐ WriteOn ☐ EDF ☐ Excel ■ EQuIS ☑ Email ☐ HardCopy ☐ ThirdParty ☐ J-flag

Report to:
Emily Sportsman
AMEC
2101 Webster Street, 12th Floor
Oakland, CA 94612
(510) 663-4232 FAX: 510-663-4141

Email: emily.sportsman@amec.com
cc/3rd Party: khalil.abusaba@amec.com;
PO:
ProjectNo: North Richmond Pump Station

Bill to:
Accounts Payable
AMEC
2101 Webster Street, 12th Floor
Oakland, CA 94612

Requested TATs: **15 days; 5 days;**

Date Received: **11/02/2015**
Date Printed: **11/05/2015**

Lab ID	Client ID	Matrix	Collection Date	Hold	Requested Tests (See legend below) 1	2	3	4	5	6	7	8	9	10	11	12
1511071-001	NRPSIS-001	Water	11/2/2015 9:37	☐	A	B	C	D								
1511071-002	NRPSIS-002	Water	11/2/2015 9:52	☐	A	B	C	D								
1511071-003	NRPSIS-003	Water	11/2/2015 9:56	☐	A	B	C	D								
1511071-004	NRPSIS-004	Water	11/2/2015 10:10	☐	A	B	C									
1511071-005	NRPSIS-005	Water	11/2/2015 10:28	☐	A	B	C	D								
1511071-006	NRPSIS-006	Water	11/2/2015 10:56	☐	A	B	C	D								
1511071-007	NRPSIS-007	Water	11/2/2015 11:00	☐	A	B	C									
1511071-008	NRPSIS-008	Water	11/2/2015 11:31	☐	A	B	C	D								
1511071-009	NRPSIS-009	Water	11/2/2015 11:24	☐	A	B	C									

Test Legend:

1	1668_PCB40_W	2	HGPSA1_W	3	MethylMercury_W	4	SSC_W
5		6		7		8	
9		10		11		12	

Prepared by: Maria Venegas

Comments:

NOTE: Soil samples are discarded 60 days after results are reported unless other arrangements are made (Water samples are 30 days).
Hazardous samples will be returned to client or disposed of at client expense.

McCampbell Analytical, Inc.
"When Quality Counts"

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Toll Free Telephone: (877) 252-9262 / Fax: (925) 252-9269
http://www.mccampbell.com / E-mail: main@mccampbell.com

WORK ORDER SUMMARY

Client Name: AMEC **QC Level:** **Work Order:** 1511071
Project: North Richmond Pump Station **Client Contact:** Emily Sportsman **Date Received:** 11/2/2015
Comments: **Contact's Email:** emily.sportsman@amec.com

☐ WaterTrax ☐ WriteOn ☐ EDF ☐ Excel ☐ Fax ☑ Email ☐ HardCopy ☐ ThirdParty ☐ J-flag

Lab ID	Client ID	Matrix	Test Name	Containers /Composites	Bottle & Preservative	De-chlorinated	Collection Date & Time	TAT	Sediment Content	Hold	SubOut
1511071-001A	NRPSIS-001	Water	E1668C (40 PCB Congeners)	2	1LA	☐	11/2/2015 9:37	15 days	Present	☐	
1511071-001B	NRPSIS-001	Water	E1631E (Mercury by CVAF)	1	500mL CG, Pre-Cl w/ HCl	☐	11/2/2015 9:37	5 days	Present	☐	
1511071-001C	NRPSIS-001	Water	EM1630 (Methyl Mercury)	1	500mL HDPE, Pre-Cl	☐	11/2/2015 9:37	5 days	Present	☐	SubOut
1511071-001D	NRPSIS-001	Water	ASTM D3977-B (SSC)	1	1L HDPE, unprsv.	☐	11/2/2015 9:37	5 days	Present	☐	
1511071-002A	NRPSIS-002	Water	E1668C (40 PCB Congeners)	2	1LA	☐	11/2/2015 9:52	15 days	Present	☐	
1511071-002B	NRPSIS-002	Water	E1631E (Mercury by CVAF)	1	500mL CG, Pre-Cl w/ HCl	☐	11/2/2015 9:52	5 days	Present	☐	
1511071-002C	NRPSIS-002	Water	EM1630 (Methyl Mercury)	1	500mL HDPE, Pre-Cl	☐	11/2/2015 9:52	5 days	Present	☐	SubOut
1511071-002D	NRPSIS-002	Water	ASTM D3977-B (SSC)	1	1L HDPE, unprsv.	☐	11/2/2015 9:52	5 days	Present	☐	
1511071-003A	NRPSIS-003	Water	E1668C (40 PCB Congeners)	2	1LA	☐	11/2/2015 9:56	15 days	Present	☐	
1511071-003B	NRPSIS-003	Water	E1631E (Mercury by CVAF)	1	500mL CG, Pre-Cl w/ HCl	☐	11/2/2015 9:56	5 days	Present	☐	
1511071-003C	NRPSIS-003	Water	EM1630 (Methyl Mercury)	1	500mL HDPE, Pre-Cl	☐	11/2/2015 9:56	5 days	Present	☐	SubOut
1511071-003D	NRPSIS-003	Water	ASTM D3977-B (SSC)	1	1L HDPE, unprsv.	☐	11/2/2015 9:56	5 days	Present	☐	
1511071-004A	NRPSIS-004	Water	E1668C (40 PCB Congeners)	2	1LA	☐	11/2/2015 10:10	15 days	None	☐	
1511071-004B	NRPSIS-004	Water	E1631E (Mercury by CVAF)	1	500mL CG, Pre-Cl w/ HCl	☐	11/2/2015 10:10	5 days	None	☐	
1511071-004C	NRPSIS-004	Water	EM1630 (Methyl Mercury)	1	500mL HDPE, Pre-Cl	☐	11/2/2015 10:10	5 days	None	☐	SubOut
1511071-005A	NRPSIS-005	Water	E1668C (40 PCB Congeners)	2	1LA	☐	11/2/2015 10:28	15 days	Present	☐	

NOTES: **- STLC and TCLP extractions require 2 days to complete; therefore, all TATs begin after the extraction is completed (i.e., One-day TAT yields results in 3 days from sample submission).**

- MAI assumes that all material present in the provided sampling container is considered part of the sample - MAI does not exclude any material from the sample prior to sample preparation unless requested in writing by the client.

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http://www.mccampbell.com / E-mail: main@mccampbell.com

WORK ORDER SUMMARY

Client Name: AMEC **QC Level:** **Work Order:** 1511071
Project: North Richmond Pump Station **Client Contact:** Emily Sportsman **Date Received:** 11/2/2015
Comments: **Contact's Email:** emily.sportsman@amec.com

☐ WaterTrax ☐ WriteOn ☐ EDF ☐ Excel ☐ Fax ☑ Email ☐ HardCopy ☐ ThirdParty ☐ J-flag

Lab ID	Client ID	Matrix	Test Name	Containers /Composites	Bottle & Preservative	De-chlorinated	Collection Date & Time	TAT	Sediment Content	Hold	SubOut
1511071-005B	NRPSIS-005	Water	E1631E (Mercury by CVAF)	1	500mL CG, Pre-Cl w/ HCl	☐	11/2/2015 10:28	5 days	Present	☐	
1511071-005C	NRPSIS-005	Water	EM1630 (Methyl Mercury)	1	500mL HDPE, Pre-Cl	☐	11/2/2015 10:28	5 days	Present	☐	SubOut
1511071-005D	NRPSIS-005	Water	ASTM D3977-B (SSC)	1	1L HDPE, unprsv.	☐	11/2/2015 10:28	5 days	Present	☐	
1511071-006A	NRPSIS-006	Water	E1668C (40 PCB Congeners)	2	1LA	☐	11/2/2015 10:56	15 days	Present	☐	
1511071-006B	NRPSIS-006	Water	E1631E (Mercury by CVAF)	1	500mL CG, Pre-Cl w/ HCl	☐	11/2/2015 10:56	5 days	Present	☐	
1511071-006C	NRPSIS-006	Water	EM1630 (Methyl Mercury)	1	500mL HDPE, Pre-Cl	☐	11/2/2015 10:56	5 days	Present	☐	SubOut
1511071-006D	NRPSIS-006	Water	ASTM D3977-B (SSC)	1	1L HDPE, unprsv.	☐	11/2/2015 10:56	5 days	Present	☐	
1511071-007A	NRPSIS-007	Water	E1668C (40 PCB Congeners)	2	1LA	☐	11/2/2015 11:00	15 days	None	☐	
1511071-007B	NRPSIS-007	Water	E1631E (Mercury by CVAF)	1	500mL CG, Pre-Cl w/ HCl	☐	11/2/2015 11:00	5 days	None	☐	
1511071-007C	NRPSIS-007	Water	EM1630 (Methyl Mercury)	1	500mL HDPE, Pre-Cl	☐	11/2/2015 11:00	5 days	None	☐	SubOut
1511071-008A	NRPSIS-008	Water	E1668C (40 PCB Congeners)	2	1LA	☐	11/2/2015 11:31	15 days		☐	
1511071-008B	NRPSIS-008	Water	E1631E (Mercury by CVAF)	1	500mL CG, Pre-Cl w/ HCl	☐	11/2/2015 11:31	5 days		☐	
1511071-008C	NRPSIS-008	Water	EM1630 (Methyl Mercury)	1	500mL HDPE, Pre-Cl	☐	11/2/2015 11:31	5 days		☐	SubOut
1511071-008D	NRPSIS-008	Water	ASTM D3977-B (SSC)	1	1L HDPE, unprsv.	☐	11/2/2015 11:31	5 days		☐	
1511071-009A	NRPSIS-009	Water	E1668C (40 PCB Congeners)	2	1LA	☐	11/2/2015 11:24	15 days	None	☐	
1511071-009B	NRPSIS-009	Water	E1631E (Mercury by CVAF)	1	500mL CG, Pre-Cl w/ HCl	☐	11/2/2015 11:24	5 days	None	☐	

NOTES: - STLC and TCLP extractions require 2 days to complete; therefore, all TATs begin after the extraction is completed (i.e., One-day TAT yields results in 3 days from sample submission).

- MAI assumes that all material present in the provided sampling container is considered part of the sample - MAI does not exclude any material from the sample prior to sample preparation unless requested in writing by the client.

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http://www.mccampbell.com / E-mail: main@mccampbell.com

WORK ORDER SUMMARY

Client Name: AMEC **QC Level:** **Work Order:** 1511071

Project: North Richmond Pump Station **Client Contact:** Emily Sportsman **Date Received:** 11/2/2015

Comments: **Contact's Email:** emily.sportsman@amec.com

☐ WaterTrax ☐ WriteOn ☐ EDF ☐ Excel ☐ Fax ☑ Email ☐ HardCopy ☐ ThirdParty ☐ J-flag

Lab ID	Client ID	Matrix	Test Name	Containers /Composites	Bottle & Preservative	De-chlorinated	Collection Date & Time	TAT	Sediment Content	Hold	SubOut
1511071-009C	NRPSIS-009	Water	EM1630 (Methyl Mercury)	1	500mL HDPE, Pre-Cl	☐	11/2/2015 11:24	5 days	None	☐	SubOut

NOTES: - STLC and TCLP extractions require 2 days to complete; therefore, all TATs begin after the extraction is completed (i.e., One-day TAT yields results in 3 days from sample submission).

- MAI assumes that all material present in the provided sampling container is considered part of the sample - MAI does not exclude any material from the sample prior to sample preparation unless requested in writing by the client.

1511071

CHAIN-OF-CUSTODY RECORD

17697

PROJECT NAME: North Richmond Pump Station	DATE: 2Nov — PAGE 1 OF 1
PROJECT NUMBER:	LABORATORY NAME: McCampbell
CLIENT INFORMATION:	REPORTING REQUIREMENTS: See email
RESULTS TO: see comments	LABORATORY ADDRESS: 1534 Willow Pass Rd, Pittsburg, CA 94565
TURNAROUND TIME: standard	
SAMPLE SHIPMENT METHOD: Courier	LABORATORY CONTACT: Rosa Venegas
	LABORATORY PHONE NUMBER: 925-252-9262
GEOTRACKER REQUIRED: YES / NO (NO circled)	SITE SPECIFIC GLOBAL ID NO.

SAMPLERS (SIGNATURE): E. Sportsman, K. AbuSaba

ANALYSES

DATE	TIME	SAMPLE NUMBER	SSC	PCB	Total Hg	Methyl Hg	CONTAINER TYPE AND SIZE	Soil (S), Water (W), Vapor (V), or Other (O)	Filtered	Preservative Type	Cooled	MS/MSD	No. of Containers	ADDITIONAL COMMENTS
2Nov	9:37	NRPS15-001	✓	✓	✓	✓		W	N		Y			
↓	9:52	002	✓	✓	✓	✓		↓	↓		↓			
↓	9:56	003	✓	✓	✓	✓		↓	↓		↓			
↓	10:10	004		✓	✓	✓		↓	↓		↓			
↓	10:28	005	✓	✓	✓	✓		↓	↓		↓			
↓	10:56	006	✓	✓	✓	✓		↓	↓		↓			
↓	11:00	007		✓	✓	✓		↓	↓		↓			
↓	11:31	008	✓	✓	✓	✓		↓	↓		↓			
↓	11:24	009		✓	✓	✓		↓	↓		↓			
			6	18	9	9 = 42 bottles								

RELINQUISHED BY:	DATE	TIME	RECEIVED BY:	DATE	TIME
SIGNATURE: [signature] / PRINTED NAME: E. Sportsman / COMPANY: AFW	2Nov	2:34	SIGNATURE: [signature] / PRINTED NAME: Julio Venegas / COMPANY: McCampbell	11/2	1750
SIGNATURE: [signature] / PRINTED NAME: Julio Venegas / COMPANY: McCampbell	11/2/15	16:00	SIGNATURE: / PRINTED NAME: / COMPANY:		
SIGNATURE: [signature] / PRINTED NAME: / COMPANY:			SIGNATURE: [signature] / PRINTED NAME: Jena Alfaro / COMPANY: MAI		

TOTAL NUMBER OF CONTAINERS: 42

SAMPLING COMMENTS: 3 coolers

1L plastic SSC, 2x 1L Amber PCB

1x 500mL THg 1x 500mL Methyl Hg

Results to: Khalil.AbuSaba@amecfw.com

emily.sportsman@amecfw.com

ICE/t° 4.7

GOOD CONDITION ___ APPROPRIATE

HEAD SPACE ABSENT ___ CONTAINERS ___

DECHLORINATED IN LAB ___ PRESERVED IN LAB ___

PRESERVATION | VOAS | O & G | METALS | OTHER

amec

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http://www.mccampbell.com / E-mail: main@mccampbell.com

Sample Receipt Checklist

Client Name:	**AMEC**	Date and Time Received:	**11/2/2015 8:38:58 PM**
Project Name:	**North Richmond Pump Station**	LogIn Reviewed by:	Maria Venegas
WorkOrder №:	**1511071** Matrix: Water	Carrier:	Courier

Chain of Custody (COC) Information

Chain of custody present?	Yes ☑	No ☐	
Chain of custody signed when relinquished and received?	Yes ☑	No ☐	
Chain of custody agrees with sample labels?	Yes ☑	No ☐	
Sample IDs noted by Client on COC?	Yes ☑	No ☐	
Date and Time of collection noted by Client on COC?	Yes ☑	No ☐	
Sampler's name noted on COC?	Yes ☑	No ☐	

Sample Receipt Information

Custody seals intact on shipping container/cooler?	Yes ☐	No ☐	NA ☑
Shipping container/cooler in good condition?	Yes ☑	No ☐	
Samples in proper containers/bottles?	Yes ☑	No ☐	
Sample containers intact?	Yes ☑	No ☐	
Sufficient sample volume for indicated test?	Yes ☑	No ☐	

Sample Preservation and Hold Time (HT) Information

All samples received within holding time?	Yes ☑	No ☐	
Sample/Temp Blank temperature	Temp: 4.7°C		NA ☐
Water - VOA vials have zero headspace / no bubbles?	Yes ☐	No ☐	NA ☑
Sample labels checked for correct preservation?	Yes ☑	No ☐	
pH acceptable upon receipt (Metal: <2; 522: <4; 218.7: >8)?	Yes ☐	No ☐	NA ☑
Samples Received on Ice?	Yes ☑	No ☐	
	(Ice Type: WET ICE)		

UCMR3 Samples:

Total Chlorine tested and acceptable upon receipt for EPA 522?	Yes ☐	No ☐	NA ☑
Free Chlorine tested and acceptable upon receipt for EPA 218.7, 300.1, 537, 539?	Yes ☐	No ☐	NA ☑

** NOTE: If the "No" box is checked, see comments below.*

Comments:

amec foster wheeler

APPENDIX B

Field Notes

2 Nov

North Richmond Pump Station
Stormwater diversion

9:10 on site. Urbanfire - has permission to divert.
Diversion in place

9:26 turned pump on @ ~ 9am
flow is 'choppy' due to debris, leaves, etc getting into line

pump @ ~ 212 gpm
based on flow meter

Samples will be
NRPS-15-001
NRPS15-001

SSC		1L plastic
methyl-Hg		500mL plastic w/ acid
THg		1L glass pre-preserved
PCB	2X	1L amber

9:37 start collecting
NRPS 15-001

9:52 NRPS 15-002
~~dup 001~~

9:56
NRPS15-003 field dup

10:10 NRPS15-004 field blank
w/DI
not for SSC (PCB & Hg only)

10:28 NRPS-005

10:56 NRPS-006

11:00 NRPS-007 field blank
no SSC
PCB & Hg only

11:31 NRPS-008

11:24 NRPS-009 field blank
no SSC
Hg & PCB only

large pumps did NOT turn on during diversion.

small pump 'kept up'

finished sampling ~11:30

Contra Costa Clean Water Program

Pollutants of Concern Integrated Monitoring Report: Water Years 2014-2019

March 18, 2020

Contra Costa Clean Water Program
255 Glacier Drive
Martinez, California 94553
Tel (925) 313-2360 • Fax (925) 313-2301
www.cccleanwater.org

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Contra Costa Clean Water Program

Pollutants of Concern Integrated Monitoring Report: Water Years 2014-2019

March 18, 2020

Prepared for

Contra Costa Clean Water Program
255 Glacier Drive
Martinez, California 94553

Contra Costa Clean Water Program Participants

- Cities of Antioch, Brentwood, Clayton, Concord, Danville (Town), El Cerrito, Hercules, Lafayette, Martinez, Moraga (Town), Oakley, Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon, and Walnut Creek
- Contra Costa County
- Contra Costa County Flood Control & Water Conservation District

Prepared by

ADH Environmental
3065 Porter Street, Suite 101
Soquel, California 95073

and

Wood Environment & Infrastructure Solutions, Inc.
180 Grand Avenue, Suite 1100
Oakland, California 94612

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Acronyms and Abbreviations

BASMAA	Bay Area Stormwater Management Agencies Association
Bay	San Francisco Bay
Bay Area	San Francisco Bay Area
BMP	best management practice
CCCWP	Contra Costa Clean Water Program
CVRWQCB	Central Valley Regional Water Quality Control Board
Delta	Sacramento-San Joaquín River Delta
EPA	United States Environmental Protection Agency
HDS	hydrodynamic separator
IMR	Integrated Monitoring Report
LID	low impact development
MeHg	methylmercury
MPC	Monitoring and Pollutants of Concern
MRP	municipal regional stormwater permit
MS4	municipal separate storm sewer system
NPDES	National Polluant Discharge Elimination System
O&M	operations and maintenance
PCBs	polychlorinated biphenyl congeners
POC	pollutants of concern
ppb	parts per billion
PSD	particle size distribution
RAA	reasonable assurance analysis
RMP	Regional Monitoring Program for Water Quality in San Francisco Bay
RWQCB	Regional Water Quality Control Board
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SSC	suspended sediment concentration
SSID	stressors/sources identification
SWRCB	State Water Resources Control Board
TMDL	total maximum daily load
TOC	total organic carbon
WTP	wastewater treatment plant
WY	water year

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1. INTRODUCTION

This integrated report summarizes pollutants of concern (POC) monitoring conducted by Contra Costa Clean Water Program (CCCWP) during water years 2014-2019 (Oct. 1-Sep. 30 of each year). This report fulfills Provision C.8.h.iv of the Municipal Regional Stormwater Permit (MRP 2.0, Order R2-2015-0049) issued in 2015 by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB, 2015).

1.1 Monitoring Goals

CCCWP Permittees prioritize monitoring pollutants of concern with the goal of identifying reasonable and foreseeable means of achieving load reductions of pollutants required by total maximum daily loads (TMDLs). TMDLs are watershed plans to attain water quality goals developed and established by the San Francisco Bay Regional Water Quality Control Board. The two most prominent TMDLs in driving stormwater monitoring, source control, and treatment projects under MRP 2.0 are the Mercury TMDL and the Polychlorinated Biphenyl (PCBs) TMDL. In the interest of protecting the beneficial uses of the surface waters for people and wildlife dependent on San Francisco Bay (the Bay) for food, these regulatory plans are intended to reduce concentrations of mercury and PCBs in fish within the Bay.

Mercury and PCBs tend to bind to sediments. The principal means of transport from watersheds is via sediments washed into the Municipal Separate Storm Sewer System (MS4); therefore, an important focus of POC monitoring is identifying the most significant sources of contaminated sediments to the MS4. An additional focus is quantifying the effectiveness of control measures. The highest POC monitoring priorities for Permittees are answering these two basic TMDL implementation questions: where are the most significant sources of pollutants of concern, and what can be done to control them?

The SFBRWQCB framed those two priority management information needs, along with three others, in MRP 2.0 as follows:

1. ***Source Identification*** — Identify which sources or watershed source areas provide the greatest opportunities for reductions of POCs in urban stormwater runoff.
2. ***Contributions to Bay Impairment*** — Identify which watershed source areas contribute most to the impairment of San Francisco Bay beneficial uses (due to source intensity and sensitivity of discharge location).
3. ***Management Action Effectiveness*** — Provide support for planning future management actions or evaluating the effectiveness or impacts of existing management actions.
4. ***Loads and Status*** — Provide information on POC loads, concentrations, and presence in local tributaries or urban stormwater discharges.

5. Trends	Evaluate trends in POC loading to San Francisco Bay and POC concentrations in urban stormwater discharges or local tributaries over time.

Provision C.8.f of the MRP does not specify monitoring details; rather, it requires a total number of samples for different pollutant types to be monitored over the permit term, along with yearly minimum numbers of samples for each POC. The effort is to be applied to the five management information needs listed above.

The MRP requires all stormwater programs to collectively reduce PCBs from stormwater by 3 kg per year. This makes management information needs 1 (sources) and 3 (effectiveness) the highest priorities for Permittees to maintain compliance. Part of management information need 2 (watershed areas which contribute most to impairment) is also directly related to achieving load reductions. In order to prioritize management actions, Permittees need to know which specific watersheds or sub-catchments are the greatest density of source areas or average sediment pollutant concentrations.

Other aspects of the five management information needs are not directly related to complying with the PCB load reduction requirement of 3 kg per year by 2020. Knowing which areas of the Bay are most sensitive (second part of management information need 2) is interesting from a planning perspective, but nothing in the language of the MRP indicates extra credit would be given for reducing loads to sensitive areas. Likewise, long-term trends of POC concentrations in urban stormwater may be interesting to follow, but short-term actions are a higher priority to comply with the numeric requirements of this permit and to make progress toward improving long-term trends. For this reason, the sensitive areas aspect of management information need 2 and the trends analysis in management information need 5 is mostly addressed by funding pilot and special studies implemented by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP).

Thinking more broadly about management questions helps address multiple questions with the same effort. For example, by identifying specific source areas through management information need 1, the concept emerged that old industrial areas contribute relatively greater amounts of PCBs per unit area. That information is responsive to management information need 2 (areas which contribute the most to impairment). Over time, source area information is aggregated into load estimates, which inform management information need 4 (loads and status). As progress is made on abating source areas and implementing green infrastructure projects, load reduction information is developed responsive to management information need 5 (trends). The loads and status aspect (management information need 4) involves watershed modeling using monitoring data to estimate current loads of POCs and potential long-term load reductions which may be achieved through source control and stormwater treatment. This addresses long-term planning to understand how implementation of stormwater treatment through green infrastructure leads to attainment of POC load reduction goals.

CCCWP is developing a model to forecast attainment of load reduction goals for a reasonable assurance analysis (RAA) in fulfillment of Provisions C.11.d.i and C.12.d.i. An RAA establishes the relationship between areal extent of green infrastructure implementation and POC reductions, estimates the amount and characteristics of land area to be treated through green infrastructure in future years, and estimates the amount of POC reductions which will result from green infrastructure implementation by specific future years.

As required by Provision C.3.j, Permittees are developing green infrastructure plans. The plans will describe how Permittees will shift their impervious surfaces and storm drain infrastructure from gray or traditional storm drain infrastructure, where runoff flows directly into the storm drain and then into the receiving water, to green – a more resilient, sustainable system that slows runoff by dispersing it to vegetated areas, harvests and uses runoff, promotes infiltration and evapotranspiration, and uses bioretention and other green infrastructure practices to clean stormwater runoff. The RAA will be performed on each Permittee's green infrastructure plan to quantify the expected volume and pollutant load reductions resulting from plan implementation.

In addition to sediment-associated TMDL pollutants, such as mercury and PCBs, Provision C.8.f also requires monitoring of copper, nutrients, and emerging contaminants (the alternative flame retardants perfluorooctane sulfonates and perfluoroalkyl sulfonates). Copper and nutrients are directly monitored by CCCWP as described in subsections below. Emerging contaminants are assessed through a regional collaboration with the Bay Area Stormwater Management Agencies Association (BASMAA) and the RMP and, therefore, are not discussed at length in this report.

1.2 Dual Regional Water Quality Control Board Jurisdictions

CCCWP is in a unique position among Bay Area stormwater programs, as the county is split between the jurisdiction of the San Francisco Bay Regional Water Quality Control Board and the Central Valley Regional Water Quality Control Board (SFBRWQCB and CVRWQCB, respectively). In addition to meeting monitoring requirements in the MRP, CCCWP is also required to meet monitoring specifications established in the East Contra Costa County National Pollution Discharge Elimination System (NPDES) permit (CVRWQCB, 2010) and the 2019 amendment revising the MRP (SFBRWQCB, 2019) . Monitoring responsive to both permits was coordinated successfully to efficiently achieve required goals. Since the Central Valley Region has been moving toward a regional permit for municipal stormwater, CCCWP requested SFBRWQCB and CVRWQCB to consolidate all areas of the county under the MRP administered by the SFBRWQCB. CCCWP will continue to be responsive to monitoring requirements established by TMDLs in the Central Valley Region which affect the east county Permittees. Monitoring results and discussion make note of information addressing methylmercury, responsive to the CVRWQCB, in addition to requirements of the MRP.

1.3 Lessons Learned from MRP 1.0 (Order R2-2009-0074) and Water Years 2016-2019

At the advent of MRP 1.0 in 2009 (SFBRWQCB, 2009), CCCWP and other BASMAA member agencies had some working knowledge of the distribution of PCBs and mercury loads across the urban landscape. Monitoring studies conducted in the 2000-2002 time-frame showed concentrations of PCBs are highest in older industrial areas where PCBs were previously used and released. Mercury is somewhat more evenly distributed across urban land use types (through aerial deposition), with exceptions where known legacy mining sources (e.g., New Almaden) exist upstream. Still, mercury concentrations also tend to be higher in older industrial urban areas, where industrial uses and disposal of mercury occurred in the past. In some places, these early assessments turned up evidence that PCBs in sediments collected from catch basins, curbs and gutters may be elevated because of release from nearby contaminated properties. Follow-up assessments solidified the evidence of specific source properties in the City of Richmond (within Contra Costa County). Other programs had similar findings of specific source properties. Along with other information, the early studies performed by CCCWP and other BASMAA member agencies were used to develop the Mercury and PCBs TMDLs for the Bay.

Source identification work conducted during MRP 1.0 confirmed two private properties in the City of Richmond with consistently high concentrations of PCBs in sediments collected from adjacent curbs, gutters and catch basins. One of the properties is a metal recycler who previously accepted and recycled used transformers; the other property was a forklift repair shop where hydraulic oil is prevalent[1]. Both properties were referred to the SFBRWQCB for remediation and are discussed in the 2014 integrated monitoring report (CCCWP, 2014).

The metals recycler is an active business regulated under the Industrial General Permit (SWRCB, 2015). As a result of CCCWP's source property screening and referral process under MRP 1.0, the property owner is now prohibited from discharging stormwater into the municipal storm sewer system and has designed an on-site stormwater treatment system. Oversight by the City of Richmond and the SFBRWQCB compelled the property owner to implement enhanced operations and maintenance control measures, such as containing stormwater on-site, installing rumble strips to remove dirt from truck tires prior to leaving the site, and conducting enhanced street sweeping with vacuum sweepers. As a follow-up investigation, CCCWP conducted stormwater monitoring in water year 2018 in the public right-of-way. The results helped determine that this property is still tracking sediments contaminated with PCBs into the MS4 system. This property was re-referred to the SFBRWQCB for enforcement in the annual report for FY 2017-18. The lesson learned from this property is that follow-up sampling is useful to ensure source control measures are mitigating pollutants as expected, especially at active businesses. By mitigating releases from this property, the distribution of pollutants by way of runoff, trackout, and windborne dispersion onto surrounding streets is expected to be diminished over time.

Wide-ranging source identification activities produced another new source property for referral to the SFBRWQCB in the City of Richmond. The property is adjacent to a 2015 sampling location containing sediment PCB levels above 1.0 mg/kg and is in San Pablo. The 10-acre property is a dormant remediation

[1] Transformer oil and hydraulic oil are known historic products containing PCBs.

site between the railroad tracks on Chesley Avenue. With the assistance of the SFBRWQCB, Permittees and property owners will implement actions to abate sediment discharge from this parcel to adjacent streets, the MS4, and directly to Wildcat Creek via a bypass drainage, and PCB loads will be further reduced. By mitigating this parcel, in addition to the City of San Pablo's redevelopment and/or abatement of the 4.45-acre former BNSF railyard site to the north, the distribution of PCB loading in this target source area is expected to diminish over time. A data gap remaining in this area is whether the railroad parcels in the area contribute PCBs to the surrounding loads.

Other than some old clean-up properties draining directly to the Bay, there are very few additional large sites which may offer high opportunity for source control. Rather, when screening is complete, CCCWP Permittees would need to wait for high likelihood parcels to change ownership or offer other opportunity for redevelopment in order to gain modest load reductions. This kind of follow-up – to address the gap between cleanup levels directed by Department of Toxic Substances Control and PCB target levels driven by TMDLs – will be a continuous, adaptive process to gradually reduce the distribution of contaminated sediments around legacy cleanup sites and old industrial areas.

One important lesson learned about monitoring low impact development (LID) facilities is that more effort needs to be directed toward quantifying exfiltration into the underlying soils (i.e., infiltration). Much of the LID monitoring in MRP 1.0 focused on comparing pollutant concentrations in stormwater flowing into a bioretention facility to concentrations in treated water flowing out of the facility underdrain. This influent-effluent monitoring focus overlooked the benefit of infiltration, which essentially provides 100 percent pollutant load reduction for flows not exceeding the facility's infiltration capacity. Monitoring during water year 2017 included water level logging using piezometers deployed across LID facilities at several locations throughout the county to better characterize the range of infiltration rates typically achieved. These data will help improve our ability to predict the load reduction benefits of existing and future LID facilities, pursuant to management information needs 3 and 5.

Information about actual and assumed infiltration rates was included in CCCWP's hydromodification technical report (CCCWP, 2017). The technical report was provided to SFBRWQCB staff for their consideration, with the goal of supporting reasonable sizing factors for facilities to attain hydromodification management criteria. An added benefit of the information is that modeling of green infrastructure can be based on measured instead of assumed infiltration rates. The CCCWP RAA modeling methodology for quantifying the pollutant loads reduced by green infrastructure projects incorporates these findings.

CCCWP monitored the Marsh Creek watershed for mercury and methylmercury, with an interest in understanding whether stormwater discharges from the historic Mount Diablo mercury mine in the upper watershed reach the Sacramento-San Joaquin River Delta (Delta) and San Francisco Bay. This activity is responsive to management information needs 1, 2, 4 and 5. A lesson learned during MRP 1.0 was that high frequency monitoring biased results toward smaller storms, while upper watershed flow is trapped behind the Marsh Creek Reservoir. Marsh Creek monitoring was amended to focus on large storms. The first storms in many years large enough to convey upper watershed flow to lower Marsh Creek occurred in water year 2017 and were successfully sampled. This monitoring also supported information needed for the methylmercury control study required by the Delta Methylmercury TMDL.

1.4 Summary of Monitoring

During water years 2014-2019, since the issuance of the previous integrated monitoring report, the following monitoring activities were completed:

- Final season of turbidity-triggered, automated sampling at Marsh Creek fixed monitoring station (MRP 1.0)
- Sediment screening for mercury and PCBs in suspected high-opportunity areas for pollutant control; Tier 1-street dirt sampling and Tier 2-MS4 drop inlet sampling (MRP 2.0)
- Stormwater sampling for mercury and PCBs-Tier 3 (MRP 2.0)
- Best management practice (BMP) effectiveness evaluation (MRP 2.0)
- Stormwater sampling for copper and nutrients (MRP 2.0)
- Methylmercury water sampling, wet and dry seasons (MRP 2.0, 2019 amendment)

In whole, these monitoring activities were responsive to the requirements of MRP 2.0 Table 8.2, fulfilling the minimum number of samples required and addressing the requisite information management needs. Additionally, sampling and analysis was conducted to comply with the 2019 MRP amendment for methylmercury monitoring in Marsh Creek.

In the following sections of this report, methods are presented for field and laboratory procedures (Section 2); results are presented and discussed (Section 3); and quality control/quality assurance results are discussed (Section 4).

2. METHODS

All monitoring activities were performed in accordance with CCCWP's Pollutants of Concern Sampling and Analysis Plan and Quality Assurance Project Plan draft guidance documents (CCCWP, 2016a; CCCWP, 2016b). Per these plans, strict field sampling procedures were followed for decontamination of sampling implements and clean, representative collection protocols. Two laboratories were contracted to perform sediment and water analyses: Caltest Analytical Laboratory of Napa, California, and ALS Global of Kelso, Washington.

2.1 Sediment Sampling

Sampling locations adjacent to or within suspected source properties were identified during desktop reconnaissance and windshield survey phases. Exact sediment sampling locations were determined in the field at the time of sampling based on sediment availability, site accessibility, signs of sediment accumulation/erosion, visible signs of potential contamination (e.g., stained soils), and topographical features which may indicate location of prior disposal (e.g., sediment mounds). Soil sample locations and coordinates were recorded on field datasheets as sampling was conducted.

In many cases, sediment was collected from the urban landscape and referred to as "street dirt" or surface material within the public right-of-way available for stormwater entrainment into the MS4. Street dirt is found in roadway gutters, on sidewalks and driveway aprons, or accumulated near MS4 entry points (e.g., adjacent to a drop inlet grate). In other cases, sediment was collected directly from the MS4 (e.g., material accumulated in the bottom of drop inlet vault or in the sump of hydrodynamic separator treatment device).

Sampling implements were cleaned prior to use, and between sampling sites, by washing with non-phosphate detergent, hydrochloric acid, and methanol. Deionized water was used to rinse the implements after each washing agent was applied.

Prior to sediment collection, each sampling point was cleared of vegetation and/or large gravel, if such material was present. Target sediment was scooped with a stainless-steel sampling implement (e. g., trowel or spoon) and placed into a stainless-steel compositing bucket or tray. In cases where sediment samples were taken from street surfaces or hardscape areas, a small nylon or natural fiber pre-cleaned brush was used in conjunction with a trowel or scoop. After homogenization within the compositing bucket or tray, subsamples were transferred to certified-cleaned, 8-ounce glass jars and cooled to 4° C. Samples were either shipped immediately to ALS Laboratory of Kelso, Washington for analysis or were held at 4° C (particle size distribution samples) and -20° C (all other samples) pending shipping to ALS. Archived samples from each location, and from each composite area if applicable, were collected and stored at ADH Environmental in Soquel, California at 4° or -20° C as appropriate for possible future analysis or reanalysis.

Tables 1 and 2 present sediment screening analytical test types, methods, reporting limits and holding times.

Table 1. Sediment Screening Analytical Tests, Methods, Reporting Limits and Holding Times

Sediment Analytical Test	Method	Target Reporting Limit	Holding Time
Total PCBs (RMP 40 congeners)[1]	EPA 8082A	0.5 µg/kg	1 year
Total Mercury	EPA 7471B	5 µg/kg	1 year
Total Organic Carbon	ASTM D4129-05M	0.05%	28 days
Particle Size Distribution[2]	ASTM D422M	0.01%	28 days

1 San Francisco Bay RMP 40 PCB congeners include PCB-8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, 105, 110, 118, 128, 132, 138, 141, 149, 151, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203.

2 Particle size distribution by the Wentworth scale; percent fines (slit and clay) are less than 62.5 microns.

Table 2. Hydrodynamic Separator Sediment Analytical Tests, Methods, Reporting Limits and Holding Times

Sediment Analytical Test	Method	Target Reporting Limit	Holding Time
Total PCBs (RMP 40 congeners)[1]	EPA 8082A	0.5 µg/kg	1 year
Total Mercury	EPA 7471B	5 µg/kg	1 year
Total Organic Carbon	ASTM D4129-05M	0.05%	28 days
Particle Size Distribution[2]	ASTM D422M	0.01%	28 days
Total Solids	EPA 160.3	%	7 days
Total Organic Matter	EPA 160.4	%	28 days
Bulk Density	ASTM E1109-86	g/cm^3	7 days

1 San Francisco Bay RMP 40 PCB congeners include PCB-8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, 105, 110, 118, 128, 132, 138, 141, 149, 151, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203.

2 Particle size distribution by the Wentworth scale; percent fines (slit and clay) are less than 62.5 microns.

2.2 Water Sampling

Creek water and stormwater samples were collected by manual grab sample methods, including “clean hands/dirty hands” protocols for low-level mercury analysis. Stormwater samples were collected on the rising limb of the storm hydrograph, near to peak runoff intensity. Samples were filtered in the field within 15 minutes of collection for all dissolved parameters, including soluble copper, orthophosphate, nitrate, nitrite and ammonia.

Tables 3 through 5 present water analytical test types, methods, reporting limits and holding times for the various types of sampling conducted.

Table 3. Stormwater Analytical Tests, Methods, Reporting Limits and Holding Times

Sediment Analytical Test	Method	Target Reporting Limit	Holding Time
Total PCBs (RMP 40 congeners)[1]	EPA 1668C	0.1 µg/kg	1 year
Total Mercury	EPA 1631E	0.5 ng/L	90 days
Suspended Sediment Concentration	ASTM D 3977-97	1.5 mg/L	7 days
Total Organic Carbon	EPA 9060	0.50 mg/L	28 days

1 San Francisco Bay RMP 40 PCB congeners include PCB-8, 18, 28, 31, 33, 44, 49, 52, 56, 60, 66, 70, 74, 87, 95, 97, 99, 101, 105, 110, 118, 128, 132, 138, 141, 149, 151, 153, 156, 158, 170, 174, 177, 180, 183, 187, 194, 195, 201, and 203.

2 Particle size distribution by the Wentworth scale; percent fines (slit and clay) are less than 62.5 microns.

Table 4. Copper and Nutrients in Water – Analytical Tests, Methods and Reporting Limits

Analytical Test	Method	Target Reporting Limit
Suspended Sediment Concentration (SSC)	ASTM D 3977-97B	3 mg/L
Copper, total recoverable and dissolved	EPA 200.8	0.5 µg/L
Hardness	SM 2340C (titration)	5 mg/L
Ammonia as N	SM 4500-NH3 C v20	0.1 mg/L
Nitrate	EPA 300.0	0.05 mg/L
Nitrite	EPA 300.0	0.05 mg/L
Total Kjeldahl Nitrogen	SM 4500 NH3-C	0.1 mg/L
Dissolved Orthophosphate	SM 4500P-E	0.01 mg/L
Total Phosphorus	SM 4500P-E	0.01 mg/L

Table 5. Mercury and Methylmercury in Water – Analytical Tests, Methods, Reporting Limits and Holding Times

Sediment Analytical Test	Method	Target Reporting Limit	Holding Time
Total Mercury	EPA 1631E	0.5 ng/L	90 days
Total Methylmercury	EPA 1631	0.05 ng/L	90 days
Suspended Sediment Concentration	ASTM D 3977-97	1.5 mg/L	7 days

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3. RESULTS AND DISCUSSION

The following subsections present a summary of POCs monitoring responsive to MRPs 1.0 and 2.0 for Water years 2014-2019. Details of monitoring activities, results, and discussion for each water year can be found in the following reference documents:

- Pollutants of Concern Loads Monitoring Progress Report, Water Years 2012, 2013 and 2014 (SFEI, 2016)
- Pollutants of Concern Sediment Screening 2015 Annual Sampling and Analysis Report (CCCWP, 2016c)
- Pollutants of Concern Monitoring Report: Water Year 2016 Sampling and Analysis (CCCWP, 2017)
- Pollutants of Concern Monitoring Report: Water Year 2017 Sampling and Analysis (CCCWP, 2018)
- Pollutants of Concern Monitoring Report: Water Year 2018 Sampling and Analysis (CCCWP, 2019a)
- Pollutants of Concern Report: Accomplishments in Water Year 2019 and Allocation of Effort for Water Year 2020 (CCCWP, 2019b)

3.1 Automated Stormwater Loads Monitoring – Fixed Station on Marsh Creek

During WY 2014, POCs sampling consisted of operation of a loads monitoring station on Lower Marsh Creek in the City of Brentwood. This monitoring station was part of a BASMAA collaborative effort to quantify POCs loads from some of the largest and/or most impaired tributaries to the Bay/Delta. The results of this monitoring work, including loads calculations, can be found in the Pollutants of Concern Loads Monitoring Progress Report, Water Years 2012, 2013, and 2014 (SFEI, 2016).

3.2 Sediment Screening for PCBs and Mercury

During WYs 2015-2019, a total of 92 sediment samples were collected and analyzed countywide by CCCWP. Sampling locations were generally selected in public rights-of-way known or suspected of having high opportunity for PCBs and/or mercury control. CCCWP permittees provided information on historic and present-day land use, prior monitoring results, and other information to assist CCCWP in developing target sampling locations.

Prior to sample collection, desktop reconnaissance and windshield surveys were conducted to inform the monitoring approach and assist in sampling logistics. Much of the sampling and analysis procedures originated from the BASMAA Clean Watersheds for a Clean Bay Task 3 study plan (BASMAA, 2012).

Samples were screened for 1) total PCB, 2) total mercury, 3) total organic carbon, and 4) particle size distribution. For quality control/quality assurance purposes, blind field duplicate samples were collected and analyzed on an approximately 10 percent basis.

Table 6 presents the sample location, date of collection, and description/selection rational for all 92 samples; Table 7 presents the analytical results; Figures 1 and 2 show the magnitude distribution of PCBs and mercury concentrations with respect to the high-opportunity thresholds of 500 ppb (PCBs) and 750 ppb (mercury); and Figures 3 through 6 show the spatial distribution of samples and concentration ranges for PCBs and mercury across the county.

For PCBs, five samples were elevated above the high opportunity threshold of 500 ppb. These samples were distributed across the county, including an unincorporated portion near Richmond, the City of San Pablo, the City of Pittsburg, and the City of Antioch. For mercury, eight samples were elevated above the high opportunity threshold of 750 ppb. These samples were distributed across the county, including an unincorporated portion near Richmond, the City of Richmond, the City of San Pablo, and the City of Pittsburg.

The source of these elevated PCB and mercury concentrations is suspected to reside within adjacent private parcels. Property referrals to the SFBRWQCB were made by CCCWP where appropriate. The details of referral action, Water Board follow-up, and any enhanced O&M action on the part of responsible parties is beyond the scope of this report.

Table 6. Sediment Sampling Site Descriptions, Date of Collection, and Location Coordinates

Site Description[1]	Sample Date	Latitude	Longitude	General Description / Selection Rationale / Sampling Notes
CC-RCH-100-R	04/21/15	37.9225	-122.33523	Local area composite
CC-RCH-101-R	04/21/15	37.92231	-122.33538	Local area composite
CC-RCH-102-R	04/21/15	37.92287	-122.33576	Local area composite
CC-RCH-103-R	04/21/15	37.92314	-122.33617	Local area composite
CC-RCH-104-R	04/21/15	37.92291	-122.33773	Local area composite
CC-RCH-105-R	04/21/15	37.92385	-122.33732	Local area composite
CC-RCH-106-R	04/21/15	37.92406	-122.35789	Local area composite
CC-RCH-200-R	04/21/15	37.94194	-122.37561	Local area composite
CC-RCH-300-P	04/22/15	37.99972	-122.35152	Site under construction took samples throughout property; escorted by City of Richmond representative
CC-RCH-301A-R	04/22/15	37.97147	-122.35573	Local area composite; truck path
CC-RCH-301B-R	04/22/15	37.97161	-122.35569	Local area composite; horse stables
CC-RCH-305-P	04/22/15	37.95066	-122.36551	4-point composite of 1 large property comprised of 10 APNs: escorted City of Richmond representative
CC-RCH-306-R	04/22/15	37.97175	-122.36529	Local area composite
CC-RCH-307-R	04/22/15	37.96828	-122.36748	Local area composite
CC-RCH-308-R	04/22/15	37.95487	-122.35949	Local area composite; vacant lot with heavy trackout
CC-RCH-309-R	04/22/15	37.95465	-122.35885	Local area composite
CC-RCH-RRC-P	04/22/15	37.92411	-122.33736	4-point composite along railroad lines:
CC-RCH-400-R	04/29/15	37.95413	-122.37417	Local area composite
CC-RCH-401-R	04/29/15	37.95411	-122.37758	Local area composite
CC-RCH-402-R	04/29/15	37.96031	-122.37435	Local area composite
CC-RCH-403-R	04/29/15	37.96043	-122.37438	Local area composite
CC-RCH-404-R	04/29/15	37.96331	-122.37315	Local area composite
CC-RCH-405-R	04/29/15	37.96327	-122.37247	Local area composite
CC-RCH-406-R	04/29/15	37.96311	-122.37111	Local area composite
CC-RCH-407-R	04/29/15	37.96801	-122.36909	Local area composite
CC-ANT-500-R	04/30/15	38.01238	-122.77036	Local area composite
CC-ANT-501-R	04/30/15	38.01239	-122.77729	Local area composite
CC-ANT-502-R	04/30/15	38.01511	-121.76111	Local area composite
CC-PTZ-200A-R	04/30/15	38.02069	-121.85654	Local area composite
CC-PTZ-200-R	04/30/15	38.01971	-121.85702	Local area composite
CC-PTZ-201A-R	04/30/15	38.01707	-121.85822	Local area composite
CC-PTZ-201-R-D	04/30/15	38.01748	-121.85775	Local area composite
CC-PTZ-202-R	04/30/15	38.01675	-121.89852	Local area composite
CC-CON-900-R	06/11/15	37.97577	-122.04899	Local area composite
CC-PIN-800-R	06/11/15	38.00531	-122.30902	Local area composite
CC-RCH-700-R	06/11/15	37.96492	-122.35792	Local area composite
CC-SPL-600-P	06/11/15	37.95335	-122.35787	Group composite: several piles of soil on property, sampled each
CC-SPL-601-R	06/11/15	37.97995	-122.35235	Group composite; sampled at various points around perimeter of property
CC-BPT-600-R	09/29/15	38.03902	-121.96115	Local area composite
CC-BPT-601-R	09/29/15	38.04293	-121.98805	Local area composite
CC-PTZ-210-R	09/29/15	38.02942	-121.91618	Sampled several points along fence line

Table 6. Sediment Sampling Site Descriptions, Date of Collection, and Location Coordinates

Site Description[1]	Sample Date	Latitude	Longitude	General Description / Selection Rationale / Sampling Notes
CC-PTZ-212-R	09/29/15	38.03007	-121.87628	Local area composite
CC-PTZ-213-R	09/29/15	38.03104	-121.87352	Local area composite
CC-PTZ-214-R	09/29/15	38.03035	-121.87101	Local area composite
CC-PTZ-215-R	09/29/15	38.01847	-121.86964	Local area composite
CC-PTZ-216-R	09/29/15	38.01444	-121.86110	Local area composite
CC-PTZ-217-R	09/29/15	38.01242	-121.84998	Local area composite
CC-PTZ-218-R	09/29/15	38.01253	-121.85755	Local area composite
CC-PTZ-219-R	09/29/15	38.01209	-121.87191	Local area composite
CC-PTZ-220-R	09/29/15	38.01241	-121.84954	Local area composite
CC-ANT-510-R	09/30/15	38.01664	-121.82357	Local area composite
CC-RCH-800-R	09/30/15	37.95861	-122.35958	Local area composite
CC-RCH-801-R	09/30/15	37.96521	-122.36306	Local area composite
CC-RDO-700-R	09/30/15	38.02756	-122.26695	Local area composite
CC-SPL-325-P	09/30/15	37.95386	-122.35759	Group composite; separate piles of soil on same property as SPL-326-093015; escorted by City of San Pablo representative
CC-SPL-326-P	09/30/15	37.95352	-122.35795	Local area composite: several piles of soil on property, sampled each
CC-ANT-511-R	10/1/15	38.01349	-121.81588	Local area composite
CC-ANT-512-R	10/1/15	38.01678	-121.75701	Local area composite
CC-GNT-940-DI	08/31/16	37.97876	-122.35315	Drop inlet at northern boundary of Giant Highway, contained sufficient sediment for sampling, no plant material, no trash
CC-GNT-941-DI	08/31/16	37.97719	-122.35355	Drop inlet contained sufficient sediment for sampling, minor plant material, no trash, flows directly into Wildcat Creek
CC-GNT-942-DI	08/31/16	37.97634	-122.35379	Drop inlet in front of industrial complex noted for elevated levels of PCBs in past testing, sufficient sediment present to sample
CC-GNT-943-DI	08/31/16	37.97319	-122.35464	Drop contained great amounts of plant material but had sufficient amount of sediment for sampling
CC-GNT-944-DI	08/31/16	37.97096	-122.35522	Drop inlet sampled contained sufficient sediment for sampling and located in area known to have elevated PCBs
CC-GNT-945-DI	08/31/16	37.9691	-122.35573	Drop inlet at southern boundary of Giant Highway, contained sufficient sediment for sampling, small amounts of plant material and trash, soil was moist
CC-GNT-946-C	08/31/16	37.973963	-122.354863	Composite sample collected from open channel that runs along southbound lane of Giant Highway
CC-RUM-947-DI	08/31/16	37.96002	-122.36148	Drop inlet contained sufficient sediment for sampling, moderate amount of plant material, no trash
CC-RUM-948-DI	08/31/16	37.9587	-122.36045	Drop inlet contained sufficient sediment for sampling, moderate amount of plant material, no trash
CC-RUM-949-DI	08/31/16	37.95855	-122.35922	Drop inlet contained sufficient sediment for sampling, no plant material, no trash
CC-RUM-950-DI	09/01/16	37.95807	-122.35686	Drop inlet contained sufficient sediment for sampling, moderate amount of plant material, no trash
CC-RUM-951-DI	09/01/16	37.95611	-122.35697	Drop inlet contained sufficient sediment for sampling, great amount of plant material, trash present
CC-RUM-952-DI-C	09/01/16	37.953363	-122.357743	Three adjacent drop inlets were sampled in this composite, all contained sufficient sediment, no plant material, no trash
CC-RUM-953-C	09/01/16	37.95208	-122.35853	Location sampled is within target area, but is a composite from an outfall pipe

Table 6. Sediment Sampling Site Descriptions, Date of Collection, and Location Coordinates

Site Description[1]	Sample Date	Latitude	Longitude	General Description / Selection Rationale / Sampling Notes
CC-ANT-901-R	09/27/16	37.99699	-121.84398	EnviroStor site. Antioch PG&E substation
CC-ANT-921-DI	09/27/16	38.01235	-121.77752	Sampled low point where contribution from two known hot sites flow into drop inlet
CC-PTZ-915-R	09/27/16	38.01571	-121.86083	Site was recommended for sampling in WY 2015, but was not sampled due to access issues. Requires a key from the county Flood Control and Water Conservation District to access the levee at 1600 Loveridge Road.
CC-RCH-926-DI	09/27/16	37.92406	-122.36285	Sampled at low point where known hot site appears to flow into drop inlet; recommended for testing by CCCWP.
CC-OAK-922-R	09/28/16	38.00763	-121.75099	Recently identified, high potential, recommended for testing by CCCWP
CC-OAK-923-R	09/28/16	38.00502	-121.74364	Recently identified, high potential, recommended for testing by CCCWP
CC-RCH-912-R	09/28/16	37.95408	-122.3769	Site does not exist in Geotracker. Site was a drum recycling facility pre-1961-1983. Received casting sand from Atlas Foundry, may have been involved in burning hazardous chemical drums, along with Atlas. Chevron removed some contaminated soil at least by 1987. Adjacent to Fass Metals, which is known to have very high levels of PCBs. The information above could not be confirmed in EnviroStor or Geotracker. Tier 1 category was designated as a conservative measure due to reported use and proximity to PCBs-impacted FASS Metals site at 818 W. Gertrude Avenue.
CC-RCH-924-R	09/28/16	37.92583	-122.36911	Known hot spot at PG&E property along 1st Street and Cutting; recommended for testing by CCCWP.
CCC-ALT-100-P1	08/23/17	37.99604	-122.34834	Adjacent to PG&E property and recommended for testing by CCCWP; sampled near drop inlet where runoff appears to flow from the substation
CCC-CHR-100-P1	08/23/17	37.95201	-122.36234	Sampled trackout from non-jurisdictional railroad property
CCC-GDN-100-P1	08/23/17	37.96307	-122.37623	Sampled at low point in channel before culvert which runs west to San Francisco Bay; previously identified as a hot spot
CCC-LBV-100-P1	08/23/17	38.03728	-122.17797	Sample collected near an off-line transformer station
CCC-LBV-101-P1	08/23/17	38.03741	-122.17609	Sample collected below an electrical pole with a transformer on the hillside
CCC-LBV-102-P1	08/23/17	38.03678	-122.17696	Sample collected at a low point in the dry local watercourse downstream of former industrial facility
CCC-PAC-100-P1	08/23/17	37.99732	-122.07687	Sampled trackout from an unpaved access road to several businesses
CCC-PAC-101-P1	08/23/17	38.00598	-122.08932	Sampled along a fence line in right-of-way
RCHMBP	08/06/19	37.9158	-122.34427	HDS sump sample, located on 8th Street in Richmond
RCHBST	09/05/19	37.92434	-122.36202	HDS sump sample located on Regatta Blvd in Richmond
CC-SNPB-C	09/18/19	37.96191	-122.35493	Rumrill PG&E natural gas distribution station in San Pablo. Samples were a 'localized composite'
CC-CNRD-C	09/25/19	37.96558	-122.00852	Single point sample in gutter on Babel Lane in Concord, site of electrical transformer spill

1 Site Description Key: ANT = Antioch, ALT = Atlas Road, C = composite, CC = Contra Costa, CCC = Contra Costa County, CHR = Cherry Street, CNRD = Concord, D = field duplicate, DI = drop inlet, DIC = drop inlet composite, LBV = Little Bull Valley, OAK = Oakley, P1 = Phase 1, PAC = Pacheco Boulevard, PTZ = Pittsburgh, R = right-of-way, RCH = Richmond, RCH8ST = Richmond, RCHMBP = Richmond

Table 7. Sediment Analytical Results and Rankings

Site Description	Sample Date	Total PCBs Concentration (ppb)[1]	Total PCBs Ranking[2]	Total Mercury Concentration (ppb)[3]	Total Mercury Ranking[2]	Total Organic Carbon (%)	Percent Fines (%)[4]
CC-RCH-100-R	04/21/15	25.62	49	129	68	1.39	33.42
CC-RCH-101-R	04/21/15	34.74	37	128	69	6.23	33.72
CC-RCH-102-R	04/21/15	3.52	84	45	88	1.13	66.75
CC-RCH-103-R	04/21/15	19.03	57	84	78	0.659	30.78
CC-RCH-104-R	04/21/15	123.7	15	607	9	1.34	46.30
CC-RCH-105-R	04/21/15	28.05	47	157	59	1.01	28.02
CC-RCH-106-R	04/21/15	57.44	27	470	15	1.07	41.63
CC-RCH-200-R	04/21/15	34.2	38	437	17	1.7	47.15
CC-RCH-300-P	04/22/15	110.7	18	83	79	0.864	44.55
CC-RCH-301A-R	04/22/15	13.55	69	393	22	3.25	39.47
CC-RCH-301B-R	04/22/15	6.61	77	402	21	1.22	41.77
CC-RCH-305-P	04/22/15	26.12	48	104	74	2.08	44.48
CC-RCH-306-R	04/22/15	5.78	80	94	77	1.19	31.82
CC-RCH-307-R	04/22/15	84.63	24	172	52	1.81	31.97
CC-RCH-308-R	04/22/15	47.16	33	144	64	2.91	36.77
CC-RCH-309-R	04/22/15	71.01	26	540	12	3.41	43.81
CC-RCH-RRC-P	04/22/15	54.22	30	***930***	6	1.61	59.76
CC-RCH-400-R	04/29/15	12.66	70	202	44	2.01	43.14
CC-RCH-401-R	04/29/15	***6383***	1	***20600***	1	4.42	55.49
CC-RCH-402-R	04/29/15	32.94	39	511	13	3.16	42.90
CC-RCH-403-R	04/29/15	30.49	43	331	28	1.21	41.18
CC-RCH-404-R	04/29/15	132.8	14	136	66	2.4	30.52
CC-RCH-405-R	04/29/15	55.68	28	161	58	2.26	46.09
CC-RCH-406-R	04/29/15	7.59	75	564	11	0.717	41.88
CC-RCH-407-R	04/29/15	22.76	53	183	47	1.13	26.20
CC-ANT-500-R	04/30/15	251.9	8	328	29	2.12	19.40
CC-ANT-501-R	04/30/15	3.46	85	17	92	0.513	23.01
CC-ANT-502-R	04/30/15	23.66	52	23	91	0.53	4.02
CC-PTZ-200A-R	04/30/15	19.33	56	194	46	1.56	46.28
CC-PTZ-200-R	04/30/15	15.34	64	227	41	1.32	49.76
CC-PTZ-201A-R	04/30/15	338.7	7	287	32	5.72	30.35
CC-PTZ-201-R-D	04/30/15	49.78	32	240	38	5.76	50.68

Table 7. Sediment Analytical Results and Rankings

Site Description	Sample Date	Total PCBs Concentration (ppb)[1]	Total PCBs Ranking[2]	Total Mercury Concentration (ppb)[3]	Total Mercury Ranking[2]	Total Organic Carbon (%)	Percent Fines (%)[4]
CC-PTZ-202-R	04/30/15	3.07	87	373	25	0.537	37.73
CC-CON-900-R	06/11/15	4.47	81	111	70	0.688	38.62
CC-PIN-800-R	06/11/15	3.46	86	49	86	1.03	18.45
CC-RCH-700-R	06/11/15	16.19	62	207	43	1.26	33.49
CC-SPL-600-P	06/11/15	***1291***	4	149	62	5.2	27.46
CC-SPL-601-R	06/11/15	116.2	17	431	18	3.33	37.81
CC-BPT-600-R	09/29/15	50.21	31	376	23	8.42	56.29
CC-BPT-601-R	09/29/15	1.79	91	78	80	3.4	47.50
CC-PTZ-210-R	09/29/15	***1061***	5	109	71	1.8	47.85
CC-PTZ-212-R	09/29/15	32.46	40	248	37	7.56	35.15
CC-PTZ-213-R	09/29/15	54.92	29	640	7	1.13	60.31
CC-PTZ-214-R	09/29/15	21.4	54	***1670***	2	10.5	48.75
CC-PTZ-215-R	09/29/15	14.09	65	151	61	14.1	46.89
CC-PTZ-216-R	09/29/15	10.48	72	606	10	3.34	39.67
CC-PTZ-217-R	09/29/15	6.26	79	637	8	1.15	42.99
CC-PTZ-218-R	09/29/15	4.3	82	229	40	2.12	27.73
CC-PTZ-219-R	09/29/15	14.03	66	167	55	21.9	36.45
CC-PTZ-220-R	09/29/15	18.87	59	***1042***	4	23.14	46.88
CC-ANT-510-R	09/30/15	***2531***	3	151	60	1.86	48.15
CC-RCH-800-R	09/30/15	29	45	260	35	1.76	38.36
CC-RCH-801-R	09/30/15	99.49	19	507	14	0.936	50.31
CC-RDO-700-R	09/30/15	16	63	95	76	4.51	30.51
CC-SPL-325-P	09/30/15	40.83	36	196	45	3.85	46.99
CC-SPL-326-P	09/30/15	84.83	23	104	73	4.09	39.60
CC-ANT-511-R	10/01/15	7.31	76	178	51	0.822	50.81
CC-ANT-512-R	10/01/15	6.55	78	27	89	0.824	20.75
CC-GNT-940-DI	08/31/16	19	46	135	65	1.39	43.00
CC-GNT-941-DI	08/31/16	30	51	170	72	5.91	15.00
CC-GNT-942-DI	08/31/16	14	71	70	42	2.01	8.00
CC-GNT-943-DI	08/31/16	29	60	143	50	3.72	10.33
CC-GNT-944-DI	08/31/16	24	13	108	54	3.21	5.33
CC-GNT-945-DI	08/31/16	12	25	217	56	4.51	28.33

Table 7. Sediment Analytical Results and Rankings

Site Description	Sample Date	Total PCBs Concentration (ppb)[1]	Total PCBs Ranking[2]	Total Mercury Concentration (ppb)[3]	Total Mercury Ranking[2]	Total Organic Carbon (%)	Percent Fines (%)[4]
CC-GNT-946-C	08/31/16	17	41	181	33	2.43	44.67
CC-RUM-947-DI	08/31/16	138	58	169	67	4.2	31.00
CC-RUM-948-DI	08/31/16	72	44	162	53	3.83	22.33
CC-RUM-949-DI	08/31/16	31	67	278	81	1.85	23.67
CC-RUM-950-DI	09/01/16	92	21	145	63	4.44	8.00
CC-RUM-951-DI	09/01/16	211	9	161	57	8.79	18.00
CC-RUM-952-DI-C	09/01/16	***4881***	2	292	31	9.11	19.67
CC-RUM-953-C	09/01/16	17	61	354	26	3.39	31.33
CC-ANT-901-R	09/27/16	3	88	65	82	1.91	34.00
CC-ANT-921-DI	09/27/16	3	89	62	84	0.567	32.67
CC-PTZ-915-R	09/27/16	4	83	265	34	2.2	45.33
CC-RCH-926-DI	09/27/16	199	10	415	20	2.63	15.00
CC-OAK-922-R	09/28/16	42	35	181	48	0.92	28.67
CC-OAK-923-R	09/28/16	185	12	373	24	1.652	33.67
CC-RCH-912-R	09/28/16	119	16	351	27	13	47.67
CC-RCH-924-R	09/28/16	87	22	312	30	3.79	29.00
CCC-ALT-100-P1	08/23/17	21	55	63	83	0.545	30.00
CCC-CHR-100-P1	08/23/17	360	6	103	75	1.32	31.67
CCC-GDN-100-P1	08/23/17	46	34	235	39	2.7	54.67
CCC-LBV-100-P1	08/23/17	14	68	48	87	0.866	64.67
CCC-LBV-101-P1	08/23/17	0	92	50	85	0.66	58.00
CCC-LBV-102-P1	08/23/17	2	90	26	90	0.983	42.67
CCC-PAC-100-P1	08/23/17	31	42	181	49	3.07	42.33
CCC-PAC-101-P1	08/23/17	25	50	421	19	1.04	45.00
RCHMBP	08/06/19	197.3	11	460	16	30	51.66
RCHBST	09/05/19	95.2	20	***1200***	3	34	44.30
CC-SNPB-C	09/18/19	9.91	73	***951***	5	2.13	45.33
CC-CNRD-C	09/25/19	7.91	74	253	36	1.48	41.46

1 High opportunity threshold Total PCBs values in ***bold italics*** exceed 500 ppb
2 PCBs and mercury concentrations ranked from highest to lowest (1-92)
3 High opportunity threshold Total mercury values in ***bold italics*** exceed 750 ppb
4 Percent fines represent silt and clay after gravel is removed and sand, silt and clay are normalized to 100 percent

Figure 1. Sediment PCBs Concentrations Presented from Highest to Lowest

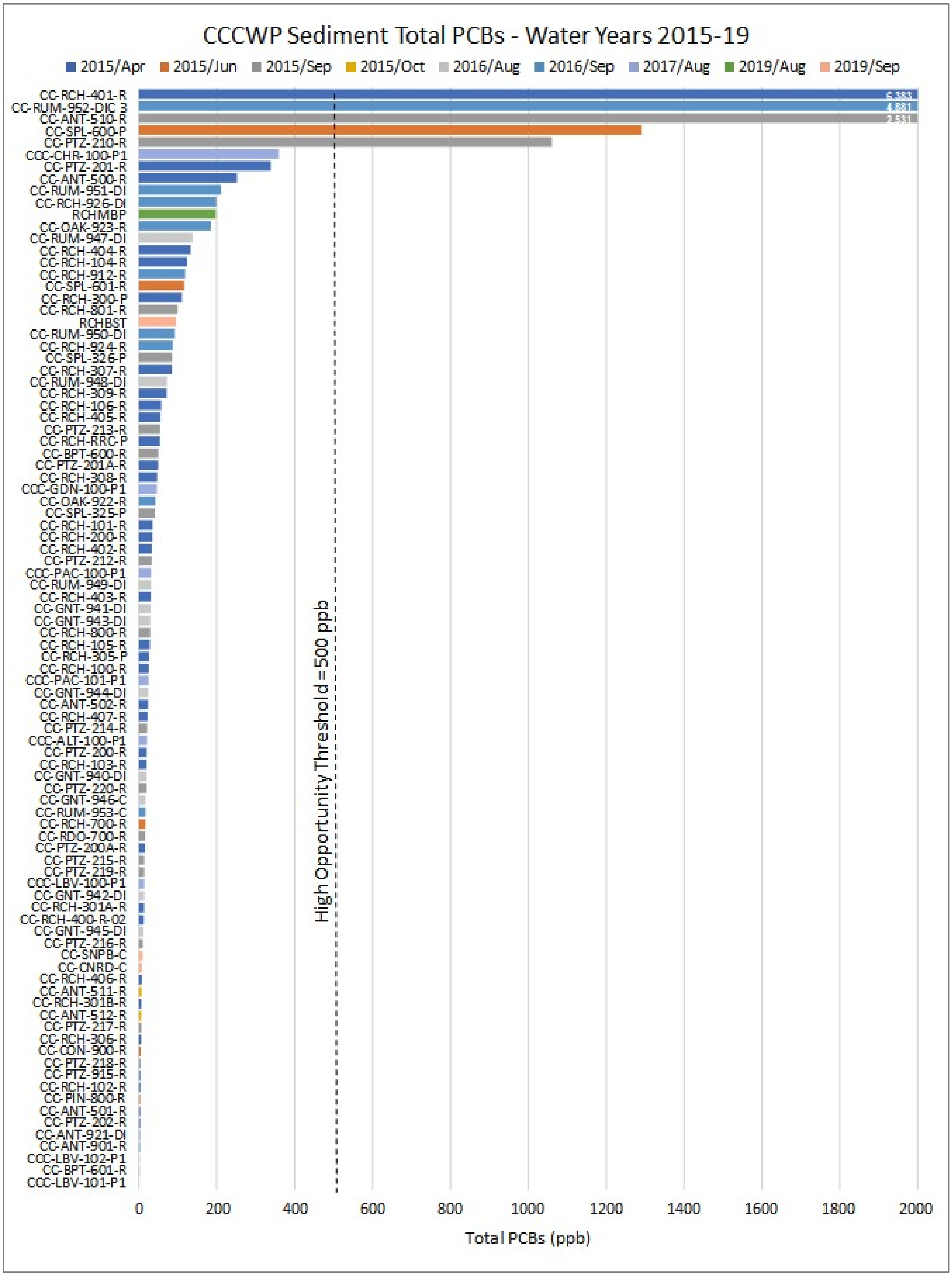


Figure 2. Sediment Mercury Concentration Presented from Highest to Lowest

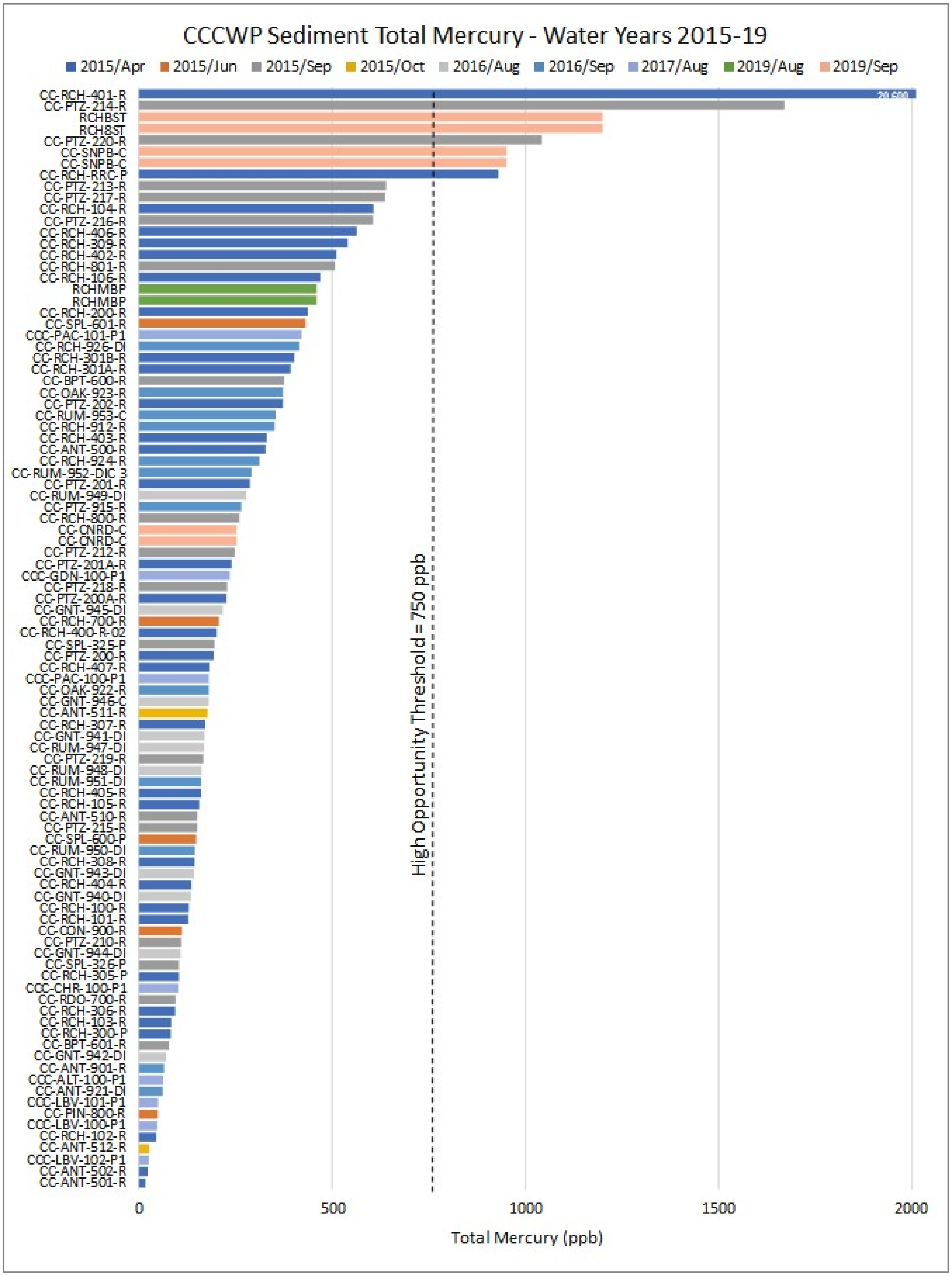


Figure 3. Sediment PCBs Sample Locations and Concentrations – West County

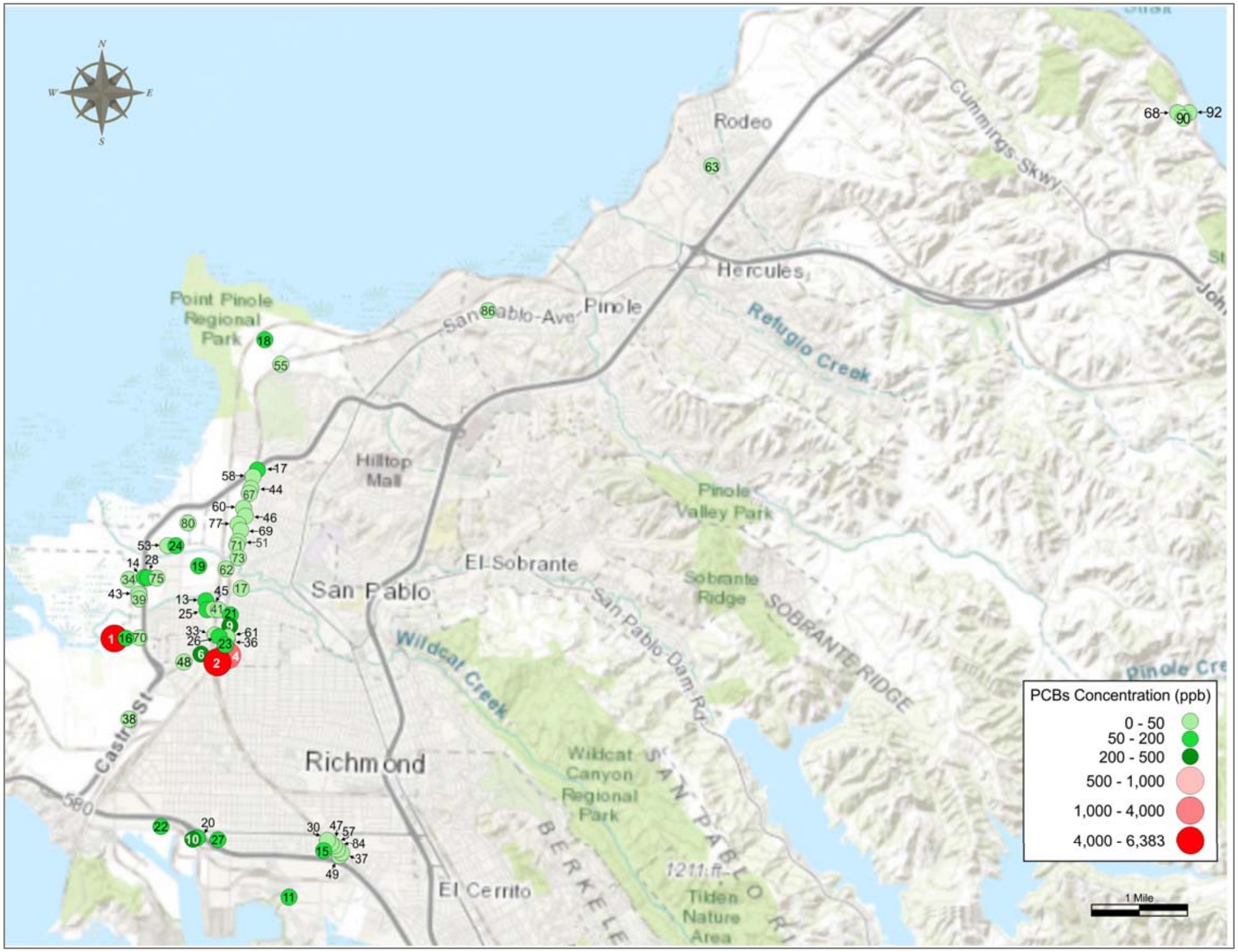


Figure 4. Sediment PCBs Sample Locations and Concentrations – East County

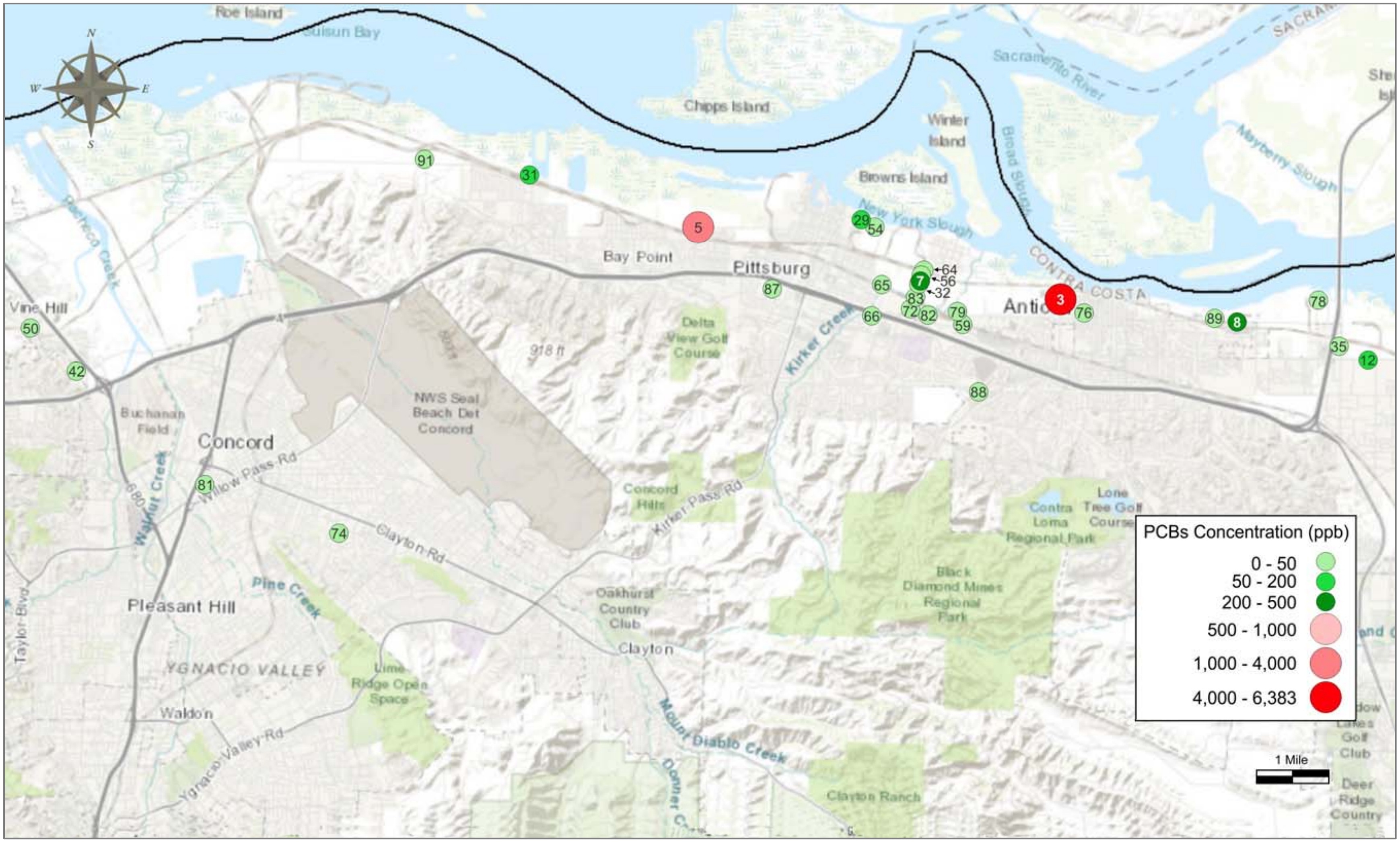


Figure 5. Sediment Mercury Sample Locations and Concentrations – West County

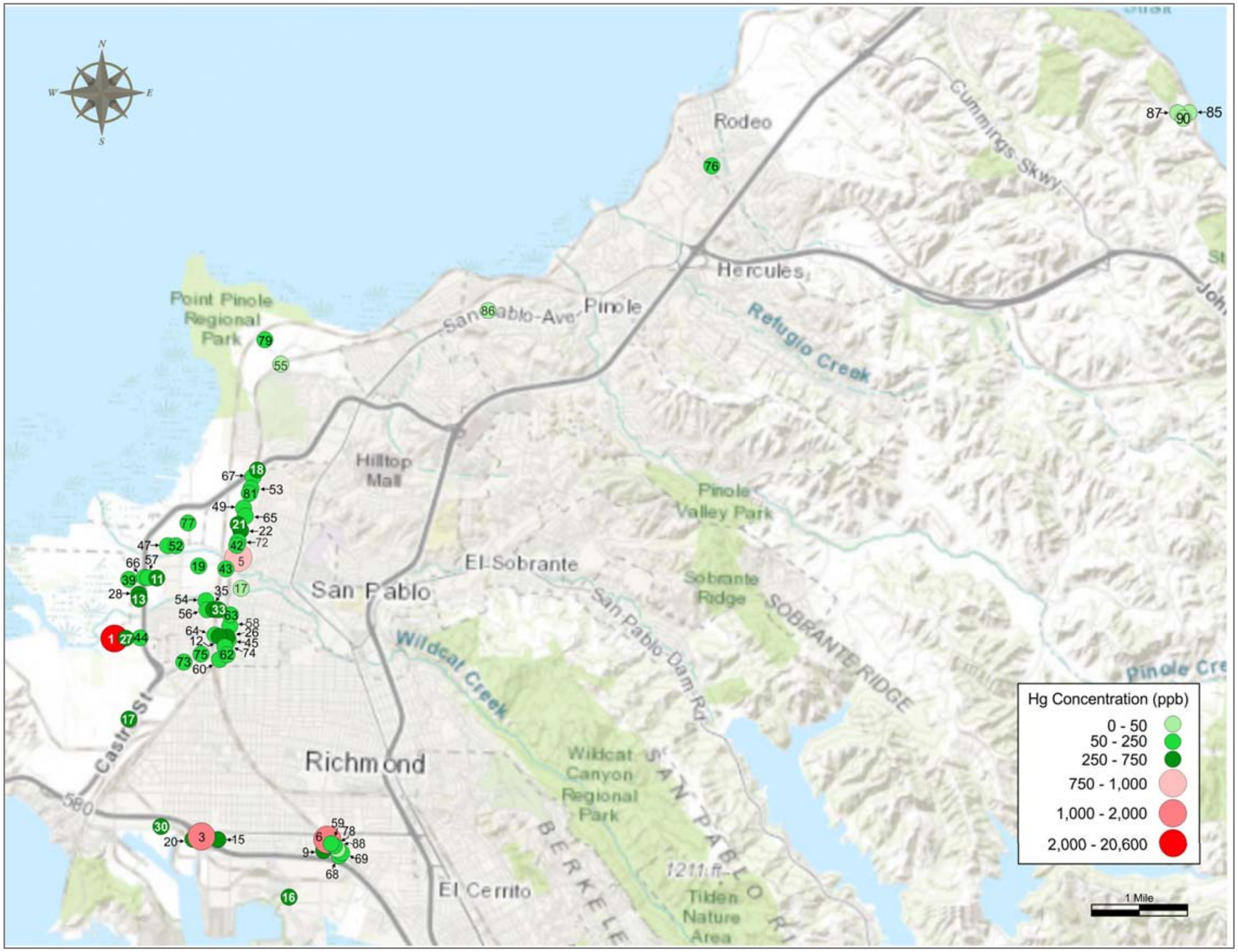
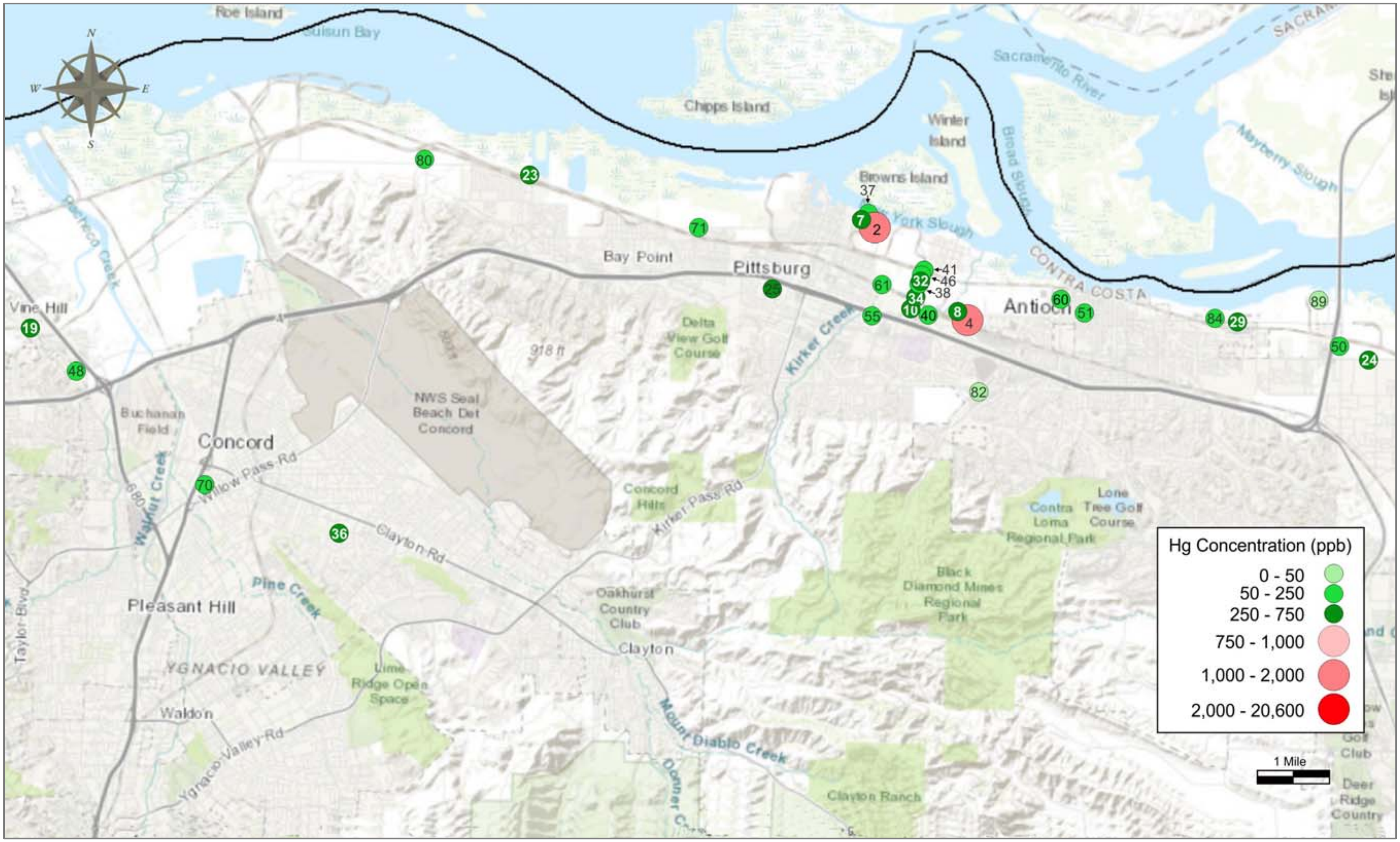


Figure 6. Sediment Mercury Sample Locations and Concentrations – East County



3.3 Stormwater and Surface Water Sampling and Analysis for PCBs and Mercury

Stormwater samples for PCBs and mercury were collected at targeted locations across the county for two reasons: 1) to confirm if elevated concentrations found in sediment samples were also present in runoff to the MS4, and 2) to determine if elevated runoff exists in areas suspected of having high opportunity for POCs control, even if sediment sampling did not indicate high concentrations. In general, stormwater sampling results corroborated street dirt and drop inlet sediment sampling results and helped build a body of evidence for property referrals to the Water Board.

Water sampling results were normalized by SSC to allow data to be presented in terms of sediment concentrations (ppb). This was done by assuming that detected concentrations of PCBs and mercury in water were solely due to association with suspended particles and not from soluble fractions or independent presence in water. For 21 stormwater samples collected for PCBs analysis, seven samples were elevated above the 500 ppb high opportunity threshold for PCBs control for 25 stormwater samples collected for mercury, and 15 samples were elevated above the 750 ppb high opportunity threshold for mercury control. These results were generally expected – elevated concentrations in stormwater runoff confirmed prior sediment sampling results and, more importantly, provided information on narrowing the source of elevated POCs by testing runoff from upstream sources.

In addition to stormwater sampling, dry weather sampling for mercury was performed in Marsh Creek, one of its tributaries (Sand Creek), and an urban comparator water body (Pinole Creek). This effort was part of the methylmercury monitoring (elemental mercury is monitored side by side with methylmercury to provide information about methylation fractioning). As expected for these creeks, mercury concentrations (normalized by SSC) were below the 750 ppb high opportunity threshold for mercury control.

Table 8 presents the sample location, date of collection, and analytical results for stormwater and surface water samples; Figures 7 and 8 show the magnitude distribution of PCBs and mercury concentrations normalized by SSC with respect to the high-opportunity thresholds of 500 ppb (PCBs) and 750 ppb (mercury); and Figures 9 through 11 show the spatial distribution of samples and concentration ranges for PCBs and mercury across the county.

Table 8. Stormwater and Surface Water Analytical Results and Rankings

Site ID[1]	Date Sampled	Time Sampled	Latitude	Longitude	Storm-water Sample?	Total PCBs[2] (ng/L)	Total Hg (µg/L)	PCBs/SSC Ratio (ppb)	PCBs/SSC Ratio Ranking[3]	Hg/SSC Ratio (ppb)	Hg/SSC Ratio Ranking[3]	SSC (mg/L)	TOC (mg/L)
WGA-DI1-01	01/19/16	0850	37.95410	-122.37758	Yes	69.5	3.75	473	8	***25500***	3	147	2.12
WGA-DI2-01	01/19/16	0920	37.95410	-122.37723	Yes	13.2	1.11	297	15	***25000***	4	44.4	1.31
WGA-DI3-01	01/19/16	0950	37.95410	-122.37672	Yes	3.88	2.01	14.8	21	***7670***	5	262	6.68
WGA-DI4-01	01/19/16	1015	37.95410	-122.37585	Yes	40.6	3.37	359	11	***29800***	2	113	6.31
WGA-DI5-01	01/19/16	1035	37.95410	-122.37480	Yes	71.1	0.97	315	13	***4290***	8	226	4.28
WGA-SF1-01	01/19/16	0900	37.95413	-122.37758	Yes	35.9	16.9	***700***	5	***329000***	1	51.3	3.8
CCC-MKT-100-SW	01/08/17	0815	37.95898	-122.357749	Yes	5.2	0.0121	157	17	364	23	33.2	1.7
CCC-RUM-101-SW	01/08/17	0845	37.956605	-122.356936	Yes	2.58	0.0102	277	16	***1100***	14	9.3	2.71
CCC-CHS-102-SW	01/08/17	0915	37.954699	-122.357417	Yes	6.53	0.00553	466	9	395	21	14	1.48
CCC-CHS-103-SW	01/08/17	0920	37.954598	-122.358093	Yes	4.39	0.0138	320	12	***1010***	15	13.7	7.6
CCC-CHS-104-SW	01/08/17	0925	37.954212	-122.358118	Yes	8.37	0.0201	***1100***	3	***2640***	11	7.6	18.8
CCC-KEL-105-SW	01/08/17	1005	37.951034	-122.363521	Yes	20.2	0.0211	***1340***	2	***1400***	13	15.1	5.9
CCC-CHS-106-SW	01/08/17	1020	37.954707	-122.359882	Yes	5.37	0.0386	***647***	6	***4650***	7	8.3	9.9
CCC-SUT-107-SW	01/08/17	1035	37.953363	-122.357754	Yes	1.98	0.00628	***825***	4	***2620***	12	2.4	1.19
CCC-RUM-108-SW	01/08/17	1045	37.952980	-122.357131	Yes	3.28	0.00223	75.9	20	51.6	36	43.2	2.4
CCC-RUM-109-SW	01/08/17	1110	37.954081	-122.357083	Yes	30.4	0.0135	141	18	62.8	35	215	1.9
LMC-M2	01/08/17	0920	37.96264	-121.68794	Yes	–	0.015	–	_	312	27	48	–
LMC-M2	01/08/17	1220	37.96264	-121.68794	Yes	–	0.023	–	_	404	20	57	–
LMC-M2	01/08/17	1445	37.96264	-121.68794	Yes	–	0.047	–	_	270	29	174	–
LMC-M2	01/08/17	1745	37.96264	-121.68794	Yes	–	0.08	–	_	339	25	236	–
MKS-1	03/20/18	2050	37.91486	-122.34386	Yes	18.1	0.038	307	14	644	17	59	3.4
MKS-2	03/20/18	2030	37.91458	-122.34186	Yes	12.1	0.027	115	19	257	30	105	4.7
SIMS-DI	03/01/18	0745	37.92516	-122.36613	Yes	99.8	0.97	432	10	***4200***	9	231	10
SIMS-DI	03/20/18	1435	37.92516	-122.36613	Yes	96.7	0.63	***531***	7	***3460***	10	182	4.7
SIMS-DI	04/6/18	0730	37.92516	-122.36613	Yes	550	2.1	***1850***	1	***7050***	6	298	5.7
LMC-M1	08/22/19	0600	37.96448	-121.68392	No	–	0.00074	–	–	370	22	2	–
LMC-M1	08/22/19	0830	37.96448	-121.68392	No	–	0.00065	–	–	325	26	2	–
LMC-M2	08/22/19	0620	37.96448	-121.68803	No	–	0.002	–	–	154	32	13	–
Pinole Creek	08/22/19	1030	38.00406	-122.28837	No	–	0.00069	–	–	300	28	2.3	–
LMC-M1	09/17/19	0615	37.96448	-121.68392	No	–	0.0033	–	–	351	24	9.4	–

Table 8. Stormwater and Surface Water Analytical Results and Rankings

Site ID[1]	Date Sampled	Time Sampled	Latitude	Longitude	Storm-water Sample?	Total PCBs[2] (ng/L)	Total Hg (µg/L)	PCBs/SSC Ratio (ppb)	PCBs/SSC Ratio Ranking[3]	Hg/SSC Ratio (ppb)	Hg/SSC Ratio Ranking[3]	SSC (mg/L)	TOC (mg/L)
LMC-M1	09/17/19	1000	37.96448	-121.68392	No	–	0.0023	–	–	657	16	3.5	–
LMC-M2	09/17/19	0635	37.96448	-121.68803	No	–	0.0039	–	–	429	19	9.1	–
LMC-M2	09/17/19	1015	37.96448	-121.68803	No	–	0.0041	–	–	466	18	8.8	–
Pinole Creek	09/17/19	1245	38.00406	-122.28837	No	–	0.0014	–	–	173	31	8.1	–
Sand Creek	09/17/19	0735	37.94765	-121.74128	No	–	0.0026	–	–	65	34	40	–
Sand Creek	09/17/19	1040	37.94765	-121.74128	No	–	0.0014	–	–	127	33	11	–

High opportunity threshold Total PCBs values in ***bold italics*** exceed 500 ppb.

High opportunity threshold Total mercury values in ***bold italics*** exceed 750 ppb.

1 Site ID Key: DI = drop inlet; SF = sheet flow; WGA = West Gertrude Avenue; MKT = Market Avenue; RUM = Rumrill Boulevard; CHS = Chesley Avenue; KEL = Kelsey Street; SUT = Sutro Avenue; MKS-1 = MS4 Discharge to Meeker Slough; MKS-2 = MS4 Discharge to Meeker Slough; SIMS-DI = Richmond Metal Recycling Facility; LMC = Lower Marsh Creek

2 PCBs in water analyzed by method EPA 1668

3 PCB (1-21) and mercury (1-36) concentrations ranked from highest to lowest.

– Not sampled

SSC = suspended sediment concentration

TOC = total organic carbon

Figure 7. Normalized Water PCBs Concentrations Presented from Highest to Lowest

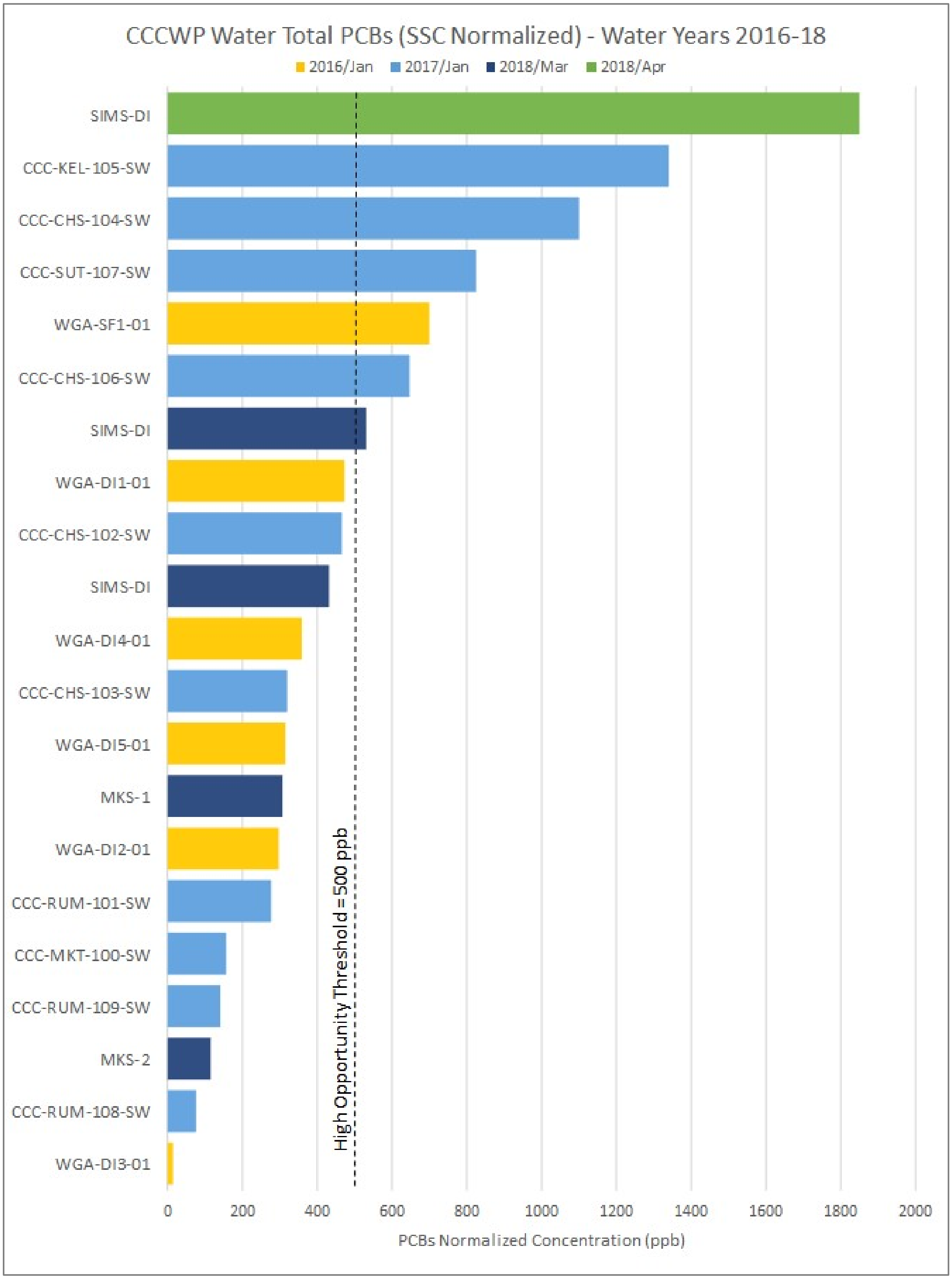


Figure 8. Normalized Water Mercury Concentrations Presented from Highest to Lowest

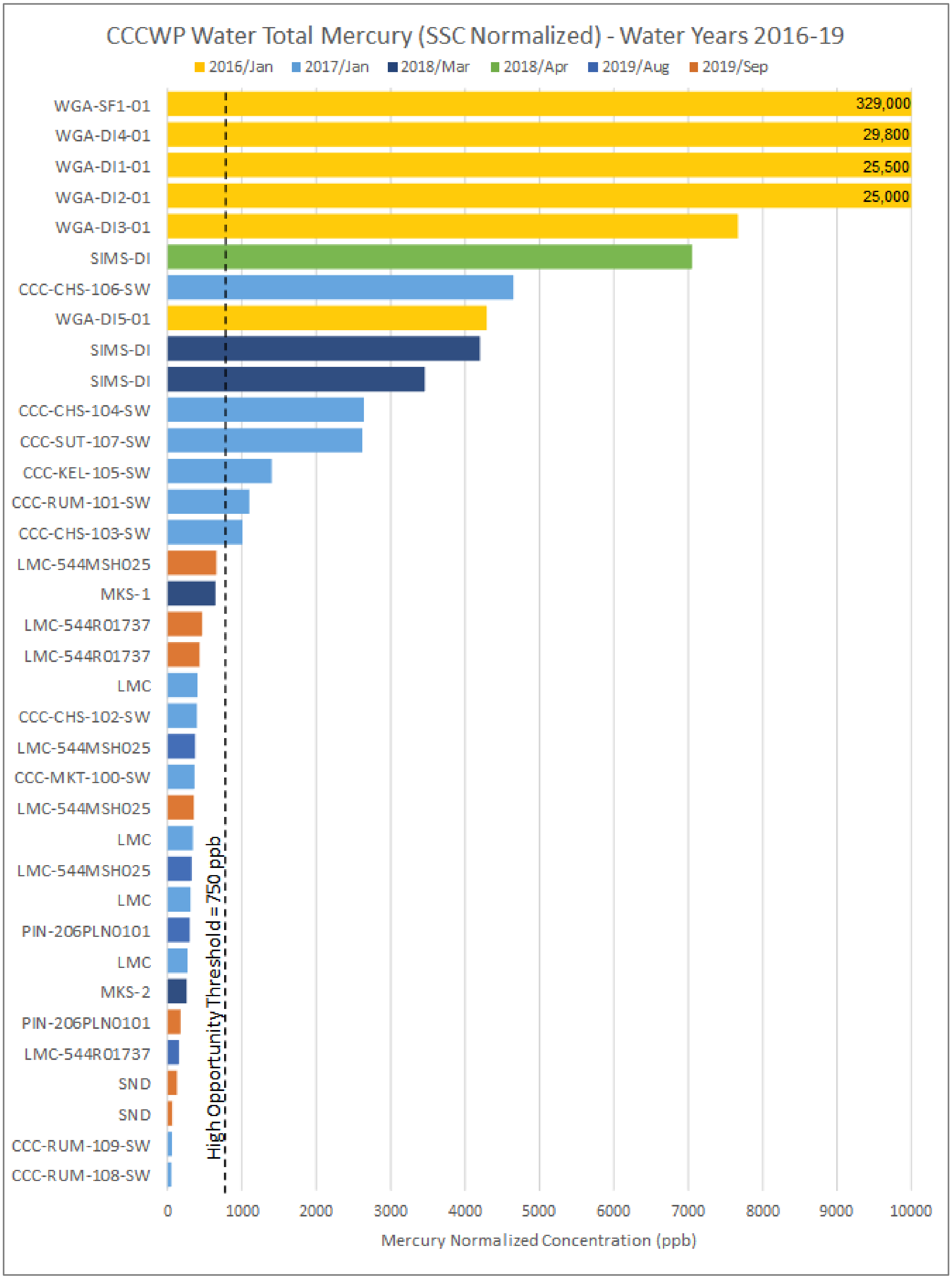


Figure 9. Stormwater PCBs Sample Locations and Normalized Concentrations

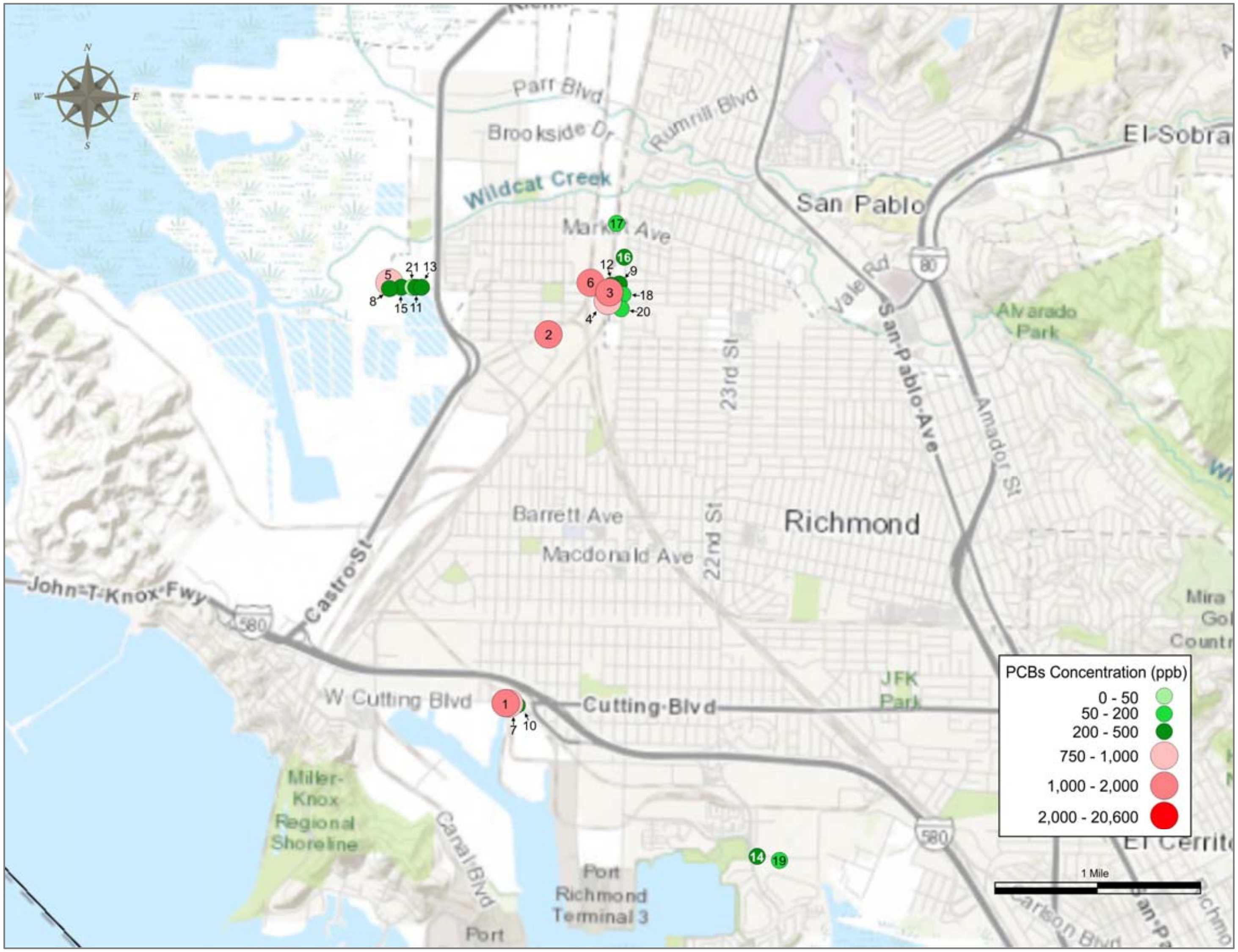


Figure 10. Stormwater and Surface Water Mercury Sample Locations and Normalized Concentrations – West County

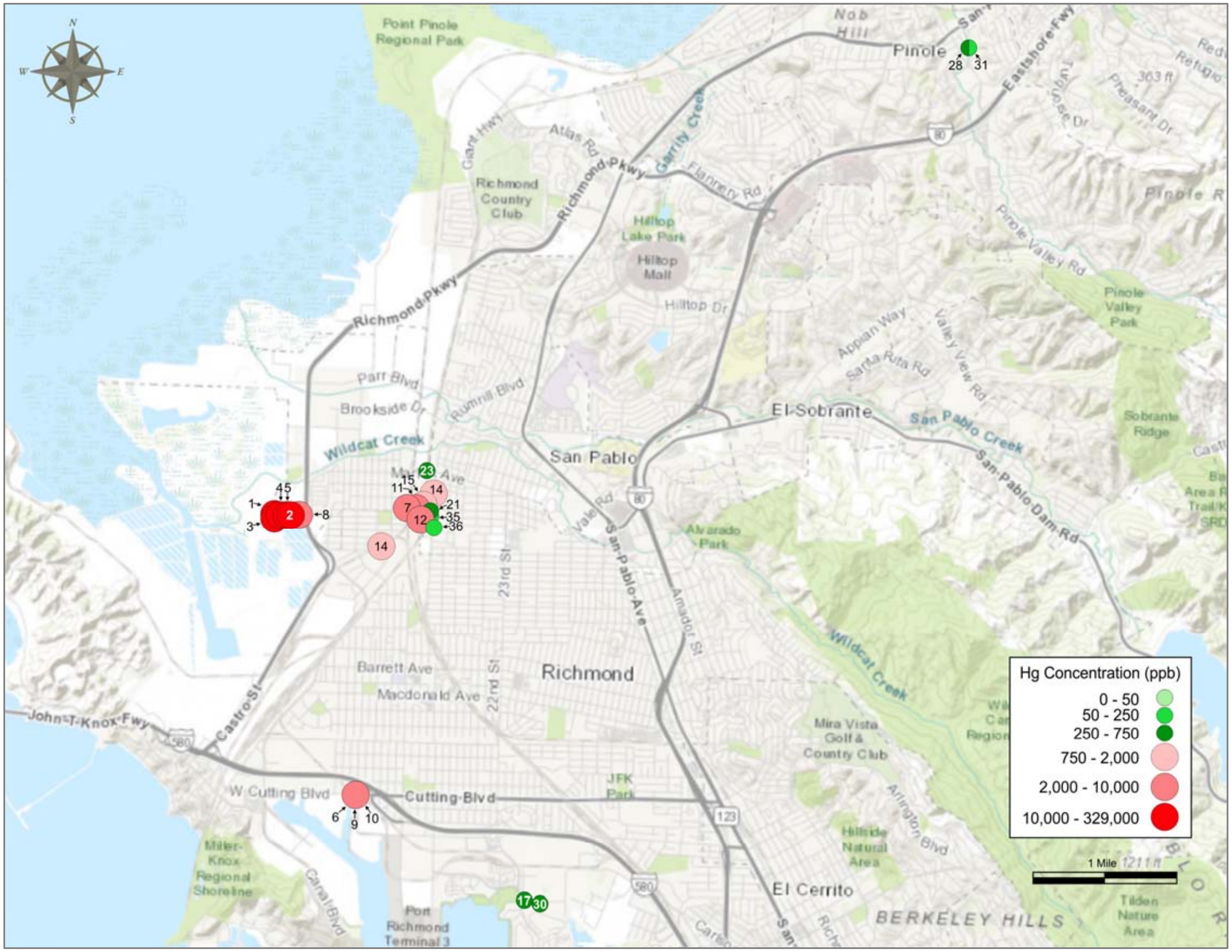
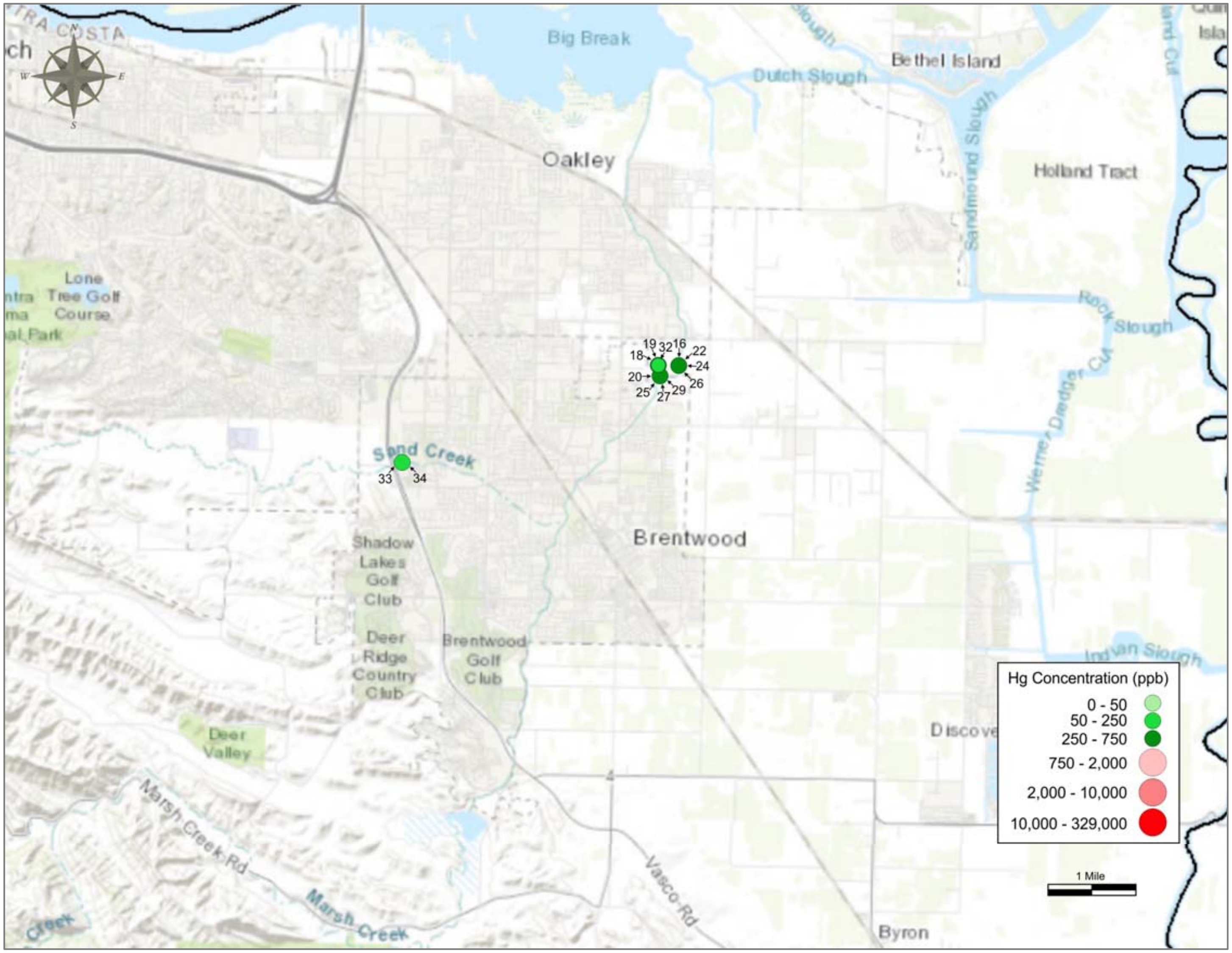


Figure 11. Stormwater and Surface Water Mercury Sample Locations and Normalized Concentrations – East County



3.4 Copper and Nutrients Monitoring

Copper and nutrients sampling in WYs 2017 and 2018 consisted of characterization monitoring during stormwater runoff events in the two largest creeks in the county – Lower Walnut Creek and Lower Marsh Creek. This monitoring was performed to measure ambient concentrations of copper and nutrients during elevated storm flows from the largest contributors of runoff to the Bay/Delta. During WY 2019, copper and nutrients sampling was conducted during non-stormwater flows on Lower Marsh Creek, one of its tributaries (Sand Creek), and an urban comparator water body (Pinole Creek). This monitoring was performed to measure ambient concentrations from sources other than stormwater and to help with the discovery process of quantifying pollutant concentrations in Marsh Creek as part of a stressor/sources identification (SSID) study of ongoing quasi-periodic fish mortality in Lower Marsh Creek.

Results of copper and nutrients monitoring are presented in Table 9, along with applicable water quality objectives. Dissolved copper concentrations ranged from 0.31 to 4 µg/L and were well below the Basin Plan freshwater quality objective, which ranged from 10 to 67 µg/L as adjusted for hardness. Total copper concentrations were low and ranged from 0.8 to 10 µg/L.

Ammonium concentrations were low and ranged from not detected to 0.19 mg/L. Nitrate concentrations ranged from not detected to 10 mg/L and did not exceed the Basin Plan maximum contaminant level for municipal supply of 10 mg/L for nitrate plus nitrite. Nitrite concentrations ranged from not detected to 0.24 mg/L and were well below the Basin Plan objective for municipal supply of 1 mg/L. Total Kjeldahl nitrogen concentrations were low and ranged from not detected to 2.6 mg/L. Dissolved orthophosphate concentrations ranged from not detected to 2 mg/L. More than half of the orthophosphate measurements exceeded the EPA Quality Criteria for Water of 0.03 mg/L. Total phosphorus concentrations ranged from 0.039 to 2 mg/L. Similar to orthophosphate, more than half of the total phosphorus measurements exceeded the EPA Quality Criteria for Water of 0.1 mg/L. Most of the elevated values of orthophosphate and total phosphorus are consistent with stormwater concentration found in Bay Area creeks and rivers, as reported in the Pollutants of Concern Loads Monitoring Progress Report, Water Years 2012, 2013, and 2014 (SFEI, 2016). The greatest exceedances of orthophosphate (1.8 and 2 mg/L) and phosphorus (1.7 and 2 mg/L) occurred on Aug. 22, 2019, in Marsh Creek at Station LMC-M1 which is located immediately downstream of the City of Brentwood WTP outfall and the East Contra Costa Irrigation District outfall. Samples collected just upstream of the outfalls at Station LMC-M2 on the same day were low for both orthophosphate and total phosphorus. This suggests that one of the outfalls may have contributed to elevated orthophosphate and total phosphorus concentrations in Marsh Creek on Aug. 22, 2019.

Table 9. Copper and Nutrients Monitoring Results and Water Quality Objectives – Lower Marsh, Lower Walnut, Pinole, and Sand Creeks (Water Years 2017-2019)

Site Description [1]	Sample Date	Sample Time	Latitude	Longitude	Stormwater Sample?	Copper, Dissolved (µg/L)	Copper, Total (µg/L)	Hardness (mg/L)	Ammonium (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Dissolved Orthophosphate (mg/L)	Total Phosphorus (mg/L)	Sampling Notes
LMC-M2	03/24/17	1215	37.96264	-121.68794	Yes	1.4	2.3	340	0.088	0.71	0.011	0.53	0.007	0.041	Rising hydrocurve
		1330			Yes	1.4	2.3	340	0.099	0.67	0.01	0.66	0.009	0.039	Near peak of hydrocurve
Walnut Creek	03/24/17	1100	37.97271	-122.05305	Yes	1.7	3	360	<0.04	0.69	0.006	0.48	***0.17***	***0.22***	Rising hydrocurve
		1400			Yes	2.2	4.4	340	<0.066	0.61	0.007	0.75	***0.17***	***0.24***	Near peak of hydrocurve
LMC-M2	03/01/18	1120	37.96264	-121.68794	Yes	3.2	3.5	180	<0.1	0.73	0.025 J	1.1	0.03	0.069	Near peak of hydrocurve
Walnut Creek	03/01/18	1000	37.97271	-122.05305	Yes	3	10	120	<0.1	0.28	0.005 J	1.5	***0.16***	***0.37***	Near peak of hydrocurve
LMC-M1	08/22/19	0600	37.96448	-121.68392	No	2.3	2.3	300	0.062 J	9.7	0.02 J	<0.07	***1.8***	***1.7***	Low flow conditions
	08/22/19	0830			No	2.6	2.6	290	0.076 J	10	0.012 J	<0.07	***2***	***2***	Low flow conditions
LMC-M2	08/22/19	0620	37.96448	-121.68803	No	0.31 J	0.82	210	0.1	0.053 J	<0.005	0.66	0.022	0.074	Low flow conditions
	08/22/19	0845			No	0.35 J	1.1	210	0.069 J	0.052 J	<0.005	0.74	0.026	0.094	Low flow conditions
Pinole Creek	08/22/19	1030	38.00406	-122.28837	No	0.81	0.94	520	<0.04	0.08 J	<0.005	0.44	***0.6***	***0.66***	Normal flow conditions
LMC-M1	09/17/19	0615	37.96448	-121.68392	Yes	4	5.3	250	0.13	4	0.24	2.6	***0.21***	***0.37***	Elevated flow conditions
	09/17/19	1000			Yes	3.7	4.4	230	0.12	6.2	0.15	2	***0.47***	***0.57***	Elevated flow conditions
LMC-M2	09/17/19	0635	37.96448	-121.68803	Yes	1.5	2.8	190	0.18	<0.02	0.061	1.8	<0.006	***0.13***	Elevated flow conditions
	09/17/19	1015			Yes	2.1	3.9	190	0.19	<0.02	<0.005	2.5	0.006 J	***0.17***	Elevated flow conditions
Pinole Creek	09/17/19	1245	38.00406	-122.28837	Yes	0.49 J	0.8	530	0.062 J	0.056	<0.005	0.99	***0.57***	***0.65***	Normal flow conditions
Sand Creek	09/17/19	0735	37.94765	-121.74128	Yes	1.3	3.2	70	0.041 J	0.6	<0.005	0.44	***0.073***	***0.12***	Elevated flow conditions
	09/17/19	1040			Yes	1.3	1.9	70	0.055 J	0.55	<0.005	0.083 J	***0.061***	0.085	Elevated flow conditions
Maximum Contaminant Level/Water Quality Objective						10-67[2]	None	None	None[3]	9.0[4]	1.0[4]	None	0.03[5]	0.1[5]	

Values presented in ***bold italics*** exceed the listed maximum contaminant level/water quality objective

1 Site Description Key: LMC = Lower Marsh Creek; M1 = Point below Brentwood Wastewater Treatment Plant, M2 = Point above Brentwood Wastewater Treatment Plant

2 Range of maximum acceptable values for dissolved copper calculated from hardness as specified in the San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan), May 2017, Table 3–4: Freshwater Water Quality Objectives for Toxic Pollutants for Surface Waters, 1-hr average for copper. The objectives for copper are based on hardness. The table values in the source assume a hardness of 100 mg/l CaCO3. At other hardnesses, the objectives are calculated using the following formula where H = ln (hardness): The 1-hour average for copper is e(0.9422H-1.700).

3 San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan), May 2017, contains maximum contaminant levels for un-ionized ammonia, but not for ammonium (ionized ammonia).

4 San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan), May 2017, Table 3-5: Water Quality Objectives for Municipal Supply. The table specifies WQOs of 10 mg/L for Nitrate+Nitrite as N and 1 mg/L for Nitrite as N.

5 Quality Criteria for Water, U.S. Environmental Protection Agency, EPA#440/5-86-001, 1986. The recommended criterion for total phosphorus is for streams which do not empty into reservoirs.

< Analyte not detected at or above the detection limit; numeric value after the "<" symbol is the value of the detection limit.

J Analyte detected below the reporting limit; result should be considered as an estimated value.

3.5 Methylmercury Monitoring

Results of methylmercury monitoring are presented in Table 10. Monitoring station locations are shown in Figure 12. Values are presented for methylmercury concentration and the ratio of methylmercury to total mercury. Monitoring efforts in WYs 2015-2017 were completed as part of CCCWP's implementation of the Methylmercury Control Study which was responsive to an earlier Central Valley Water Board requirement (CCCWP, 2018b). Efforts in WY 2019 were responsive to the 2019 MRP amendment to collect at least eight methylmercury samples on Marsh Creek annually (SFBRWQCB, 2019).

Methylmercury concentrations from WYs 2015-2019 ranged from less than 0.02 ng/L to 0.30 ng/L. Of 21 samples collected in Marsh Creek, half of the results exceed the Delta Methylmercury TMDL of 0.06 ng/L. This outcome is not surprising for surface waters such as Marsh Creek which carry an appreciable load of suspended sediment (CCCWP, 2018b). As expected, some of the highest methylmercury concentrations were accompanied by very high suspended sediment concentrations (i.e., methylmercury is associated with particles, so if the water column is high in suspended sediments then the methylmercury concentration will be correspondingly high). For example, the sample at Station LMC-M2 collected on Jan. 8, 2017, has the highest suspended sediment concentration (236 mg/L) and the highest methylmercury concentration (0.30 ng/L). In other cases, elevated methylmercury concentrations are associated with elevated methylmercury to mercury ratios. The occurrence of elevated ratios (greater than about 5 percent) can indicate the presence of enhanced methylation efficiency in areas of standing or slow-moving water (CCCWP, 2018b). This occurrence of enhanced methylation is not limited to Marsh Creek; the Aug. 22, 2019 samples from Pinole Creek and Marsh Creek had the highest ratios (14.5 percent at both locations).

Table 10. Methylmercury Analytical Results

Site Description[1]	Sample Date	Time	Stormwater Sample?	Latitude	Longitude	SSC (mg/L)	Total Hg (ng/L)	Total Hg/SSC Ratio (ppb)	Total MeHg (ng/L)	MeHg to Hg Ratio (%)
LMC-M5	01/14/15	0942	Yes	37.92311	-121.71506	3.7	1.1	297	< 0.02	NA
LMC-M4	01/14/15	1017	Yes	37.93642	-121.70918	7.7	3	390	0.04 J	1.3
LMC-M3	01/14/15	1030	Yes	37.93803	-121.70766	7.5	1.4	187	0.03 J	2.1
LMC-M1	01/14/15	1130	Yes	37.96393	-121.68366	< 2	1	500	< 0.02	NA
LMC-M5	02/26/15	1100	Yes	37.92311	-121.71506	35	2	57	0.04 J	2.0
LMC-M3	02/26/15	1130	Yes	37.93803	-121.70766	17	1.8	106	0.04 J	2.2
LMC-M4	02/26/15	1150	Yes	37.93642	-121.70918	11	3.4	309	0.047 J	1.4
LMC-M1	02/26/15	1220	Yes	37.96393	-121.68366	4.7	1.1	234	< 0.02	NA
LMC-M2	01/08/17	0920	Yes	37.96264	-121.68794	48	15	312	***0.09***	0.6
LMC-M2	01/08/17	1220	Yes	37.96264	-121.68794	57	23	404	***0.11***	0.5
LMC-M2	01/08/17	1445	Yes	37.96264	-121.68794	174	47	270	***0.23***	0.5
LMC-M2	01/08/17	1745	Yes	37.96264	-121.68794	236	80	339	***0.30***	0.4
LMC-M1	08/22/19	0600	No	37.96393	-121.68366	< 2	0.74	370	0.04 J	***5.4***
LMC-M1	08/22/19	0830	No	37.96393	-121.68366	< 2	0.65	325	0.03 J	4.5
LMC-M2	08/22/19	0620	No	37.96264	-121.68794	13	2.0	154	***0.29***	***14.5***
Pinole Creek	08/22/19	1030	No	38.00408	-122.28843	2.3 J	0.69	300	***0.10***	***14.5***
LMC-M1	09/17/19	0615	No	37.96393	-121.68366	9.4	3.3	351	***0.11***	3.3
LMC-M1	09/17/19	1000	No	37.96393	-121.68366	3.5	2.3	657	***0.07***	3.0
LMC-M2	09/17/19	0635	No	37.96264	-121.68794	9.1	3.9	429	***0.20***	***5.1***
LMC-M2	09/17/19	1015	No	37.96264	-121.68794	8.8	4.1	466	***0.24***	***5.9***
LMC-M3	09/17/19	0735	No	37.93803	-121.70766	40	2.6	65	0.05	1.9
LMC-M3	09/17/19	1040	No	37.93803	-121.70766	11	1.4	127	0.04 J	2.9
Pinole Creek	09/17/19	1245	No	38.00408	-122.28843	8.1	1.4	173	***0.11***	***7.9***

1 Site Description Key: M1 = Marsh Creek, downstream of Brentwood WTP; M2 = Marsh Creek at fish ladder, upstream of Brentwood WTP; M3 = Sand Creek, tributary to Marsh Creek; M4 = Deer Creek, tributary to Marsh Creek; M5 = Dry Creek, tributary to Marsh Creek; PIN = Pinole Creek, 0.5 miles north of Highway 80

J Estimated value: measurement falls between the MDL and the MRL

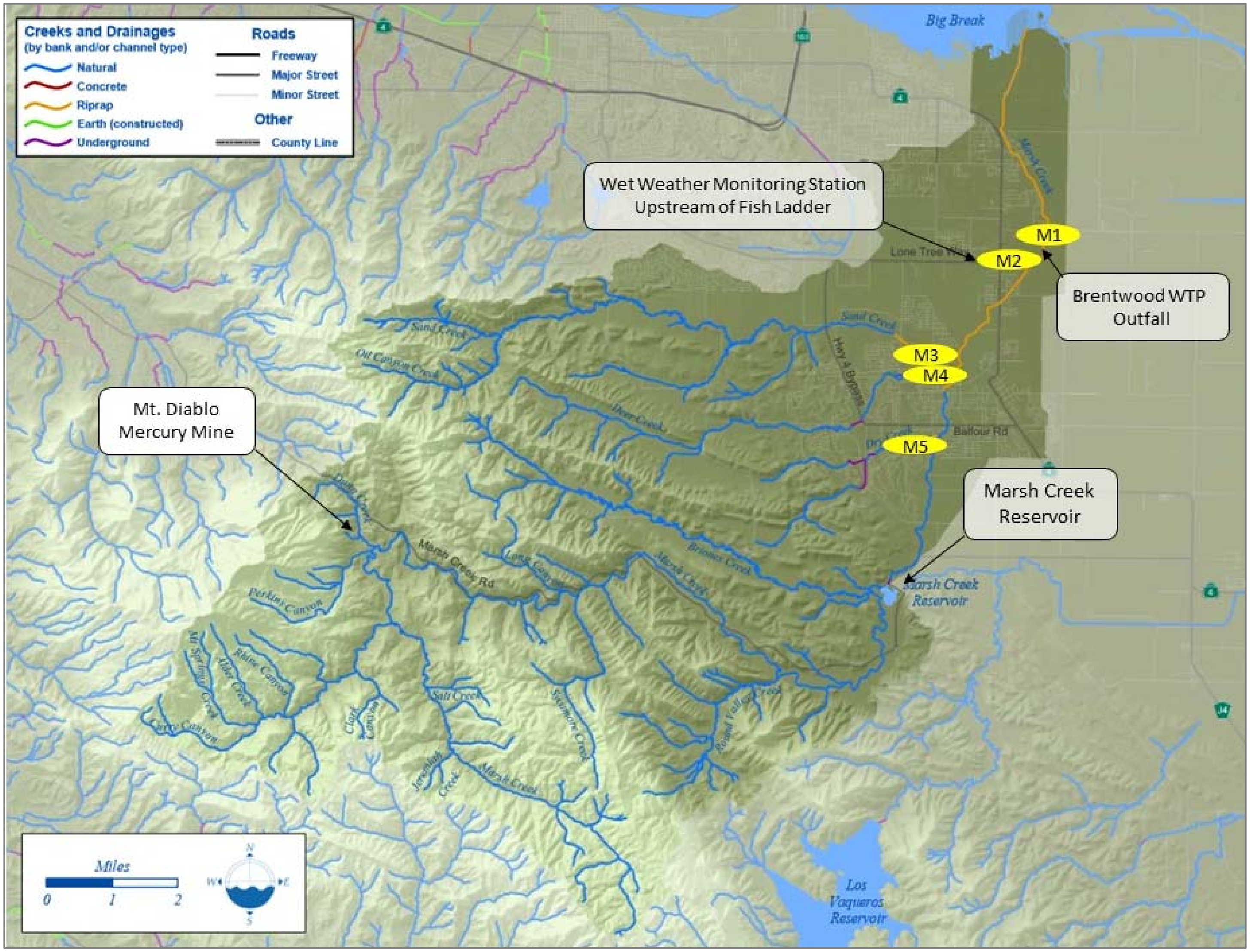
MeHg methylmercury

NA Not applicable

< Analyte not detected at or above the MDL; numeric value following the "<" symbol is the associated MDL value

Values in ***bold italics*** exceed the Delta TMDL for methylmercury of 0.06 ng/L or indicate enhanced methylation efficiency above 5 percent

Figure 12. Methylmercury Station Locations on Marsh Creek and Tributaries



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4. DATA QUALITY ASSURANCE/QUALITY CONTROL ANALYSIS

In each water year, ADH performed quality assurance/quality control (QA/QC) verification and validation of laboratory data per the Quality Assurance Project Plan (CCCWP, 2016b), and consistent with SWAMP 2008 or 2013 measurement quality objectives, as appropriate (SWAMP, 2008; SWAMP, 2013).

Refer to the QA/QC section of each annual POCs report for details of data review in each water year. For water year 2019, the complete QA/QC discussion is presented below.

4.1 Water Year 2019 Summary

No contamination was found in any laboratory blank for any analyte. All samples were analyzed well within analyte-specific hold times. Some particle size precision results were affected by insufficient sample size and flagged accordingly.

Otherwise, almost all samples for all analyses met laboratory quality control objectives. Exceptions to this are shown in Table 11. Given that all quality control issues described in the table show the issues were of relatively minor consequence, the data from these samples are of acceptable quality and are included in the data set for this annual report.

Table 11. Quality Control Issues and Analysis in the WY 2019 Project Data Set

Sample ID & Type	Issue	Analysis
Copper & Nutrients Field Samples LMC-544MSH025-01 LMC-544MSH025-02 LMC-544R01737-01 LMC-544R01737-02 PIN-206PLN0101-01 SND-1909170735-01 SND-1909171040-02	Hardness was requested to be analyzed by EPA method SM 2310 C, but the laboratory used SM 2340 C.	Method SM 2340C is an acceptable alternative method to SM 2310 C for analysis of hardness.
Laboratory Control Samples 908014 908015	LCS methyl mercury spike recovery and associated LCSD RPD outside control limits.	Results meet all pertinent method criteria. Analytical results were flagged appropriately; no further action required.
HDS Field Samples RCHMBP-1908061545-HDS RCH8ST-1909061545-HDS	Several PCB congeners had elevated MDLs and RLs due to chromatic interference.	Analytical results were flagged appropriately; no further action required.
	The ion abundance ratios did not meet the acceptance criteria for some PCB congeners.	Reported values are estimated maxima. All analytical results were flagged appropriately; no further action required.
Laboratory Control Sample KQ1903094-05 Matrix Spike Samples KQ1913094-01 KQ1913094-02	The recoveries of a few PCB congeners in an LCS and an MS/MSD pair were outside the project control limits.	Based on the method and historic data, the recoveries observed were in the range expected for this analysis. Analytical results were flagged appropriately; No further corrective action was required.
Matrix Spike Sample U081060006 MS	MS recovery of total mercury outside of control limits.	The high recovery was due to possible matrix interference in the QC sample. The analytical batch was accepted based on LCS and RPD results. Analytical results were flagged appropriately; No further corrective action was required.
Laboratory Duplicate U090411001 DUP	RPDs of particle size fractions greater than 2mm in size were above the control limit.	Sample size was too small to reproduce results for these particle sizes. Analytical results were flagged appropriately; No further corrective action was required.
Laboratory Duplicate RCHMBP-1908061545-HDS DUP	RPDs of several particle size fractions were above the control limit.	The sample was very heterogeneous. The high RPD of the larger size fractions can be explained as needing a larger sample size, but even the smaller size fractions showed showing high variation. Analytical results were flagged appropriately; No further corrective action was required.
Street Dirt Field Samples CC-SNPB-1909181340-C CC-CNRD-1909251430-C	Several PCB congeners had elevated MDLs and RLs due to chromatic interference.	Analytical results were flagged appropriately; no further action required.
	The ion abundance ratios did not meet the acceptance criteria for some PCB congeners.	Reported values are estimated maxima. All analytical results were flagged appropriately; no further action required.
Matrix Spike Duplicate Sample KQ1914232-04	The MSD RPD and recovery of the congener PCB 60 were outside control criteria.	Recovery in the LCS was acceptable, which indicated the analytical batch was in control. The matrix spike outlier suggested a potential high bias in this matrix. Analytical results were flagged appropriately; no further corrective action was appropriate.

LCS laboratory control sample
LCSD laboratory control sample duplicate
MS matrix spike
MSD matrix spike duplicate
RPD relative percent difference

5. LESSONS LEARNED AND RECOMMENDATIONS FOR MRP 3.0

5.1 POC Lessons Learned – 2014-2019

This section summarizes lessons learned from monitoring PCBs, mercury and methylmercury, nutrients, and copper from 2014 to 2019. Monitoring priorities in future permit cycles are discussed as they flow from the lessons learned.

5.1.1 PCBs

Source property investigation is progressing and continues to be an important pathway to make progress toward target load reductions. Eight potential source properties have been either referred to the Water Board (three sites) or identified as self-abated (five sites). For sites that have been referred, Water Board is granting half credit for the countywide required load reduction estimate using accounting methods established through the Reasonable Assurance Analysis (BASMAA, 2020). For sites that have been self-abated, the Water Board grants full credit.

Partial credit for referral sites is conditioned on Permittees performing enhanced operations and maintenance (O&M) around the site to intervene with the transport of PCB-contaminated sediments from source properties to the MS4. Enhanced O&M include more frequent street sweeping, installation of stormwater treatment devices (such as green infrastructure), full trash capture screens, and hydrodynamic separators. Future monitoring efforts will support enhanced O&M in two ways: 1) monitoring resources will be used to help define the migration pathways for contaminated sediments to leave the site and enter the MS4; and 2) monitoring will be used to evaluate the effectiveness of enhanced O&M.

Over the past five years monitoring PCBs in urban settings, it has become increasingly apparent to CCCWP that “low hanging fruit” in the form of obvious source properties is hard to find. The latest RMP reconnaissance report notes that only 15 percent of old industrial acreage within Contra Costa County has been monitored for PCBs to date. This reflects a significant challenge faced by CCCWP in monitoring watershed management areas for PCBs. Old industrial land areas in Contra Costa County do not generally drain to a single outlet to the Bay. Rather, the old industrialized shoreline of Contra Costa County contains numerous facilities regulated under the Industrial General Permit, many of which discharge directly to the Bay rather than to the local MS4.

In effect, achieving the TMDL WLAs for PCBs assigned to Contra Costa County may require control measures at facilities that are beyond the reach of the Contra Costa Permittee’s regulatory jurisdiction. CCCWP anticipates that a substantial amount of POC investigation effort in MRP 3.0 will be dedicated to carefully documenting where potential source properties may be directly impacting the MS4, and where there are potential source properties that are outside the reach of direct investigation and regulation by municipal Permittees.

The stormwater diversion to sanitary treatment pilot project from MRP 1.0 yielded disappointingly small loads. Construction of the project was delayed, and so monitoring did not occur until 2015 and is therefore reported in Appendix 4C of the IMR (CCCWP, 2020). The low mercury and PCB loads diverted to sanitary treatment resulted from three factors:

- The capacity of the receiving sanitary sewer conveyance system constrains diversion flow rates to 250 gpm, for a stormwater pump station that is rated for 135,000 gpm
- The total suspended solids (TSS) concentrations of the diverted stormwater were not very high in the pilot watershed – 34 mg/L and 52 mg/L for dry and wet weather diversions, respectively
- The PCB/TSS ratios (11-134 ng/g) and Mercury/TSS ratios (270-690 ng/g) were more typical of Bay Area background concentrations than of the elevated concentrations often found in old industrial areas

Based on these lessons learned, cost-benefit analysis, and the outcomes of the diversion pilot, CCCWP does not recommend further monitoring of this type of control measure in future permit cycles.

CCCWP supported two BASMAA regional studies of the effectiveness of stormwater treatment. *Evaluation of Mercury and PCBs Removal Effectiveness of Full Trash Capture Hydrodynamic Separator Units* (Appendix 4B of the IMR; CCCWP, 2020) established unit removal efficiencies used in the source control load reduction accounting. Demonstrating that full trash capture provides some PCB and mercury removal also justifies using trash capture as an enhanced O&M tool around PCB referral sites.

Pollutant Removal from Stormwater with Biochar Amended Bioretention Soil Media (BSM) (Appendix 4A of the IMR; CCCWP, 2020) investigated whether the addition of biochar to bioretention soil media would improve removal effectiveness for mercury and PCBs. Biochar is a form of activated carbon that is known to adsorb and retain organic pollutants. The improvement of PCB removal effectiveness by adding biochar was marginal at best. Influent PCBs in the study ranged from approximately 10,000 to 20,000 pg/L. Effluent PCBs for the control and the biochar-amended soils ranged from approximately 400 to 4,700 pg/L. The minimum and range appeared to move down, but the improvement was not statistically significant because the effluent data were highly variable. No statistically significant differences between biochar brands was demonstrable.

For mercury, the control biofiltration soil media (BSM), with no biochar added, slightly <u>increased</u> mercury concentrations from 4 to 10 ng/L in the influent and from to 7 to 15 ng/L in the effluent. In contrast, the effluent from biochar-amended BSM ranged from 2 to 15 ng/L. Repeated runs showed highly variable performance for each type of biochar tested.

The fact that the control media <u>increased</u> mercury concentrations points to an issue previously noted in pilot studies of bioretention for treating mercury (e.g., Caltrans, 2013). Mercury is ubiquitous, present in soils, sediments, and water at some detectable concentration. Leaching of soil particles from BSM can <u>increase</u> mercury concentrations in water, as occurred in this study. Any potential ameliorating benefit of adding biochar was barely discernable – statistical analysis revealed no difference between the different types of biochar tested.

The lesson learned from the biochar amendment study is that municipal resources for effectiveness monitoring should focus on established technologies. Applied research to develop new technology is best carried out by product manufacturers and vendors. CCCWP Permittees seek to implement controls for pollutants of concern, including PCBs, using established technologies to the maximum extent practicable. Innovative technologies should be tested and optimized by product manufacturers and independently verified, rather than developed and proven by the municipal stormwater agencies who would be the ultimate buyers of such technologies.

In summary, for future permit cycles, key questions to resolve through monitoring include:

- Clearly defining investigation endpoints – how much evidence is needed to determine a watershed as "fully investigated" and halt further exploration for potential source properties?
- Clearly defining the process for closing a case (i.e., what information is needed to call the investigation and abatement of a particular site complete)?
- Where are the remaining potential source properties that discharge to the MS4, and where are there potential source properties that are beyond the direct jurisdiction of municipal Permittees.
    - What are specific activities that qualify as "enhanced O&M?"
    - How much good do they do?
    - What are the costs and consequences of those activities?

5.1.2 Mercury and Methylmercury[2]

CCCWP monitors mercury and methylmercury to fulfill not only the SFBRWQCB TMDL requirements adopted in Provisions C.8 and C.11 of the MRP, but also to fulfill the CVRWQCB TMDL requirements for methylmercury monitoring adopted in Provision C.16.5.g of the MRP. In October 2018, CCCWP submitted a methylmercury control study report (CCCWP, 2018c) to the CVRWQCB. Key findings from the study include:

- Mercury and methylmercury are both associated with suspended sediment in urban stormwater.
- Particle ratios help differentiate contaminated sediments from background sediments

[2] Methylmercury is mercury bonded to a carbon atom. It is a form of mercury that poses greater risks of accumulation in aquatic food webs to levels considered harmful to human and wildlife consumers of fish.

- **Total Mercury**: Typical Bay Area background mercury concentrations in suspended sediments are approximately 0.3 mg/kg. In contrast, suspended sediments in an old industrial area of Richmond have approximately 1 mg/kg mercury. Concentrations exceeding 1 mg/kg are also more typical of watersheds draining old mercury mines.

- **Methylmercury:** Typical Bay Area background methylmercury concentrations in suspended sediments range from 3 to 15 µg/kg, or about 1 to 5 percent of the total mercury concentration. This is consistent with national studies of methylmercury, which showed that in typical watersheds 1 to 5 percent of the total mercury is present as methylmercury, whereas watersheds with substantial wetland areas that efficiently convert mercury to methylmercury have more than 10 percent of the total mercury present as methylmercury. Thus, the study did not reveal evidence of persistent biogeochemical conditions that increase methylmercury in urban stormwater discharges.

- There was no evidence for elevated mercury or methylmercury in sediments reaching Lower Marsh Creek from Upper Marsh Creek[3]. This finding is important because the historic Mount Diablo Mercury Mine is located in Upper Marsh Creek. A key monitoring question has been whether elevated mercury or methylmercury in suspended sediments is observed in Lower Marsh Creek when upper watershed flows overtop Marsh Creek Reservoir and reach Lower Marsh Creek.

- Monitoring in Lower Marsh Creek detected some preliminary evidence for episodic occurrence of suspended sediments having elevated methylmercury concentrations (i.e., 6 ng/g, compared to background concentrations of 1 to 3 ng/g). This occurred during the rise of the hydrograph in a late season (April 2013) storm. This could indicate the influence of microbial activity either upland or in-stream as a result of ponds that form between erosion control check dams constructed along the creek bottom.

- Background concentrations of methylmercury can easily lead to mercury concentrations in stormwater exceeding the 0.06 ng/L "implementation goal" cited in the Delta Methylmercury TMDL. Achieving 0.06 ng/L methylmercury as an annual average `in surface waters or stormwater discharges is not deemed technically or economically feasible.

In response to concerns raised by CCCWP over the technological and economic feasibility of achieving 0.06 ng/L methylmercury in stormwater discharges, technical peer reviewers inquired through their review of CCCWP's report whether achieving load reductions is feasible by reducing the volume of stormwater discharged. This will lead to a reasonable assurance analysis study to model how much stormwater infiltration may be achieved after implementing all reasonable and foreseeable green infrastructure capital projects in the jurisdiction of the Permittees subject to the Delta Methylmercury TMDL (the Cities of Brentwood, Antioch and Oakley).

[3] Upper Marsh Creek and Lower Marsh Creek are divided by the Marsh Creek Reservoir, which only sporadically flows into Lower Marsh Creek during high rainfall years after extended periods of rain.

5.1.3 Nutrients

CCCWP monitors nutrients to help characterize the nutrient concentrations of urban stormwater, addressing a data gap identified in the San Francisco Bay Nutrient Management Strategy. A summary of external nutrient loads to San Francisco Bay (Novick and Senn, 2014) found that, based on initial order-of-magnitude estimates, stormwater does not contribute substantially to loads at the sub embayment scale in South and Central Bay, but may contribute non-trivial loads to San Pablo and Suisun Bays during certain times of the year. As these are the receiving waters of much of Contra Costa County, CCCWP is interested in tracking further developments of the San Francisco Bay Nutrient Management Strategy. CCCWP collected and analyzed 18 samples for nutrients from a variety of locations and is on track to complete the requisite minimum 20 nutrient samples by the end of the permit term.

The SFEI External Nutrient Loads to San Francisco Bay report (Novick and Senn, 2014) also stated that urban stormwater loads were estimated based on modifications of the Regional Watershed Spreadsheet Model (RWSM) developed by the RMP's Small Tributaries Loading Strategy Workgroup. Table 12 compares RWSM assumptions about nutrient concentrations in urban and agricultural stormwater to measurements from CCCWP. Monitoring data generally support RWSM assumptions about nutrients in urban stormwater. The CCCWP samples for agricultural runoff are generally lower than RWSM assumptions but should not be considered representative – they were only two samples collected after a single storm event from the Sand Creek drainage.

Table 12. Comparison of Nutrient Concentrations Measured by CCCWP with Regional Watershed Spreadsheet Model Assumptions

Land Use	Ammonia		Nitrate		Dissolved Phosphorus	
	RWSM Assumption	CCCWP Measured	RWSM Assumption	CCCWP Measured	RWSM Assumption	CCCWP Measured
Open	0.1	NA	0.3	NA	0.1	NA
Urban[1]	0.2-0.4	0.09-0.19	0.4-0.7	<0.02-0.73	0.4-0.5	<0.01-0.03
Agricultural[2]	1.3	0.04-0.06	8.9	0.6	0.6	0.06-0.07

1 Five samples collected in Lower Marsh Creek in water years 2017-2019
2 Two samples collected in Sand Creek, tributary to Mash Creek, on Sep. 17, 2019
NA Parameter not analyzed
RWSM Regional Watershed Spreadsheet Model

The snapshot of nutrient concentrations by land use presented in Table 12 suggests the assumptions made in the RWSM are generally supported. The need for additional information, and what kind of additional information about urban stormwater would be helpful, is unclear.

5.1.4 Copper

CCCWP has collected 18 of the 20 required copper samples and is on track to complete the rest by the end of the permit term. None of the 18 samples collected from 2014 to 2019 exceeded water quality objectives for dissolved copper in surface waters (see Table 9).

Discerning background copper from human-caused sources is challenging because copper is a naturally occurring trace element, present at about 60 mg/kg in the continental crust of the earth (Lide, 2004). Much of the variation of the total copper concentration in stormwater results from variation in suspended sediments concentration. For source assessment and trends analysis, evaluating human-caused enrichment of copper in sediments is one way to discern human sources from natural background.

Copper concentrations in sediments and, in particular, storm-borne sediments from urban settings are especially relevant to understanding the effect of brake pad wear on urban stormwater quality. Copper was formerly present in high performance brakes and is released from abrasion during braking. Recognizing this, municipal stormwater programs banded together and successfully lobbied the brake pad manufacturing industry to negotiate a long-term reformulation of brake pad materials, leading to eventual product substitution and less release of copper into urban settings from brake pads. Product reformulation and substitution is a long-term process, as is the aging and replacement of the U.S. vehicle fleet. The gradual decline of copper in urban sediments is likely on the timescale of decades rather than years.

Table 13 provides a snapshot comparing copper concentrations in storm-borne sediments from the urbanized area of Lower Marsh Creek to storm-borne sediments from the open/agricultural land areas of Sand Creek, a tributary to Marsh Creek. The last column shows that the copper concentrations in suspended sediments present in urban stormwater was about ten-fold greater than the average crustal abundance of copper, and much higher compared to agricultural/open space sediments of Sand Creek.

Table 13. Summary of Copper, Suspended Sediment Concentration, and Ratios in the Marsh Creek Watershed During the Storm Event of Sep. 17, 2019

Station Code	Sample Date	Collection Time	Dissolved Copper (µg/L)	Total Copper (µg/L)	Suspended Sediment Concentration (mg/L)	Total Cu/SSC Ratio[1] (mg/kg)	Average +/- Standard Deviation Total Cu/SSC Ratios[1] (mg/kg)
LMC-544MSH025	09/17/19	6:15	4	5.3	9.4	564	643 +/- 422 (Urban)
		10:00	3.7	4.4	3.5	1257	
LMC-544R01737	09/17/19	6:35	1.5	2.8	9.1	308	
		10:15	2.1	3.9	8.8	443	
SND	09/17/19	7:35	1.3	3.2	40	80	126 +/- 65 (Open/Agricultural)
		10:40	1.3	1.9	11	173	

1 Copper to suspended sediment concentration ratio

This is a glimpse of how two different land uses have different particle ratios of copper, for understandable reasons. A more helpful story would be data from a variety of locations, and a monitoring design that addresses the anticipated timescale of changes in the copper particle ratios as a result of phasing out copper in brake pads. The current paradigm of minimum numbers of annual copper samples does not aid or incentivize monitoring efforts addressing these types of more thoughtful studies of human copper sources and the effects of copper control measures.

5.2 Recommendations

CCCWP intends to focus POC monitoring efforts for PCBs on source property investigations and effectiveness evaluations. Effectiveness evaluations will address the efficacy and outcomes of enhanced O&M near source properties that have been referred to the Water Board. Consistent with recommendations for creek status monitoring, CCCWP also recommends that minimum sampling effort be prescribed for the permit term, rather than annually. This request also applies to copper monitoring – the level of effort is best prescribed for the permit term, not annually.

Additional nutrient monitoring does not seem helpful to CCCWP's priorities at this point, as there are no obvious management actions or data gaps related to nutrient monitoring. If some additional attention to nutrients in stormwater is warranted, a better approach may be to include language requiring Permittees to "conduct or cause to be conducted" a study of nutrients from stormwater, targeting needs identified through the San Francisco Bay Nutrient Management Strategy.

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Pollutants of Concern Reconnaissance Monitoring Progress Report, Water Years 2015 - 2019

Prepared by

Alicia Gilbreath, Jennifer Hunt and Lester McKee

San Francisco Estuary Institute

CONTRIBUTION NO. / XXX 2020

Preface

Reconnaissance monitoring for water years 2015, 2016, 2017, 2018 and 2019 was completed with funding provided by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). This report is designed to be updated each year until completion of the study. At least one additional water year (2020) is planned for this study. This draft report was prepared for the Bay Area Stormwater Management Agencies Association (BASMAA) in support of materials submitted on or before March 31st 2020 in compliance with the Municipal Regional Stormwater Permit (MRP) Order No. R2-2015-0049.

Acknowledgements

We appreciate the support and guidance from members of the Sources, Pathways, and Loadings Workgroup of the RMP. The detailed work plan for this study was developed by the RMP Small Tributaries Loading Strategy (STLS) Team during a series of meetings in the summer of 2014, with slight modifications made during the summers of 2015, 2016, 2017, 2018 and 2019. Local members on the STLS Team at that time were Jim Scanlin (and Arleen Feng in earlier years [Alameda Countywide Clean Water Program]), Bonnie de Berry (San Mateo Countywide Water Pollution Prevention Program), Lucile Paquette (Contra Costa Clean Water Program), Chris Sommers and Lisa Sabin (Santa Clara Valley Urban Runoff Pollution Prevention Program), and Richard Looker and Jan O'Hara (San Francisco Bay Regional Water Board). RMP field and logistical support provided by San Francisco Estuary Institute (SFEI) in water year (WY) 2015 included Patrick Kim, Carolyn Doehring, and Phil Trowbridge; WY 2016 included Patrick Kim, Amy Richey, and Jennifer Sun; WY 2017 included Ila Shimabuku, Amy Richey, Steven Hagerty, Diana Lin, Margaret Sedlak, Jennifer Sun, Katie McKnight, Emily Clark, Don Yee, and Jennifer Hunt; WY 2018 included Nina Buzby, Amy Richey, Ila Shimabuku, Margaret Sedlak, and Don Yee; and WY 2019 included Ila Shimabuku, Margaret Sedlak, Jennifer Sun, Micha Salomon, and Don Yee. The RMP data management team is acknowledged for their diligent delivery of quality-assured well-managed data. This team was comprised of Amy Franz, Adam Wong, Michael Weaver, John Ross, and Don Yee in WYs 2015, 2016, 2017, 2018 and 2019. Helpful written reviews of this report were provided by members of BASMAA (Bonnie de Berry, EOA Inc. on behalf of the San Mateo Countywide Water Pollution Prevention Program; Lisa Austin, Geosyntec, Khalil Abusaba, Wood, and Christian Kocher, ADH Environmental on behalf of the Contra Costa Clean Water Program; Jim Scanlin, Alameda Countywide Clean Water Program); Barbara Mahler (USGS) and Richard Looker (SFBRWQCB). External independent review was provided by SPLWG advisors (Daniel Cain and Barbara Mahler, both of the USGS).

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Executive Summary

The San Francisco Bay polychlorinated biphenyl (PCB) and mercury (Hg) total maximum daily loads (TMDLs) call for implementation of control measures to reduce PCB and Hg loads entering the Bay via stormwater. In 2009, the San Francisco Bay Regional Water Quality Control Board (Regional Water Board) issued the first Municipal Regional Stormwater Permit (MRP). This MRP contained a provision aimed at improving information on stormwater pollutant loads in selected watersheds (Provision C.8.) and piloted a number of management techniques to reduce PCB and Hg loading to the Bay from smaller urbanized tributaries (Provisions C.11. and C.12.). In 2015, the Regional Water Board issued the second iteration of the MRP. "MRP 2.0" placed an increased focus on identifying those watersheds, source areas, and source properties that are potentially the most polluted and are therefore most likely to be cost-effective areas for addressing load-reduction requirements.

To support this increased focus, a stormwater reconnaissance monitoring field protocol was developed and implemented in water years (WYs) 2015 through 2019. Most of the sites monitored were in Alameda, Santa Clara, and San Mateo Counties, with fewer sites in Contra Costa and one in Solano County. At 67 sampling sites, time-weighted composite water samples were collected during individual storm events and analyzed for 40 PCB congeners, total Hg (HgT), and suspended sediment concentration (SSC). At a subset of sites, additional samples were analyzed for selected trace metals, organic carbon (OC), and grain size. Where possible, sampling efficiency was increased by sampling two or three sites during a single storm if the sites were near enough to one another that alternating between them was safe and rapid. This same field protocol is being implemented in the winter of WY 2020 by the RMP. The San Mateo Countywide Water Pollution Prevention Program and the Santa Clara Valley Urban Runoff Pollution Prevention Program have also implemented the sampling protocol with their own funding.

During this study, beginning in WY 2015, the RMP began piloting the use of un-staffed "remote" suspended sediment samplers (Hamlin samplers and Walling Tube samplers). These remote samplers were designed to enhance settling and capture of suspended sediment from the water column.

In summary, we now have three distinct stormwater sampling methods.

> Method 1. Fixed location multi-year turbidity-based sampling protocol for accurate loads estimation.
>
> Method 2. Water-based composite sampling protocol for single storm reconnaissance characterization and site comparisons to support management prioritization.
>
> Method 3. Remotely deployable sedimentation sampling for preliminary screening to support further field sampling using the water-based composite sampling protocol.

This report presents all available stormwater data[1] collected by SFEI since WY 2003 when stormwater studies first began through SFEI contracts or RMP projects, not just the data collected for this WY 2015-2019 reconnaissance monitoring study (total of 88 sites). Prior to WY 2015, studies mostly employed Method 1, whereas beginning in WY 2015, sampling employed Methods 2 and 3.

Key Findings

Based on this dataset a number of sites with elevated PCB and Hg stormwater concentrations and estimated concentrations on particles were identified. Including RMP sampling prior to WY 2015, 25 sites (28%) with estimated particle concentrations of PCBs greater than 200 ng/g and 31 sites (35%) with estimated particle concentrations of Hg greater than 0.5 µg/g have been identified. Total PCB concentrations measured ranged 840-fold, from 533 to 448,000 pg/L (excluding one sample where PCBs were below the detection limit). The three highest ranking sites for PCB water concentrations were Pulgas Pump Station South (448,000 pg/L), Santa Fe Channel (198,000 pg/L), and Industrial Rd Ditch in San Carlos (160,000 pg/L). When normalized by SSC to generate estimated particle concentrations, the three sites with highest estimated particle concentrations were Pulgas Pump Station South (8,220 ng/g), Industrial Rd Ditch in San Carlos (6,139 ng/g), and Line 12H at Coliseum Way in Oakland (2,601 ng/g).

Total Hg concentrations in samples collected in water years since 2003 ranged 112-fold, from 5.4 to 600 ng/L. The lower variation in HgT concentrations relative to PCBs is consistent with conceptual models for these substances. HgT is thought to be more uniformly distributed than PCBs because it has more widespread sources in the urban environment, and Hg has a larger atmospheric component to its cycle. The highest HgT concentrations were measured at the Guadalupe River at Hwy 101 (603 ng/L), Guadalupe River at Foxworthy Road/Almaden (529 ng/L), and Zone 5 Line M (505 ng/L). The highest estimated particle concentrations were measured at Guadalupe River at Foxworthy Road/Almaden (4.1 µg/g), Guadalupe River at Hwy 101 (3.6 µg/g), and the outfall at Gilman St. in Berkeley (2.8 µg/g). The two Guadalupe River stations are downstream of the historic New Almaden Mining District.

The sites with the highest particle concentrations for PCBs were typically not the sites with the highest concentrations for HgT.

Remote Suspended Sediment Samplers

Pilot results from the two remote suspended sediment sampler types showed generally good consistency with the composite stormwater sampling methods. Sites with higher concentrations in the sediment collected by the remote samplers were the same as those with higher concentrations in the composite samples. Therefore, the remote suspended sediment sampler method was accepted in spring 2018 and used in WY 2019 as a stand-alone method (side-by-side sampling with the composite method ceased and just the remote samplers were deployed at three sites) to support decisions about further sampling.

[1] Similar data collected by BASMAA in Santa Clara and San Mateo Counties is not included in this report. Also, BASMAA partners analyze sediment collected in upland areas (e.g., catch basins, roadside ditches, private property, etc.).

Further Data Interpretation

Relationships between PCB and HgT estimated particle concentrations, watershed characteristics, and other water quality measurements were evaluated. Based on data collected since WY 2003, PCB particle concentrations were positively correlated with impervious cover (r_s = 0.57), old industrial land use (r_s = 0.61), and HgT particle concentrations (r_s = 0.19). PCB particle concentrations were negatively correlated with watershed area and particle concentrations for arsenic, cadmium, copper, lead, and zinc. HgT particle concentrations were not correlated with those of other trace metals and had similar but weaker relationships as PCBs to impervious cover, old industrial land use, and watershed area. Overall, the data collected to date do not support the use of any of the trace metals analyzed as a proxy for either PCB or HgT pollution sources.

Old industrial land use is believed to have both the greatest yields and loads of PCBs in the region. The watersheds/catchments for the 87 sites that have been sampled for PCBs with RMP and grant funding since WY 2003 cover about 33% of the old industrial area in the region. Of the remaining areas in the region with old industrial land use yet to be sampled (77 km^2), 48% of it lies within 1 km of the Bay and 74% is within 2 km of the Bay. These areas nearer the Bay are more likely to be tidal and to include heavy industrial areas that were historically serviced by rail and ship-based transport and are often very difficult to sample because of a lack of public rights-of-way and tidal-related constraints. These areas may have relatively high concentrations compared to industrial areas further from the Bay margin due to a longer use period and the nature of heavy machinery associated with rail and ship transport. A different sampling strategy may be needed to effectively estimate what mass of pollution is associated with these areas.

This Pollutants of Concern Reconnaissance Monitoring study will continue at least into WY 2020 with the goal to identify areas for follow-up investigation and possible management action. The focus will continue to be on finding new areas of concern, although follow-up sampling will occur at some sites to verify previous sampling results.

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1. Introduction

The San Francisco Bay polychlorinated biphenyl (PCB) and mercury total maximum daily loads (TMDLs) (SFBRWQCB, 2006; 2007) call for implementation of control measures to reduce stormwater polychlorinated biphenyl (PCB) loads from an estimated annual baseline load of 20 kg to 2 kg by 2030 and total mercury (HgT) loads from about 160 kg to 80 kg by 2028. Shortly after adoption of the TMDLs, in 2009 the San Francisco Bay Regional Water Quality Control Board (Regional Water Board) issued the first Municipal Regional Stormwater Permit (MRP) for MS4 phase I stormwater agencies (SFBRWQCB, 2009; 2011). In support of the TMDLs, MRP 1.0, as it came to be known, contained a provision for improved information on stormwater loads for pollutants of concern (POCs) in selected watersheds (Provision C.8.) and specific provisions for Hg, methylmercury and PCBs (Provisions C.11 and C.12) that called for reducing Hg and PCB loads from smaller urbanized tributaries. To help address these permit requirements, a Small Tributaries Loading Strategy (STLS) was developed that outlined four key management questions (MQs) as well as a general plan to address these questions (SFEI, 2009).

MQ1. Which Bay tributaries (including stormwater conveyances) contribute most to Bay impairment from POCs?

MQ2. What are the annual loads or concentrations of POCs from tributaries to the Bay?

MQ3. What are the decadal-scale loading or concentration trends of POCs from small tributaries to the Bay?

MQ4. What are the projected impacts of management actions (including control measures) on tributaries and where should these management actions be implemented to have the greatest beneficial impact?

During the first MRP term (2009-15), the majority of STLS effort was focused on refining pollutant loading estimates and finding and prioritizing potential "high leverage" watersheds and subwatersheds that contribute disproportionately high concentrations or loads to sensitive Bay margins. This work was funded by the RMP and the Bay Area Stormwater Management Agencies Association (BASMAA)[2]. Sufficient pollutant data were collected at 11 urban sites to estimate pollutant loads with varying degrees of certainty (McKee et al., 2015, Gilbreath et al., 2015a). Also, during the first MRP term, a Regional Watershed Spreadsheet Model (RWSM) was developed as a regional-scale planning tool, primarily to estimate long-term pollutant loads from the small tributaries, and secondarily to provide supporting information for prioritizing watersheds or sub-watershed areas for management (Wu et al., 2016; 2017).

In November 2015, the Regional Water Board issued the second iteration of the MRP (SFBRWQCB, 2015). MRP 2.0 places an increased focus on finding high-leverage watersheds, source areas, and source properties that are more polluted, and that are located upstream of sensitive Bay margin areas. Specifically, the permit adds a stipulation that calls for identification of sources or watershed source

[2] BASMAA is made up of a number of programs that represent Permittees and other local agencies

areas that provide the greatest opportunities for reductions of PCBs and Hg in urban stormwater runoff. To help support this focus and also to refine information to address other Management Questions, the Sources, Pathways, and Loadings Work Group (SPLWG) and the Small Tributaries Loading Strategy Team developed and implemented a stormwater reconnaissance field monitoring protocol in WYs 2015-2019 to provide data, as part of multiple lines of evidence, for the identification of potential high-leverage areas. The monitoring protocol was adapted from the one first implemented in WY 2011 (McKee et al., 2012) and benefited from lessons learned from that effort. This same field monitoring protocol was also implemented in WYs 2016 - 2019 by the San Mateo Countywide Water Pollution Prevention Program and the Santa Clara Valley Urban Runoff Pollution Prevention Program (EOA, 2017a and 2017b).

This report summarizes and provides a preliminary interpretation and summarization of data collected during WYs 2015-2019, as well as from previous studies by this workgroup dating back to WY 2003. The data collected and presented here contribute to a broad effort of identifying potential management areas for pollutant reduction. During Calendar Year (CY) 2018, the RMP funded a data analysis project that aims to mine and analyze all existing stormwater PCB data. The primary goals of that analysis were to develop additional and improved methods for identifying and ranking watersheds/catchments of management interest for further investigation, and to guide future sampling design (McKee et al., in review). In addition, the STLS team is evaluating sampling protocols for monitoring stormwater loading trends in response to management efforts (Melwani et al., 2018) and has developed a trends strategy that outlines key elements including modeling needs (Wu, et. al., 2018). Reconnaissance data collected in WYs 2011 and 2015-2019 may provide “baseline” data for identifying concentration or particle concentration trends over time, with the understanding that management actions to control PCB and Hg loads are increasingly being implemented throughout this period.

The report is designed to be updated annually and will be updated again in approximately 12 months to include WY 2020 sampling data currently being collected.

2. Methods

2.1 Sampling locations

Four objectives were used as a basis for site selection.

1. Identify potential high-leverage watersheds and catchments, including
    a. Watersheds/catchments with suspected high pollution,
    b. Sites with ongoing or planned management actions,
    c. Source identification within a larger watershed of known concern (nested sampling design).
2. Sample strategic large watersheds with USGS gauges to provide first-order loading estimates and to support calibration of the Regional Watershed Spreadsheet Model (RWSM),
3. Validate unexpected low (potential false negative) concentrations to address the possibility of a single storm composite poorly characterizing a sampling location,

4. Fill data gaps along environmental gradients or source areas to allow for the continuing reevaluation of our conceptual understanding of relationships between land uses, source areas and pollutant concentrations and loads.

The majority of samples during WYs 2015-2017 (60-80% of the effort) were dedicated to identifying potential high-leverage watersheds, subwatersheds, and storm drain catchments (Objective 1). The remaining resources were allocated to addressing the other three objectives. In WYs 2018 and 2019, approximately 50% of the resources were allocated to identifying potential high-leverage watersheds/catchments, while the other 50% was allocated to resampling stations previously measured in reconnaissance sampling in order to validate previously measured concentrations. RMP staff worked with the respective Countywide Programs to identify priority drainages for monitoring including storm drains, ditches/culverts, tidally influenced channels and culverts, and natural channels. During the summers of 2014-2018, approximately 100 sites were visited, and each was surveyed for safety, logistical constraints, and feasible drainage-line entry points. From this larger set, a final set of 10-20 sites was selected each year to form the sampling location pool from which field staff would select from for each storm, depending on logistics.

Watershed sites with a wide variety of characteristics were sampled in WYs 2015-2019 (Figure 1 and Table 1). Of these sites, 21 were in Santa Clara County, 19 in San Mateo County, 16 in Alameda County, 10 in Contra Costa County[3] and 1 in Solano County. The drainage area for each sampling location ranged from 0.02 to 233 km^2 and imperviousness based on the National Land Cover Database (Homer et al., 2015) ranged from 2%-88%. Typically, however, the reconnaissance watersheds/catchments were characterized as small (75% were smaller than 5.2 km^2) with a high degree of imperviousness (75% of watersheds/catchments were greater than 60% impervious). The percentage of old industrial[4] area in watersheds/catchments ranged from 0 to 87% (mean 22%) (dataset used included the land use dataset input to the Regional Watershed Spreadsheet Model) (SFEI, 2018). Although most of the sampling sites were selected primarily to identify potential high-leverage watersheds/catchments, some sites were resampled to verify whether the first sample collected at these locations was a false negative (unexpectedly low concentration). Guadalupe River at Hwy 101 was also resampled for PCBs in WY 2017 as a piggyback opportunity during a large and rare storm sampled primarily to assess trends for mercury (McKee et al., 2018). A matrix of site characteristics for sampling strategic larger watersheds was also developed (Appendix A), but no larger watersheds were sampled in WYs 2015 or 2016 because the sampling trigger criteria for rainfall and flow were not met, and only one (Colma Creek) was sampled in WY 2017. Trigger criteria were met in January and February 2017 for other strategic larger watersheds under consideration (Alameda Creek at EBRPD Bridge at Quarry Lakes, Dry Creek at Arizona Street, San Francisquito Creek at University Avenue, Matadero Creek at Waverly Street, and Colma Creek at West Orange Avenue), but none were sampled because staff and budgetary resources were allocated

[3] Given the long history of industrial zoning along much of the Contra Costa County waterfront relative to other counties, more sampling is needed to characterize these areas.

[4] Note that the definition of “old Industrial” land use used here is based on definitions developed by the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) building on GIS development work completed during the development of the RWSM (Wu et al., 2016; 2017).

elsewhere. The sampling carried out at the reconnaissance monitoring sites completed so far complements the more in-depth sampling campaigns (2-8 years of sampling at each site) that have been carried out at sites designated as the "Loadings Study" (Figure 1).

2.2 Field methods

Mobilization and preparing to sample

Mobilization for sampling was typically triggered by storm forecast. When a minimum rainfall of at least one-half inch[5] over 6 hours was forecast, sampling teams were deployed, ideally reaching the sampling site about one hour before the onset of rainfall[6]. When possible, one team sampled two sites close to one another to increase efficiency and reduce staffing costs. Upon arrival, the team assembled equipment and carried out final safety checks. Sampling equipment used at a site depended on the accessibility of drainage lines. Some sites were sampled by attaching laboratory-prepared trace-metal-clean Teflon sampling tubing to a painter's pole and a peristaltic pump with laboratory-cleaned silicone pump-roller tubing (Figure 2a). During sampling, the tube was dipped into the channel or drainage line at mid-channel mid-depth (if shallow) or depth integrating if the depth was more than 0.5 m. In other cases, a DH 81 (Teflon) sampler was used without a pump (Figure 2b).

Manual time-paced composite stormwater sampling procedures

At each site, a time-paced composite sample was collected with a variable number of sub-samples, or aliquots. Based on the weather forecast, prevailing on-site conditions, and radar imagery, field staff estimated the duration of the storm and selected an aliquot size for each analyte (0.1-0.5 L) and number of aliquots (minimum=2; mode=5) to ensure the minimum volume requirements for each analyte (Hg, 0.25 L; SSC, 0.3 L; PCBs, 1 L; Grain Size, 1 L; TOC, 0.25 L) were reached before the end of the storm. Because the minimum volume requirements were less than the size of the sample bottles, there was flexibility to add aliquots in the event a storm continued longer than predicted. The final volume of the aliquots was determined just before the first aliquot was taken and remained fixed for the sampling event. Similarly, the time period between aliquots was decided just before the second aliquot was taken and then remained the same for the rest of the event. All aliquots for a storm were collected into the same bottle, which was kept in a cooler on ice during sampling and then refrigerated at 4 °C before transport to a laboratory (see Yee et al. 2017 for information about bottles, preservatives and holding times).

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[5] This was relaxed in some years due to a lack of larger storms.

[6] Antecedent dry-weather was not considered prior to deployment. Antecedent conditions can have impacts on the concentration of certain build-up/wash-off pollutants like metals. For PCBs, however, antecedent dry-weather may be less important for the mobilization of in-situ legacy sources.

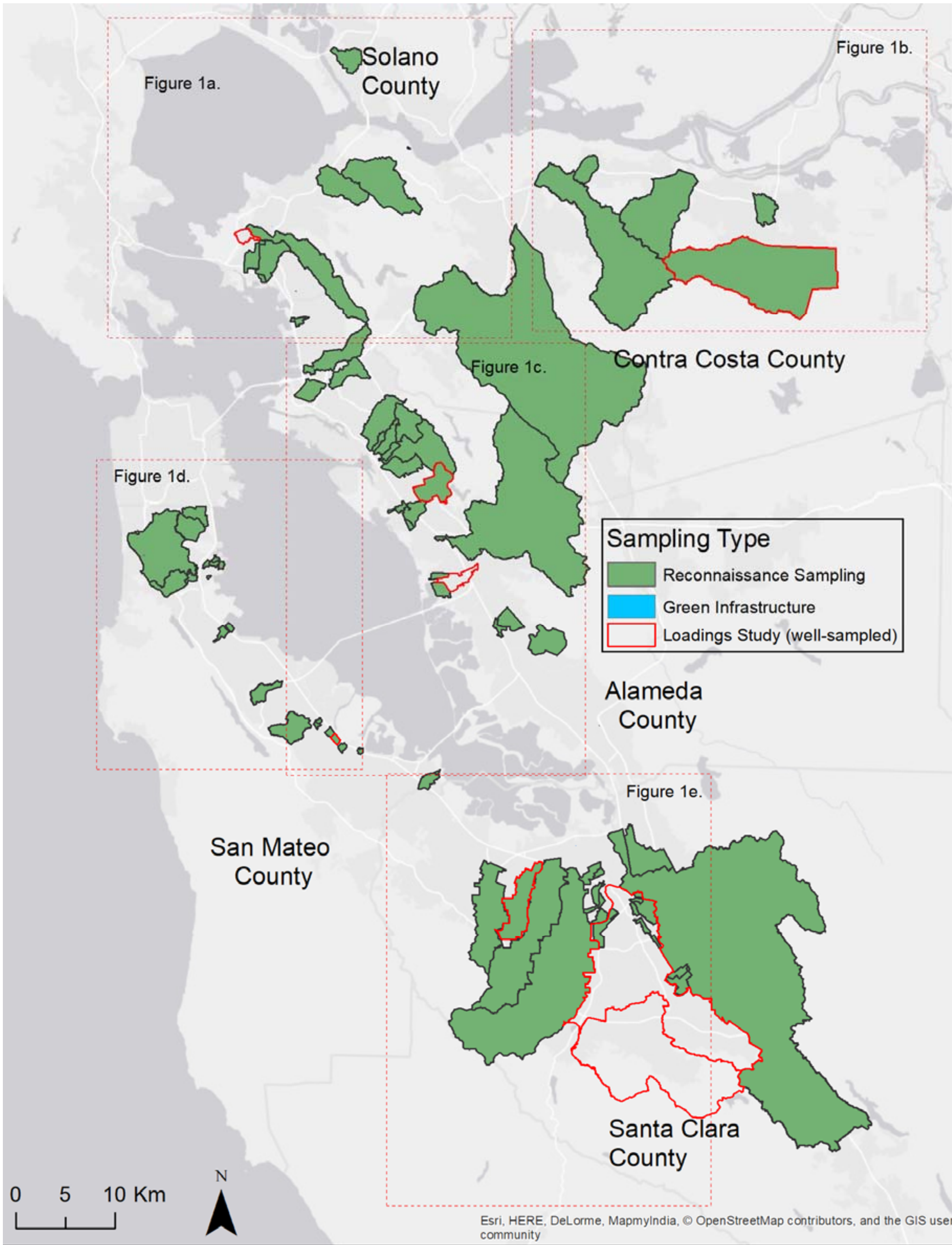

Figure 1. Watersheds/catchments sampled to date. Note: The drainage management areas (DMAs) of the Green Infrastructure sampling sites are so small they are not visible, though they are given a numeric map key identifier.

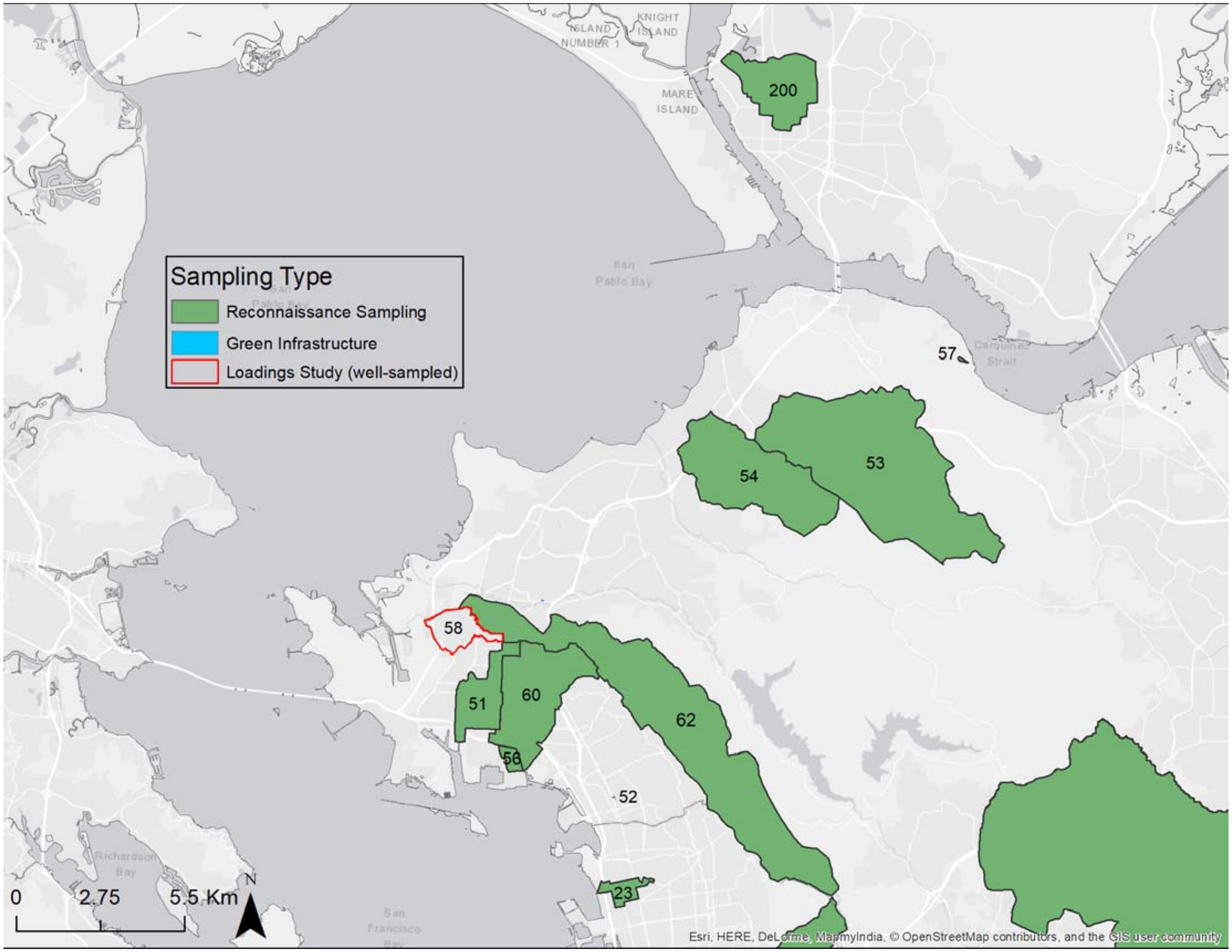

Figure 1a. Watershed boundaries of sites sampled in western Contra Costa County and Solano County. Note: The drainage management areas (DMAs) of the Green Infrastructure sampling sites are so small they are not visible, though they are given a numeric map key identifier. See Table 1 for information on each numbered watershed or drainage management area.

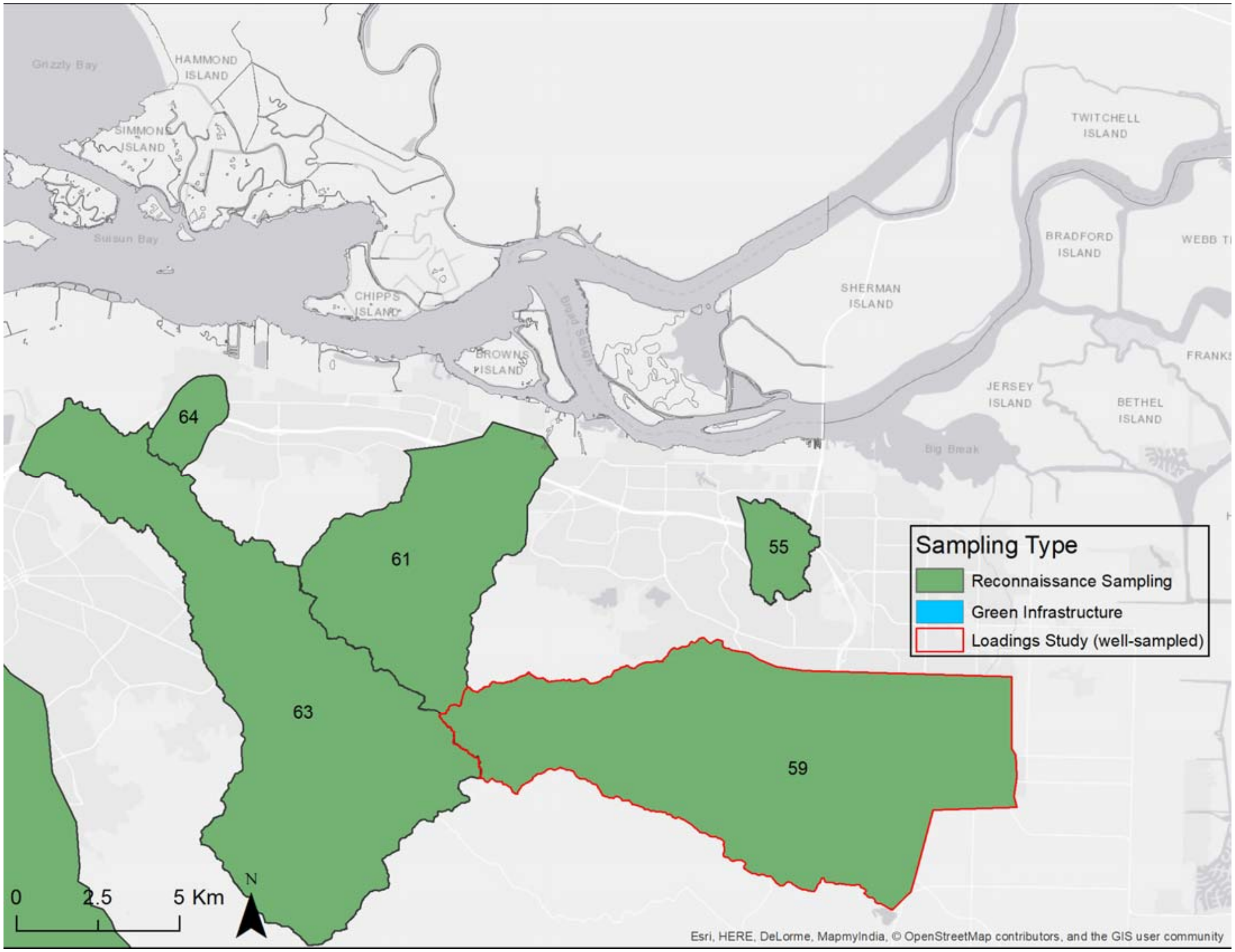

Figure 1b. Watershed boundaries of sites sampled in eastern Contra Costa County. Note: The drainage management areas (DMAs) of the Green Infrastructure sampling sites are so small they are not visible, though they are given a numeric map key identifier. See Table 1 for information on each numbered watershed or drainage management area.

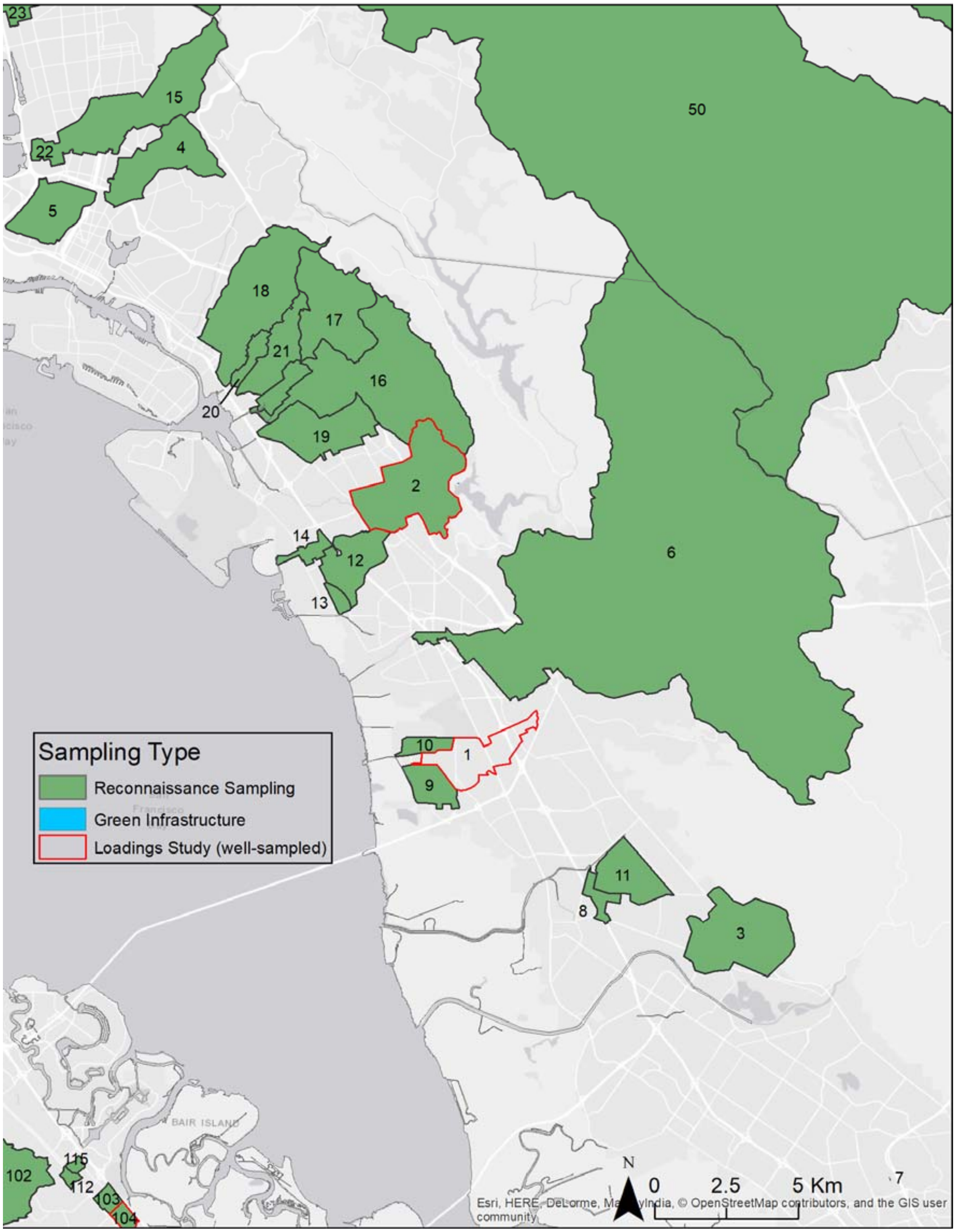

Figure 1c. Watershed boundaries of sites sampled in Alameda County. Note: The drainage management areas (DMAs) of the Green Infrastructure sampling sites are so small they are not visible, though they are given a numeric map key identifier. See Table 1 for information on each numbered watershed or drainage management area.

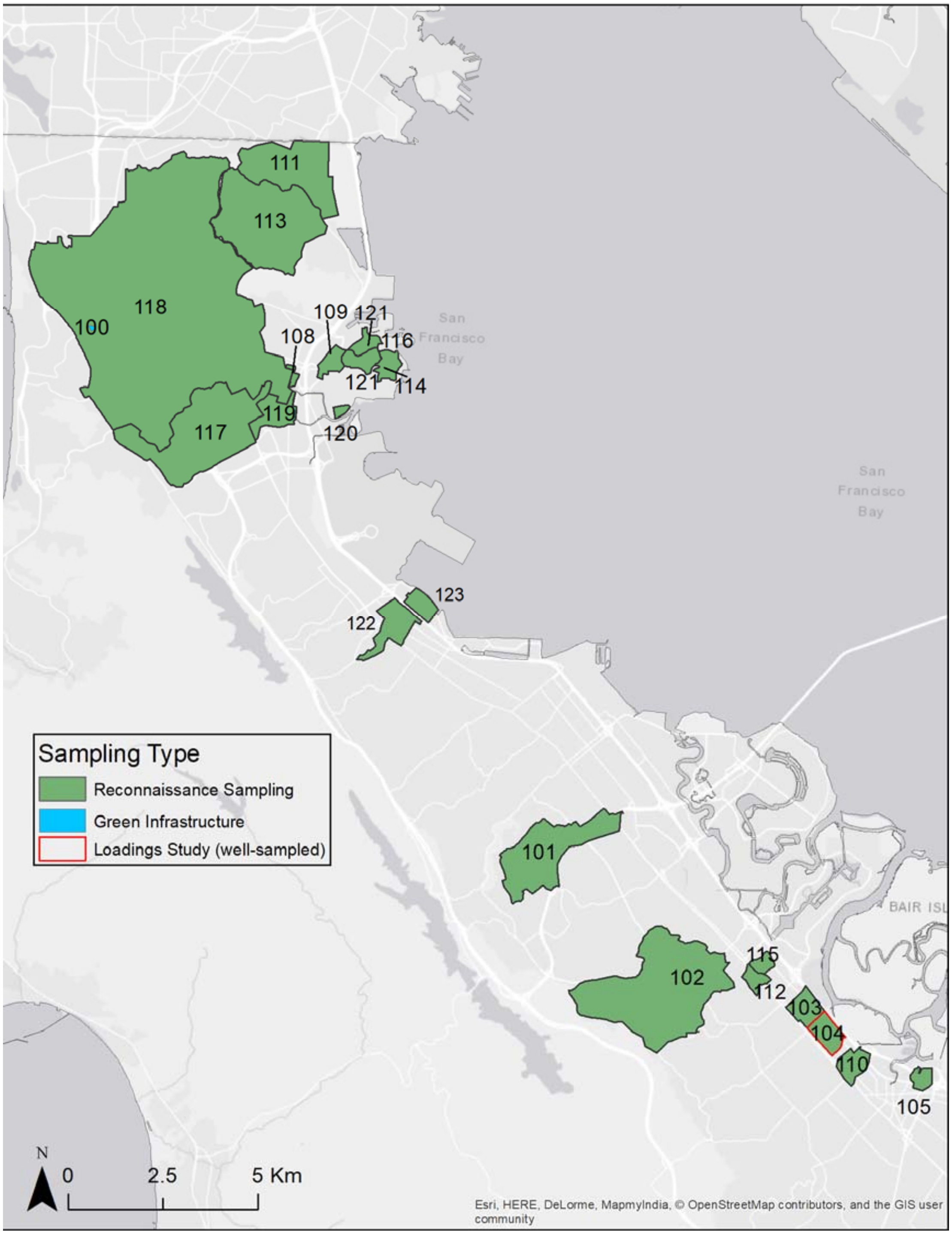

Figure 1d. Watershed boundaries of sites sampled in northern San Mateo County. Note: The drainage management areas (DMAs) of the Green Infrastructure sampling sites are so small they are not visible, though they are given a numeric map key identifier. See Table 1 for information on each numbered watershed or drainage management area.

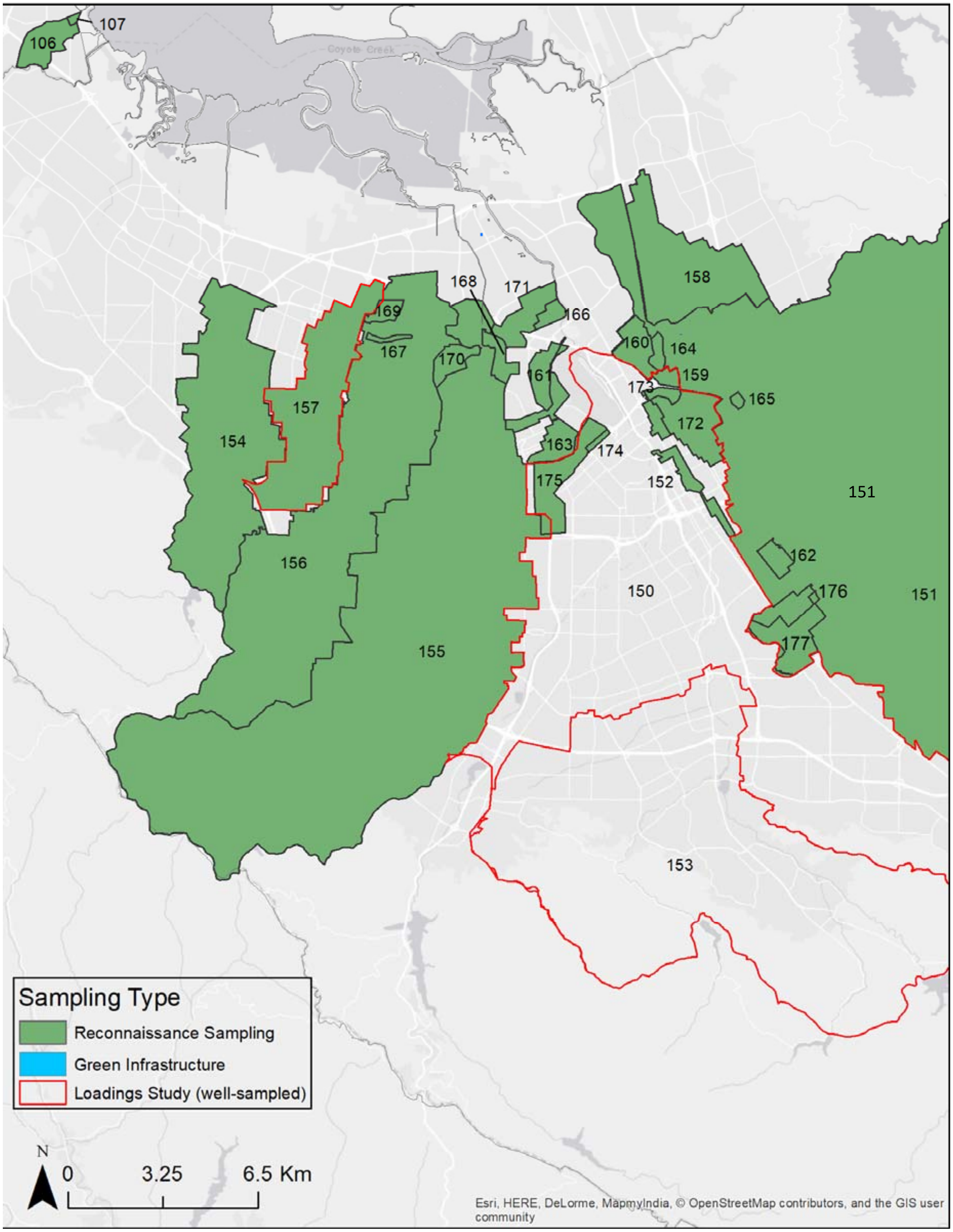

Figure 1e. Watershed boundaries of sites sampled in Santa Clara County. Note: The drainage management areas (DMAs) of the Green Infrastructure sampling sites are so small they are not visible, though they are given a numeric map key identifier. See Table 1 for information on each numbered watershed or drainage management area.

Table 1. Key characteristics of the 91[7] sampling locations. Gaps in continuous numbering allow for the future addition of locations so that the unique identifying numbers for each county remain in the same count of 50.

Map Key	County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
1	Alameda	Hayward	Zone 4 Line A	Z4LA	MS4	37.645328	-122.137364	WY 2007-2010	4.2	68%	12%
2	Alameda	San Leandro	San Leandro Creek	SLC	MS4	37.726119	-122.162696	12/5/10 & 12/19/10; WYs 2012-14	8.9	38%	0%
3	Alameda	Union City	Zone 5 Line M	Z5LM	MS4	37.586476	-122.028427	12/17/10 & 3/19/11	8.1	34%	5%
4	Alameda	Oakland	Glen Echo Creek	Glen Echo Creek	MS4	37.818271	-122.260326	2/15/11	5.5	39%	0%
5	Alameda	Oakland	Ettie Street Pump Station	ESPS	MS4	37.826043	-122.288942	2/17/11	4.0	75%	22%
6	Alameda	San Leandro	San Lorenzo Creek	San Lorenzo Creek	MS4	37.684836	-122.138599	12/17/10 & 12/19/10	125	13%	0%
7	Alameda	Fremont	Fremont Osgood Road Bioretention Influent	Fremont Osgood Road Bioretention Influent	Bioretention Influent	37.518394	-121.945225	2012, 2013	0.00	76%	0%
8	Alameda	Union City	Line 3A-M at 3A-D	AC-Line 3A-M	MS4	37.61285	-122.06629	12/11/14	0.88	73%	12%
9	Alameda	Hayward	Line 4-E	AC-Line 4-E	MS4	37.64415	-122.14127	12/16/14	2.00	81%	27%
10	Alameda	Hayward	Line 4-B-1	AC-Line 4-B-1	MS4	37.64752	-122.14362	12/16/14	0.96	85%	28%
11	Alameda	Union City	Line 3A-M-1 at Industrial PS	AC-Line 3A-M-1	MS4	37.61893	-122.05949	12/11/14	3.44	78%	26%
12	Alameda	San Leandro	Line 9-D	AC-Line 9-D	MS4	37.69383	-122.16248	4/7/15	3.59	78%	46%
13	Alameda	San Leandro	Line 9-D-1 PS at outfall to Line 9-D	AC-2016-15	MS4	37.69168	-122.16679	1/5/16	0.48	88%	62%
14	Alameda	San Leandro	Line 13-A at end of slough	AC-2016-14	MS4	37.70497	-122.19137	3/10/16	0.83	84%	68%
15	Alameda	Emeryville	Zone 12 Line A under Temescal Ck Park	AC-2016-3	MS4	37.83450	-122.29159	1/6/16	9.41	42%	0.6%
16	Alameda	Oakland	Line 12K at Coliseum Entrance	Line12KEntrance	MS4	37.75446	-122.20431	2/9/17	16.40	31%	1%
17	Alameda	Oakland	Line 12J at mouth to 12K	Line12J	MS4	37.75474	-122.20136	12/15/16	8.81	30%	2%
18	Alameda	Oakland	Line 12F below PG&E station	Line12F	MS4	37.76218	-122.21431	12/15/16	10.18	56%	3%

[7] There are 91 total sampling locations. Of these, 67 were sampled during WYs 2015-2019, 87 had water concentrations for PCBs, and 88 had water concentrations for HgT.

Map Key	County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
19	Alameda	Oakland	Line 12M at Coliseum Way	Line12MColWay	MS4	37.74689	-122.20069	2/9/17 & 11/28/2018	5.30	69%	22%
20	Alameda	Oakland	Line 12H at Coliseum Way	Line12H	MS4	37.76238	-122.21217	12/15/16	0.97	71%	10%
21	Alameda	Oakland	Line 12I at Coliseum Way	Line12I	MS4	37.75998	-122.21020	12/15/16	3.41	63%	9%
22	Alameda	Emeryville	Zone 12 Line A at Shellmound	Line12AShell	MS4	37.83424	-122.29352	1/8/18	10.48	41%	6%
23	Alameda	Berkeley	Outfall at Gilman St.	AC-2016-1	MS4	37.87761	-122.30984	12/21/15 & 1/9/18	0.84	76%	32%
50	Contra Costa	Concord	Walnut Creek	Walnut Creek	Receiving Water	37.96962	-122.053778	12/28/10	232	15%	0%
51	Contra Costa	Richmond	Santa Fe Channel	Santa Fe Channel	MS4	37.92118056	-122.3619972	12/05/10	3.3	69%	3%
52	Contra Costa	El Cerrito	El Cerrito Bioretention Influent	ELC	Bioretention Influent	37.905884	-122.304929	WY 2012, 2014-15, 2017	0.00	74%	0%
53	Contra Costa	Rodeo	Rodeo Creek at Seacliff Ct. Pedestrian Br.	RodeoCk	Receiving Water	38.01604	-122.25381	1/18/17	23.41	2%	3%
53[8]	Contra Costa	Rodeo	Rodeo Creek at Viewpoint Blvd.	RodeoCk	Receiving Water	38.018472	-122.256647	1/6/2019	23.5	2%	3%
54	Contra Costa	Hercules	Refugio Ck at Tsushima St	RefugioCk	Receiving Water	38.01775	-122.27710	1/18/17	10.73	23%	0%
55	Contra Costa	Antioch	East Antioch nr Trembath	EAntioch	Receiving Water	38.00333	-121.78106	1/8/17	5.26	26%	3%
56	Contra Costa	Richmond	MeekerWest	MeekerWest	Receiving Water	37.91313	-122.33871	1/9/18	0.41	70%	69%
57	Contra Costa	Port Costa	Little Bull Valley	Little Bull Valley	Receiving Water	38.03680	-122.17662	3/1/18	0.02	67%	2%
58	Contra Costa	Richmond	North Richmond Pump Station	NRPS	MS4	37.953903	-122.373997	WY 2011, 2013-14	2.0	62%	18%
59	Contra Costa	Oakley	Lower Marsh Creek	LMC	Receiving Water	37.990723	-121.696118	3/24/11; WYs 2012-14	84	10%	0%
60	Contra Costa	Richmond	Meeker Slough	Meeker Slough	Receiving Water	37.91786	-122.33838	12/3/14 & 1/9/18	7.34	64%	6%
61	Contra Costa	Pittsburg	Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	KirkerCk	Receiving Water	38.01275	-121.84345	1/8/17 & 4/6/18	36.67	18%	5%
62	Contra Costa	Richmond	Wildcat Creek	Wildcat Creek	Receiving Water	37.960329°	-122.366840°	1/30/19	23.44	53%	1%
63	Contra Costa	Concord	Mount Diablo Creek	Mount Diablo Creek	Receiving Water	38.018756°	-122.026878°	1/15/19	75.56	9%	0%
64	Contra Costa	BayPoint	BayPoint	BayPoint	Receiving Water	38.034075°	-121.962504°	1/15/19	4.35	21%	0%
100	San Mateo	Daly City	Gellert Park Daly City Library Bioretention Influent	Gellert Park	Bioretention Influent	37.663037	-122.470585	WY 2009	0.02	40%	0%

[8] At the scale of the map, the two Rodeo Creek sampling points are close enough that the watershed polygon on the map is the same.

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Map Key	County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
101	San Mateo	San Mateo	Borel Creek	Borel Creek	MS4	37.551273	-122.309424	3/18/11	3.2	31%	0%
102	San Mateo	Belmont	Belmont Creek	Belmont Creek	MS4	37.517328	-122.276109	3/18/11	7.2	27%	0%
103	San Mateo	San Carlos	Pulgas Pump Station-North	Pulgas Pump Station-North	MS4	37.5045833	-122.2490056	2/17/11 & 3/18/11	0.55	84%	52%
104	San Mateo	San Carlos	Pulgas Pump Station-South	Pulgas Pump Station-South	MS4	37.5045833	-122.2490056	2/17/11 & 3/18/11; WYs 2013-14	0.58	87%	54%
105	San Mateo	Redwood City	Oddstad PS	SM-267	MS4	37.49172	-122.21886	12/2/14	0.28	74%	11%
106	San Mateo	East Palo Alto	Runnymede Ditch	SM-70	MS4	37.46883	-122.12701	2/6/15	2.05	53%	2%
107	San Mateo	East Palo Alto	SD near Cooley Landing	SM-72	MS4	37.47492	-122.12640	2/6/15	0.11	73%	39%
108	San Mateo	South San Francisco	South Linden PS	SM-306	MS4	37.65018	-122.41127	2/6/15	0.14	83%	22%
109	San Mateo	South San Francisco	Gateway Ave SD	SM-293	MS4	37.65244	-122.40257	2/6/15	0.36	69%	52%
110	San Mateo	Redwood City	Veterans PS	SM-337	MS4	37.49723	-122.23693	12/15/14	0.52	67%	7%
111	San Mateo	Brisbane	Tunnel Ave Ditch	SM-350/368/more	Receiving Water	37.69490	-122.39946	3/5/16	3.02	47%	8%
112	San Mateo	San Carlos	Taylor Way SD	SM-32	MS4	37.51320	-122.26466	3/11/16	0.27	67%	11%
113	San Mateo	Brisbane	Valley Dr SD	SM-17	MS4	37.68694	-122.40215	3/5/16	5.22	21%	7%
114	San Mateo	South San Francisco	Forbes Blvd Outfall	SM-319	MS4	37.65889	-122.37996	3/5/16	0.40	79%	0%
115	San Mateo	San Carlos	Industrial Rd Ditch	SM-75	MS4	37.51831	-122.26371	3/11/16	0.23	85%	79%
116	San Mateo	South San Francisco	Gull Dr SD	SM-314	MS4	37.66033	-122.38510	3/5/16 & 1/9/18	0.30	78%	54%
117	San Mateo	South San Francisco	S Spruce Ave SD at Mayfair Ave (296)	SSpruce	MS4	37.65084	-122.41811	1/8/17	5.15	39%	1%
118	San Mateo	South San Francisco	Colma Ck at S. Linden Blvd	ColmaCk	MS4	37.65017	-122.41189	2/7/17	35.07	41%	3%
119	San Mateo	South San Francisco	S Linden Ave SD (291)	SLinden	MS4	37.64420	-122.41390	1/8/17	0.78	88%	57%
120	San Mateo	South San Francisco	Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	ColmaCkOut	MS4	37.64290	-122.39677	2/7/17	0.09	88%	87%
121	San Mateo	South San Francisco	Gull Dr Outfall	SM-315	MS4	37.66033	-122.38502	3/5/16 & 1/9/18	0.43	75%	42%
122	San Mateo	Burlingame	SMBUR164A	SMBUR164A	MS4	37.5995966	-122.3752573	11/28/18	0.98	71%	37%

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Map Key	County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
123	San Mateo	Burlingame	SMBUR85A	SMBUR85A	MS4	37.60194467	-122.3749872	11/28/18	0.42	81%	44%
150	Santa Clara	San Jose	Guadalupe River at Hwy 101	Guad 101	Receiving Water	37.37355	-121.93269	WYs 2003-2006, 2010, 2012-2014; 1/8/17	233.00	39%	3%
151	Santa Clara	Milpitas	Lower Coyote Creek	Lower Coyote Creek	Receiving Water	37.421814	-121.928153	2005	327	22%	1%
152	Santa Clara	San Jose	San Pedro Storm Drain	San Pedro Storm Drain	MS4	37.343769	-121.900781	2006	1.3	72%	16%
153	Santa Clara	San Jose	Guadalupe River at Foxworthy Road/ Almaden Expressway	GRFOX	Receiving Water	37.278396	-121.877944	2010	107	22%	0%
154	Santa Clara	Mountain View	Stevens Creek	Stevens Creek	Receiving Water	37.391306	-122.069586	2/18/11	26	38%	1%
155	Santa Clara	Santa Clara	San Tomas Creek	San Tomas Creek	Receiving Water	37.388992	-121.968634	12/28/10	108	33%	0%
156	Santa Clara	Santa Clara	Calabazas Creek	Calabazas Creek	Receiving Water	37.4034556	-121.9867056	12/28/10	50	44%	3%
157	Santa Clara	Sunnyvale	Sunnyvale East Channel	SunCh	Receiving Water	37.394728	-122.010441	3/19/11; WYs 2012-14	15	59%	4%
158	Santa Clara	Milpitas	Lower Penitencia Ck	Lower Penitencia	Receiving Water	37.42985	-121.90913	WY 2011; 12/11/14	11.50	65%	2%
159	Santa Clara	San Jose	E. Gish Rd SD	SC-066GAC550	MS4	37.36632	-121.90203	12/11/14	0.44	84%	71%
160	Santa Clara	San Jose	Charcot Ave SD	SC-051CTC275	MS4	37.38413	-121.91076	4/7/15	1.79	79%	25%
161	Santa Clara	Santa Clara	Seabord Ave SD SC-050GAC580	SC-050GAC580	MS4	37.37637	-121.93793	12/11/14	1.35	81%	68%
162	Santa Clara	San Jose	Rock Springs Dr SD	SC-084CTC625	MS4	37.31751	-121.85459	2/6/15	0.83	80%	10%
163	Santa Clara	Santa Clara	Seabord Ave SD SC-050GAC600	SC-050GAC600	MS4	37.37636	-121.93767	12/11/14	2.80	62%	18%
164	Santa Clara	San Jose	Ridder Park Dr SD	SC-051CTC400	MS4	37.37784	-121.90302	12/15/14	0.50	72%	57%
165	Santa Clara	San Jose	Outfall to Lower Silver Ck	SC-067SCL080	MS4	37.35789	-121.86741	2/6/15	0.17	79%	78%
166	Santa Clara	Santa Clara	Victor Nelo PS Outfall	SC-050GAC190	MS4	37.38991	-121.93952	1/19/16	0.58	87%	4%
167	Santa Clara	Santa Clara	Lawrence & Central Expwys SD	SC-049CZC800	MS4	37.37742	-121.99566	1/6/16	1.20	66%	1%
168	Santa Clara	Santa Clara	E Outfall to San Tomas at Scott Blvd	SC-049STA550	MS4	37.37991	-121.96842	3/6/16	0.67	66%	31%
169	Santa Clara	Santa Clara	Duane Ct and Ave Triangle SD	SC-049CZC200	MS4	37.38852	-121.99901	12/13/15 & 1/6/2016	1.00	79%	23%
170	Santa Clara	Santa Clara	Condensa St SD	SC-049STA710	MS4	37.37426	-121.96918	1/19/16	0.24	70%	32%

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Map Key	County	City	Watershed Name	Catchment Code	MS4 or Receiving Water	Latitude	Longitude	Sample Date	Area (sq km)	Impervious Cover (%)	Old Industrial (%)
171	Santa Clara	Santa Clara	Haig St SD	SC-050GAC030	MS4	37.38664	-121.95223	3/6/16	2.12	72%	10%
172	Santa Clara	San Jose	Rosemary St SD 066GAC550C	Rosemary	MS4	37.36118	-121.90594	1/8/17	3.67	64%	11%
173	Santa Clara	San Jose	North Fourth St SD 066GAC550B	NFourth	MS4	37.36196	-121.90535	1/8/17	1.01	68%	27%
174	Santa Clara	San Jose	GR outfall 066GAC900	GR outfall 066GAC900	MS4	37.35392	-121.91223	4/7/18	0.17	66%	1%
175	Santa Clara	San Jose	GR outfall 066GAC850	GR outfall 066GAC850	MS4	37.35469	-121.91279	4/7/18	3.35	61%	6%
176	Santa Clara	San Jose	SC100CTC400A	SC100CTC400A	MS4	37.30299651	-121.8399512	1/16/19	1.38	63%	8%
177	Santa Clara	San Jose	SC100CTC500A	SC100CTC500A	MS4	37.30148661	-121.8381464	1/16/19	3.01	54%	7%
200	Solano	Vallejo	Austin Ck at Hwy 37	AustinCk	Receiving Water	38.12670	-122.26791	3/24/17	4.88	61%	2%

Remote suspended sediment sampling procedures

In spring 2018, the SPLWG oversight committee recommended the use of remote samplers as an acceptable screening tool based on data collected between WYs 2015-2018 (see Gilbreath et al. 2019 for in depth review of the pilot data for the remote sampler trial).

During WY 2019 sampling, a Walling Tube (Phillips et al., 2000) suspended sediment sampler was deployed at three sites prior to a storm and retrieved within two days of the storm's end. Only the remote sampler was used at these sites to characterize water quality; no manual sampling was performed simultaneously. The Walling Tube was used in open channels, deployed at approximately mid-channel, and secured to the natural bed with hose clamps attached to temporarily installed rebar (Figure 2c).

Water and sediment collected in the samplers were decanted into one or two large bottles. When additional water was needed to flush the settled sediment from the remote samplers into the collecting bottles, site water from the sampled channel was used. The collected samples were split and placed into laboratory containers and shipped to the laboratory for analysis. Samples were analyzed as whole-water samples (because of insufficient solid mass to analyze as a sediment sample). Between sampling sites, the remote samplers were thoroughly cleaned using a brush and Alconox detergent, followed by a deionized water (DI) rinse.

Figure 2. Sampling equipment used in the field. (a) Painter's pole, Teflon tubing and an ISCO used as a slave pump; (b) Teflon bottle attached to the end of a DH81 sampling pole; (c) a Walling Tube suspended sediment sampler secured by 5-lb weights along the body of the tube (because it is sitting atop a concrete bed) and rebar driven into the natural bed at the back of the sampler.

Table 2. Locations where remote sediment samplers were pilot tested in previous sampling years and the three locations where the samplers were deployed in WY 2019.

Site	County	Date	Sampler(s) deployed	Comments	Pilot test or solo deployment?
Meeker Slough	Contra Costa	11/2015	Hamlin and Walling Tube	Sampling effort was unsuccessful because of very high velocities. Both samplers washed downstream because they were not sufficiently weighted down and debris caught on the securing lines.	Pilot test
Outfall to Lower Silver Creek	Santa Clara	2/06/15	Hamlin and Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Charcot Ave Storm Drain	Santa Clara	4/07/15	Hamlin	Sampling effort was successful. This sample was analyzed as a sediment sample.	Pilot test
Cooley Landing Storm Drain	San Mateo	2/06/15	Hamlin	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Duane Ct and Ave Triangle SD	Santa Clara	1/6/2016	Hamlin	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Victor Nelo PS Outfall	Santa Clara	1/19/2016	Hamlin and Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Forbes Blvd Outfall	San Mateo	3/5/2016	Hamlin	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Tunnel Ave Ditch	San Mateo	3/5/2016	Hamlin and Walling Tuber	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Taylor Way SD	San Mateo	3/11/2016	Hamlin	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Colma Creek Outfall	San Mateo	2/7/2017	Walling Tube	Sampling effort was successful; however, sampler became submerged for several hours during a high tide cycle and was retrieved afterwards. We hypothesize that this may have added cleaner sediment into the sampler and therefore the result may be biased low. This sample was analyzed as a water sample.	Pilot test
Austin Creek	Solano	3/24/2017	Hamlin and Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Refugio Creek	Contra Costa	1/18/2017	Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Rodeo Creek	Contra Costa	1/18/2017	Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Outfall at Gilman St.	Contra Costa	1/9/2018	Hamlin and Walling Tube	Sampling effort was successful; however, Hamlin sampler could not be gently lowered into place on the bed and instead was dropped from approximately 1.5 ft above the bed;	Pilot test

				it is possible, therefore, that the sampler did not lie horizontally along the bed. This sample was analyzed as a water sample.	
Meeker West	Contra Costa	1/9/2018	Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.	Pilot test
Bay Point	Contra Costa	1/15/2019	Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.	Solo deployment
Mount Diablo Creek	Contra Costa	1/15/2019	Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.	Solo deployment
Wildcat Creek	Contra Costa	1/30/2019	Walling Tube	Sampling effort was successful. This sample was analyzed as a water sample.	Solo deployment

2.3 Laboratory analytical methods

The target analytes for this study are listed in Table 3. The analytical methods and quality control tests are further described in the RMP Quality Assurance Program Plan (Yee et al., 2019). Laboratory methods were chosen based on a combination of factors, including method detection limits, accuracy and precision, and cost (BASMAA, 2011; 2012) (Table 3). For some sites where remote samplers were deployed, both particulate and dissolved phases of Hg, PCBs, and organic carbon (OC) were analyzed for comparison with whole-water concentrations and particulate-only concentrations from manually collected water samples.

Table 3. Laboratory analysis methods.

Analysis	Matrix	Analytical Method	Lab	Filtered	Field Preservation	Contract Lab / Preservation Hold Time
PCBs (40)[9]-Total	Water	EPA 1668	SGS AXYS	No	NA	NA
PCBs (40)[8]-Dissolved	Water	EPA 1668	SGS AXYS	Yes	NA	NA
PCBs (40)[8]	Sediment	EPA 1668	SGS AXYS	NA	NA	NA
Mercury-Total	Water	EPA 1631E	BRL	No	NA	BRL preservation with BrCl within 28 days
Mercury-Dissolved	Water	EPA 1631E	BRL	Yes	Na	BRL preservation with BrCl within 28 days
Mercury	Sediment	EPA 1631E, Appendix	BRL	NA	NA	7 days
Metals-Total (As, Cd, Pb, Cu, Zn)	Water	EPA 1638 mod	BRL	No	HNO_3	BRL preservation with Nitric acid within 14 days
SSC	Water	ASTM D3977	USGS	No	NA	NA
Grain size	Water	USGS GS method	USGS	No	NA	NA
Organic carbon-Total (WY 2015)	Water	5310 C	EBMUD	No	HCL	NA
Organic carbon-Dissolved (WY 2015)	Water	5310 C	EBMUD	Yes	HCL	NA
Organic carbon-Total (WY 2016-2018)	Water	EPA 9060A	ALS	No	HCL	NA
Organic carbon-Dissolved (WY 2016, 2017)	Water	EPA 9060A	ALS	Yes	HCL	NA
Organic carbon (WY 2016, 2017)	Particulate	EPA 440.0	ALS	NA	NA	NA

[9] Samples were analyzed for 40 PCB congeners (PCB-8, PCB-18, PCB-28, PCB-31, PCB-33, PCB-44, PCB-49, PCB-52, PCB-56, PCB-60, PCB-66, PCB-70, PCB-74, PCB-87, PCB-95, PCB-97, PCB-99, PCB-101, PCB-105, PCB-110, PCB-118, PCB-128, PCB-132, PCB-138, PCB-141, PCB-149, PCB-151, PCB-153, PCB-156, PCB-158, PCB-170, PCB-174, PCB-177, PCB-180, PCB-183, PCB-187, PCB-194, PCB-195, PCB-201, PCB-203).

2.4 Interpretive methods

Estimated particle concentrations

The reconnaissance monitoring field protocol is designed to collect one composite whole water sample during a single storm at each site to characterize concentrations during storm flow. Measured PCB and Hg concentrations at a site could have large inter-storm variability related to storm size, intensity and antecedent conditions, as observed from previous studies when a large number of storms were sampled (Gilbreath et al., 2015a); this variability cannot be captured in a single composite sample. However, variability can be reduced if concentrations are normalized to SSC, which produces an estimate of the pollutant concentration associated with particles in the sample. The estimated particle concentration (EPC; ratio of mass of a given pollutant of concern to mass of suspended sediment) has been demonstrated to have less inter-storm variability than whole water concentrations, and therefore the EPC is likely a better characterization of water quality at a site than water concentration alone, and is also a better metric for comparison between sites (McKee et al., 2012; Rügner et al., 2013; McKee et al., 2015). EPCs were used as the primary index to compare sites without regard to climate or rainfall intensity. For each analyte at each site the EPC was computed for each composite water sample (Equation 1):

$$EPC\ (ng/mg) = \ (pollutant\ concentration\ (ng/L))/(SSC\ (mg/L)\ ) \quad (1)$$

Although normalizing PCB and Hg concentrations to SSC provides an improved metric for comparing sites, climatic conditions can nonetheless influence relative ranking based on EPCs. The nature of that influence may differ between watershed locations depending on source characteristics. For example, a higher proportion of polluted sediment may be triggered during dry years when there is little dilution by sediment erosion from rural parts of the watershed. This scenario is most likely to occur in mixed land-use watersheds with large amounts of pervious area. In contrast, a small patch of polluted soil in a highly impervious watershed may be eroded and transported any time rainfall intensity reaches some threshold. In this instance, a false negative could occur if sampling only occurs during rain events that do not meet that intensity threshold. Only with many years of data during many types of storms can such processes be identified.

Because of concerns regarding inter-storm variability, relative ranking of sites based on EPC from only one or two storms should be interpreted with caution and added to a broad set of evidence. Such comparisons may be sufficient for providing evidence to differentiate a group of sites with higher pollutant concentrations from a contrasting group with lower pollutant concentrations (acknowledging the risk that some data for watersheds/catchments in this group will be false negatives). However, to generate information on the absolute relative ranking between individual sites, a more rigorous sampling campaign targeting many storms over many years would be required (c.f. the Guadalupe River study: McKee et al., 2017; McKee et al., 2018, or the Zone 4 Line A study: Gilbreath and McKee, 2015; McKee and Gilbreath, 2015). Alternatively, a more advanced data analysis would be needed that takes into account a variety of parameters (PCB and suspended sediment sources and mobilization processes, PCB congeners, rainfall intensity, rainfall antecedence, flow production and volume) in the normalization and ranking procedure. As mentioned above, the RMP has funded a project in CYs 2018 and 2019 to complete this type of investigation (McKee et al., 2019; Davis, J.A. and Gilbreath, A.N., 2019).

Derivations of central tendency for comparisons with past data

A mean, median, geometric mean, time-weighted mean, or flow-weighted mean have all been used to summarize the central tendency of data from RMP studies with discrete stormwater samples. To compare the composite sample concentrations (comprised of multiple individual grab samples composited into a single bottle) collected in WYs 2015-19 with discrete grab samples collected at several time points in a storm in previous studies, the average of the discrete grab sample concentrations for the pollutant of interest for an event at a site was divided by the average of the SSC discrete grab sample concentrations. Because of the use of this alternative method, EPCs reported here differ slightly from those reported previously for some sites (McKee et al., 2012; McKee et al., 2014; Wu et al., 2016).

3. Results and Discussion

This report presents all available stormwater data[10] collected since WY 2003 when stormwater studies first began through SFEI contracts or RMP projects, including data collected in intensive loading studies from WYs 2003-2010 and 2012-2014, a similar reconnaissance study done in WY 2011, and studies of green infrastructure have been done intermittently since WY 2009. The data are presented in the context of three key questions.

a) What are the concentrations and EPCs observed at each of the sites based on the composite water samples? (related to MQs 1 and 2; see page 1)
b) How do the EPCs measured at each of the sites for composite water samples compare to EPCs derived from samples collected by the remote suspended-sediment samplers? (influences collection of data to address MQs 1 & 2. The analysis related to this question is presented in Gilbreath et al., 2019)
c) How do concentrations and EPCs for PCBs and Hg relate to other trace contaminant concentrations and land use? (related to MQs 1 & 2)

These data contribute to a broad effort to identify potential management areas, and the rankings based on either stormwater concentration or EPCs are part of a weight-of-evidence approach for locating and prioritizing areas that may be disproportionately impacting downstream water quality. As the number of sample sites has increased, the relative rankings of particular sites have changed, but the highest-ranking sites have generally remained high.

[10] Similar data collected by BASMAA in Santa Clara and San Mateo Counties are not included in this report.

3.1 Stormwater SSC concentrations

Suspended sediment concentrations from the 88[11] sampling locations ranged from 16 to 1,354 mg/L, with a median of 93 mg/L. About 30% of the watersheds included in these statistics have greater than 5% agricultural and uncompacted open spaces. If those watersheds/catchments are removed, the 63 remaining are nearly wholly urban (maximum agricultural plus uncompacted open space of 2.1%). The urban, impervious watersheds/catchments have low SSC (relative to the watersheds with greater than 5% open and uncompacted area). Summary statistics for SSC for these 63 urban watersheds/catchments are given in Table 4.

Table 4. Summary statistics (count, minimum, maximum and percentiles) of SSC (in mg/L) for urban watersheds/catchments with agricultural and uncompacted open space <2.2%.

	All Counties	Alameda	Contra Costa	San Mateo	Santa Clara
Number of sampled (n)	63	18	5	18	21
Minimum	16	60	57	16	27
10th Percentile	26	68	NA	21	34
25th Percentile	45	81	57	26	46
50th Percentile	77	133	61	44	73
75th Percentile	143	203	123	83	118
90th Percentile	223	388	NA	160	148
Maximum	671	671	151	265	250

3.2 PCBs stormwater concentrations and estimated particle concentrations

Total PCB concentrations from 87 sampling sites[12] ranged from 533 to 448,000 pg/L, excluding one sample that had a large number of individual congeners below the method detection limit (<MDL; Table 5). Based on water composite concentrations for all available data, the 10 highest ranking sites for PCBs were (from high to low): Pulgas Pump Station-South, Santa Fe Channel, Industrial Rd Ditch, Line 12H at Coliseum Way, Sunnyvale East Channel, Line 12M at Coliseum Way, Pulgas Pump Station-North, Ettie Street Pump Station, Ridder Park Dr Storm Drain and Gull Dr. Outfall (Table 5, Figure 3). Old industrial land use and PCB concentration were moderately correlated (r = 0.61); old industrial land use for these 10 sites ranges from 3-79% (mean 35%, median 32%), illustrating that land use alone is insufficient to identify high leverage areas. Rather, localized sources (e.g., former transformer manufacturing locations, locations of transformer spills, properties that used PCBs where the soils have been contaminated but not remediated to TMDL levels) are likely the most important factor controlling PCB concentrations, although these sources frequently are located in old industrial areas.

[11] This count excludes the sites in which only a remote suspended sediment sampler was deployed. Because those samplers are intended to concentrate suspended sediment, the measurement of SSC is not comparable to the composite sampling. There are 91 total sampling locations. Of these, 67 were sampled during WYs 2015-2019, 87 had water concentrations for PCBs, and 88 had water concentrations for HgT.

[12] There are 91 sites in Table 5 but one site, San Pedro Storm drain, only analyzed samples for Hg, not PCBs, and three samples were measured using suspended sediment samplers in which only the particle ratio is comparable to the other manually collected data.

Based on EPCs, the 10 highest-ranking sites for PCBs were: Pulgas Pump Station-South, Industrial Rd Ditch, Line 12H at Coliseum Way, Santa Fe Channel, Gull Dr SD, Pulgas Pump Station-North, Outfall to Colma Ck on service road near Littlefield Ave., Outfall to Lower Silver Creek, Ettie Street Pump Station, and South Linden Ave. SD. Sites ranked highest based on stormwater concentrations and those ranked highest based on EPCs corresponded well. Six sampling sites were among the 10 highest-ranking sites for both metrics (Figure 4); most sites in the top 10 for either concentrations or EPCs were within the top 20 of the other list, while only one site (South Linden Ave. SD) was ranked high (10^{th}) in EPCs but low on water concentration (35^{th}) because of very low SSC.

A high rank in water concentration and a low rank in EPC indicates the presence of PCB sources but dilution by relatively high loading of clean sediment (e.g., >75^{th} percentile of SSC, Table 5). Examples include Line 13A at end of slough (357 mg SS/L) and Line 12K at Coliseum Entrance (671 mg SS/L). Conversely, a high rank in EPC and low rank in water concentration indicates that mobilization of PCB-contaminated sediment is high relative to mobilization of cleaner sediment; these samples often have a relatively low SSC. Examples include South Linden Ave. SD (16 mg SS/L), Austin Ck at Hwy 37 (20 mg SS/L) and Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Circle (27 mg SS/L). This latter scenario is more likely to occur in watersheds/catchments that are highly impervious with little erosion and transport of clean sediment from undeveloped areas.

Most of the sites investigated had PCB EPCs that were higher than those needed for attainment of the TMDL. The PCB load allocation of 2 kg from the TMDL (SFBRWQCB 2008) translates to a mean water concentration of 1,330 pg/L and a mean particle concentration of 1.4 ng/g. These calculations assume an annual average flow from small tributaries of 1.5 km^3 (Wu et al., 2017) and an average annual suspended sediment load of 1.4 million metric tons (McKee et al., 2013). Only five sampling locations investigated to date (Gellert Park bioretention influent stormwater, Duane Ct. and Triangle Ave., East Antioch nr Trembath, Refugio Ck at Tsushima St. and Little Bull Valley) had a composite averaged PCB water concentration of <1,330 pg/L (Table 5) and none of the 87 sampling locations had composite averaged PCB EPCs of <1.4 ng/g (Table 5; Figure 3). The lowest PCB EPC measured to date was for Mount Diablo Creek (1.8 ng/g).

Table 5. PCB and total mercury (HgT) water concentrations and estimated particle concentrations (EPCs) measured in the Bay Area based on all RMP data collected in stormwater since water year 2003. The data are sorted from high-to-low for PCB EPC to provide preliminary information on potential leverage. Note: Ranks with a half number (.5) indicate two watersheds/catchments with the same rank. NR = not ranked because concentration was below the MDL or because the study was part of a bioretention study and data is based on a relatively very small watershed.

Watershed/ Catchment	County	Water Year sampled	Area (km^2)	Impervious cover (%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Pulgas Pump Station-South	San Mateo	2011, 2013-2014	0.58	87%	54%	8222	1	448	1	350	46.5	19	62	54	66
Industrial Rd Ditch	San Mateo	2016	0.23	85%	79%	6139	2	160	3	535	27	14	72	26	83
Line 12H at Coliseum Way	Alameda	2017	0.97	71%	10%	2601	3	156	4	602	19	36	45	60	59.5
Santa Fe Channel	Contra Costa	2011	3.3	69%	3%	1295	4	198	2	570	22.5	86	12.5	151	23
Gull Dr SD	San Mateo	2016	0.30	78%	54%	903	5	39.8	12	320	53	5.4	85	43	74
Pulgas Pump Station-North	San Mateo	2011	0.55	84%	52%	893	6	60.3	7	400	40	24	56.5	60	59.5
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	San Mateo	2017	0.09	88%	87%	788	7	33.9	17	210	69	9	82	43	72.5
Outfall to Lower Silver Creek	Santa Clara	2015	0.17	79%	78%	783	8	44.6	11	420	37	24	56.5	57	64
Ettie Street Pump Station	Alameda	2011	4.0	75%	22%	759	9	59.0	8	690	14	55	25.5	80	51
S Linden Ave SD (291)	San Mateo	2017	0.78	88%	57%	736	10	11.8	35	775	10	12	78	16	88
Gull Dr Outfall	San Mateo	2016 & 2018	0.43	75%	42%	599	11	49.5	10	180	74.5	7.6	83	62	57
Austin Ck at Hwy 37	Solano	2017	4.9	61%	2%	573	12	11.5	37	640	17	13	76.5	20	87
Ridder Park Dr Storm Drain	Santa Clara	2015	0.50	72%	57%	488	13	55.5	9	330	51	37	44	114	34
MeekerWest	Contra Costa	2018	0.41	70%	69%	458	14	28.0	22	530	29	32	48	61	58

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Watershed/ Catchment	County	Water Year sampled	Area (km^2)	Impervious cover (%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Outfall at Gilman St.	Alameda	2016 & 2018	0.84	76%	32%	451	15	37.2	14	2820	3	233	5	81	49
Line 12I at Coliseum Way	Alameda	2017	3.4	63%	9%	398	16	37.0	15	129	82	12	80	93	44.5
Sunnyvale East Channel	Santa Clara	2011	15	59%	4%	343	17	96.6	5	200	71	50	29	250	14
Line 3A-M at 3A-D	Alameda	2015	0.88	73%	12%	337	18	24.8	23	1170	4	86	12.5	74	53
SMBUR85A	San Mateo	2019	0.42	81%	44%	334	19	31.1	19	440	34	41	40	93	44.5
Line 12M at Coliseum Way	Alameda	2017, 2019	5.3	69%	22%	280	20	82.7	6	348	48	89	11	263	13
North Richmond Pump Station	Contra Costa	2011-2014	2.0	62%	18%	241	21	13.2	33	810	9	47	30.5	58	62
Seabord Ave Storm Drain SC-050GAC580	Santa Clara	2015	1.4	81%	68%	236	22	19.9	27	550	25	47	30.5	85	46
Line 4-E	Alameda	2015	2.0	81%	27%	219	23	37.4	13	350	46.5	59	22	170	20
Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	Contra Costa	2017 & 2018	36.67	18%	5%	219	24	5.64	57	540	26	16	66	27	81.5
Glen Echo Creek	Alameda	2011	5.5	39%	0%	191	25	31.1	20	210	70	73	17	348	11
Seabord Ave Storm Drain SC-050GAC600	Santa Clara	2015	2.8	62%	18%	186	26	13.5	32	530	28	38	42.5	73	54
Line 12F below PG&E station	Alameda	2017	10	56%	3%	184	27	21.0	26	373	42	43	37	114	34
South Linden Pump Station	San Mateo	2015	0.14	83%	22%	182	28	7.81	50	680	15	29	52	43	72.5
Taylor Way SD	San Mateo	2016	0.27	67%	11%	169	29	4.23	62	1156	5	29	53	25	84
Line 9-D	Alameda	2015	3.6	78%	46%	153	30	10.5	41	240	63.5	17	64.5	69	56
Meeker Slough	Contra Costa	2015 & 2018	7.3	64%	6%	140	31	7.91	49	770	11	45	33	57	65
Rock Springs Dr Storm Drain	Santa Clara	2015	0.83	80%	10%	128	32	5.25	58	930	7	38	42.5	41	75.5

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Watershed/ Catchment	County	Water Year sampled	Area (km^2)	Impervious cover (%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
GR outfall 066GAC900	Santa Clara	2018	0.17	66%	1%	125	33	3.36	68	644	16	17	63	27	81.5
Charcot Ave Storm Drain	Santa Clara	2015	1.8	79%	24%	123	34	14.9	30	560	24	67	19	121	32
Veterans Pump Station	San Mateo	2015	0.52	67%	7%	121	35	3.52	67	470	32	14	71	29	80
Gateway Ave Storm Drain	San Mateo	2015	0.36	69%	52%	117	36	5.24	59	440	33	20	61	45	70.5
Guadalupe River at Hwy 101	Santa Clara	2003-2006, 2010, 2012-2014	233	39%	3%	115	37	23.7	24	3600	2	603	1	560	5
Line 9D1 PS at outfall to Line 9D	Alameda	2016	0.48	88%	62%	110	38	18.1	29	720	13	118	7.5	164	21
Tunnel Ave Ditch	San Mateo	2016	3.0	47%	8%	109	39	10.5	39	760	12	73	18	96	40.5
Valley Dr SD	San Mateo	2016	5.2	21%	7%	109	40	10.4	42	276	61	27	55	96	40.5
Runnymede Ditch	San Mateo	2015	2.1	53%	2%	108	41	28.5	21	190	73	52	28	265	12
E Gish Rd Storm Drain	Santa Clara	2015	0.45	84%	70%	99	42	14.4	31	590	21	85	14	145	26
Line 3A-M-1 at Industrial Pump Station	Alameda	2015	3.4	78%	26%	96	43	8.92	44	340	49	31	49	93	43
Line 13A at end of slough	Alameda	2016	0.83	84%	68%	96	44	34.3	16	331	50	118	7.5	357	9
Line 12A at Shellmound	Alameda	2018	10.48	41%	6%	95	45	10.8	38	406	38	46	32	114	34
SC100CTC500A	Santa Clara	2019	3.01	54%	7%	94	46	10.5	40	386	41	43	36	111	36.5
Rosemary St SD 066GAC550C	Santa Clara	2017	3.7	64%	11%	89	47	4.11	64	591	20	27	54	46	69

WYs 2015 through 2019 POC Reconnaissance Monitoring

Watershed/ Catchment	County	Water Year sampled	Area (km^2)	Impervious cover (%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
North Fourth St SD 066GAC550B	Santa Clara	2017	1.0	68%	27%	87	48	4.17	63	477	31	23	59	48	67.5
Zone 4 Line A	Alameda	2007-2010	4.2	68%	12%	82	49	18.4	28	170	76	30	51	176	19
Forbes Blvd Outfall	San Mateo	2016	0.40	79%	0%	80	50	1.84	77	637	18	15	70	23	85
Storm Drain near Cooley Landing	San Mateo	2015	0.11	73%	39%	79	51	6.47	55	430	35	35	46	82	48
Lawrence & Central Expwys SD	Santa Clara	2016	1.2	66%	1%	78	52	4.51	61	226	65	13	73.5	58	63
Condensa St SD	Santa Clara	2016	0.24	70%	32%	74	53	2.60	75	329	52	12	81	35	78
San Leandro Creek	Alameda	2011-2014	8.9	38%	0%	66	54	8.61	47	860	8	117	9	136	30
Oddstad Pump Station	San Mateo	2015	0.28	74%	11%	62	55	9.20	43	370	43	55	25.5	148	25
Line 4-B-1	Alameda	2015	1.0	85%	28%	57	56	8.67	46	280	58.5	43	35	152	22
Line 12A under Temescal Ck Park	Alameda	2016	9.4		1%	54	57	7.80	51	290	57	42	38	143	27
Victor Nelo PS Outfall	Santa Clara	2016	0.58	87%	4%	51	58	2.29	76	351	44	16	68	45	70.5
SMBUR164A	San Mateo	2019	0.98	71%	37%	48	59	3.87	65	276	60	22	60	80	50
Line 12K at Coliseum Entrance	Alameda	2017	16	31%	1%	48	60	32.0	18	429	36	288	4	671	4
GR outfall 066GAC850	Santa Clara	2018	3.35	61%	6%	45	61	6.63	53	107	85	16	67	149	24
Haig St SD	Santa Clara	2016	2.1	72%	10%	43	62	1.45	79	194	72	7	84	34	79
SC100CTC400A	Santa Clara	2019	1.38	63%	8%	38	63	2.92	71	303	56	23	58	77	52
Colma Ck at S. Linden Blvd	San Mateo	2017	35	41%	3%	37	64	2.65	74	215	68	15	69	71	55
Line 12J at mouth to 12K	Alameda	2017	8.8	30%	2%	35	65	6.48	54	401	39	73	16	183	18

WYs 2015 through 2019 POC Reconnaissance Monitoring

Watershed/ Catchment	County	Water Year sampled	Area (km^2)	Impervious cover (%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Wildcat Creek	Contra Costa	2019	23.44	53%	1%	32	66	NA	NA	No data	No data	No data	No data	**	NR
S Spruce Ave SD at Mayfair Ave (296)	San Mateo	2017	5.1	39%	1%	30	67	3.36	69	350	45	39	41	111	36.5
Lower Coyote Creek	Santa Clara	2005	327	22%	1%	30	68	4.58	60	240	63.5	34	47	142	29
Calabazas Creek	Santa Clara	2011	50	44%	3%	29	69	11.5	36	150	80	59	22	393	7
E Outfall to San Tomas at Scott Blvd	Santa Clara	2016	0.67	66%	31%	27	70	2.80	73	127	83	13	73.5	103	39
San Lorenzo Creek	Alameda	2011	125	13%	0%	25	71	12.9	34	180	74.5	41	39	228	16
Stevens Creek	Santa Clara	2011	26	38%	1%	23	72	8.16	48	220	66.5	77	15	350	10
Guadalupe River at Foxworthy Road/ Almaden Expressway	Santa Clara	2010	107	22%	0%	19	73	3.12	70	4090	1	529	2	129	31
Duane Ct and Ave Triangle SD	Santa Clara	2016	1.0	79%	23%	17	74	0.832	81	268	62	13	75	48	67.5
Lower Penitencia Creek	Santa Clara	2011, 2015	12	65%	2%	16	75	1.59	78	160	77.5	17	64.5	106	38
Borel Creek	San Mateo	2011	3.2	31%	0%	15	76	6.13	56	160	77.5	58	24	363	8
San Tomas Creek	Santa Clara	2011	108	33%	0%	14	77	2.83	72	280	58.5	59	22	211	17
Little Bull Valley	Contra Costa	2018	0.02	67%	2%	13	78	0.543	82	312	55	13	76.5	41	75.5
Zone 5 Line M	Alameda	2011	8.1	34%	5%	13	79.5	21.1	25	570	22.5	505	3	886	3
Belmont Creek	San Mateo	2011	7.2	27%	0%	13	79.5	3.60	66	220	66.5	53	27	241	15
BayPoint	Contra Costa	2019	4.35	21%	0%	12	81	NA	NA	140	81	NA	NA	**	NR

WYs 2015 through 2019 POC Reconnaissance Monitoring

Watershed/ Catchment	County	Water Year sampled	Area (km^2)	Impervious cover (%)	Old Industrial land use (%)	Polychlorinated biphenyls (PCBs)				Total Mercury (HgT)				Suspended Sediment Concentration (SSC)	
						Estimated Particle Concentration		Composite /mean water concentration		Estimated Particle Concentration		Composite /mean water concentration		Composite /mean water concentration	
						(ng/g)	Rank	(ng/L)	Rank	(ng/g)	Rank	(ng/L)	Rank	(mg/L)	Rank
Refugio Ck at Tsushima St	Contra Costa	2017	11	23%	0%	9	82	0.533	83	509	30	30	50	59	61
Walnut Creek	Contra Costa	2011	232	15%	0%	7	83	8.83	45	70	87	94	10	1343	2
Rodeo Creek at Seacliff Ct. Pedestrian Br.[13]	Contra Costa	2017, 2019	23.41	2%	1%	6	84	7.21	52	93	86	65	20	1354	1
Lower Marsh Creek	Contra Costa	2011-2014	84	10%	0%	3	85	1.45	80	110	84	44	34	400	6
Mount Diablo Creek	Contra Costa	2019	75.56	9%	0%	2	86	NA	NA	157	79	NA	NA	**	NR
San Pedro Storm Drain	Santa Clara	2006	1.3	72%	16%	No data	No data	No data	No data	1120	6	160	6	143	28
Gellert Park Daly City Library Bioretention Influent	San Mateo	2009	0.02	40%	0%	36	NR[a]	0.725	NR[a]	1010	NR[a]	22	NR[a]	22	86
Fremont Osgood Road Bioretention Influent	Alameda	2012, 2013	0.00	76%	0%	45	NR[a]	2.91	NR[a]	120	NR[a]	10	NR[a]	83	47
El Cerrito Bioretention Influent	Contra Costa	2012, 2014-15, 2017	0.00	74%	0%	310	NR[a]	29.7	NR[a]	196	NR[a]	19	NR[a]	96	42
East Antioch nr Trembath	Contra Costa	2017	5.3	26%	3%	NR[a]	NR[a]	<MDL	NR[a]	313	54	12	79	39	77

NR[a] = site not included in ranking. These are very small catchments with unique sampling designs for evaluation of green infrastructure.
** Collection was done using a suspended sediment sampler, which concentrates suspended sediment and therefore is not comparable to the samples collected using manual compositing techniques of whole water.

[13] Rodeo Creek was sampled in WY 2017 at Seacliff Ct, Pedestrian Bridge. In WY 2019, the bridge was closed and instead sampling occurred downstream 370 m at Viewpoint Blvd. The results from the two nearby locations are combined in this row.

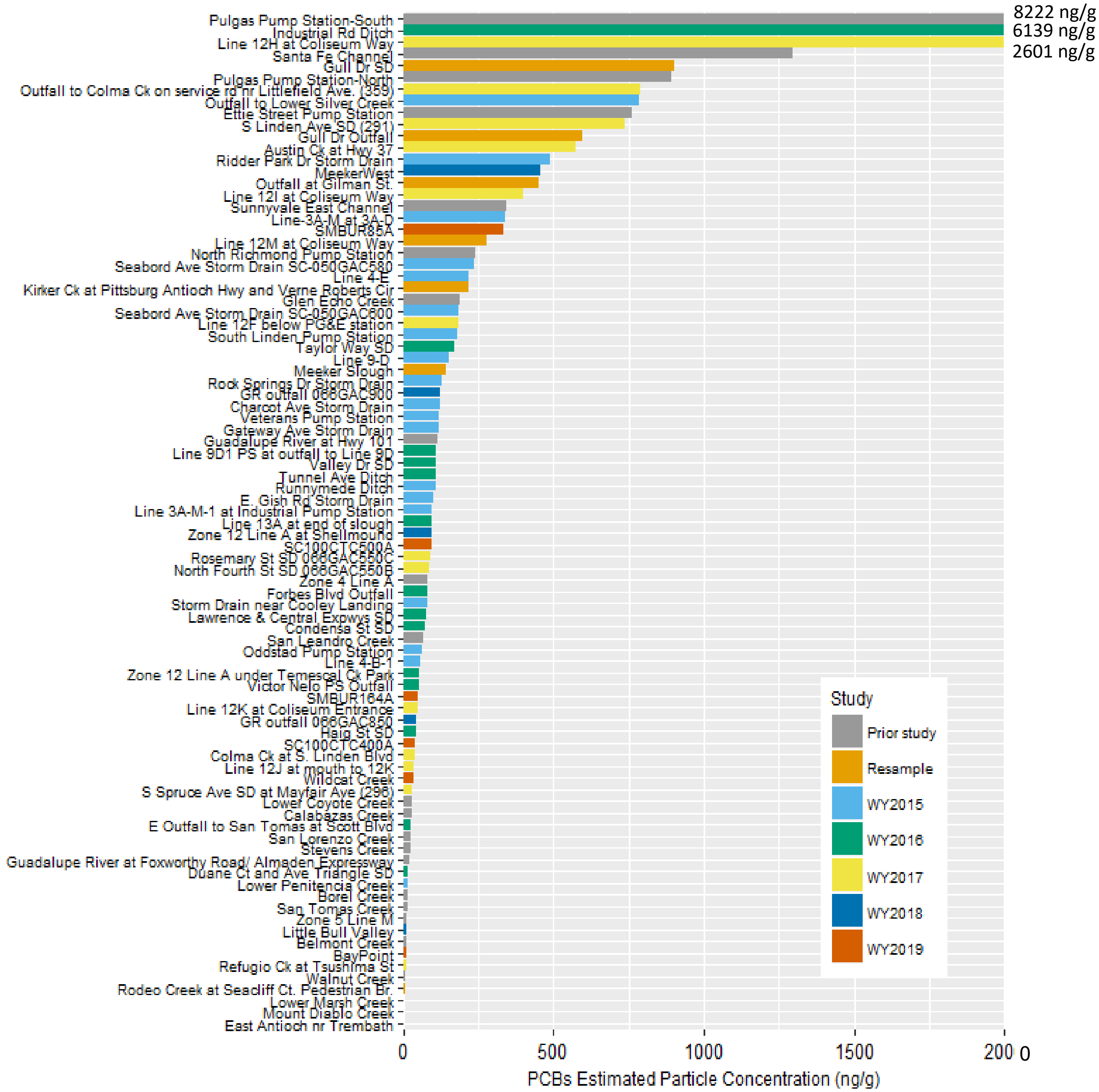

Figure 3. PCB estimated particle concentrations (EPCs) for watershed and catchment sampling sites measured in water years 2003-2019 (where more than one storm was sampled at a site, the reported concentration is the average of the storm composite samples). Note that PCB EPCs for Pulgas Pump Station-South (8,222 ng/g), Industrial Road Ditch (6,139 ng/g), and Line 12H at Coliseum Way (2,601 ng/g) extend beyond upper bound of the graph. The sample count represented by each bar in the graph is provided in Appendix D.

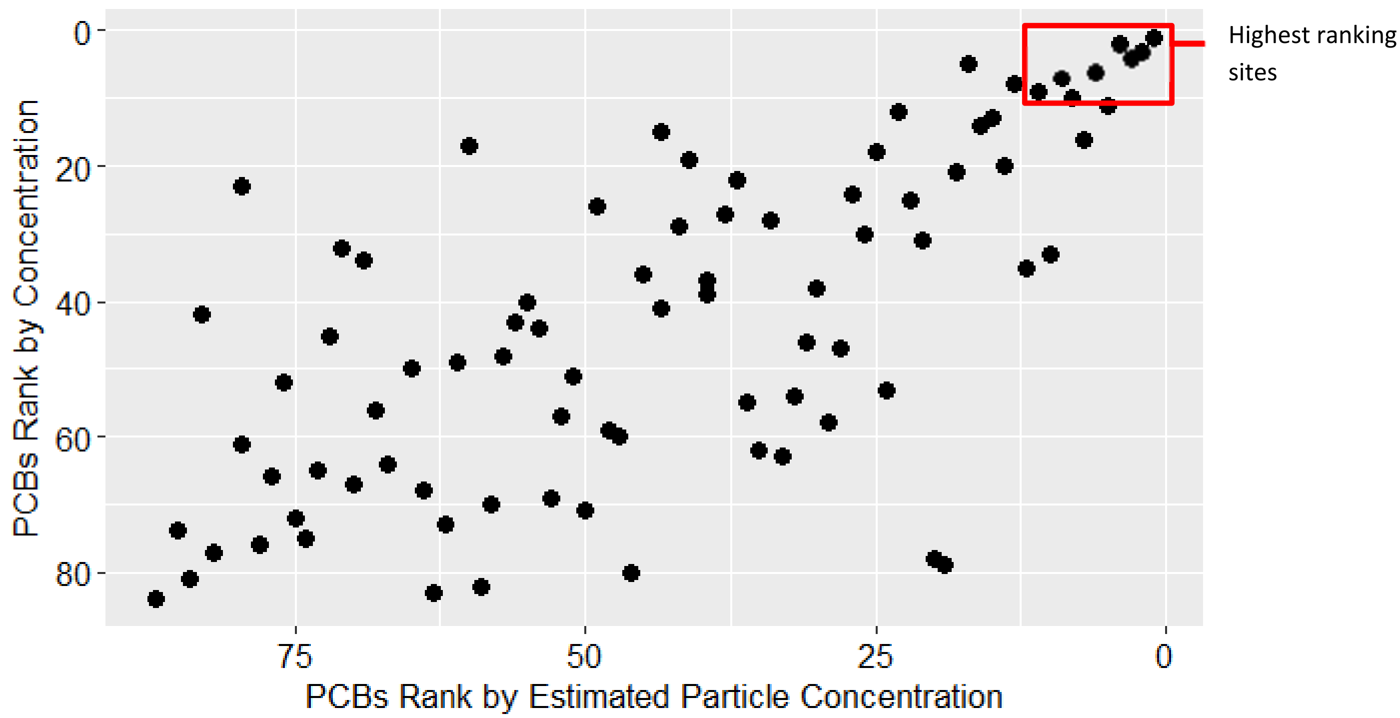

Figure 4. Comparison of site rankings for PCBs based on estimated particle concentrations (EPCs) and on water concentrations. 1 = highest rank; 84 = lowest rank.

3.3 Mercury stormwater concentrations and estimated particle concentrations

Total mercury concentrations in composite water samples ranged 110-fold from 5.4 to 603 ng/L among the 88 sites sampled to date (Table 4). Based on water concentrations, the 10 highest ranking sites for HgT are the Guadalupe River at Hwy 101 (3% old industrial and the legacy New Almaden Mining District upstream), Guadalupe River at Foxworthy Road/ Almaden Expressway (0% old industrial and the legacy New Almaden Mining District upstream), Zone 5 Line M (5% old industrial), Line 12K at the Coliseum Entrance (1% old industrial), Outfall at Gilman St. (32% old industrial), San Pedro Storm Drain (16% old industrial), Line 13-A at end of slough (68% old industrial), Line 9-D-1 PS at outfall to Line 9-D (62% old industrial), San Leandro Creek at San Leandro Blvd. (0% old industrial) and Walnut Creek (0% old industrial) (Table 4). There is a weak and positive relationship between mercury concentrations and old industrial land use, in contrast to the stronger relationship between PCB concentrations and industrial land use. None of the top 10 sites for Hg were among the top 10 for PCBs, also suggesting there is no direct relationship between mercury and PCBs in stormwater runoff in the Bay Area.

There are several watersheds/catchments with relatively low Hg concentrations. The HgT load allocation of 82 kg from the TMDL (SFBRWQCB, 2006) translates to a mean water concentration of 53 ng/L, based on an annual average flow from small tributaries of 1.5 km^3 (Wu et al., 2017). Sixty-one of 88 sampling locations have composite HgT water concentrations below this concentration (Table 4). There are likely few Hg sources in these watersheds/catchments besides atmospheric deposition[14].

Estimated particle concentrations of HgT ranged between 45 and 4,090 ng/g. The 10 most polluted sites for HgT based on EPCs were Guadalupe River at Foxworthy Road/ Almaden Expressway, Guadalupe River at Hwy 101, Outfall at Gilman St., Line 3A-M at 3A-D, Taylor Way SD, San Pedro Storm Drain, Rock Springs Dr. Storm Drain, San Leandro Creek, North Richmond Pump Station and South Linden Ave. SD (Table 4; Figure 5). Only one of these 10 sites was among the 10 most highly-ranked sites for PCBs (South Linden Ave. SD), but 6 additional watersheds/catchments rank in the 20 most highly-ranked sites for both pollutants (Figure 6), providing the opportunity to address both PCBs and HgT. Twenty-seven sites sampled to date have EPCs <250 ng/g, which, given a reasonable expectation of error of 25% around the measurements, could be considered equivalent to or less than 200 ng/g of Hg on suspended solids, the particulate Hg concentration specified in the Bay and Guadalupe River TMDLs (SFBRWQCB, 2006; 2008). Unlike PCBs, there is no relation between water concentration and EPC for HgT (Figure 7). Therefore, ranking of sites for HgT should be approached more cautiously than for PCBs.

[14] Multiple studies in the Bay Area on atmospheric deposition rates for HgT reported very similar wet deposition rates of 4.2 µg/m^2/y (Tsai and Hoenicke, 2001) and 4.4 µg/m^2/y (Steding and Flegal, 2002), and Tsai and Hoenicke reported a total (wet + dry) deposition rate of 18-21 µg/m^2/y. Tsai and Hoenicke computed volume-weighted mean mercury concentrations in precipitation based on 59 samples collected across the Bay Area of 8.0 ng/L. They reported that wet deposition contributed 18% of total annual deposition; scaled to volume of runoff, an equivalent stormwater concentration is 44 ng/L (8 ng/L/0.18 = 44 ng/L).

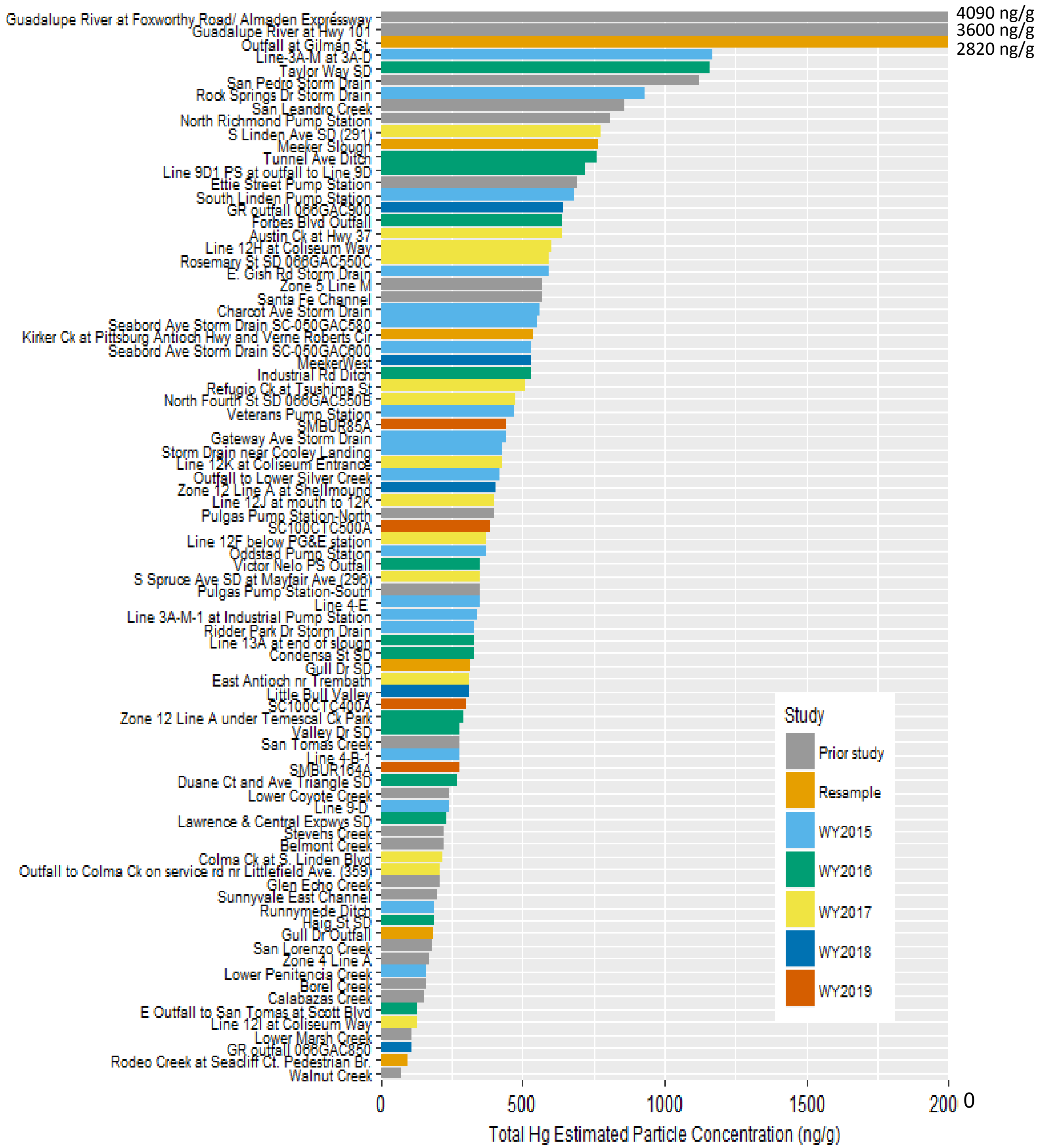

Figure 5. All sampling locations measured to date (water years 2003-2019) ranked by total mercury (HgT) estimated particle concentrations (EPCs). The sample count represented by each bar in the graph is provided in Appendix D.

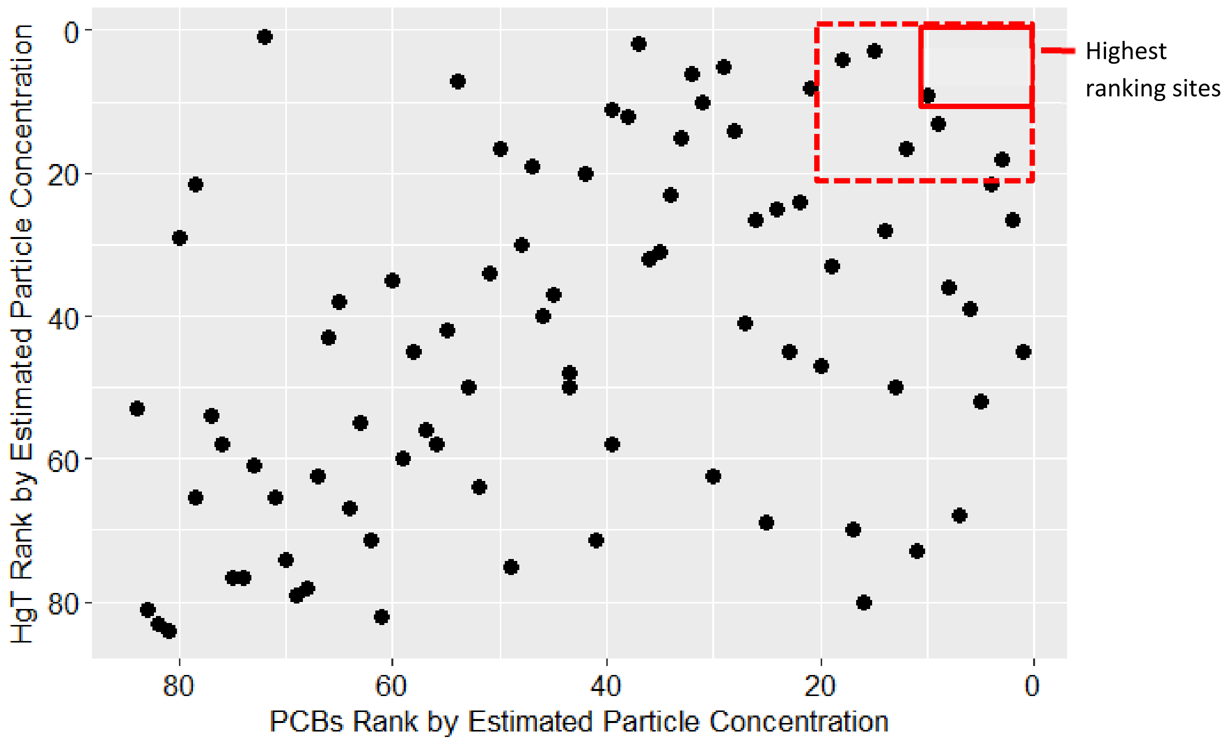

Figure 6. Comparison of site rankings for PCB and total mercury (HgT) estimated particle concentrations (EPCs). 1 = highest rank; 84 = lowest rank. One watershed ranks in the top 10 for both PCBs and HgT (in the solid red box), and seven watersheds rank in the top 20 for both pollutants (in the dashed red box).

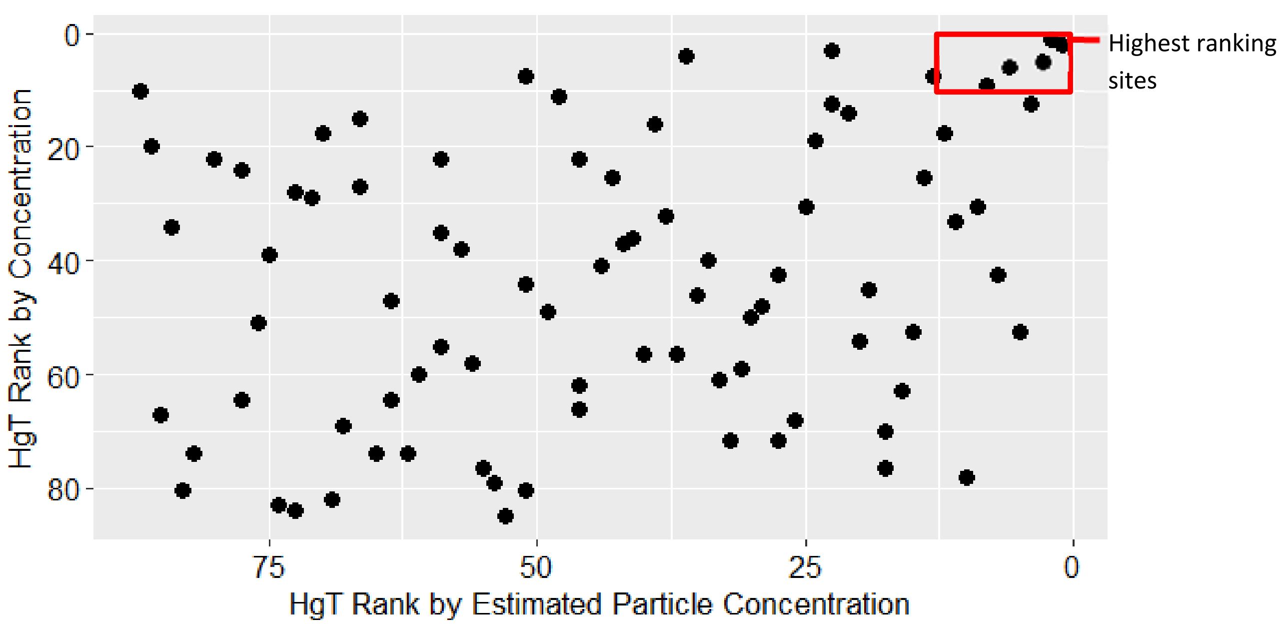

Figure 7. Comparison of site rankings for total mercury (HgT) estimated particle concentrations and water concentrations. 1 = highest rank; 85 = lowest rank.

3.4 Trace element (As, Cd, Cu, Mg, Pb, Se and Zn) concentrations

Trace metal (As, Cd, Cu, Pb and Zn) concentrations measured in selected watersheds during WYs 2015, 2016, and 2017[15] were similar in range to those previously measured in the Bay Area.

- Arsenic (As): Concentrations ranged from less than the MDL (0.34 µg/L for that sample) to 2.66 µg/L (Table 6). Total As concentrations of this magnitude have been measured in the Bay Area previously (Guadalupe River at Hwy 101: mean=1.9 µg/L; Zone 4 Line A: mean=1.6 µg/L) and are lower than those measured at the North Richmond Pump Station (mean=11 µg/L) (Appendix A3 in McKee et al., 2015).
- Cadmium (Cd): Concentrations ranged from 0.023-0.55 µg/L (Table 6), similar to mean concentrations measured at Guadalupe River at Hwy 101 (0.23 µg/L), North Richmond Pump Station (mean = 0.32 µg/L), and Zone 4 Line A (mean = 0.25 µg/L) (Appendix A3 in McKee et al., 2015).
- Copper (Cu): Concentrations ranged from 3.63 to 52.7 µg/L (Table 6). These concentrations are typical of those measured in other Bay Area watersheds (mean concentrations for all of the following: Guadalupe River at Hwy 101: 19 µg/L; Lower Marsh Creek: 14 µg/L; North Richmond Pump Station: Cu 16 µg/L; Pulgas Pump Station-South: Cu 44 µg/L; San Leandro Creek: Cu 16 µg/L; Sunnyvale East Channel: Cu 18 µg/L; and Zone 4 Line A: Cu 16 µg/L) (Appendix A3 in McKee et al., 2015).
- Lead (Pb): Concentrations ranged from 0.910 to 21.3 µg/L (Table 6). Total Pb concentrations of this magnitude have been measured in the Bay Area previously (mean concentrations for all of the following: Guadalupe River at Hwy 101: 14 µg/L; North Richmond Pump Station: Pb 1.8 µg/L; and Zone 4 Line A: 12 µg/L) (Appendix A3 in McKee et al., 2015).
- Zinc (Zn): Concentrations ranged from 39.4-337 µg/L (Table 6). Zinc were comparable to mean concentrations measured in the Bay Area previously (Zone 4 Line A: 105 µg/L; Guadalupe River at Hwy 101: 72 µg/L) (see Appendix A3 in McKee et al., 2015).

In WY 2016, magnesium (Mg; 528-7350 µg/L) and selenium (Se; <MDL-0.39 µg/L) were added to the list of analytes. Both Mg and Se largely reflect geologic sources in watersheds. No measurements of Mg have been previously reported in the Bay Area. The measured concentrations of Se are on the lower end of previously reported concentrations (North Richmond Pump Station: 2.7 µg/L; Walnut Creek: 2.7 µg/L; Lower Marsh Creek: 1.5 µg/L; Guadalupe River at Hwy 101: 1.3 µg/L; Pulgas Creek Pump Station - South: 0.93 µg/L; Sunnyvale East Channel: 0.62 µg/L; Zone 4 Line A: 0.48 µg/L; Mallard Island: 0.46 µg/L; Santa Fe Channel - Richmond: 0.28 µg/L; San Leandro Creek: 0.22 µg/L) (Table A3: McKee et al., 2015). Given the high proportion of Se transported in the dissolved phase and the inverse correlation with flow (David et al., 2015; McKee and Gilbreath, 2015; McKee et al., 2017), Se concentrations measured with the current sampling protocol, with a focus on high flow, likely were biased low relative to those measured with sampling designs that included low flow and baseflow samples (North Richmond Pump Station: 2.7 µg/L; Guadalupe River at Hwy 101: 1.3 µg/L; Zone 4 Line A: 0.48 µg/L; Mallard Island: 0.46

[15] Trace elements were not measured in WYs 2018 or 2019.

µg/). Care, therefore, should be taken if Se concentrations reported here were to be used in the future to estimate regional loads.

Table 6. Concentrations of selected trace elements measured during water years 2015, 2016, and 2017. The highest and lowest concentration for each trace element is in bold.

Watershed/Catchment	Sample Date	As (µg/L)	Cd (µg/L)	Cu (µg/L)	Pb (µg/L)	Mg (µg/L)	Se (µg/L)	Zn (µg/L)
Charcot Ave SD	4/7/2015	0.623	0.0825	16.1	2.02			115
Condensa St SD	1/19/2016	1.07	0.055	6.66	3.37	3,650	0.39	54.3
E. Gish Rd SD	12/11/2014	1.52	**0.552**	23.3	19.4			152
East Antioch nr Trembath	1/8/2017	1.57	0.119	**3.53**	1.68	5,363	0.53	**36.3**
Forbes Blvd Outfall	3/5/2016	1.5	0.093	31.7	3.22	7,350	**<MDL**	246
Gateway Ave SD	2/6/2015	1.18	0.053	24.3	1.04			78.8
Gull Dr SD	3/5/2016	**<MDL**	**0.023**	3.63	1.18	**528**	**<MDL**	39.4
Line 9-D-1 PS at outfall to Line 9-D	1/5/2016	1.07	0.524	22.5	20.9	2,822	0.2	217
Line 3A-M at 3A-D	12/11/2014	2.08	0.423	19.9	17.3			118
Line 3A-M-1 at Industrial PS	12/11/2014	1.07	0.176	14.8	7.78			105
Line 4-B-1	12/16/2014	1.46	0.225	17.7	8.95			108
Line 4-E	12/16/2014	2.12	0.246	20.6	13.3			144
Line 9-D	4/7/2015	0.47	0.053	6.24	**0.91**			67
Lower Penitencia Ck	12/11/2014	2.39	0.113	16.4	4.71			64.6
Meeker Slough	12/3/2014	1.75	0.152	13.6	14.0			85.1
North Fourth St SD 066GAC550B	1/8/2017	1.15	0.125	14.0	5.70	**11,100**	**0.67**	75.7
Oddstad PS	12/2/2014	2.45	0.205	23.8	5.65			117
Outfall to Lower Silver Ck	2/6/2015	2.11	0.267	21.8	5.43			**337**
Ridder Park Dr SD	12/15/2014	**2.66**	0.335	19.6	11.0			116
Rock Springs Dr SD	2/6/2015	0.749	0.096	20.4	2.14			99.2
Runnymede Ditch	2/6/2015	1.84	0.202	**52.7**	**21.3**			128
S Spruce Ave SD at Mayfair Ave (296)	1/8/2017	2.2	0.079	9.87	5.31	3,850	0.13	54.8
SD near Cooley Landing	2/6/2015	1.74	0.100	9.66	1.94			48.4
Seabord Ave SD SC-050GAC580	12/11/2014	1.29	0.295	27.6	10.2			168
Seabord Ave SD SC-050GAC600	12/11/2014	1.11	0.187	21	8.76			132
South Linden PS	2/6/2015	0.792	0.145	16.7	3.98			141
Taylor Way SD	3/11/2016	1.47	0.0955	10.0	4.19	5,482	**<MDL**	61.6
Veterans PS	12/15/2014	1.32	0.093	8.83	3.86			41.7
Victor Nelo PS Outfall	1/19/2016	0.83	0.140	16.3	3.63	1,110	0.04	118
Minimum		<MDL	0.023	3.53	0.91	528	<MDL	36.3
Maximum		2.66	0.552	52.7	21.3	11,100	0.67	337

3.5 Relationships between PCBs and Hg and other trace elements and land-cover attributes

Spearman rank correlations were analyzed to identify potential relationships between PCBs, HgT, trace elements, and land use variables[16] (Table 7). Beginning in WY 2003, numerous sites have been evaluated for selected trace elements in addition to HgT. These sites include the fixed loads monitoring sites on Guadalupe River at Hwy 101 (McKee et al., 2017, Zone 4 Line A (Gilbreath and McKee, 2015; McKee and Gilbreath, 2015), North Richmond Pump Station (Hunt et al., 2012) and four sites at which only Cu was measured (Lower Marsh Creek, San Leandro Creek, Pulgas Pump Station-South, and Sunnyvale East Channel) (Gilbreath et al., 2015a). Copper data were also collected at the inlets to multiple pilot performance studies for bioretention (El Cerrito: Gilbreath et al., 2012; Fremont: Gilbreath et al., 2015b), and Cu, Cd, Pb, and Zn data were collected at the Daly City Library Gellert Park demonstration bioretention site (David et al., 2015). During WYs 2015, 2016, and 2017, trace element data were collected at an additional 29 locations (Table 6). The pooled data comprise 39 sites for Cu; 33 for Cd, Pb, and Zn; and 32 for As. Data for Mg and Se were not included because of small sample size. Organic carbon was collected at 28 locations in this study and at an additional 21 locations in previous studies.

PCBs correlate positively with impervious cover and old industrial land use, and inversely with watershed area (Table 7), on the basis of Spearman rank correlation analysis[17]. The highest PCB concentrations were measured in small watersheds with a high proportion of impervious cover and old industrial area (Figure 8). However, the lack of a stronger correlation between PCBs and these geospatial variables indicates that not all small, highly impervious watersheds have high PCB concentrations. The data also indicate the presence of outliers that may be worth exploring with additional sampling. PCBs did not correlate with any of the trace elements with the exception of a negative correlation with arsenic.

These observations are consistent with previous analysis (McKee et al., 2012), and with the concept that larger watersheds tend to have mixed land use and thus a lower proportional amount of PCB source areas relative to smaller watersheds that are more urbanized and more industrialized. There was also a positive but relatively weak correlation between PCBs and HgT, consistent with the general relationships between impervious cover and both PCBs and HgT. This observation contrasts with conclusions drawn from the WY 2011 dataset, for which there was a stronger correlation between PCBs and HgT (McKee et al., 2012). This difference might reflect a stronger focus on PCBs during the WY 2015-2019 sampling campaigns, which included more drainage-line outfalls to creeks with higher imperviousness and old industrial land use, or it might be an artifact of small sample size without sample representation along

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[16] HgT data associated with the main channel of the Guadalupe River were removed from the analysis because of historic mining influence in the watershed. Historic mining in the Guadalupe River watershed caused a unique positive relationship between Hg, Cr, and Ni, and unique inverse correlations between Hg and other typically urban metals such as Cu and Pb (McKee et al., 2017).

[17] The rank correlation was preferred because it makes no assumption of the type of relationship (linear or other) or the data distribution (normal data distribution is a requirement of a Pearson Product Moment correlation); in the Spearman correlation, every data pair has an equal influence on the coefficient.

all environmental gradients. Additionally, or alternatively, the weakness of the relationship between PCBs and HgT may partly be associated with the larger role of atmospheric recirculation in the mercury cycle than the PCB cycle and with large differences between the use history of each pollutant. Correlations between HgT and impervious cover, old industrial land use, and watershed area were similar to but weaker than those for PCBs and these geospatial variables. Neither PCBs nor Hg were strongly correlated with other trace metals. Based on the available pooled data, there is no support for the use of trace metals as a surrogate investigative tool for either PCB or HgT pollution sources.

Table 7. Spearman Rank correlation matrix based on estimated particle concentrations (EPCs) of stormwater samples collected in the Bay Area since water year 2003 (see text for data sources and exclusions). Sample size in correlations ranged from 28 to 95. Correlation coefficients (r) shaded in light blue have a *p*-value <0.05.

	PCBs (pg/mg)	*HgT (ng/mg)*	*Arsenic (ug/mg)*	*Cadmium (ug/mg)*	*Copper (ug/mg)*	*Lead (ug/mg)*	*Zinc (ug/mg)*	*Area (sq km)*	*% Imperviousness*	*% Old Industrial*	*% Clay (<0.0039 mm)*	*% Silt (0.0039 to <0.0625 mm)*	*% Sands (0.0625 to <2.0 mm)*
HgT (ng/mg)	0.4												
Arsenic (ug/mg)	-0.61	-0.03											
Cadmium (ug/mg)	-0.28	0.25	0.67										
Copper (ug/mg)	-0.07	0.15	0.56	0.743									
Lead (ug/mg)	-0.25	0.16	0.583	0.863	0.711								
Zinc (ug/mg)	-0.24	-0.24	0.497	0.801	0.894	0.691							
Area (sq km)	-0.44	-0.28	0.00	-0.24	-0.43	-0.08	-0.41						
% Imperviousness	0.567	0.28	-0.35	0.00	0.181	-0.10	0.167	-0.76					
% Old Industrial	0.61	0.26	-0.48	-0.2	-0.21	-0.25	-0.15	-0.55	0.754				
% Clay (<0.0039 mm)	0.23	0.08	-0.12	0.046	-0.23	-0.03	-0.16	-0.19	-0.03	0.081			
% Silt (0.0039 to <0.0625 mm)	-0.07	0.15	-0.14	-0.17	0.274	0.00	0.174	0.147	0.051	-0	-0.37		
% Sands (0.0625 to <2.0 mm)	-0.13	-0.19	0.094	0.006	-0.02	0.094	-0.03	0.259	-0.09	-0.08	-0.83	-0.07	
TOC (mg/mg)	0.224	0.4	0.70	0.60	0.875	0.466	0.756	-0.46	0.406	0.157	-0.2	0.204	-0.02

p value <0.05

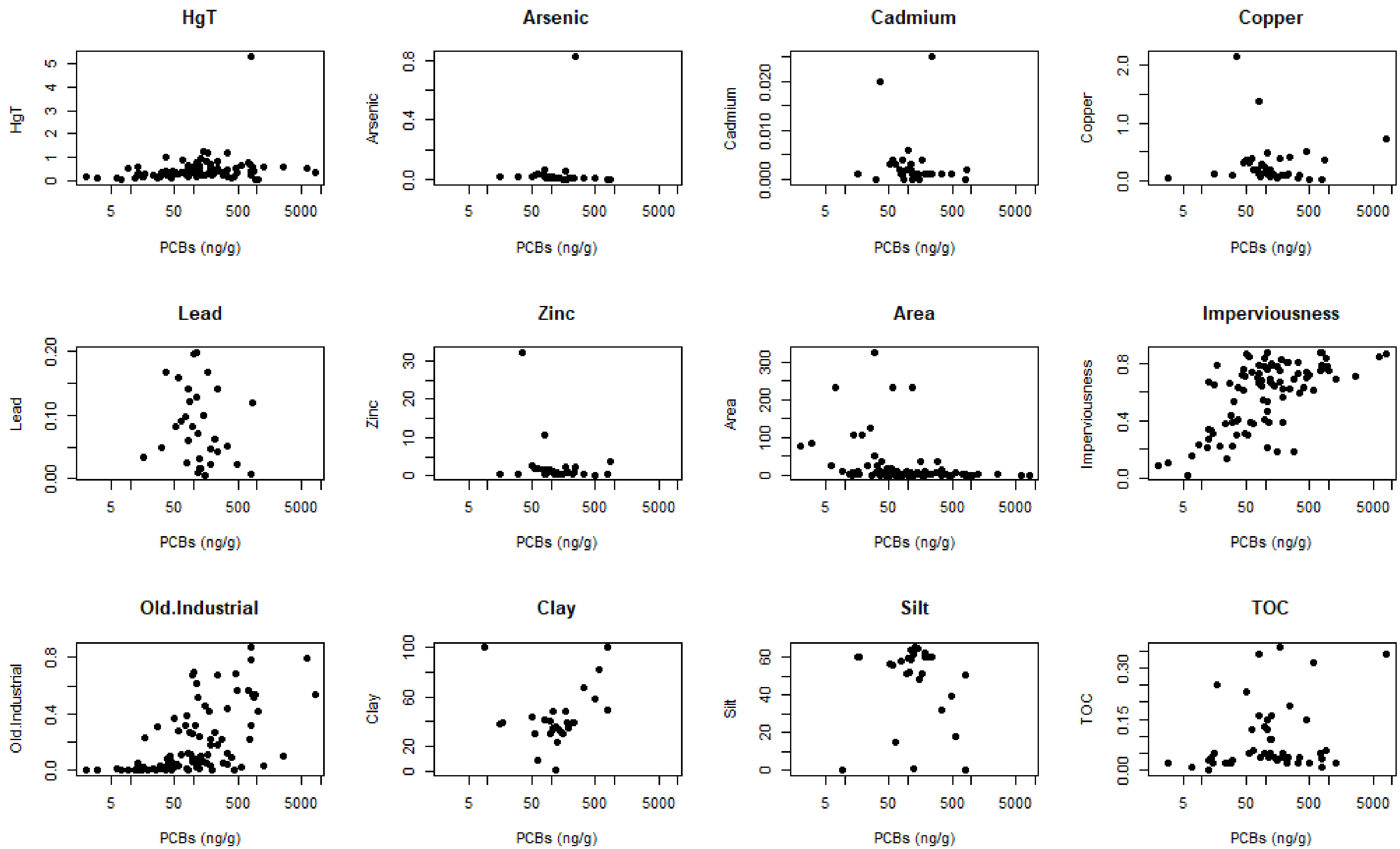

Figure 8. Relationships between observed estimated particle concentrations (EPCs) of PCBs and total mercury (HgT), trace elements, and impervious land cover, old industrial land use, grainsize (clay and silt), and total organic carbon (TOC).

3.7 Sampling progress in relation to data uses

It has been argued that old industrial land use and the specific source areas found within or in association with older industrial areas are likely to have higher concentrations and loads of PCBs and HgT (McKee et al., 2012; McKee et al., 2015). RMP sampling for PCBs and HgT since WY 2003 has included 33% of the old industrial land use in the region. The best coverage to date has occurred in Santa Clara County (78% of old industrial land use in the county is in watersheds that have been sampled), followed by San Mateo County (36%) and Alameda County (31%). In Contra Costa County, only 15%[18] of old industrial land use is in watersheds that have been sampled, and just 1% in Solano County. The disproportional coverage in Santa Clara County is a result of sampling several large watersheds (Lower Penitencia Creek, Lower Coyote Creek, Guadalupe River at Hwy 101, Sunnyvale East Channel, Stevens Creek and San Tomas Creek) that have relatively large proportions of older industrial land use upstream from their sampling points. Of the remaining older industrial land use yet to be sampled, 48% of it lies within 1 km and 74% within 2 km of the Bay. These areas are more likely to be tidal and are likely to include heavy industrial areas that were historically serviced by rail and ship-based transport and military areas but are often very difficult to sample because of a lack of public rights-of-way and tidal conditions. A different sampling strategy may be required to effectively assess what pollution might be associated with these areas to better identify areas for potential management.

4. Summary and Recommendations

This report presents all available stormwater data[19] collected since WY 2003 when stormwater studies first began through SFEI contracts or RMP projects, not just the data collected for this WY 2015-2019 reconnaissance monitoring study (total of 91 sites). Prior to WY 2015, studies mostly employed Method 1, whereas beginning in WY 2015, sampling employed Methods 2 and 3.

Method 1. Fixed location multi-year turbidity-based sampling protocol for accurate loads estimation

Method 2. Water based composite sampling protocol for single storm reconnaissance characterization and relative site comparisons to support management prioritization

Method 3. Remotely deployable sedimentation sampling protocol for preliminary screening to support further field sampling using our water based composite sampling protocol

During WYs 2015-2019, composite water samples were collected at 66 sites during at least one storm event and analyzed for PCBs, HgT, and SSC, and, for a subset of samples, trace metals, organic carbon, and grain size[20]. Sampling efficiency was increased, when possible, by sampling two nearby sites during a single storm. At three of these sites, collection was done using a remote sampler only – a method that was pilot tested during WYs 2015-2018 and approved for use in spring 2018. Several sites with elevated PCB and HgT concentrations and EPCs were identified, in part because of an improved site selection

[18] This result is largely due to the fact that fewer samples have been collected in Contra Costa County than the Alameda, San Mateo and Santa Clara Counties.

[19] Similar data collected by BASMAA in Santa Clara and San Mateo Counties is not included in this report.

[20] Another 25 sites were sampled prior to WY 2015.

process that focused on older industrial landscapes. The following recommendations are based on the WY 2015-2019 results.

- Continue to select sites based on the four main selection objectives (Section 2.2). Most of the sampling effort should be devoted to identifying potential high leverage areas with high unit area loads (yields) or concentrations/EPCs. Selecting sites by focusing on older industrial and highly impervious landscapes appears to be successful in identifying high leverage areas for PCBs.
- Continue to use the composite sampling field protocol as developed and applied during WYs 2015-2019 without further modifications. In the event of a higher rainfall wet season, when there is a greater likelihood that more storm events will fall within the required tidal windows, it may be possible to sample tidally influenced sites.
- Results from the remote sampler pilot study indicated reasonable comparability to manually collected sample concentrations. It is recommended that future sampling continue to include the use of remote samplers as a low-cost screening tool to identify sites for further sampling using the reconnaissance characterization monitoring protocol.
- Finish development of an advanced data analysis method for identifying and ranking watersheds of management interest for further characterization or investigation. This recommendation will be fully implemented as of the 2020 calendar year and possibly be ready to contribute to site selection in WY 2021. Develop a procedure for identifying sites that return lower-than-expected concentrations or EPCs and consider re-sampling those sites. This method is being developed as part of the advanced data analysis project.

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6. Appendices

Appendix A: Characteristics of Larger Watersheds

Characteristics of larger watersheds to be monitored, proposed sampling location, and proposed sampling trigger criteria. In WY 2017, the sampling trigger criteria for flow and rainfall were met but large watershed sampling was focused on the Guadalupe River rather than the watersheds on this list due to a piggybacking opportunity associated with Hg.

Proposed sampling location							Relevant USGS gauge for 1st order loads computations	
Watershed system	Watershed Area (km^2)	Impervious Surface (%)	Industrial (%)	Sampling Objective	Commentary	Proposed Sampling Triggers	Gauge number	Area at USGS Gauge (sq^2
Alameda Creek at EBRPD Bridge at Quarry Lakes	913	8.5	2.3	2, 4	Operating flow and sediment gauge at Niles just upstream will allow the computation of 1st order loads to support the calibration of the RWSM for a large, urbanizing type watershed.	7” of antecedent rainfall in Livermore (reliable web published rain gauge), after at least an annual storm has already occurred (~2000 cfs at the Niles gauge), and a forecast for the East Bay interior valleys of 2-3” over 12 hrs.	11179000	906
Dry Creek at Arizona Street (purposely downstream from historic industrial influences)	25.3	3.5	0.3	2, 4	Operating flow gauge at Union City just upstream will allow the computation of 1st order loads to support the calibration of the RWSM for mostly undeveloped land use type watersheds.	7” of antecedent rainfall in Union City, after at least a common annual storm has already occurred (~200 cfs at the Union City gauge), and a forecast for the East Bay Hills of 2-3” over 12 hrs.	11180500	24.3
San Francisquito Creek at University Avenue (as far down as possible to capture urban influence upstream from tide)	81.8	11.9	0.5	2, 4	Operating flow gauge at Stanford upstream will allow the computation of 1st order loads to support the calibration of the RWSM for larger mixed land use type watersheds. Sample pair with Matadero Ck.	7” of antecedent rainfall in Palo Alto, after at least a common annual storm has already occurred (~1000 cfs at the Stanford gauge), and a forecast for the Peninsula Hills of 3-4” over 12 hrs.	11164500	61.1
Matadero Creek at Waverly Street (purposely downstream from the railroad)	25.3	22.4	3.7	2, 4	Operating flow gauge at Palo Alto upstream will allow the computation of 1st order loads to support the calibration of the RWSM for mixed land use type watersheds. Sample pair with San Francisquito Ck.	7” of antecedent rainfall in Palo Alto, after at least a common annual storm has already occurred (~200 cfs at the Palo Alto gauge), and a forecast for the Peninsula Hills of 3-4” over 12 hrs.	11166000	18.8
Colma Creek at West Orange Avenue or further downstream (as far down as possible to capture urban and historic influence upstream from tide)	27.5	38	0.8	2, 4 (possibly 1)	Historic flow gauge (ending 1996) in the park a few hundred feet upstream will allow the computation of 1st order loads estimates to support the calibration of the RWSM for mixed land use type watersheds.	Since this is a very urban watershed, precursor conditions are more relaxed: 4” of antecedent rainfall, and a forecast for South San Francisco of 2-3” over 12 hrs. Measurement of discharge and manual staff plate readings during sampling will verify the historic rating.	11162720	27.5

Appendix B – Sampling Method Development

The monitoring protocol implemented in WYs 2015-2019 was based on a previous monitoring design that was trialed in WY 2011 when multiple sites were visited during one or two storm events. In that study, multiple discrete stormwater samples were collected at each site and analyzed for a number of pollutants of concern (POCs) (McKee et al., 2012). At the 2014 SPLWG meeting, an analysis of previously collected stormwater sample data from both reconnaissance and fixed station monitoring was presented (SPLWG et al. 2014). A comparison of three sampling designs for Guadalupe River at Hwy 101 (sampling 1, 2, or 4 storms, respectively: functionally 4, 8, and 16 discrete samples) showed that PCB estimated particle concentrations (EPC) at this site can vary from 45-287 ng/g (1 storm design), 59-257 ng/g (2 storm design), and 74-183 ng/g (4 storm design) between designs, suggesting that the number of storms sampled for a given watershed has big impacts on the EPCs and therefore the potential relative ranking among sites. A similar analysis that explores the relative ranking based on a random 1-storm composite or 2-storm composite design was also presented for other monitoring sites (Pulgas Pump Station-South, Sunnyvale East Channel, North Richmond Pump Station, San Leandro Creek, Zone 4 Line A, and Lower Marsh Creek). This analysis showed that the potential for a false negative could occur due to a low number of sampled storms, especially in smaller and more urbanized watersheds where transport events can be more acute due to lack of channel storage. The analysis further highlighted the trade-off between gathering information at fewer sites with more certainty versus at more sites with less certainty. Based on these analyses, the SPLWG recommended a 1-storm composite per site design with allowances that a site could be revisited if the measured concentrations were lower than expected, either because a low-intensity storm was sampled or other information suggested that potential sources exist.

In addition to composite sampling, a pilot study was designed and implemented to test remote suspended sediment samplers based on enhanced water column settling. Four sampler types were considered: the single-stage siphon sampler, the CLAM sampler, the Hamlin sampler, and the Walling Tube. The SPLWG recommended the single-stage siphon sampler be dropped because it allowed for collection of only a single stormwater sample at a single time point, and therefore offers no advantage over manual sampling but requires more effort and expense to deploy. The CLAM sampler was also dropped as it had limitations affecting the interpretation of the data; primarily its inability to estimate the volume of water passing through the filters and the lack of performance tests in high turbidity environments. As a result, the remaining two samplers (Hamlin sampler and Walling Tube) were selected for the pilot study as previous studies showed the promise of using these devices in similar systems (Phillips et al., 2000; Lubliner, 2012). The SPLWG recommended piloting these samplers at 12 locations where manual water composites would be collected in parallel to test the comparability between sampling methods.

Appendix C – Quality assurance

The sections below report quality assurance reviews on WYs 2015-18 data only. The data were reviewed using the quality assurance program plan (QAPP) developed for the San Francisco Bay Regional Monitoring Program for Water Quality (Yee et al., 2017). That QAPP describes how RMP data are reviewed for possible issues with hold times, sensitivity, blank contamination, precision, accuracy, comparison of dissolved and total phases, magnitude of concentrations versus concentrations from previous years, other similar local studies or studies described from elsewhere in peer-reviewed literature and PCB (or other organics) fingerprinting. Data handling procedures and acceptance criteria can differ among monitoring protocols, however, for the RMP the underlying data were never discarded. Because the results for “censored” data were maintained, the effects of applying different QA protocols can be assessed by a future analyst if desired.

Suspended Sediment Concentration and Particle Size Distribution

In WY 2015, the SSC and particle size distribution (PSD)[21] data from USGS-PCMSC were acceptable, aside from failing hold-time targets. SSC samples were all analyzed outside of hold time (between 9 and 93 days after collection, exceeding the 7-day hold time specified in the RMP QAPP; the USGS hold time is 100 days); hold times are not specified in the RMP QAPP for PSD. Minimum detection limits (MDLs) were generally sufficient, with <20% non-detects (NDs) reported for SSC and the more abundant Clay and Silt fractions. Extensive NDs (>50%) were generally reported for the sand fractions starting as fine as 0.125 mm and larger, with 100% NDs for the coarsest (Granule + Pebble/2.0 to <64 mm) fraction. Method blanks and spiked samples are not typically reported for SSC and PSD. Blind field replicates were used to evaluate precision in the absence of any other replicates. The relative standard deviation (RSD) for two field blind replicates of SSC were well below the 10% target. Particle size fractions had average RSDs ranging from 12% for silt to 62% for fine sand. Although some individual fractions had average relative percent difference (RPD) or RSDs >40%, suspended sediment in runoff (and particle size distributions within that SSC) can be highly variable, even when collected by minutes, so results were flagged as estimated concentrations rather than rejected. Fines (clay and silt) represented the largest proportion (~89% average) of the mass.

In 2016 samples, SSC and PSD was analyzed beyond the specified 7-day hold time (between 20 and 93 days after collection) and qualified for holding-time violation but not censored. No hold time is specified for grain-size analysis. Method detection limits were sufficient to have some reportable results for nearly all the finer fractions, with extensive NDs (> 50%) for many of the coarser fractions. No method blanks or spiked samples were analyzed/reported, common with SSC and PSD. Precision for PSD could not be evaluated as no replicates were analyzed for 2016. Precision of the SSC analysis was evaluated using the field blind replicates and the average RSD of 2.12% was well within the 10% target Method Quality Objective (MQO). PSD results were similar to other years, dominated by around 80% Fines. Average SSC for whole-water samples (excluding those from passive samplers) was in a reasonable range of a few hundred mg/L.

In 2017, method detection limits were sufficient to have at least one reportable result for all analyte/fraction combinations. Extensive non-detects (NDs > 50%) were reported for only Granule + Pebble/2.0 to <64 mm (90%). The analyte/fraction combinations Silt/0.0039 to <0.0625 mm;

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[21] Particle size data were captured for % Clay (<0.0039 mm), % Silt (0.0039 to <0.0625 mm), % V. Fine Sand (0.0625 to <0.125 mm), % Fine Sand (0.125 to <0.25 mm), % Medium Sand (0.25 to <0.5 mm), % Coarse Sand (0.5 to <1.0 mm), % V. Coarse Sand (1.0 to <2.0 mm), and % Granule + Pebble (>2.0 mm).

Sand/Medium 0.25 to <0.5 mm; Sand/Coarse 0.5 to <1.0 mm; Sand/V. Coarse 1.0 to <2.0 mm all had 20% (2 out of 10) non-detects. No method blanks were analyzed for grain size analysis. SSC was found in one of the five method blanks at a concentration of 1 mg/L. The average SSC concentration for the three method blanks in that batch was 0.33 mg/L, less than the average method blank method detection limit of 0.5 mg/L. No blank contamination qualifiers were added. No spiked samples were analyzed/reported. Precision for grain size could not be evaluated as there was insufficient amount of sample for analysis of the field blind replicate. Precision of the SSC analysis was examined using the field blind replicates with the average RSD of 29.24% being well above the 10% target MQO, therefore they were flagged with the non-censoring qualifier "VIL" as an indication of possible uncertainty in precision.

In WY 2018, the SSC and particle size distribution (PSD)[22] data from USGS-PCMSC were acceptable, aside from failing hold-time targets. SSC samples were all analyzed outside of hold time (between 25 and 62 days after collection, exceeding the 7-day hold time specified in the RMP QAPP); hold times are not specified in the RMP QAPP for PSD. Minimum detection limits (MDLs) were generally sufficient, with zero non-detects (NDs) reported for SSC and the more abundant clay and silt fractions. Extensive NDs (>50%) were generally reported for the sand fractions starting as fine as 0.125 mm and larger, with 100% NDs for the coarsest (Granule + Pebble/2.0 to <64 mm) fraction. Method blanks and spiked samples are not typically reported for SSC and PSD. Blind field replicates were used to evaluate precision in the absence of any other replicates. The relative standard deviation (RSD) for the field blind replicate of SSC was 8.22%, below the 10% target. Particle size fractions had average RSDs ranging from 10.6% - 10.7% for Fine, Clay and Silt fractions.

In WY 2019, the SSC data from USGS-PCMSC were acceptable, aside from failing hold-time targets. SSC samples were all analyzed outside of hold time (between 98 and 175 days after collection, exceeding the 7-day hold time specified in the RMP QAPP). Minimum detection limits (MDLs) were generally sufficient, with zero non-detects (NDs) reported. Two method blanks were analyzed and both were below the MDL. Spiked samples are not typically reported for SSC. Blind field replicates were used to evaluate precision in the absence of any other replicates. The relative standard deviation (RSD) for the field blind replicate of SSC was 0%, below the 10% target.

No samples for PSD analysis were collected in WY 2019.

Organic Carbon in Water

Reported TOC and DOC data from EBMUD and ALS were acceptable. In 2015, TOC samples were field acidified on collection, DOC samples were field or lab filtered as soon as practical (usually within a day) and acidified after, so were generally within the recommended 24-hour holding time. MDLs were sufficient with no NDs reported for any field samples. TOC was detected in only one method blank (0.026 mg/L), just above the MDL (0.024 mg/L), but the average blank concentration (0.013 mg/L) was still below the MDL, so results were not flagged. Matrix spike samples were used to evaluate accuracy, although many samples were not spiked high enough for adequate evaluation (must be at least two

[22] Particle size data were captured for % Clay (<0.0039 mm), % Silt (0.0039 to <0.0625 mm), % V. Fine Sand (0.0625 to <0.125 mm), % Fine Sand (0.125 to <0.25 mm), % Medium Sand (0.25 to <0.5 mm), % Coarse Sand (0.5 to <1.0 mm), % V. Coarse Sand (1.0 to <2.0 mm), and % Granule + Pebble (>2.0 mm).

times the parent sample concentration). Recovery errors in the remaining DOC matrix spikes were all below the 10% target MQO. TOC errors in WY 2015 averaged 14%, above the 10% MQO, and TOC was therefore qualified but not censored. Laboratory replicate samples evaluated for precision had an average RSD of <2% for DOC and TOC, and 5.5% for POC, within the 10% target MQO. RSDs for field replicates were also within the target MQO of 10% (3% for DOC and 9% for TOC), so no precision qualifiers were needed.

POC and DOC were also analyzed by ALS in 2016. One POC sample was flagged for a holding time of 104 days (past the specified 100 days). All OC analytes were detected in all field samples and were not detected in method blanks, but DOC was detected in filter blanks at 1.6% of the average field sample and 5% of the lowest field sample. The average recovery error was 4% for POC evaluated in LCS samples, and 2% for DOC and TOC in matrix spikes, within the target MQO of 10%. Precision on POC LCS replicates averaged 5.5% RSD, and 2% for DOC and TOC field sample lab replicates, well within the 10% target MQO. No recovery or precision qualifiers were needed. The average 2016 POC was about three times higher than 2014 results. DOC and TOC were 55% and 117% of 2016 results, respectively.

In 2017, method detection limits were sufficient with no non-detects (NDs) reported except for method blanks. DOC and TOC were found in one method blank in one lab batch for both analytes. Four DOC and eight TOC results were flagged with the non-censoring qualifier "VIP". TOC was found in the field blank and it's three lab replicates at an average concentration of 0.5375 mg/L which is 8.6% of the average concentration found in the field and lab replicate samples (6.24 mg/L). Accuracy was evaluated using the matrix spikes except for POC which was evaluated using the laboratory control samples. The average %error was less than the target MQO of 10% for all three analytes; DOC (5.2%), POC (1.96%), and TOC (6.5%). The laboratory control samples were also examined for DOC and TOC and the average %error was once again less than the 10% target MQO. No qualifying flags were needed. Precision was evaluated using the lab replicates with the average RSD being well below the 10% target MQO for all three analytes; DOC (1.85%), POC (0.97%), and TOC (1.89%). The average RSD for TOC including the blind field replicate and its lab replicates was 2.32% less than the target MQO of 10%. The laboratory control sample replicates were examined and the average RSD was once again well below the 10% target MQO. No qualifying flags were added.

In WY 2018, all TOC samples were censored. Accuracy was evaluated using the matrix spikes. The average %error for TOC in the matrix spikes of 47.68% (average recovery 147.68%) was above the 10% target MQO.

No samples for TOC analysis were collected in WY 2019.

PCBs in Water and Sediment

PCBs samples were analyzed for 40 PCB congeners (PCB-8, PCB-18, PCB-28, PCB-31, PCB-33, PCB-44, PCB-49, PCB-52, PCB-56, PCB-60, PCB-66, PCB-70, PCB-74, PCB-87, PCB-95, PCB-97, PCB-99, PCB-101, PCB-105, PCB-110, PCB-118, PCB-128, PCB-132, PCB-138, PCB-141, PCB-149, PCB-151, PCB-153, PCB-156, PCB-158, PCB-170, PCB-174, PCB-177, PCB-180, PCB-183, PCB-187, PCB-194, PCB-195, PCB-201, PCB-203). Water (whole water and dissolved) and sediment (separately analyzed particulate) PCB data from SGS AXYS were acceptable. EPA 1668 methods for PCBs recommend analysis within a year, and all samples were analyzed well within that time (maximum 64 days). MDLs were sufficient with no NDs reported for any of the PCB congeners measured. Some blank contamination was detected in method blanks for about 20 of the more abundant congeners, with only two PCB 008 field sample results censored for blank contamination exceeding one-third the concentration of PCB 008 in those field samples. Many of the same congeners detected in the method blank also were detected in the field blank, but at concentrations <1% the average measured in the field samples and (per RMP data quality guidelines) always less than one-third the lowest measured field concentration in the batch. Three target analytes (part of the "RMP 40 congeners"), PCBs 105, 118, and 156, and numerous other congeners were reported in laboratory control samples (LCS) to evaluate accuracy, with good recovery (average error on target compounds always <16%, well within the target MQO of 35%). A laboratory control material (modified NIST 1493) was also reported, with average error 22% or better for all congeners. Average RSDs for congeners in the field replicate were all <18%, within the MQO target of 35%, and LCS RSDs were ~2% or better. PCB concentrations have not been analyzed in remote sediment sampler sediment for previous POC studies, so no inter-annual comparisons could be made. PCBs in water samples were similar to those measured in previous years (2012-2014), ranging from 0.25 to 3 times previous averages, depending on the congener. Ratios of congeners generally followed expected abundances in the environment.

SGS AXYS analyzed PCBs in dissolved, particulate, and total fraction water samples for 2016. Numerous congeners had several NDs, but extensive NDs (>50%) were reported for only PCBs 099 and 201 (both 60% NDs). Some blank contamination was detected in method blanks, with results for some congeners in field samples censored due to concentrations that were less than 3 times higher than the highest concentration measured in a blank. This was especially true for dissolved-fraction field samples with low concentrations. Accuracy was evaluated using the laboratory control samples. Again, only three of the PCBs (PCB 105, PCB 118, and PCB 156) reported in the field samples were included in LCS samples (most being non-target congeners), with average recovery errors for those of <10%, well below the target MQO of 35%. Precision on LCS and blind field replicates was also good, with average RSDs <5% and <15%, respectively, well below the 35% target MQO. Average PCB concentrations in total fraction water samples were similar to those measured to previous years, but total fraction samples were around 1% of those measured in 2015, possibly due to differences in the stations sampled.

SGS AXYS also analyzed PCBs in dissolved, particulate, and total fraction water samples for 2017. Numerous congeners had several NDs but none extensively. Some blank contamination was detected in method blanks, with results for some congeners in field samples censored due to concentrations that were less than 3 times higher than the highest concentration measured in a blank. This was especially true for dissolved-fraction field samples with low concentrations. Accuracy was evaluated using the laboratory control samples. Again, only three of the PCBs (PCB 105, PCB 118, and PCB 156) reported in the field samples were included in LCS samples (most being non-target congeners), with average recovery errors for those of <10%, well below the target MQO of 35%. Precision on LCS replicates was also good, with average RSDs <5%, well below the 35% target MQO.

In WY 2018, SGS AXYS analyzed total water samples for PCBs (no samples for dissolved or particulate fractions were submitted for analysis). Method detection limits were acceptable with non-detects (NDs) reported for a single PCB 170 result (7.14%; 1 out of 14 PCB 170 results). PCB 008, PCB 018, PCB 028, PCB 031, PCB 033, PCB 044, PCB 049, PCB 052, PCB 056, PCB 066, PCB 070, PCB 087, PCB 095, PCB 099, PCB 101, PCB 105, PCB 110, PCB 118, PCB 138, PCB 149, PCB 151, and PCB 174 were found in at least one and often both method blanks at concentrations above the method detection limits. Two PCB 008 results (14.29%; 2 out of 14 results) were flagged with the censoring qualifier VRIP; other blank contaminated results were flagged by the laboratory and did not need to be censored. Contamination was found in the field blank for PCB 008, PCB 018, PCB 028, PCB 031, PCB 033, PCB 044, PCB 049, PCB 052, PCB 056, PCB 060, PCB 066, PCB 070, PCB 087, PCB 095, PCB 099, PCB 101, PCB 110, PCB 118, PCB 138, PCB 151, PCB 153, and PCB187 at concentrations generally less than 1% of the average concentrations found in the field samples (the only exception was PCB 008 which was found in the field blank at a concentration representing ~2% of the average field sample concentration). Accuracy was evaluated using the laboratory control samples (LCSs); the only spiked samples reported. PCB 105, PCB 118, and PCB 156 were the only target congeners included in the LCS samples with an average %error of 8.35%, 9.25%, and 13.63%, respectively, all well below the 35% target MQO. No qualifiers were needed. Precision was evaluated using the blind field replicates. The average RSD ranged from 0.10% to 17.99% for the 40 target PCB congeners; all below the target MQO of 35% target. Laboratory control sample replicates were examined, but not used in the evaluation. The respective RSD’s for PCB 105, PCB 118, and PCB 156 were 11.07%, 12.25%, and 3.27%, respectively. No qualification was necessary.

In WY 2019, SGS AXYS analyzed total water samples for PCBs (no samples for dissolved or particulate fractions were submitted for analysis). Method detection limits (MDLs) were satisfactory for the PCBs with only four non-detects reported (one for PCB008, PCB019, PCB049 and PCB15). PCB concentrations above the MDL were reported for the one method blank for PCB 028, PCB 031, PCB 033, PCB 044, PCB 049, PCB 052, PCB 066, PCB 070, PCB 105, PCB 110, PCB 149, PCB 153, and PCB 180. As a consequence, one PCB 049 result was flagged with the censoring QA code of “VRIP” (Data rejected - Analyte detected in field or lab generated blank, flagged by QAO) for blank contamination. The other blank contaminated results were flagged by the analyzing laboratory so no additional flags had to be added.

PCB concentrations above the MDL were reported in the field blanks for PCB 018, PCB 028, PCB 031, PCB 033, PCB 044, PCB 049, PCB 052, PCB 066, PCB 070, PCB 095, PCB 132, PCB 138, and PCB 149. But the average concentrations in the field blanks were less than 1% of the average field sample concentrations. No certified reference material samples, and no matrix spike samples were analyzed/reported. The percent error for the three PCBs included in the single laboratory control sample (PCB 105, PCB 118, and PCB 156) were 2%, 3%, and 3%, respectively (recoveries were 102%, 103%, and 97%) all well below the 35% target MQO. No qualifiers were added. Lab replicates were not analyzed/reported so blind field replicates were used to decide whether precision flags were needed for the PCB results. The RPDs were all below the MQO target of 35%, ranging from 1.87% to 29.58%. No qualifiers were needed.

Trace Elements in Water

Overall, the 2015 water trace elements (As, Cd, Pb, Cu, Zn, Hg) data from Brooks Rand Labs (BRL) were acceptable. MDLs were sufficient with no NDs reported for any field samples. Arsenic was detected in one method blank, and mercury in four method blanks; the results were blank corrected, and blank variation was <MDL. No analytes were detected in the field blank. Recoveries in certified reference materials (CRMs) were good, averaging 2% error for mercury to 5% for zinc, all well below the target MQOs (35% for arsenic and mercury; 25% for all others). Matrix spike and LCS recovery errors all averaged below 10%, well within the accuracy MQOs. Precision was evaluated in laboratory replicates, except for mercury, which was evaluated in certified reference material replicates (no mercury lab replicates were analyzed). RSDs on lab replicates ranged from <1% for zinc to 4% for arsenic, well within target MQOs (35% for arsenic and mercury; 25% for all the other analytes). Mercury CRM replicate RSD was 1%, also well within the target MQO. Matrix spike and laboratory control sample replicates similarly had average RSDs well within their respective target MQOs. Even including the field heterogeneity from blind field replicates, precision MQOs were easily met. Average concentrations were up to 12 times higher than the average concentrations of 2012-2014 POC water samples, but whole water composite samples were in a similar range those measured in as previous years.

For 2016 the quality assurance for trace elements in water reported by Brooks Applied Lab (BRL's name post-merger) was good. Blank corrected results were reported for all elements (As, Cd, Ca, Cu, Hardness (as $CaCO_3$), Pb, Mg, Hg, Se, and Zn). MDLs were sufficient for the water samples with no NDs reported for Cd, Cu, Pb, Hg, and Zn. Around 20% NDs were reported for As, Ca, Hardness, and Mg, and 56% for Se. Mercury was detected in a filter blank, and in one of the three field blanks, but at concentrations <4% of the average in field samples and (per RMP data quality guidelines) always less than one-third the lowest measured field concentration in the batch. Accuracy on certified reference materials was good, with average %error for the CRMs ranging from 2 to 18%, well within target MQOs (25% for Cd, Ca, Cu, Pb, Mg, Zn; 35% for As, Hg, and Se). Recovery errors on matrix spike and LCS results on these compounds was also good, with the average errors all below 9%, well within target MQOs. The average error of 4.8% on a Hardness LCS was within the target MQO of 5%. Precision was evaluated for field sample replicates, except for Hg, where matrix spike replicates were used. Average RSDs were all < 8%, and all below their relevant target MQOs (5% for Hardness; 25% for Cd, Ca, Cu, Pb, Mg, Zn; 35% for As, Hg, and Se). Blind field replicates were also consistent, with average RSDs ranging from 1% to 17%, all within target MQOs. Precision on matrix spike and LCS replicates was also good. No qualifiers were added. Average concentrations in the 2016 water samples were in a similar range of POC samples from previous years (2003-2015), with averages ranging 0.1x to 2x previous years' averages.

In 2017, the data was overall good and all field samples were usable. Blank corrected results were reported for all elements (As, Cd, Ca, Cu, Hardness (as $CaCO_3$), Pb, Mg, Hg, Se, and Zn). MDLs were sufficient for the water samples with no NDs reported. The Hg was also not detected. Accuracy on certified reference materials was good, with average % error for the CRMs within 12%, well within target MQOs (25% for Cd, Ca, Cu, Pb, Mg, Zn; 35% for As, Hg, and Se). Recovery errors on matrix spike and LCS results on these compounds were also all within target MQOs. Precision was evaluated for field sample replicates. Average RSDs were all < 8%, and all below their relevant target MQOs (5% for Hardness; 25% for Cd, Ca, Cu, Pb, Mg, Zn; 35% for As, Hg, and Se).

In WY 2018, samples were only analyzed for mercury. Samples were all measured well within hold time. Method detection limits were acceptable as no non-detects (NDs) were reported for mercury. Mercury was not found in the method blanks at concentrations above the method detection limits. All method blank results were NDs. The single field blank contained mercury at a low concentration (0.00015 ug/L) equal to ~0.1% of the average mercury concentration measured in the field samples. Accuracy was evaluated using the matrix spikes. The average % error for mercury in the matrix spikes of 4% was well below the 35% target MQO. Laboratory control material samples were examined, but not used in the evaluation. The average % error of 6% was also well below the target MQO of 35%. No qualifiers were needed. Precision was evaluated using the lab replicates. The average RSD for Mercury was 3% well below the target MQO of 35% target (average RSD for lab replicates and field replicates combined was 6%). Matrix spike replicates were examined, but not used in the evaluation. The average RSD of 2% was also below the 35% target MQO. The laboratory control materials were not used because they had different though similar target concentrations. No additional qualifiers were added.

In WY 2019, samples were only analyzed for mercury. Samples were all measured well within hold time. Method detection limits were acceptable as no non-detects (NDs) were reported for mercury. Total mercury was measured/reported at concentrations above the MDL for two lab blanks in one of the lab batches, and as a consequence four sample concentrations were flagged with the QACode “VIP” (Analyte detected in field or lab generated blank, flagged by QAO) for blank contamination. The average percent error for total mercury in the certified reference materials was 1.21% (average recovery 101.21%) well below the target MQO of 35%. No qualifiers were added. The average percent error for total mercury in the matrix spike samples was 8.32% (average recovery 91.68%) below the target MQO listed in the 2018 RMP QAPP of 35%. The percent error for total mercury in the single laboratory control samples was 3.35% (recovery 96.65%) below the 35% target MQO. Lab replicates were used to decide whether precision flags were needed for the total mercury results. The average RPD of 0.76% was below the MQO target of 35%. No qualifiers were needed. The average certified reference material samples RPD was 1.39% below the 35% MQO target. The average RPD for the matrix spike replicates of 2.21% was likewise below the target MQO of 35%. No field replicates were analyzed/reported.

Trace Elements in Sediment

A single sediment sample was obtained in 2015 from fractionating one Hamlin sampler and analyzing for As, Cd, Pb, Cu, Zn, and Hg concentration on sediment. Overall the data were acceptable. MDLs were sufficient with no NDs for any analytes in field samples. Arsenic was detected in one method blank (0.08 mg/kg dw) just above the MDL (0.06 mg/kg dw), but results were blank corrected and the blank standard deviation was less than the MDL so results were not blank flagged. All other analytes were not detected in method blanks. CRM recoveries showed average errors ranging from 1% for copper to 24% for mercury, all within their target MQOs (35% for arsenic and mercury; 25% for others). Matrix spike and LCS average recoveries were also within target MQOs when spiked at least 2 times the native concentrations. Laboratory replicate RSDs were good, averaging from <1% for zinc to 5% for arsenic, all well within the target MQOs (35% for arsenic and mercury; 25% for others). Matrix spike RSDs were all

5% or less, also well within target MQOs. Average results ranged from 1 to 14 times higher than the average concentrations for the RMP Status and Trend sediment samples (2009-2014). Results were reported for Mercury and Total Solids in one sediment sample analyzed in two laboratory batches. Other client samples (including lab replicates and Matrix Spike/Matrix Spike replicates), a certified reference material (CRM), and method blanks were also analyzed. Mercury results were reported blank corrected.

In 2016, a single sediment sample was obtained from a Hamlin sampler, which was analyzed for total Hg by BAL. MDLs were sufficient with no NDs reported, and no target analytes were detected in the method blanks. Accuracy for mercury was evaluated in a CRM sample (NRC MESS-4). The average recovery error for mercury was 13%, well within the target MQO of 35%. Precision was evaluated using the laboratory replicates of the other client samples concurrently analyzed by BAL. Average RSDs for Hg and Total Solids were 3% and 0.14%, respectively, well below the 35% target MQO. Other client sample matrix spike replicates also had RSDs well below the target MQO, so no qualifiers were needed for recovery or precision issues. The Hg concentration was 30% lower than the 2015 POC sediment sample.

Appendix D – Figures 7 and 10 Supplementary Info

Sample counts for data displayed in Figures 7 and 10 bar graphs. For samples with a count of two or more, the central tendency was used which was calculated as the sum of the pollutant water concentrations divided by the sum of the SSC data.

Catchment	Year Sampled	Discrete Grabs	Composite Samples	Number of Aliquots per composite sample	Remote Sample
Belmont Creek	Prior to WY2015	4	0	NA	0
Borel Creek	Prior to WY2015	5	0	NA	0
Calabazas Creek	Prior to WY2015	5	0	NA	0
Ettie Street Pump Station	Prior to WY2015	4	0	NA	0
Glen Echo Creek	Prior to WY2015	4	0	NA	0
Guadalupe River at Foxworthy Road/ Almaden Expressway	Prior to WY2015	14 PCB; 46 Hg	0	NA	0
Guadalupe River at Hwy 101	Prior to WY2015	119 PCB; 261 Hg	0	NA	0
Lower Coyote Creek	Prior to WY2015	5 PCB; 6 Hg	0	NA	0
Lower Marsh Creek	Prior to WY2015	28 PCB; 31 Hg	0	NA	0
Lower Penitencia Creek	Prior to WY2015	4	0	NA	0
North Richmond Pump Station	Prior to WY2015	38	0	NA	0
Pulgas Pump Station-North	Prior to WY2015	4	0	NA	0
Pulgas Pump Station-South	Prior to WY2015	29 PCB; 26 Hg	0	NA	0
San Leandro Creek	Prior to WY2015	39 PCB; 38 Hg	0	NA	0
San Lorenzo Creek	Prior to WY2015	5 PCB; 6 Hg	0	NA	0
San Pedro Storm Drain	Prior to WY2015	0 PCB; 3 Hg	0	NA	0
San Tomas Creek	Prior to WY2015	5	0	NA	0
Santa Fe Channel	Prior to WY2015	5	0	NA	0
Stevens Creek	Prior to WY2015	6	0	NA	0
Sunnyvale East Channel	Prior to WY2015	42 PCB; 41 Hg	0	NA	0
Walnut Creek	Prior to WY2015	6 PCB; 5 Hg	0	NA	0
Zone 4 Line A	Prior to WY2015	69 PCB; 94 Hg	0	NA	0
Zone 5 Line M	Prior to WY2015	4	0	NA	0
Charcot Ave Storm Drain	WY2015	0	1	6	1
E. Gish Rd Storm Drain	WY2015	0	1	5	0
Gateway Ave Storm Drain	WY2015	0	1	6	0
Line 3A-M-1 at Industrial Pump Station	WY2015	0	1	6	0
Line 4-B-1	WY2015	0	1	5	0
Line 9-D	WY2015	0	1	8	0
Line-3A-M at 3A-D	WY2015	0	1	5	0
Line4-E	WY2015	0	1	6	0
Lower Penitencia Creek	WY2015	0	1	7	0
Meeker Slough	WY2015	0	1	6	0
Oddstad Pump Station	WY2015	0	1	6	0
Outfall to Lower Silver Creek	WY2015	0	1	5	1
Ridder Park Dr Storm Drain	WY2015	0	1	5	0
Rock Springs Dr Storm Drain	WY2015	0	1	5	0
Runnymede Ditch	WY2015	0	1	6	0
Seabord Ave Storm Drain SC-050GAC580	WY2015	0	1	5	0
Seabord Ave Storm Drain SC-050GAC600	WY2015	0	1	5	0
South Linden Pump Station	WY2015	0	1	5	0
Storm Drain near Cooley Landing	WY2015	0	1	6	1

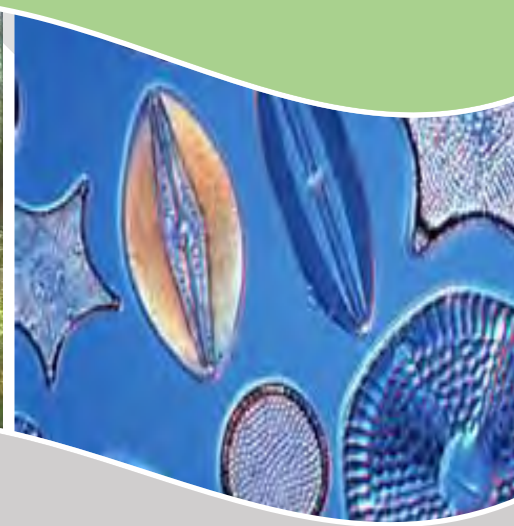
Catchment	Year Sampled	Discrete Grabs	Composite Samples	Number of Aliquots per composite sample	Remote Sample
Veterans Pump Station	WY2015	0	1	5	0
Condensa St SD	WY2016	0	1	6	0
Duane Ct and Ave Triangle SD	WY2016	0	1	5	0
Duane Ct and Ave Triangle SD	WY2016	0	1	3	1
E Outfall to San Tomas at Scott Blvd	WY2016	0	1	6	0
Forbes Blvd Outfall	WY2016	0	1	5	1
Gull Dr Outfall	WY2016	0	1	5	0
Gull Dr SD	WY2016	0	1	5	0
Haig St SD	WY2016	0	1	6	0
Industrial Rd Ditch	WY2016	0	1	4	0
Lawrence & Central Expwys SD	WY2016	0	1	3	0
Line 13A at end of slough	WY2016	0	1	7	0
Line 9D1 PS at outfall to Line 9D	WY2016	0	1	8	0
Outfall at Gilman St.	WY2016	0	1	9	0
Taylor Way SD	WY2016	0	1	5	1
Tunnel Ave Ditch	WY2016	0	1	6	1
Valley Dr SD	WY2016	0	1	6	0
Victor Nelo PS Outfall	WY2016	0	1	9	1
Zone 12 Line A under Temescal Ck Park	WY2016	0	1	8	0
Line 12H at Coliseum Way	WY2017	0	1	3	0
Outfall to Colma Ck on service rd nr Littlefield Ave. (359)	WY2017	0	1	2	1
S Linden Ave SD (291)	WY2017	0	1	7	0
Austin Ck at Hwy 37	WY2017	0	1	6	1
Line 12I at Coliseum Way	WY2017	0	1	3	0
Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	WY2017	0	1	4	0
Line 12M at Coliseum Way	WY2017	0	1	4	0
Line 12F below PG&E station	WY2017	0	1	3	0
Rosemary St SD 066GAC550C	WY2017	0	1	5	0
North Fourth St SD 066GAC550B	WY2017	0	1	5	0
Line 12K at Coliseum Entrance	WY2017	0	1	4	0
Colma Ck at S. Linden Blvd	WY2017	0	1	5	0
Line 12J at mouth to 12K	WY2017	0	1	3	0
S Spruce Ave SD at Mayfair Ave (296)	WY2017	0	1	8	0
Guadalupe River at Hwy 101	WY2017	0	0	7	0
Refugio Ck at Tsushima St	WY2017	0	1	6	1
Rodeo Creek at Seacliff Ct. Pedestrian Br.	WY2017	0	1	7	1
East Antioch nr Trembath	WY2017	0	1	6	0
Outfall at Gilman St.	WY2018	0	1	5	1
Zone 12 Line A at Shellmound	WY2018	0	1	6	0
Meeker Slough	WY2018	0	1	5	0
MeekerWest	WY2018	0	1	5	1
Little Bull Valley	WY2018	0	1	2	0
Kirker Ck at Pittsburg Antioch Hwy and Verne Roberts Cir	WY2018	0	1	5	0
Gull Dr Outfall	WY2018	0	1	6	0
Gull Dr SD	WY2018	0	1	5	0
GR outfall 066GAC850	WY2018	0	1	4	0
GR outfall 066GAC900	WY2018	0	1	4	0
SC100CTC400A	WY2019	0	1	5	0

Catchment	Year Sampled	Discrete Grabs	Composite Samples	Number of Aliquots per composite sample	Remote Sample
SC100CTC500A	WY2019	0	1	5	0
Line 12M at Coliseum Way	WY2019	0	1	4	0
Rodeo Creek	WY2019	0	1	5	0
SMBUR164A	WY2019	0	1	4	0
SMBUR85A	WY2019	0	1	4	0
Bay Point	WY2019	0	0	NA	1
Mount Diablo Creek	WY2019	0	0	NA	1
Wildcat Creek	WY2019	0	0	NA	1

BASMAA Regional Monitoring Coalition Five-Year Bioassessment Report

Water Years 2012 - 2016





Prepared for:

Bay Area Stormwater Management Agencies Association

Prepared by:

EOA inc.

Applied Marine Sciences

DRAFT August 23, 2018

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EXECUTIVE SUMMARY

Biological assessment (bioassessment) is an evaluation of the condition of a waterbody based on the organisms living within it. In 2009, the Bay Area Stormwater Management Agencies Association (BASMAA) Regional Monitoring Coalition (RMC) developed a bioassessment monitoring program to answer management questions identified in the Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit (referred to as the Municipal Regional Permit or MRP).

- *Are water quality objectives, both numeric and narrative, being met in local receiving waters, including creeks, rivers and tributaries?*
- *Are conditions in local receiving waters supportive or likely to be supportive of beneficial uses?*

The RMC's monitoring design addresses these management questions on a regional Bay Area scale and allows for comparison of monitoring results across the five participating counties.

This report compiles and evaluates bioassessment data collected over the first five years of monitoring. Three key questions, essential to watershed management, are addressed:

1) What is the biological condition of perennial and non-perennial streams in the region?
2) What stressors are associated with poor condition?
3) Are conditions changing over time?

The findings are intended to help stormwater programs better understand the current condition of these water bodies, prioritize stream reaches in need of protection or restoration, and identify stressors that are likely to pose the greatest risk to the health of streams in the Bay Area.

This report also evaluates the existing RMC monitoring design and identifies a range of potential options for revising the design (if desired) to better address the questions posed. These options area intended to provide considerations for discussion during the planning for reissuance of the Municipal Regional Permit, which is likely to adopted in 2021.

KEY FINDINGS

What is the Biological Condition of Streams in the Region? The biological condition of streams in the RMC area is assessed using two ecological indicators: benthic macroinvertebrates (BMIs) and algae. Results of the survey for the 2012 – 2016 study period indicate that streams in the RMC area are generally in poor biological condition. Nearly 60% of streams are ranked in the lowest condition category of the California Stream Condition Index (CSCI), which is based on BMIs. For algae indices (D18 and S2), stream conditions appear slightly less degraded, with approximately 40% of the streams ranked in lowest condition category. These findings should be interpreted with the understanding that the survey focused on urban stream conditions.

What Stressors are Associated with Poor Condition? This question is addressed by evaluating the association between biological indicators (CSCI and D18) with stressor data through random forest and relative risk analyses. The study results showed that each of the biological indicators responded to different types of stressors. Biological condition, based on CSCI scores, was strongly influenced by physical habitat variables, as well as land use; while condition, based on D18 scores, was moderately influenced by water quality variables. Since these two indicators respond to different types of stressors, they can be used in combination to assess causes of poor (or good) conditions. In general, CSCI scores at urban sites were consistently low, indicating that degraded physical habitat conditions do not support healthy BMI assemblages. D18 scores at urban sites were more variable, indicating that healthy diatom assemblages can occur at sites with poor habitat, but might be impacted by poor water quality.

Are Conditions Changing Over Time? The short time frame of the survey (five years) limited our ability to detect trends. Since new sites are surveyed every year, it is expected that a much longer time period is needed to detect trends at a regional scale. The variability in biological condition observed over the five years of the current analysis may have been associated with annual variation in precipitation, which included drought conditions during the first three years of the survey.

EVALUATION OF THE MONITORING DESIGN

Over the first five years of monitoring (2012 – 2016), the RMC evaluated about 25% (1455 out of 5740) of the sites in the sample frame to obtain 354 samples. Approximately 46% (873 out of 1896) of the total number of urban sites in the sample frame were evaluated during that time. At this time (2018), it is anticipated that urban sites will be exhausted in two to three years.

The RMC sample design was created to probabilistically sample all streams within the RMC area, which resulted in a master list of 33% urban sites and 67% non-urban sites. However, because participating municipalities are primarily concerned with runoff from urban areas, the RMC focused sampling efforts on urban sites (80%) over non-urban sites (20%). As a result, non-urban samples are under-represented in the dataset resulting in lower overall biological condition scores than would be expected for a spatially balanced dataset. Depending on the goals for the RMC moving forward, the RMC may want to consider developing a new sample draw that establishes a new list of sites that are weighted for specific land uses categories and Program areas of interest.

Based on evaluation of data collected during the first five years of the survey, several options to revise the RMC Monitoring Design are presented. These options will be further developed, and recommendations will be made through a future BASMAA Regional Project.

1) Continue to sample new probabilistic sites
2) Re-visit probabilistic sites for a trends assessment
3) Monitor targeted sites for special studies
4) Combination of two or more of the above

1 INTRODUCTION

1.1 BACKGROUND

The Bay Area Stormwater Management Agencies Association (BASMAA) Regional Monitoring Coalition (RMC) is a consortium of six San Francisco Bay Area municipal stormwater programs that joined together in 2010 to coordinate and oversee water quality monitoring required by the Municipal Regional Stormwater National Pollutant Discharge Elimination System (NPDES) Permit (referred to as the Municipal Regional Permit or "MRP"). The MRP requires bioassessment monitoring in accordance with Standard Operating Procedures (SOPs) established by the California Surface Water Ambient Monitoring Program (SWAMP) including sampling of benthic macroinvertebrates (BMIs), benthic algae, and water chemistry, and characterization of physical habitat.

The MRP identifies two management questions that the bioassessment monitoring (and other Provision C.8.c monitoring requirements) are intended to address:

- *Are water quality objectives, both numeric and narrative, being met in local receiving waters, including creeks, rivers and tributaries?*
- *Are conditions in local receiving waters supportive or likely to be supportive of beneficial uses?*

Consistent with the requirements of the MRP, the RMC developed a probabilistic monitoring design to address the management questions on a regional scale and compare monitoring results across stormwater programs. The probabilistic design is based on the Generalized Random Tessellation Stratified (GRTS) approach (Stevens and Olson 2004) for evaluating and selecting sampling stations in perennial and nonperennial streams. A power analysis predicted a minimum sample size of 30 to evaluate the condition of aquatic life within a confidence interval of approximately 12%. This was considered sufficient for decision-making in the RMC area. Under the MRP, each municipal Stormwater Program is required to assess a minimum number of sites based on their relative population. As a result, the number of samples required each year varies by county: 20 samples for Santa Clara and Alameda counties and 10 samples for San Mateo and Contra Costa counties. Fairfield-Suisun and Vallejo are required to sample 8 and 4 samples, respectively, each five-year period. In addition, the San Francisco Bay Regional Water Quality Control Board (SF Bay Water Board) collaborated with the RMC by collecting additional samples in non-urban areas in each of the counties.

1.2 PROJECT GOAL

This goal of this project was to compile and evaluate bioassessment data collected over the first five years of bioassessment monitoring conducted by the RMC (2012 – 2016). The evaluation was designed to address three main questions:

1) What is the biological condition of perennial and non-perennial streams in the region?
2) What stressors are associated with poor condition?
3) Are conditions changing over time?

The findings are intended to help stormwater programs better understand the current condition of these water bodies, prioritize stream reaches in need of protection or restoration, and identify stressors that are likely to pose the greatest risk to the health of streams in the Bay Area.

This report also evaluates the existing RMC monitoring design and identifies a range of potential options for revising the design (if desired) to be implemented during the next version of the MRP, which is likely to adopted in 2021. These options can guide the monitoring re-design process as part of a future BASMAA Regional Project.

This project was implemented by a Project Team comprised of EOA, Inc. and Applied Marine Sciences (AMS) with technical review provided by the Southern California Coastal Water Research Project (SCCWRP). A BASMAA Project Management Team (PMT) consisting of representatives from BASMAA stormwater programs and municipalities provided oversight and guidance to the Project Team.

Sections of this report are organized according to the following topics:

- **Section 1.0** – Introduction including summary of other Regional Monitoring Programs using biological assessments, development of State policies that are relevant to bioassessment data collection, and description of the goals for this report
- **Section 2.0** – Methods including monitoring survey design, site evaluation procedures, field sampling and data analyses.
- **Section 3.0** – Results summarizing biological conditions, stressor association with conditions, and trends.
- **Section 4.0** – Discussion organized by the management questions and goals.
- **Section 5.0** – Conclusions and recommendations

1.3 BIOASSESSMENTS BY PARTNER AGENCIES IN CALIFORNIA

As context, a brief description of other regional biological assessment programs being conducted in the State of California is provided. The RMC's monitoring design is consistent with the design used by the statewide Perennial Streams Assessment (PSA) program and is specifically intended to allow for future integration of data between the two monitoring programs. The RMC has also integrated lessons learned from the Southern California Stormwater Monitoring Coalition (SMC) in the development of alternatives for potential re-design of the RMC monitoring survey described at the end of this report.

Since 2000, the State of California has conducted probability surveys of its perennial streams and rivers with a focus on biological endpoints. These surveys are managed collectively by the Surface Water Ambient Monitoring Program (SWAMP) under its Perennial Streams Assessment program. The PSA collects samples for biological indicators (BMIs and algae), chemical constituents (nutrients, major ions, etc.), and physical habitat assessments for both in-stream and riparian corridor conditions. As of 2012, over 1300 unique perennial stream sites have been monitored by PSA and its partner programs[1]. The PSA developed a management memo summarizing biological conditions (based on California Stream Condition Index score) and associated stressor data collected at probabilistic sites over a 13-year time period (2000 – 2012) (SWRCB 2015).

The Stormwater Monitoring Coalition, a coalition of multiple state, federal, and local agencies, initiated a regional monitoring program in 2009. The SMC uses multiple biological indicators to assess ecological health of streams, including BMIs, benthic algae (diatoms and soft algae) and riparian wetland condition. The SMC also collects water chemistry, water column toxicity, and physical habitat data to evaluate potential stressors to biological health. During the first five years of the program (2009 to 2013), the SMC monitored more than 500 probabilistic sites in 15 major watersheds in California's South Coast region, with a focus on perennial streams (Mazor 2015). Evolution of those data suggested that few perennial, wadeable streams in the SMC study area are in good biological condition (Mazor 2015a). Recognizing that perennial streams account for only 25% of stream-miles in the region, in 2015, the SMC expanded its monitoring program to include nonperennial streams which account for approximately 59% of stream-miles (Mazor 2015b). The SMC program also focused about 30% of the monitoring effort towards revisiting probabilistic sites to provide an estimate of change in condition (Mazor 2015b). The next iteration of the SMC monitoring program will likely include a larger focus on trends monitoring (Rafael Mazor, SCCWRP, personal communication, 2018).

1.4 Biostimulatory/Biointegrity Policy Development

Bioassessment monitoring conducted by the RMC not only provides information about beneficial use attainment in the RMC study area and how RMC streams compare to other regions (i.e., SMC), it also generates a significant baseline dataset that will provide context for potential future water quality objectives and initiatives being developed by the State Water Resources Control Board (State Water Board).

The State Water Board is developing a statewide water quality objective for biostimulatory substances along with an implementation program as an amendment to the Water Quality Control Plan for Inland Surface Water, Enclosed Bays and Estuaries of California (ISWEBE Plan)[2]. The Biostimulatory Substances Amendment may include either a numeric or narrative objective (statewide). The implementation plan for the water quality objective for biostimulatory substances is expected to be established in three phases, with each phase including a plan that would be unique for each of the three different water body types. The first phase of the Biostimulatory Amendment would be applicable to wadeable streams.

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[1] The Southern Monitoring Coalition has collected a majority of samples at probabilistic sites in Coastal Southern California watersheds and the US Forest Service has collected PSA-comparable data from sites in National Forests of the Sierra Nevada.

[2] Information obtained from:
https://www.waterboards.ca.gov/water_issues/programs/biostimulatory_substances_biointegrity

The Biostimulatory Substances Amendment will also include a water quality control policy (i.e., Biointegrity Policy) to establish and implement biological condition assessment methods, scoring tools, and targets aimed at protecting the biological integrity in wadeable streams. The policy will utilize a multi-indicator approach that includes the California Stream Condition Index (CSCI) for benthic macroinvertebrates and statewide algal stream condition index (ACSI) (currently in development). The plan is to establish "assessment endpoints" as primary lines of evidence to assess beneficial use support in wadeable streams. These endpoints may be used to establish default nutrient targets for the state, with potential option to refine under a "watershed approach".

The Biostimulatory/Biointegrity Project has been delayed due to several unresolved policy issues that need to be addressed prior to development of the policy, including[3]:

1) Consideration of channels in highly developed channels (i.e., where assessment endpoints may not be achieved);
2) Identify Beneficial Uses;
3) Relationship between established biological assessment endpoints and nutrient endpoints; and
4) Define process for coordinated watershed approach.

The State Water Board is planning to develop draft policy options to present to Stakeholder Advisory and Regulatory Groups during the fall 2018.

[3] Information obtained from presentation by Jessie Maxfield, California State Water Board, given at the 2017 California Aquatic Bioassessment Workgroup conference in Davis, Ca.

2 METHODS

2.1 STUDY AREA

The study area for the BASMAA RMC Creek Status Monitoring consists of the perennial and non-perennial streams and rivers within the portions of the five participating counties (San Mateo, Santa Clara, Alameda, Contra Costa, Solano) that overlap with the San Francisco Bay Regional Water Quality Control Board (Region 2) boundary, and the eastern portion of Contra Costa County that drains to the Central Valley region (Region 5). The RMC Sample Frame consists of a GIS stream network representing the RMC area. The source data set used to create the sample frame was the 1:100,000 National Hydrography Dataset (NHD).

2.2 SURVEY DESIGN AND SAMPLING SITES

Sites were selected based on a probabilistic survey design consisting of a master draw of 5740 sites (approximately one site for every stream kilometer in the sample frame). The selection procedure employed the U.S. EPA's Generalized Random Tessellation Stratified survey design methodology (Stevens and Olson, 2004). Employing the GRTS approach in the BASMAA RMC region generated a spatially balanced distribution of sites covering the majority of the Bay Area. It should be noted that the sample draw of 5740 sites was not conducted with any land use designations or other emphases (i.e., County); therefore, the master draw of sample sites was weighted towards commonly occurring conditions (i.e. non-urban sites), while less common conditions (i.e., reference, urban sites) were less represented based on their lower relative abundance in the sample frame.

The RMC sampling design targeted the population of accessible streams with flow conditions suitable for sampling (i.e., adequate flow during spring index period). A random set of potential sampling sites (i.e., the master draw) was established, with each site having an equal, non-zero weight, proportional to the inverse of its selection probability. Thus, all sites were assumed to have an equal probability of selection throughout the sample frame. The weights represent the amount of stream length encompassed by each site in the overall target population.

Once the master draw was performed, the list of sites was separated into several categories to facilitate site evaluations and implement sampling (Table 1). The following attributes were used to generate the categories:

- County (n=5): San Mateo, Santa Clara, Alameda, Contra Costa, Solano (source: California Department of Forestry and Fire, 2009);
- Water Quality Control Board Region (n=2): Region 2, Region 5 (source: San Francisco Regional Water Quality Control Board, undated);
- Land use Category (n = 4): Urban or nonurban in all counties, except Solano ('urban_V' and ' urban_FS' in Solano County). Urban land use was defined as a combination of US Census (2000)

areas classified as urban, and areas within Census City boundaries. This definition of urban land use results in some relatively undeveloped areas and parks along the fringes of cities to be classified as urban. Urban sites therefore represent a broad range of developed (i.e., impervious surface) conditions. Non-urban area was defined as all remaining area in the RMC boundary not classified as urban.

Table 1. Number of sites from the master draw in each post-stratification category.

County	Urban	Non-Urban	Total
San Mateo	222	528	750
Santa Clara	542	1376	1918
Alameda	454	842	1296
Contra Costa (Region 2)	482	363	845
Contra Costa (Region 5)	105	349	454
Solano (Vallejo)	12	386	477
Solano (Fairfield-Suisun)	79		
		Overall Total	**5740**

To maintain a spatially balanced pool of sites, sites were selected for evaluation in the order that they appeared in the master draw list (with a few exceptions). Sites were evaluated for sampling using both desktop and field reconnaissance. Field crews attempted to locate a reach suitable for sampling within 300 m of the target coordinates. Sites without a suitable reach were rejected for sampling. Reasons for rejection included physical barriers, lack of flowing water, refusal or lack of response from landowners, water depth (i.e., >1 m deep for at least 50% of the reach) and inappropriate waterbody types (e.g., tidally influenced). Sites with temporary inaccessibility or permission issues (e.g., construction, lack of response from landowners) were re-evaluated for sampling in subsequent years. All program participants were instructed to use a standard set of codes to identify the reason behind exclusion of sites.

In contrast to the PSA and SMC regional monitoring designs, which targeted perennial streams, the RMC sampled both perennial and non-perennial streams. Additionally, at the outset, each countywide Program agreed they would attempt to assess up to 20% of their required sites in non-urban areas.

2.3 Sampling Protocols/Data Collection

Biological sample collection and processing was consistent with the BASMAA RMC Quality Assurance Project Plan (QAPP) (BASMAA 2016a) and Standard Operating Protocols (SOPs) (BASMAA 2016b) which were developed to be consistent with the current SWAMP Quality Assurance Program Plan (QAPrP) and SOPs. Bioassessments were conducted during the spring index period (approximately April 15 – July 15) with the goal to sample a minimum of 30 days after any significant storm (defined as at least 0.5-inch of rainfall within a 24-hour period). A 30-day grace period allows diatom and soft algae communities to recover from peak flows that may scour benthic algae from the bottom of the stream channel.

2.3.1 Biological Indicators

Each bioassessment sampling site consisted of an approximately 150-meter stream reach that was divided into 11 equidistant transects placed perpendicular to the direction of flow. Benthic macroinvertebrate (BMI) and algae (i.e., diatom and soft algae) samples were collected at each transect using the Reachwide Benthos (RWB) method described in Ode et al. (2016). The algae composite sample was also used to collect chlorophyll a and ash free dry mass (AFDM) samples following methods described in Ode et al. (2016).

Biological samples were sent to laboratories for analysis. The laboratory analytical methods used for BMIs followed Woodward et al. (2012), using the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT) Level 1 Standard Taxonomic Level of Effort, with the additional effort of identifying chironomids (midges) to subfamily/tribe instead of family (Chironomidae). Soft algae and diatom samples were analyzed following SWAMP protocols (Stancheva et al. 2015). The taxonomic resolution for all data was standardized to the SWAMP master taxonomic list.

2.3.2 Physical Habitat

Both quantitative and qualitative measurements of physical habitat structure were taken at each of the 11 transects and 10 inter-transects. At the outset of the monitoring program in 2012, Physical habitat measurements followed procedures defined in the “BASIC” level of effort (Ode 2007), with the following exceptions as defined in the “FULL level of effort: stream depth and pebble count + coarse particulate organic matter (CPOM), cobble embeddedness, and discharge measurements. In 2016, the entire “FULL ” level of effort for the characterization of physical habitat described in Ode et al. (2016) was adopted, consistent with the reissued MRP. Physical habitat measurements include channel morphology (e.g., channel width and depth), habitat features (e.g., substrate size, algal cover, flow types, and in-stream habitat diversity) and human disturbance in the riparian zone (e.g., presence of buildings, roads, vegetation management). In addition, a qualitative Physical Habitat Assessment (PHAB) score was assessed for the entire bioassessment reach. The PHAB score is composed of three characteristics for the reach, including channel alteration, epifaunal substrate, and sediment deposition. Each attribute is individually scored on a scale of 0 to 20, with a score of 20 representing good condition.

2.3.3 Water Quality

Immediately prior to biological and physical habitat data collection, general water quality parameters (dissolved oxygen, pH, specific conductance and temperature) were measured at or near the centroid of the stream flow using pre-calibrated multi-parameter probes. In addition, water samples were collected for nutrients and conventional analytes analysis using the Standard Grab Sample Collection Method as described in SOP FS-2 (BASMAA 2016b).

2.3.4 Stressor Variables

Physical habitat, land-use, and water quality data were compiled and evaluated as potential stressor variables for biological condition. Land-use variables were calculated in GIS by overlaying the drainage area for sample locations with land use and road data. The variables included percent urbanization, percent impervious, total number of road crossings and road density at three different spatial scales (1 km, 5 km' and entire watershed).

Physical habitat metrics were calculated using the SWAMP Bioassessment Reporting Module (SWAMP RM). The SWAMP RM output includes calculations based on parameters that are measured using EPA's Environmental Monitoring and Assessment Program (EMAP) for freshwater wadeable streams (Kaufmann et al. 1999), as well as parameters collected under the SWAMP protocol (Marco Sigala, personal communication, 2017). The RM produces a total of 176 different metrics based on data collected using the SWAMP "FULL" habitat protocol. Ten of the best performing metrics (Andy Rehn, CDFW, personal communication) were selected based on best professional judgment from the SWAMP RM output to analyze physical habitat data collected by the RMC.

General water quality (e.g., DO, SpCond) and chemistry (e.g., nitrate and phosphorus) data collected at the bioassessment sites were also included. Some of the water chemistry variables were calculated from the analytes that were measured. These include Total Nitrogen (sum of nitrate, nitrite and Total Kjeldahl nitrogen) and unionized ammonia (calculated using pH and temperature).

2.3.5 Rainfall Data

For evaluation of trends, a representative rainfall dataset was collated for San Mateo, Santa Clara, Contra Costa, and Alameda counties. The total accumulated rainfall in each water year during the period 2012-2016 was calculated. The rainfall dataset assembled were derived from: San Jose Airport for Santa Clara; San Francisco Airport for San Mateo; Oakland Airport for Alameda; and Walnut Creek for Contra Costa.

2.4 Data Analyses

All statistical, tabular, and graphical analyses were conducted in R Studio, running R version 3.4.3 (R Core Team 2016). For analyses involving water quality data, censored results (i.e., below the method detection limit) were substituted with 50% of the method detection limit (MDL). Generally, analytical sensitivity was good, with only three variables having > 30% non-detects (Suspended Sediment Concentration, Nitrite, Ammonia). To facilitate use of the data for random forest and relative risk analyses, missing values were subject to an imputation method to fill in data gaps. Seven variables were found to have missing values. Three of these; Suspended Sediment Concentration (SSC), Dissolved Organic Carbon (DOC), Alkalinity[4], consisted of more than 50 missing values, and were excluded from further analysis. The remaining four variables (Silica, Ash Free Dry Mass, Chlorophyll a, Nitrate) were subject to imputation using the R-package *mice* (van Buuren and Groothuis-Oudshoorn, 2011). Overall, less than 25 values were imputed for any variable (Silica, n = 24; AFDM, n = 4; Nitrate, n = 1; Chl a, n = 1), and thus their influence on the analysis is assumed to be minor.

[4] Suspended Sediment Concentration (SSC), Dissolved Organic Carbon (DOC) and alkalinity were not monitored in 2016, due to the removal of these parameters in Provision C.8.c of the reissued MRP.

2.4.1 Biological Condition Indices

The California Stream Condition Index (CSCI) was developed by the State Water Board as a standardized measure of benthic macroinvertebrate community condition in perennial wadeable rivers and streams. The CSCI was developed using a large reference data set representing the range of natural conditions in California (Rehn et al. 2015). The CSCI tool (Mazor et al. 2016) translates BMI data into an overall measure of stream health by combining two types of indices: 1) ratio of observed-to-expected taxa (O/E) (used as a measure of taxonomic completeness), and 2) a predictive multi-metric index (pMMI) for reference conditions (used as a measure of ecological structure and function). The CSCI score is computed as the average of the sum of O/E and pMMI.

The CSCI scoring tool was used to assess BMI data collected at both perennial and non-perennial sites in the RMC area. The CSCI scores for RMC sites should be interpreted with caution, as the CSCI tool has not been fully validated at non-perennial sites. In addition, the performance of the CSCI in Bay Area streams has not been fully evaluated.

The algae data were analyzed using algal indices of biological integrity (IBIs) that were developed for streams in Southern California (Fetscher 2014). These include a soft algae index (S2), diatom index (D18) and soft algae-diatom hybrid index (H20). The algal indices were calculated using the SWAMP Algae Reporting Module (Algae RM). The interpretation of algae data collected in San Francisco Bay area using IBIs developed in Southern California (SoCal) should be considered preliminary. The State Board and SCCWRP are currently developing and testing a statewide index using benthic algae data as a measure of biological condition for streams in California. The statewide Algae Stream Condition Indices (ASCIs) were not available at the time this project was conducted, but are expected to be available in late 2018 (personal communication, Jessie Maxfield, SWRCB).

2.4.2 Biological Indicator Thresholds

Existing thresholds for biological indicator scores (CSCI, D18, S2) defined in Mazor (2015) were used to evaluate bioassessment data compiled and analyzed in this report (Table 2, Figure 1). The thresholds for each index were based on the distribution of scores for data collected at reference calibration sites in California (BMI) or in Southern California (algae). Four condition categories are defined by these thresholds: "likely intact" (greater than 30th percentile of reference site scores); "possibly altered" (between the 10th and the 30th percentiles); "likely altered" (between the 1st and 10th percentiles; and " very likely altered" (less than the 1st percentile). The probability-based approach to develop the threshold classes was consistent across indices, allowing comparison for all indicators across sites.

The performance of CSCI on a statewide basis is the subject of ongoing review by the State Water Board. In the current MRP, the SF Bay Water Board defined a CSCI score of 0.795 as a threshold for identifying sites with degraded biological condition that should be considered candidates for Stressor Source Identification (SSID) projects. No MRP threshold has been established for any of the algae indices.

Table 2. Index classes of biological condition

Index	Likely Intact	Possibly Altered	Likely Altered	Very Likely Altered
Benthic Macroinvertebrates (BMI)				
CSCI Score	≥ 0.92	≥ 0.795 to < 0.92	≥ 0.63 to < 0.795	< 0.63
Benthic Algae				
S2 Score	≥ 60	≥ 47 to < 60	≥ 29 to < 47	< 29
D18 Score	≥ 72	≥ 62 to < 72	≥ 49 to < 62	< 49

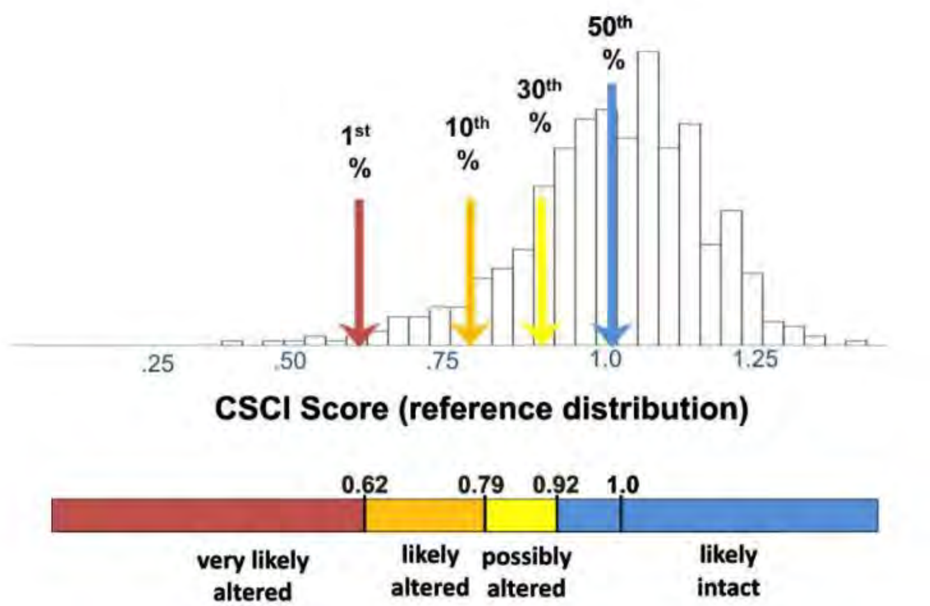

Figure 1. Distribution of CSCI scores at reference sites with thresholds and condition categories used to evaluate CSCI scores (from Rehn et al. 2015)

2.4.3 Cumulative Distribution Functions

To generate cumulative distribution functions (CDFs) of biological condition scores, sample weights were re-calculated for each site. Sample weights were recalculated for urban and non-urban land use categories, as the total stream length in the sample frame, divided by the stream length evaluated in each category. Therefore, sites contribute a proportional amount of stream length to the extent estimates based on the number of sites assessed in each land use category. Sites without evaluations (6%) were excluded from the analysis. The adjusted sample weights were used to estimate the proportion of stream-length represented by CSCI, D18, and S2 scores both regionwide and for urban sites only. Estimates for non-urban stream miles were not calculated due to the low number of samples collected at non-urban sites. Condition estimates and 95% confidence intervals were calculated for all sampled sites in the RMC sample frame and for urban sites only. Post-stratification of the urban sites by County was also performed. However, Solano County was excluded from this assessment, due to the relatively low sample size compared to the other areas. All calculations were conducted using the R-package *spsurvey* (Kincaid and Olsen 2016). See Section 4.4 for further discussion of the RMC sample design.

2.4.4 Random Forest

Random forest analysis is a non-parametric classification and regression tree (CART) method commonly applied to large datasets of multiple explanatory variables. Recent papers describe their use for stressor identification in stream bioassessment studies (e.g., Maloney et al. 2009, Waite et al. 2012, Mazor et al. 2016). Random Forest models use bootstrap averaging to determine splits of numerous trees (Elith et al., 2008) for reducing error and optimizing model predictions. Model outputs provide an ordered list of importance of the explanatory variables that can be applied to a new or validation dataset for prediction.

Random forest models were developed using the R-package *randomForest* to determine a list of explanatory variables related to biological condition scores (CSCI or D18 score). The stressor data consisted of 49 variables, related to (1) water quality; (2) habitat; and (3) land use factors that could potentially influence conditions scores (Appendix 7.1, Table A). Subsequently, the data were partitioned into training (80%) and validation (20%) sets for model testing. A random selection of samples was generated by sub-sampling from within each RMC County to maintain a regional balance of samples within the partitioned datasets. The training dataset had 278 sites, while the validation data encompassed 76 sites across all counties.

First, several iterations of the model procedure were performed with the training data set to optimize the random forests, including tuning the model to the maximum number of predictors per branch, the number of trees to build, and validation of the predictions. Appendix 7.1 presents the results of initial steps to optimize the random forest model outputs. The final set of models evaluated a maximum of 6 predictor interactions, and 1000 trees. Two variable importance statistics were used to estimate the relative influence of predictor variables: (1) % Increase in MSE = percent increase in mean-square-error of predictions as a result of variable values being permuted; (2) Increase in Node Purity = difference between the residual sum-of-squares before and after a split in the tree. More important variables achieve larger changes in MSE and node purity. K-fold cross validation of the selected models was performed to assess prediction error, by evaluating residual error and R-squared differences.

Random forest models were developed in two steps: (1) random forest models were run with all variables included (N = 49), retaining the top 10 variables in the variable relative importance list ranked by % increase in MSE, and (2) random forest models were re-run with just the top 10 variables from step 1. Subsequently, the variable list was further trimmed by evaluating the corresponding variable importance scores, partial dependency plots, and the change in R^2 once the variable was excluded. Partial dependency plots show the predicted biological response based on an individual explanatory variable with all other variables removed. No variable with less than 10% influence on CSCI or D18 predictions was retained in the final models. Finally, random forest models were used to predict biological condition scores for the validation data set. Appendix 7.1, Figure B presents the observed and predicted values for the validation models with CSCI and D18 in Steps 1 and 2 of the model development.

2.4.5 Stressor Thresholds and Relative Risk Assessment

From the list of potential stressors discussed in Section 2.3.4, eight variables were selected to conduct a relative risk analyses (Table 3). Six of the stressor thresholds were derived from statewide data collected for the Perennial Streams Assessment (SWAMP 2015). The thresholds were based on the 90th percentile of data collected at bioassessment sites that exhibited good biological condition (i.e., CSCI scores > 0.92, likely intact). The 90th percentile of stressor values at these sites was used to define the most-disturbed thresholds for variables where higher values indicate more disturbance (SWRCB 2015). Similarly, the chlorophyll a threshold (100 mg/m2) used for this report (Table 3) was based on 90th percentile of data that was collected at all RMC sites that had CSCI scores > 0.92 (Figure 2). The threshold for Dissolved Oxygen (7.0 mg/l) was based on Water Quality Objectives (WQOs) for COLD Freshwater Habitat Beneficial Use in the Basin Plan (SFBRWQCB 2017).

Table 3. Biological Condition and stressor variable thresholds used for Relative Risk Assessment

Variable Used for RR	Thresholds		Units	Reference	Criteria
Biological Condition	*Poor*	*Good*			
CSCI Score	< 0.625	≥ 0.925		Mazor 2015	
Stressor Condition	*High*	*Low*			
Dissolved Oxygen (DO)	<7.0	≥ 7.0	mg/L	Basin Plan	WQO
Specific Conductivity (SpCon)	> 1460	≤ 1460	us/cm	SWAMP 2015	90th Percentile of sites with CSCI score > 0.925
Chloride	> 122	≤ 122	mg/L		
Total Nitrogen (TotN)	> 2.3	≤ 2.3	mg/L		
Total Phosphorus (TotP)	> 0.122	≤ 0.122	mg/L		
Chlorophyll a (Chla)	> 100	≤ 100	mg/m2	RMC data	
Sand and Fines (SaFn)	> 69	≤ 69	%	SWAMP 2015	
Human Disturbance Index (HDI)	> 1.3	≤ 1.3			

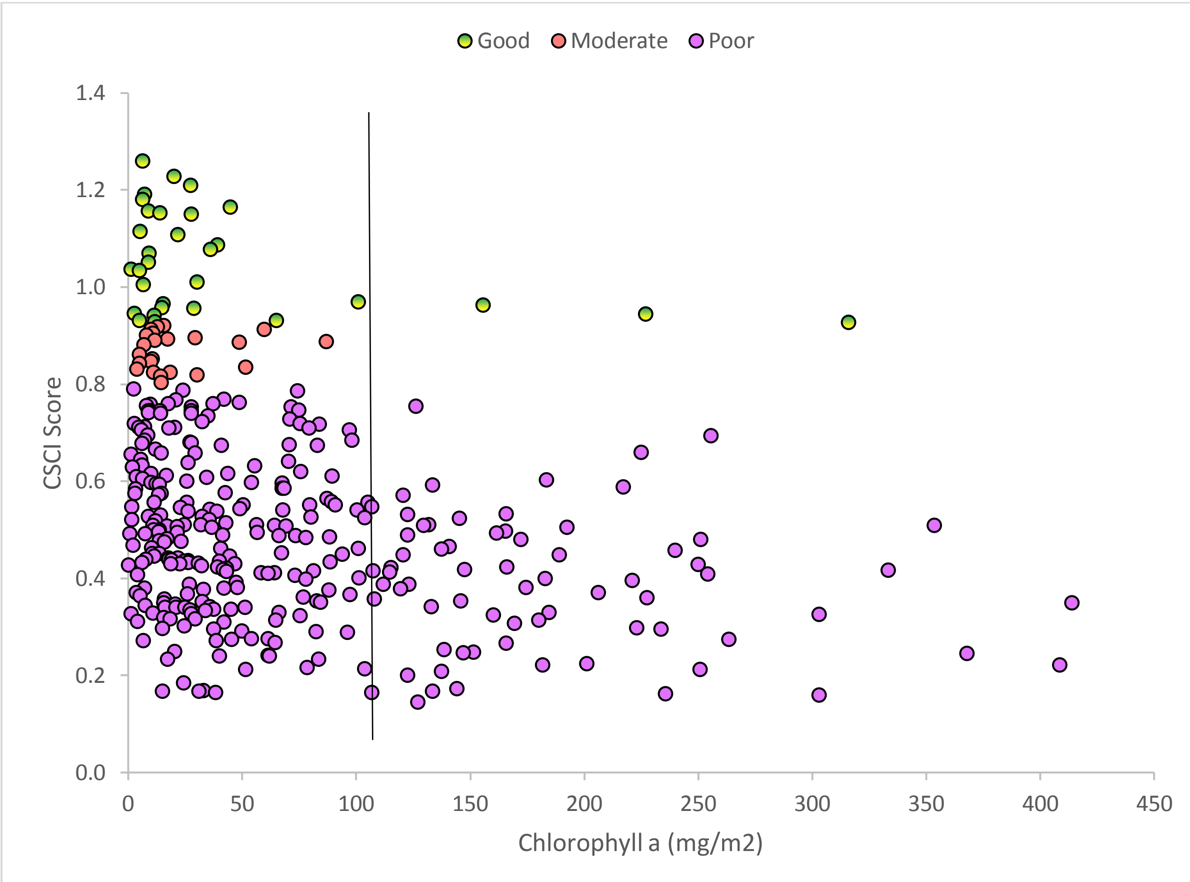

Figure 2. Plot of CSCI score and chlorophyll a concentration at RMC sites. Threshold for chlorophyll a used for relative risk assessment is shown. Sites classified as "good" include the two highest condition categories.

The Relative Risk approach was used to evaluate the association between stressors and biological condition (Van Sickle et al., 2008). The relative risk is a conditional probability representing the likelihood that poor biological condition is associated with high stressor levels and is calculated as follows:

$$\text{Relative Risk} = \frac{\text{Pr}\ (\text{CSCI}_p)/S_h}{\text{Pr}\ (\text{CSCI}_p)/S_l}$$

The numerator is the probability of finding poor biological condition (CSCI_p) given high stressor scores (S_h) and denominator is the probability of finding poor biological condition given low stressor scores (S_l). Poor biological conditions were defined as CSCI scores < 0.625. High and low stressor levels are defined in Table 3. In cases where RR is equal to 1, there is no association between stressor and biological indicator score. Where RR > 1, the higher the value, the more likely poor biological condition would occur given high stressor levels.

3 RESULTS

3.1 SITE EVALUATION RESULTS

A total of 354 probabilistic sites were sampled in the RMC region between 2012 and 2016. These are identified as “target” sites in Figure 3 and Table 4. Samples were collected at 284 urban sites (80%) and 70 non-urban sites (20%) (Table 4). The greatest number of non-urban sampling locations were in Santa Clara (n=25) and San Mateo Counties (n=19). Samples were collected at 8 or 9 non-urban sites for each of the other counties. The percent of non-urban sites sampled among the counties ranged from 9% (Alameda) to 22% (Santa Clara).

The sample population size of 354 sites was obtained through the evaluation of 1455 unique sites, a rejection rate of 76% for all RMC area. Solano County had the highest rejection rate (90%) and San Mateo County had the lowest (65%). The most common reason for site rejection (55% of all evaluated sites) was the inability to sample the site. These “non-target sites” were rejected for several reasons, including lack of flowing water, site was not a stream (e.g., aquaduct, pipeline), tidally influenced, or non-wadeable. The lack of flow was the most common reason for rejection. The extended drought period between 2012 and 2014 may have resulted in an unusually high number of sites with no or low flow conditions.

Another reason for site rejection (21% of all evaluated sites) was the inability to obtain access to conduct the sampling (e.g., physical access or obtain private land/permission). These “target not sampled” sites are often located on private land in non-urban areas. Obtaining access to sites in urban areas was variable by county. For example, most of the streams in the urban area of San Mateo County are privately owned while most of the urban sites in Santa Clara County are owned by municipal jurisdictions and water district agencies.

Table 4. Number of sites in each site evaluation class.

County	Target Not Sampled		Non Target		Target		Total by County
	Non-Urban	Urban	Non-Urban	Urban	Non-Urban	Urban	
Alameda	12	74	162	91	9	96	444
Contra Costa	12	34	32	89	9	48	224
San Mateo	21	42	9	37	19	41	169
Santa Clara	37	24	74	161	25	87	408
Solano	44	3	109	34	8	12	210
Total RMC	126	177	386	412	70	284	1455
% of Total	9	12	27	28	5	20	-

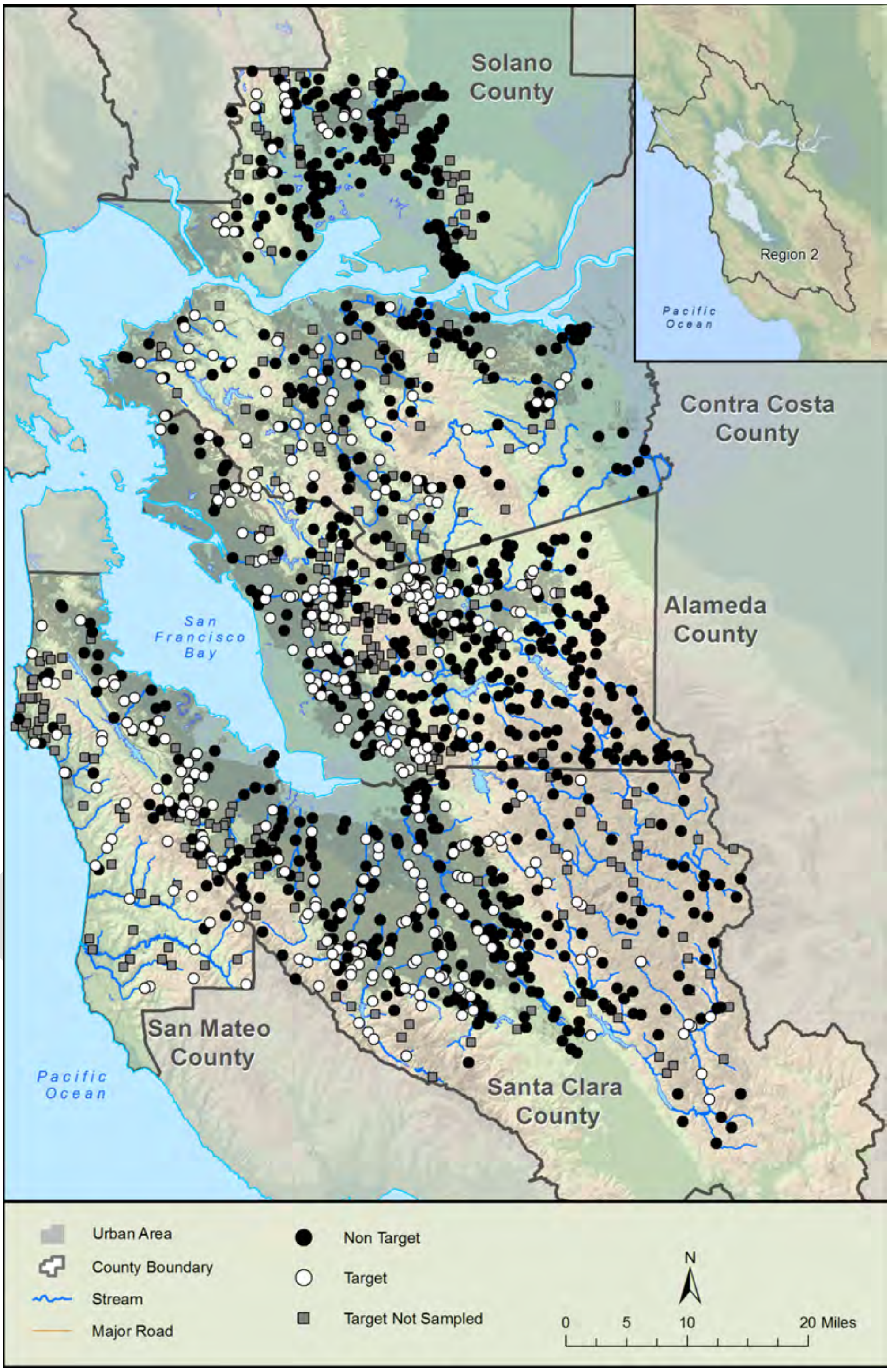

Figure 3. Map of site evaluation class

Figure 4 presents rainfall that was recorded during 2012-2016. Rainfall was generally below average, especially in 2014. Therefore, the climatic pattern of the survey design occurred in a drier-than-normal period and may not be representative over the long term.

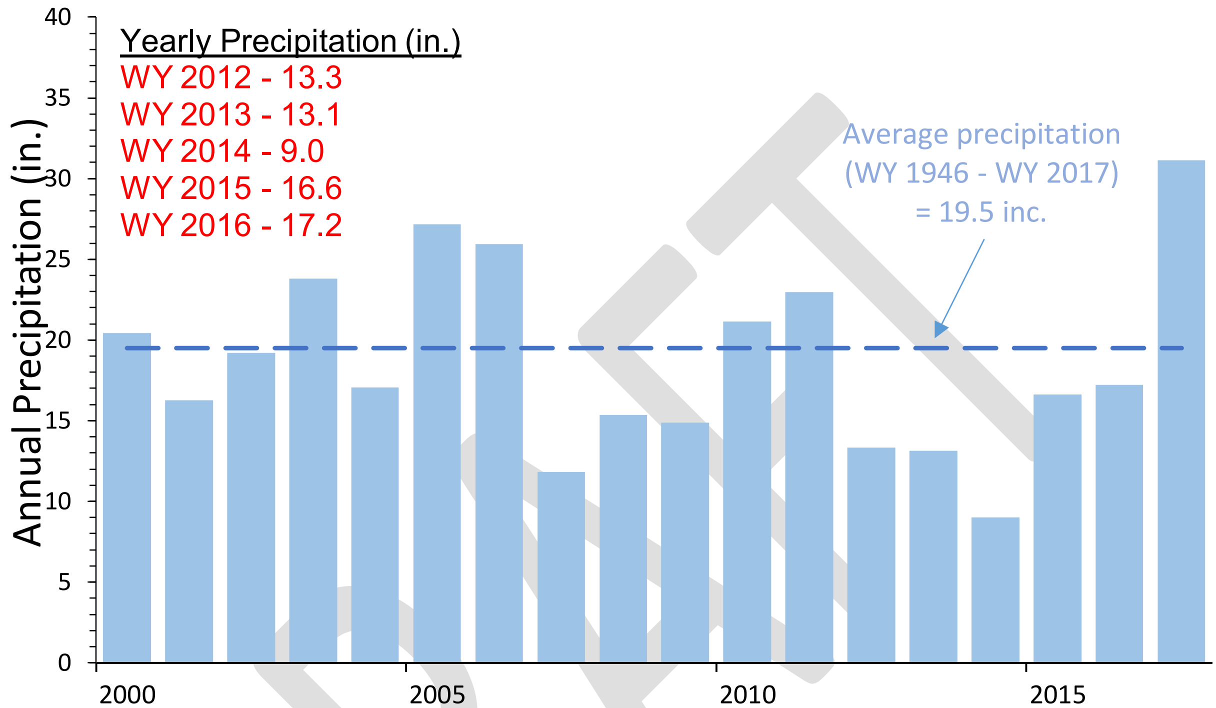

Figure 4. Annual Precipitation at San Francisco Airport 2000-2017

3.2 Biological Condition of Streams

3.2.1 Regional Assessment

The distribution of BMI and algae index scores observed during 2012-2016 suggests that the majority of streams in the RMC sample area do not support healthy biological conditions. Figures 5-7 show cumulative distribution functions of the index scores for the entire regional dataset (i.e., all sites) and the urban dataset. Across all sites, over half (58%) of the stream-length was in the lowest condition class for CSCI (Very Likely Altered), while only 15% of the stream-length was in the highest condition class (Likely Intact) (Figure 5).

Both of the algae index scores (D18 and S2) exhibited higher condition scores than CSCI. For D18 (diatoms), 41% of the stream-length in the Bay Area was in the Very Likely Altered condition class, while 19% of the stream-length was in the Likely Intact condition class (Figure 6). Similar distribution of scores was evident with S2 (soft-algae), where less than half (44%) of the stream-length was in the Very Likely Altered condition class, while 21% of the stream-length was in the Likely Intact condition class (Figure 7). The higher proportion of sites in the Likely Intact condition for algae indices compared to CSCI suggest that streams may be less degraded for the algae community, compared to the BMI assemblage.

Urban sites were responsible for the majority of poor scores. Seventy-nine percent (79%) of the stream length in urban areas was in the Very Likely Altered condition for CSCI, while only 3.5% was in the Likely Intact class (Figure 5). Additionally, over 80% of the sampled stream length in urban areas was below the MRP trigger for CSCI scores (0.795).

The influence of urban sites on stream condition was also apparent for algae scores, although to a lesser degree than for CSCI scores. For D18, just over half (53%) of the stream length in urban areas was in the Very Likely Altered condition class, compared to 9% in the Likely Intact class (Figure 5). For S2 scores, 65% of stream length in urban areas was in the Very Likely Altered class, and only 7% in the Likely Intact class (Figure 7). These patterns suggest that stressors in the urban landscape may still exert influence on algae condition. Section 4.0 provides additional discussion about the results presented here.

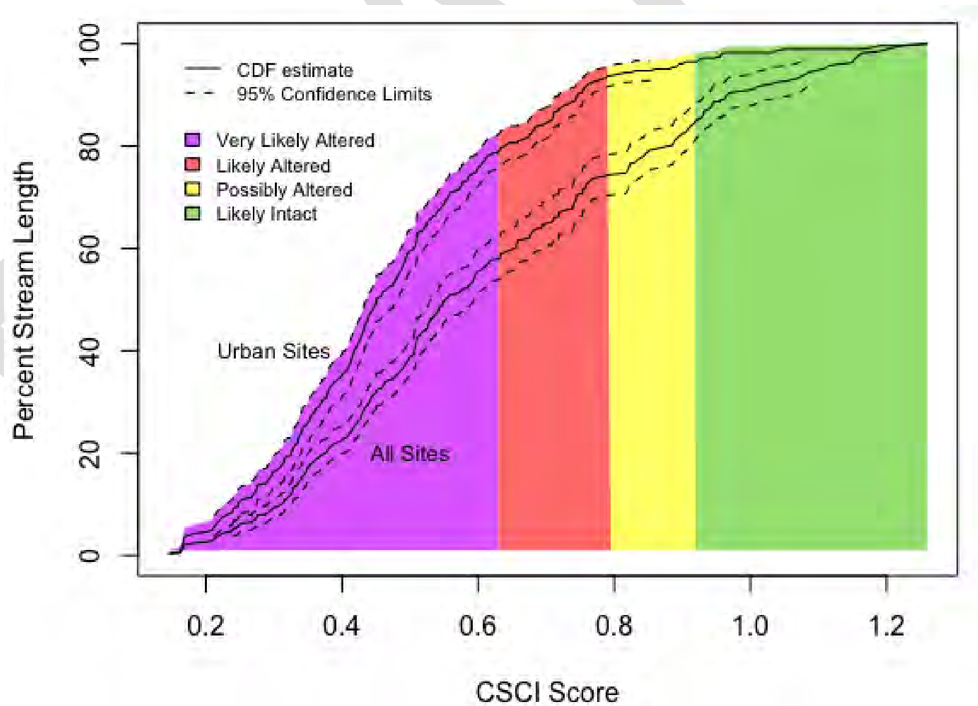

Figure 5. Cumulative distribution function (CDF) of CSCI scores.

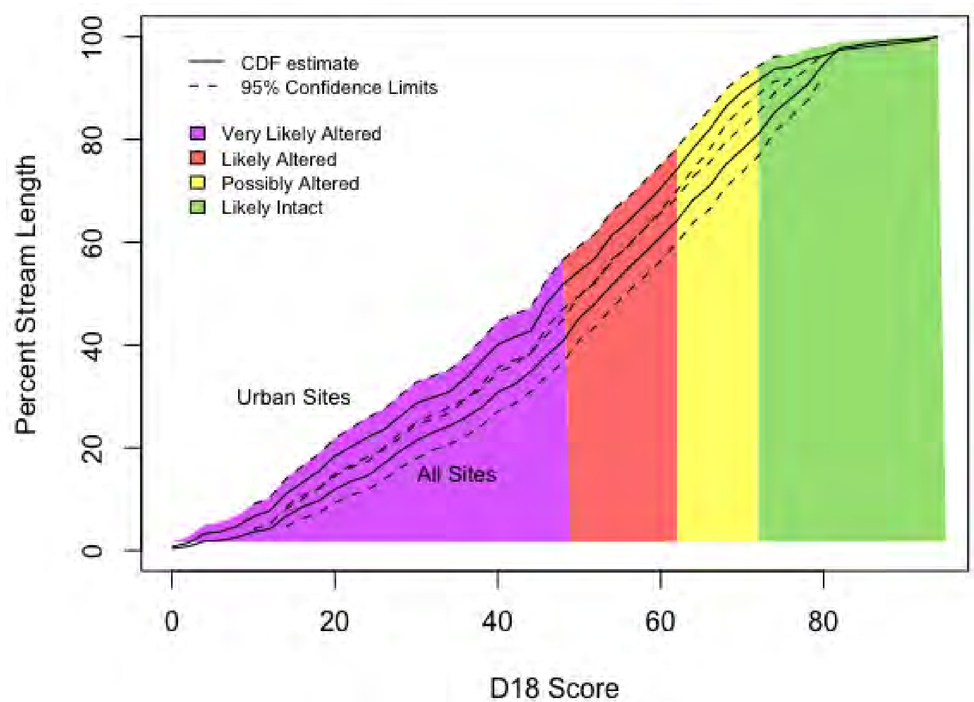

Figure 6. Cumulative distribution function (CDF) of D18 scores.

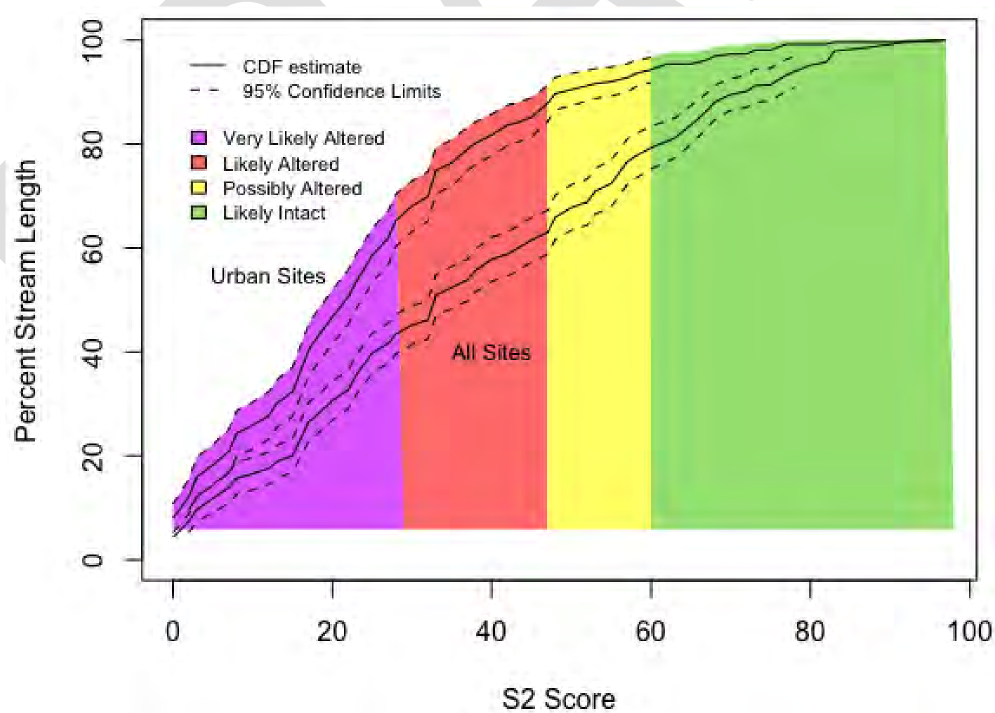

Figure 7. Cumulative distribution function (CDF) of S2 scores.

3.2.2 County Assessment

Post-stratification of the CSCI condition estimates for urban sites in each County (excluding Solano County due to low sample size) suggests poor condition scores are widespread in Bay Area streams. The proportion of urban stream length in the Very Likely Altered condition was highest for Contra Costa (96%), followed by Alameda County (83%), San Mateo County (73%), and Santa Clara County (64%) (Figure 8). Less than 10% of the urban stream length in each of the counties was in the Likely Intact condition class. The highest proportion occurred in San Mateo and Santa Clara (7% each) and was lower in Alameda (1%) and Contra Costa (0%).

Comparison of the urban-wide condition estimates to the MRP threshold of 0.795 indicates that the vast majority of urban stream length in each County is above this threshold. 100% of the urban stream length assessed in Contra Costa, 97% in Alameda, 90% in Santa Clara, and 85% in San Mateo was above 0.795.

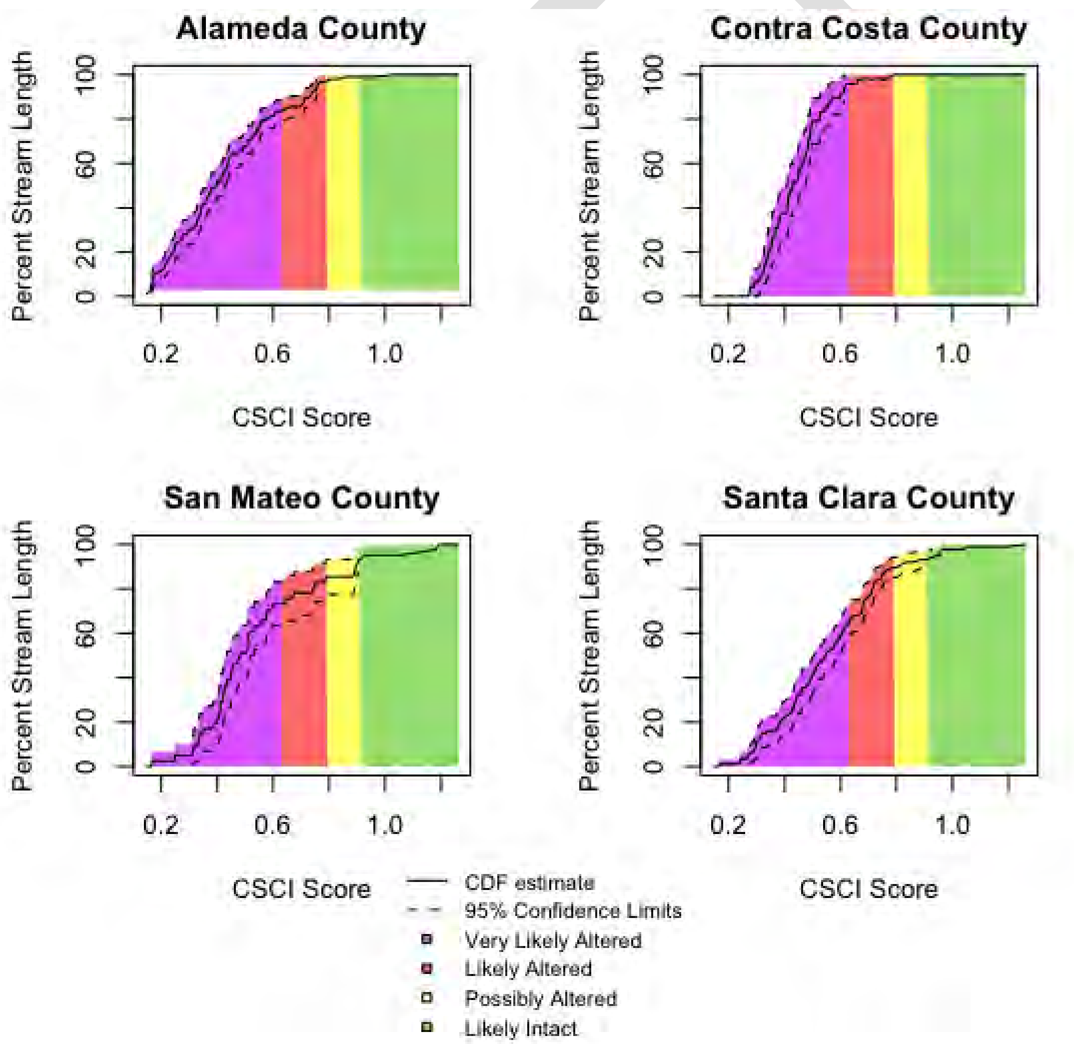

Figure 8. Cumulative distribution functions of CSCI scores at urban sites by County.

3.2.3 Urban vs. Non Urban Condition

Figure 9 maps CSCI scores (by condition category) for the region and includes county boundaries and urban areas for reference. Biological condition maps, based on CSCI and D18 scores, for individual counties are included in Appendix 7-4.

Figure 9. Biological condition of streams based on CSCI scores in RMC area.

CSCI scores grouped by land use class (urban vs. non-urban) showed that all counties except for Solano exhibit higher scores in the non-urban area (Figure 10), and generally span a narrower distribution than urban sites. Santa Clara and San Mateo counties had the highest median CSCI scores compared to other counties, with several sites in both counties receiving scores greater than 1.0, which typically represents reference conditions. However, CSCI scores below the MRP trigger (0.795) also occurred at non-urban sites for all five counties, indicating sites are also degraded in streams within non-urban areas.

Stratification of D18 and S2 scores by land use (urban vs non-urban; Figures 11 and 12) suggested that overall condition scores mirror that of CSCI. Generally, algae scores in the non-urban area were higher than scores in the urban area for each county. Contra Costa had sites in the non-urban area that were clearly impacted similar to urban sites. The low sample sizes of the non-urban population preclude making any definitive comparisons, however, it was noteworthy that sites in the urban areas may receive similar or higher condition algae scores than sites in the non-urban area.

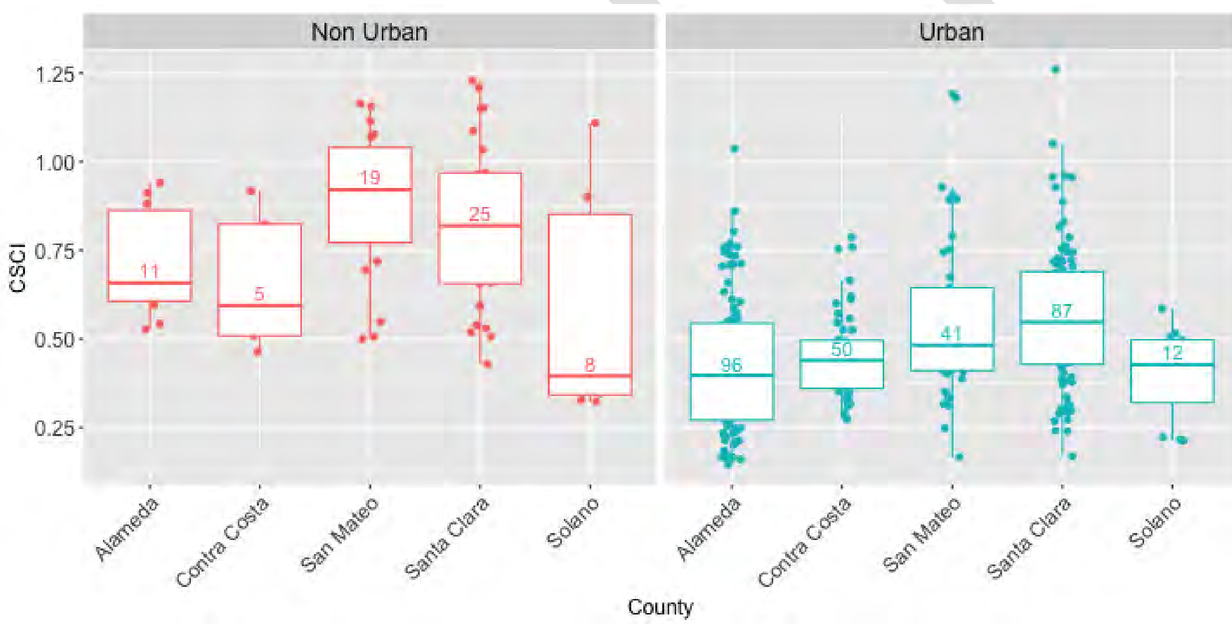

Figure 10. CSCI scores for each County grouped by non-urban and urban sites. Numbers in each boxplot are the sample sizes for each group.

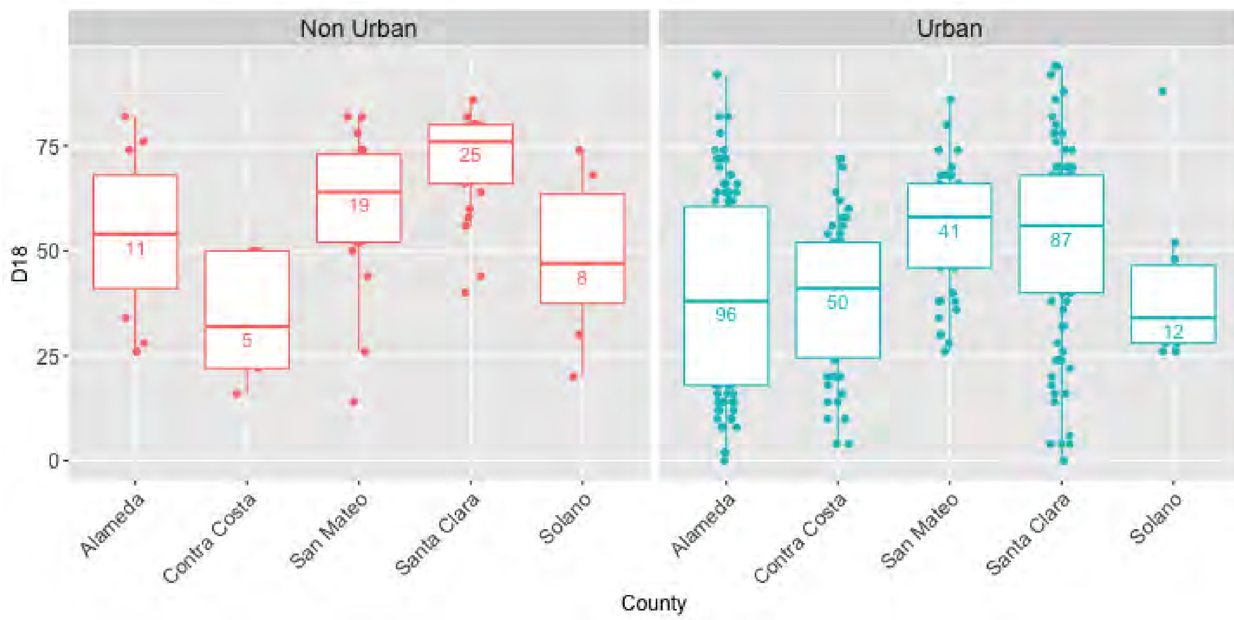

Figure 11. D18 scores for each County grouped by non-urban and urban sites. Numbers in each boxplot are the sample sizes for each group.

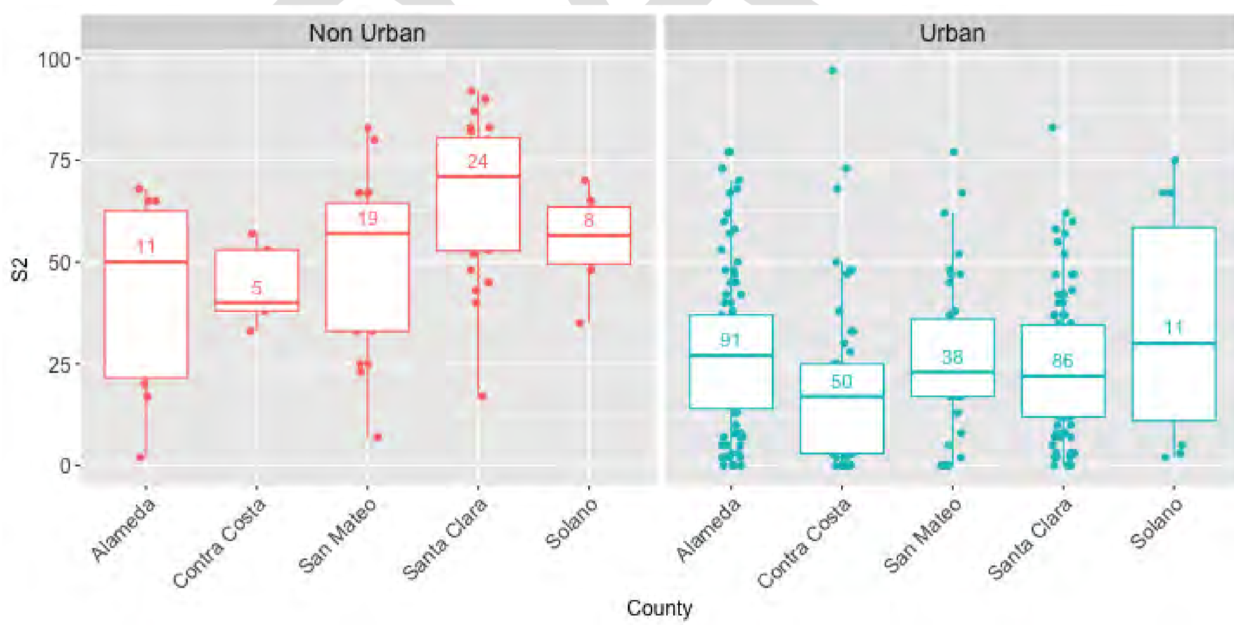

Figure 12. S2 scores for each County grouped by non-urban and urban sites. Numbers in each boxplot are the sample sizes for each group.

3.3 Stressors Associated with Condition

3.3.1 Random forest model outputs

Random forest models were developed using the CSCI and D18 index results, to evaluate stressors associated with biological condition within the RMC area. A parallel analysis was not performed for the S2 indicator due to the lack of soft algae at some of the sites. The stressor data consists of 49 variables grouped into three types: (1) water quality; (2) habitat; and (3) land use (Appendix 7.1, Table A). Comparison of the model results clearly indicated better model performance using CSCI over D18 scores. Validation of the final random forest models showed that the CSCI model explained 61% of the variance using eight predictor variables, while the D18 model only explained 34% of the variance using six predictors.

The CSCI random forest model indicated that land use and physical habitat were the variables that most influenced biological condition (Table 5). Of the eight variables in the final model, four were landscape-based(HDI, PctImp_5K, PctImp_1K, PctImp), three were habitat associated(PctFines, PctGra, PctFstH20), and one was a water quality variable (DO). It was notable that none of the nutrient variables were identified as indicators of biological condition scores (Appendix 7.3 Figure A). The same may be true for DO, for which the apparent relationship was driven by a few high values (Appendix 7.3 Figure B). However, there was general consistency amongst the individual variables for both the landscape and habitat groups, with the landscape predictors being related to the degree of human impact/imperviousness, and the habitat variables being related to the characteristics of the sediment substrate and flow. Overall, the largest influence on the CSCI random forest model was percent impervious area within a5 km radius (35.2%) of the site. The other seven variables in the final model exerted a lesser, but similar degree of influence (18.8 – 25.3%) in the model.

Table 5. Summary Statistics for Random Forest model with CSCI scores. Rank of importance of selected stressor variables colored according to categories of physical habitat (green), land use (brown), and water quality (blue). Rho statistic shows the correlation coefficient (rho) with CSCI score in the full dataset.

Variable	% Increase MSE	Increase Node Purity	Rank Correlation Coefficient (Rho)
Percent Impervious Area in 5km (PctImp_5K)	35.21	4.74	-0.62
Percent Impervious Areas of Reach (PctImp)	25.37	1.03	-0.59
Dissolved Oxygen (DO)	24.43	1.60	0.24
Percent Fask Water of Reach) PctFstH20	22.52	1.62	0.51
Percent Fines (PctFin)	20.73	1.13	-0.36
Percent Substrate Smaller than Sand (PctSmalSnd)	20.64	1.36	-0.46
Percent Impervious Area in 1km (PctImp_1K)	20.64	2.26	-0.61
Human disturbance Index (HDI)	18.81	1.45	-0.62

The random forest model for D18 indicated a different pattern to the explanatory variables compared to CSCI.Water quality variables exerting greater influence (Table 6). Of the six variables in the final D18 model, four were water quality variables (SpCond, Chloride, AFDM, Phosphorus), one was a habitat variable (PctSmalSnd), and one was a landscape variable (RdDen_1k). The list of water quality variables suggests that general water quality impairment influencing algae condition scores rather than specific type of water quality stress, such as from nutrients. Overall, the variable with the largest influence on the random forest model was specific conductivity (29.5%). The remaining five variables exerted a lesser, but similar influence (12.5 – 22.0%) on the model.

Table 6. Summary Statistics for Random Forest Modeling with D18 scores. Rank of importance of selected stressor variables colored according to categories of physical habitat (green), land use (brown), and water quality (blue). Rho statistic shows the correlation coefficient (rho) with D18 score in the full dataset.

Variable	% Increase MSE	Increase Node Purity	Rank Correlation Coefficient (Rho)
Specific Conductivity (SpCond)	29.55	35357.81	-0.49
Percent Substrate Smaller than Sand (PctSmalSnd)	21.99	24671.80	-0.46
Phosphorus	21.93	17465.87	-0.33
Chloride	18.53	18873.52	-0.51
Ash Free Dry Mass (AFDM)	15.09	21937.23	-0.44
Road Density in 1km (RdDen_1k)	12.51	16383.17	-0.33

Using the random forest model outputs, plots of individual stressor variables versus observed and predicted response values (i.e., CSCI and D18 scores) were used to assess conditions that delineated good or poor condition (Figures 13 to 18 and Appendix 7.2). For the CSCI model output, the plots of habitat and landscape variables indicate patterns of dose-response. For example, the HDI stressor variable (i.e., Human Disturbance Index) indicated that poor condition scores are predicted when HDI exceeds a value of 2. This pattern was also evident in the regressions of observed CSCI values, relative to HDI and separating out HDI scores by their condition class (Figure 13). It is worth noting that Ode et al. (2016) identified a cutoff of HDI = 1.5 for reference sites (Ode et al. 2016). Here, the range between 1.5 and 2.0 appeared to separate out the urban and non-urban sites supporting the indication that sites below this range are closer to reference.

Similar to HDI, the stressor variables related to imperviousness indicated a threshold-style response with CSCI scores. For the variable 'percent imperviousness in 5km' a value above 10% appeared to correspond to poor condition scores (Figure 14). All sites that had less than 10% impervious area in 5km were classed as either Possibly Intact or Likely Intact condition. In the case of the habitat variables included in the final model, response patterns were less pronounced than for the landscape ones (Figure 15). For example, the variable 'percent reach habitat smaller than sand', indicated that poor sites spanned a wide range in stressor values, while sites in the top three condition classes had a much narrower range in this metric. Streams where more than 50% of the reach had substrate smaller than sand appeared a delineation point between sites in the good versus poor condition classes.

In the D18 model output, all four of the water quality variables (i.e. SpCond, Chloride, AFDM, Phosphorus) showed apparent dose-response relationships. But, there were less obvious patterns to delineate good and bad sites. For example, the partial dependency plots indicated that D18 scores would be associated with poor condition when chloride was above 200 mg/L (Figure 16) and specific conductivity was above 1200 µS/cm[5] (Figure 17). However, the plots of observed D18 values relative to these variables suggested that only some of the worst sites could be delineated using these threshold values. Similarly, response patterns of the habitat variables were inconclusive for delineating good and poor condition scores. A value of approximately 60% or greater of the stream habitat smaller than sand corresponded to lower D18 scores (Figure 18), but there was considerable variability to this signal.

[5] This corresponds well with the MRP threshold of 2000 uS/cm^2 for evaluating continuous monitoring data. Sites with 20% or more of instantaneous specific conductance results greater than 2000 uS/cm^2 are considered as candidates for SSID projects.

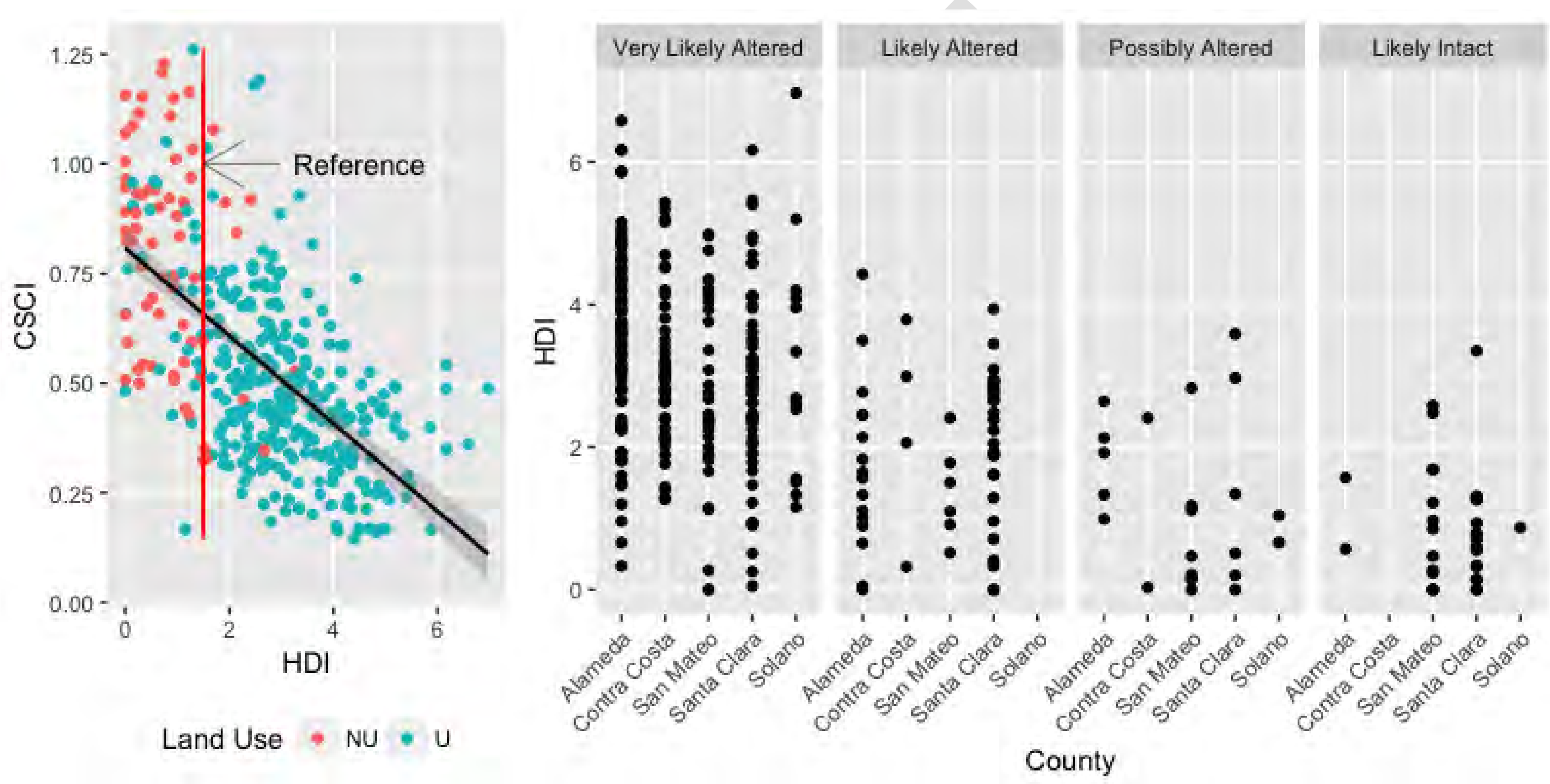

Figure 13. Relationship of the HDI stressor (Combined Riparian / Human Disturbance Index, SWAMP etc.) to CSCI scores. Red line indicates a reference condition cutoff of 1.5 (Ode et al. 2016).

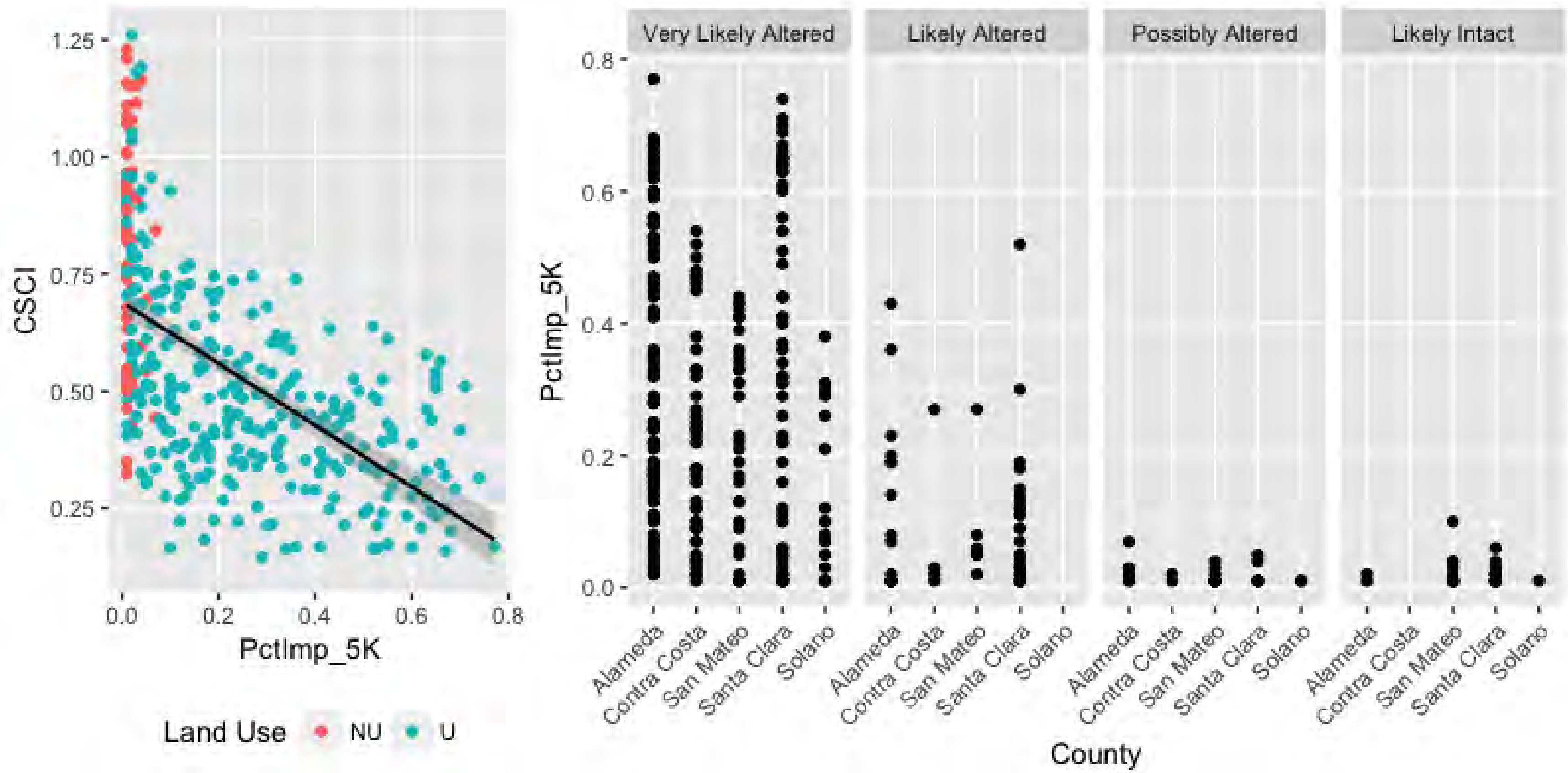

Figure 14. Relationship of the percent impervious area in 5km radius (km^2) to CSCI scores.

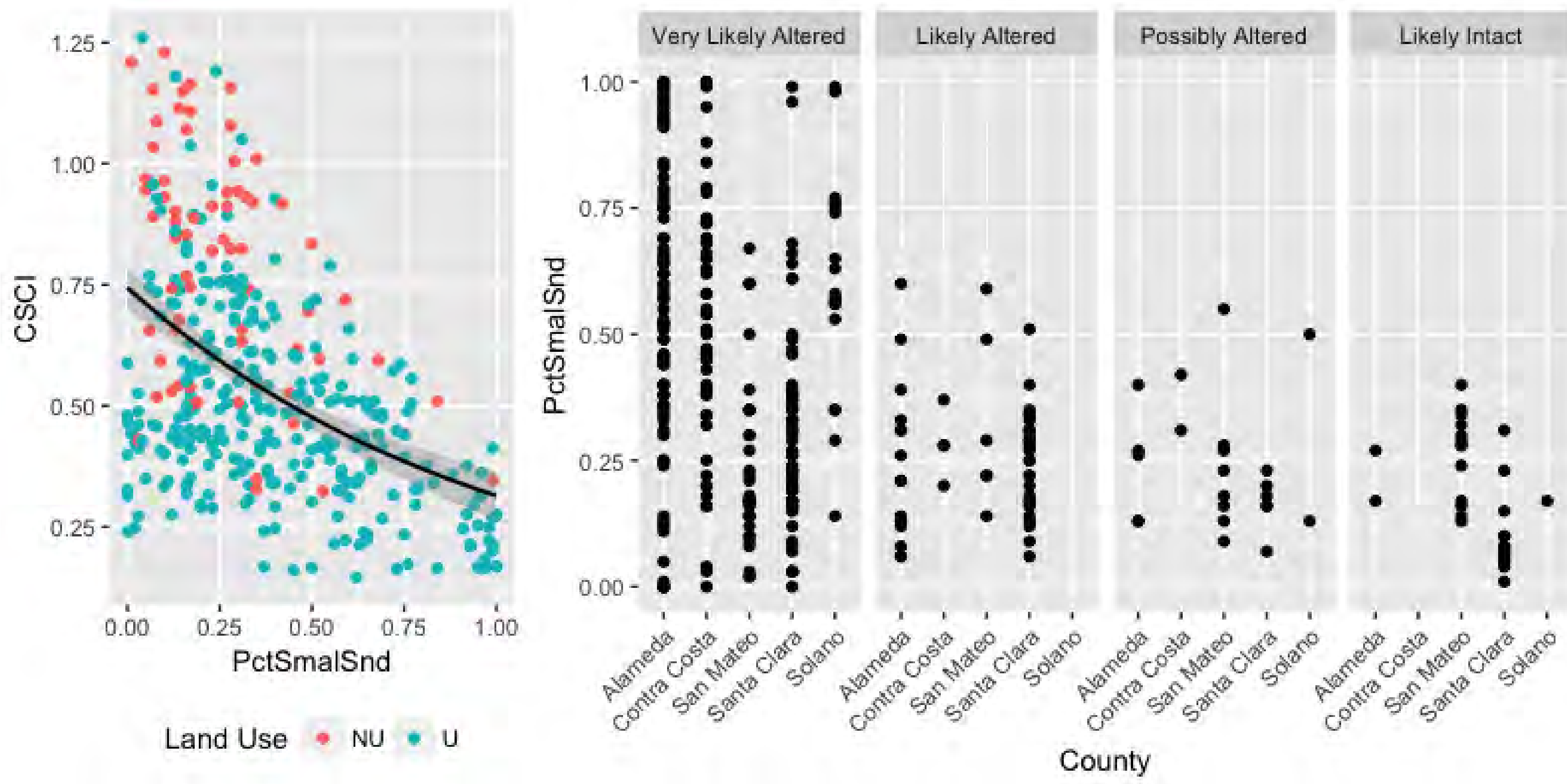

Figure 15. Relationship of CSCI score to the percent of stream habitat smaller than sand.

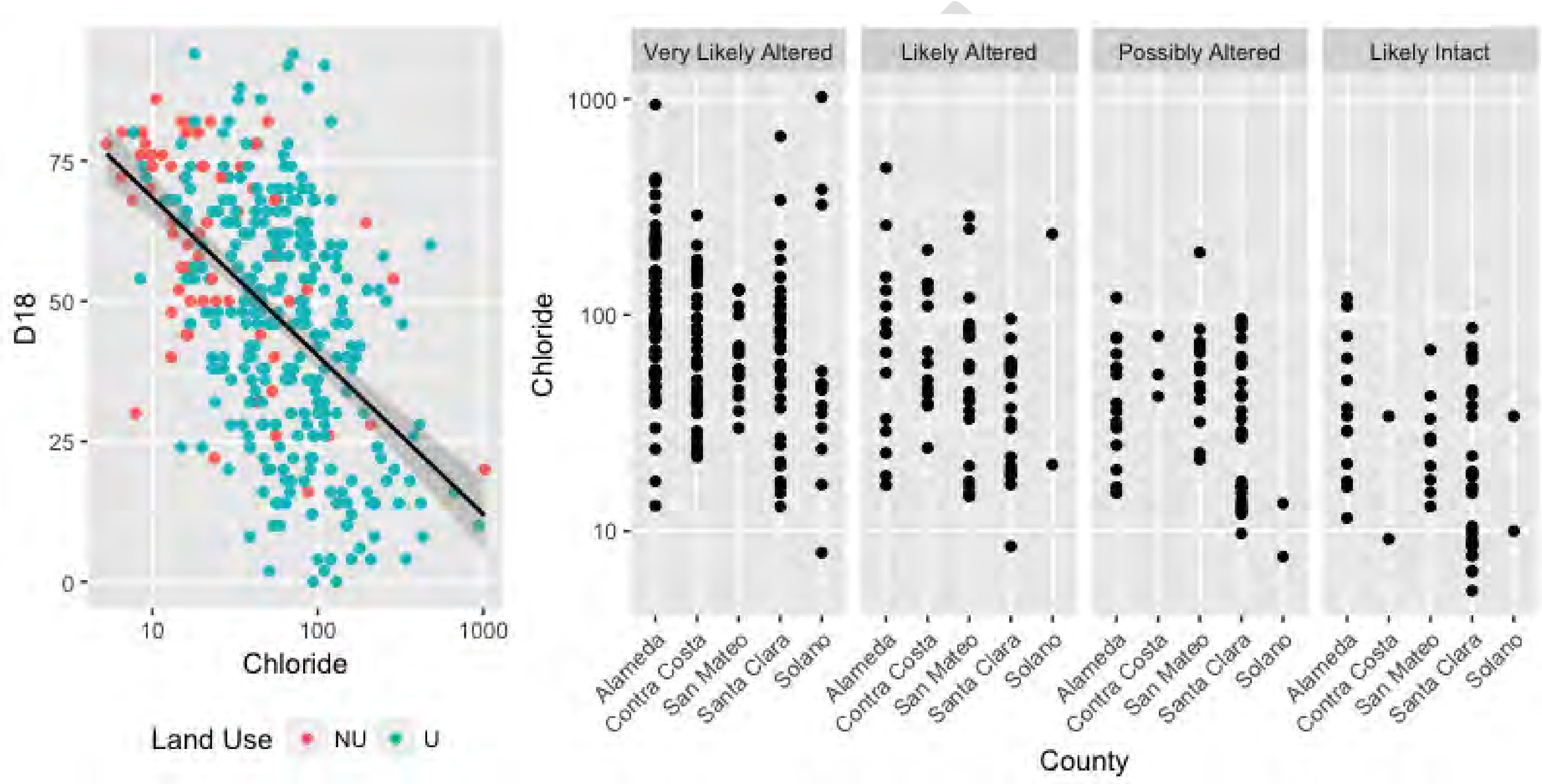

Figure 16. Relationship of D18 score to chloride concentration (mg/L). Note the chloride concentration scale is displayed in log units

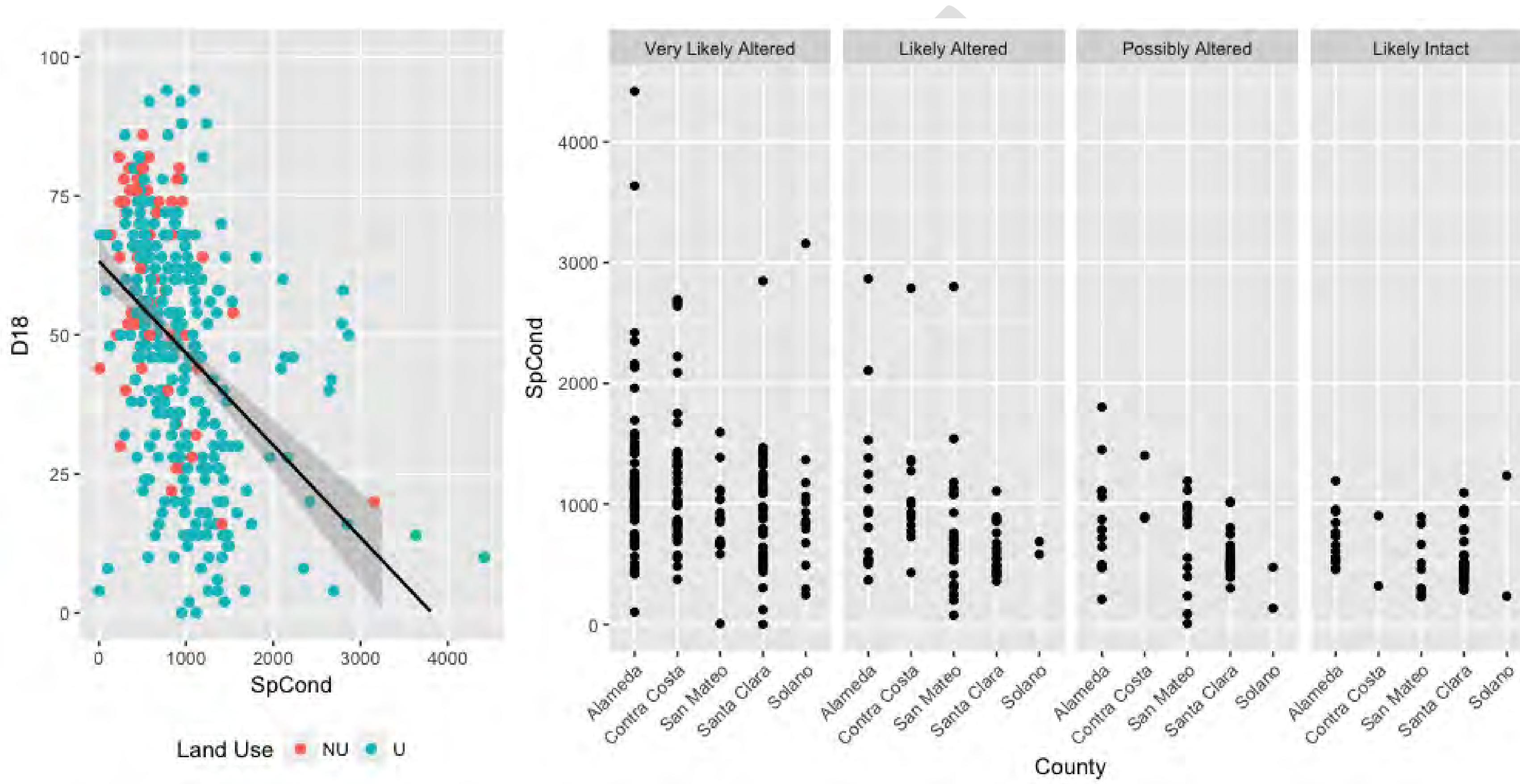

Figure 17. Relationship of D18 score specific conductivity (µS/cm).

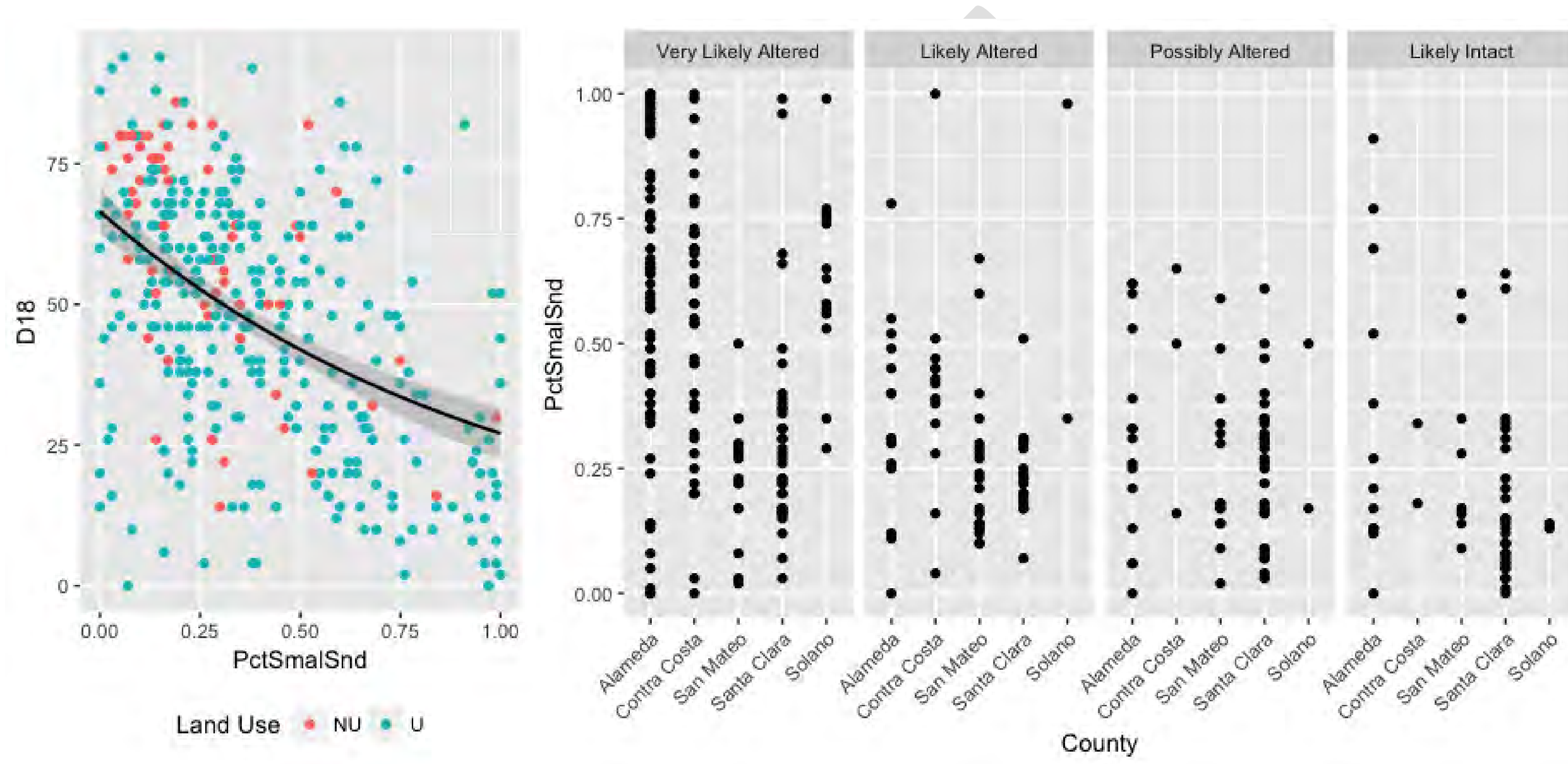

Figure 18. Relationship of the percent of reach smaller than sand to D18 scores

3.3.2 Relative Risk

The relative risk of several stressors associated with poor biological condition (based on CSCI scores) for all RMC data is shown in Figure 19. (See Section 2.4.5 for definitions of abbreviations and threshold values.) The Human Disturbance Index was the stressor with the greatest association (> 3.0) with poor biological condition. Of the remaining physical habitat stressor variables, percent substrate smaller than sand (SmalSnd) had the second highest association (1.56) with poor biological condition. The remaining six stressors, associated with water quality and water chemistry, had Relative Risk values ranging between 1.26 and 1.51. These results are consistent with the random forest model results, suggesting that physical habitat variables are more strongly associated with biological condition (based on CSCI scores) in the Bay Area compared to water quality variables.

The relative risks for the eight stressors evaluated for RMC study were consistent with the relative risks of the same stressors evaluated by SMC (Mazor 2015a), with the exception of nutrients. The SMC study showed relative risks for both Total Nitrogen and Phosphorus slightly under 3.0. The differences in relative risk suggest there may be regional differences in associations between nutrient stressors and biological condition (based on CSCI). However, it is important to note that the threshold values used by the SMC for Total Nitrogen and Phosphorus were lower than those used in the RMC data analyses.

The relative risk estimates for these stressors could not be compared among counties due to insufficient number of sites in some of the counties with either good or poor biological conditions (i.e., numerator or denominator was too small to calculate Relative Risk). Thus, potential differences between the counties for nutrient association with biological conditions could not be assessed.

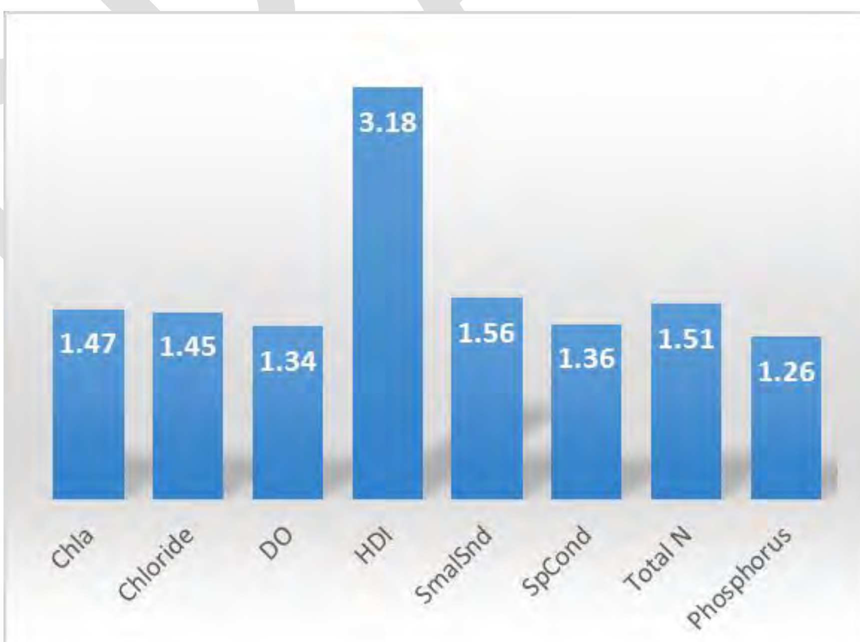

Figure 19. Relative risk of poor biological condition for eight stressors that exceed disturbance thresholds.

3.4 Trends

During the 2012-2016 monitoring period, there was no obvious trend in biological index scores. The median annual CSCI score for the non-urban sites fluctuated between 0.518 and 0.931, but estimates in three of five years (2012, 2015, 2016) were based on 10 sites or less. Estimates were particularly imprecise for 2016, where only 5 non-urban sites were sampled. In urban areas, the median score for CSCI ranged from 0.408 to 0.510. There was a clear lack of trend, with 2016 exhibiting the highest median of the five years monitored (Figure 20).

D18 and S2 scores in each of the water years followed a similar pattern to CSCI. Scores in non-urban areas tended to vary widely depending on the water year and number of sites assessed (Figures 21 and 22). However, the urban sites tended to be relatively consistent, with distributions generally corresponding to a similar range each year. One observation of note was that S2 scores at urban sites were generally lower in 2016 compared to the preceding years of the survey, while CSCI scores were higher in 2016.

Comparison of median scores for CSCI (considering all sites) and accumulated rainfall in each County did not reveal any clear patterns (Figure 23). Rainfall (measured at San Francisco International Airport) was generally low during the sampling period, relative to the long-term average (Figure 5). Regional differences in accumulated rainfall additionally contribute to the lack of discernible changes in condition over time at a regional scale. Notably, Alameda experienced the driest water year during the five-year period in 2016, while the other counties experienced the wettest year of the five years monitored. Conversely, 2012 was a relatively wetter year in Alameda but among the driest of the five-year period in the other counties.

Contra Costa exhibited the highest range in accumulated rainfall during the monitoring period (10-20 inches), and generally had lower median CSCI scores, while Alameda and Santa Clara counties experienced a similar range in accumulated rainfall (5-15 inches) but very different median CSCI scores in each water year. Future analyses to evaluated trends in biological conditions will need to consider the influence of climatic variation at the county and regional-scales.

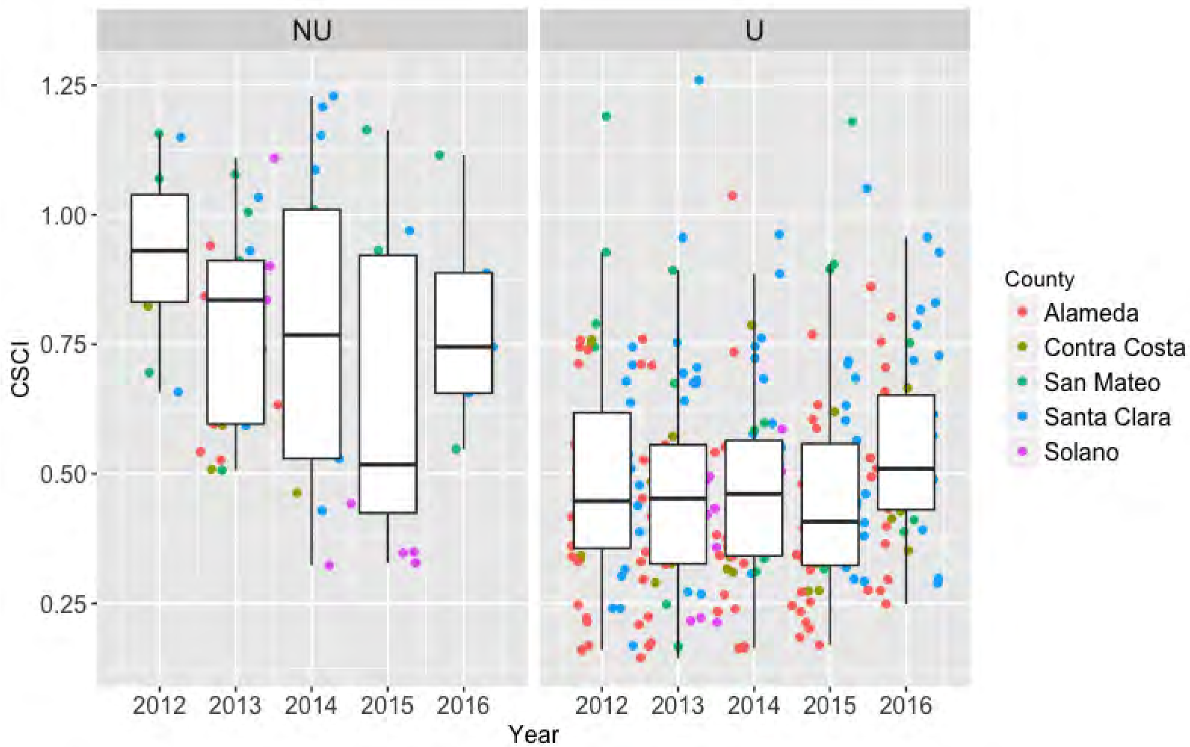

Figure 20. Distribution of CSCI scores during 2012-2016. NU = non-urban, U= urban

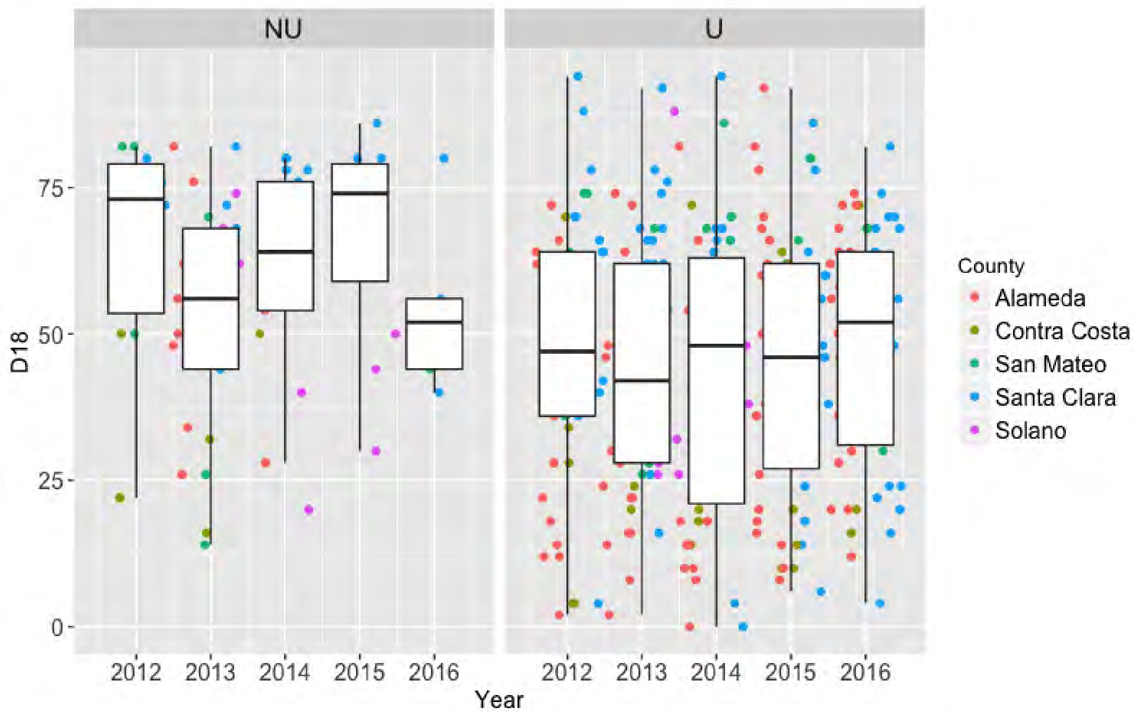

Figure 21. Distribution of D18 scores during 2012-2016. NU = non-urban, U= urban

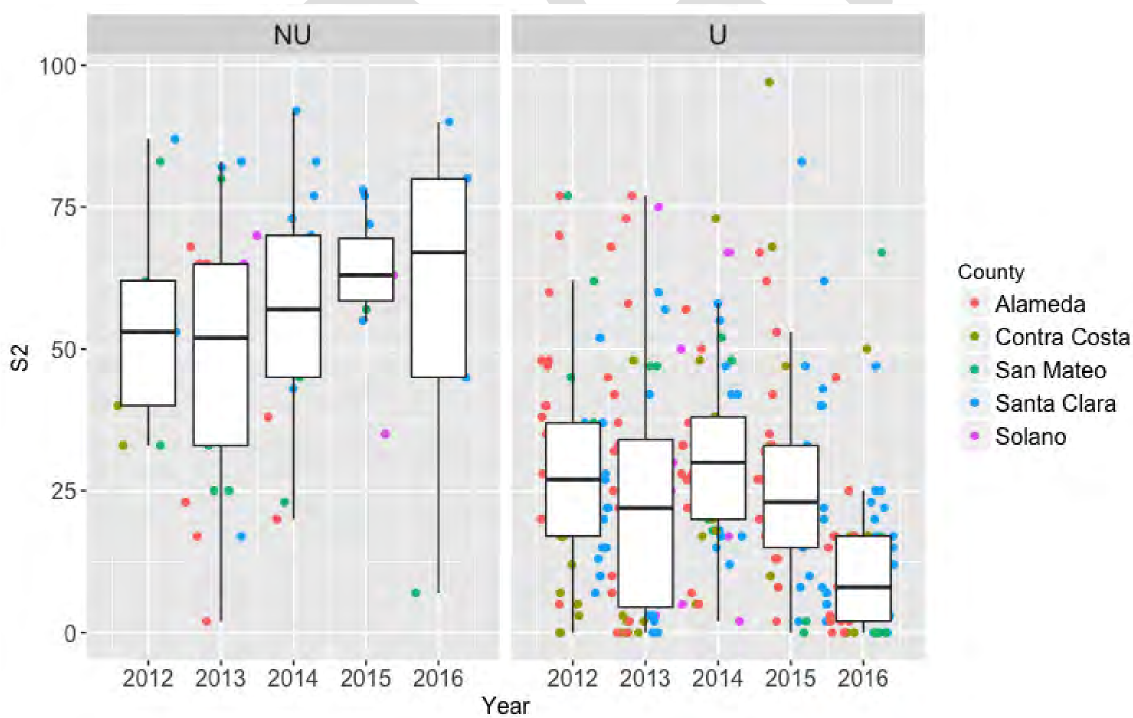

Figure 22. Distribution of S2 scores during 2012-2016. NU = non-urban, U= urban

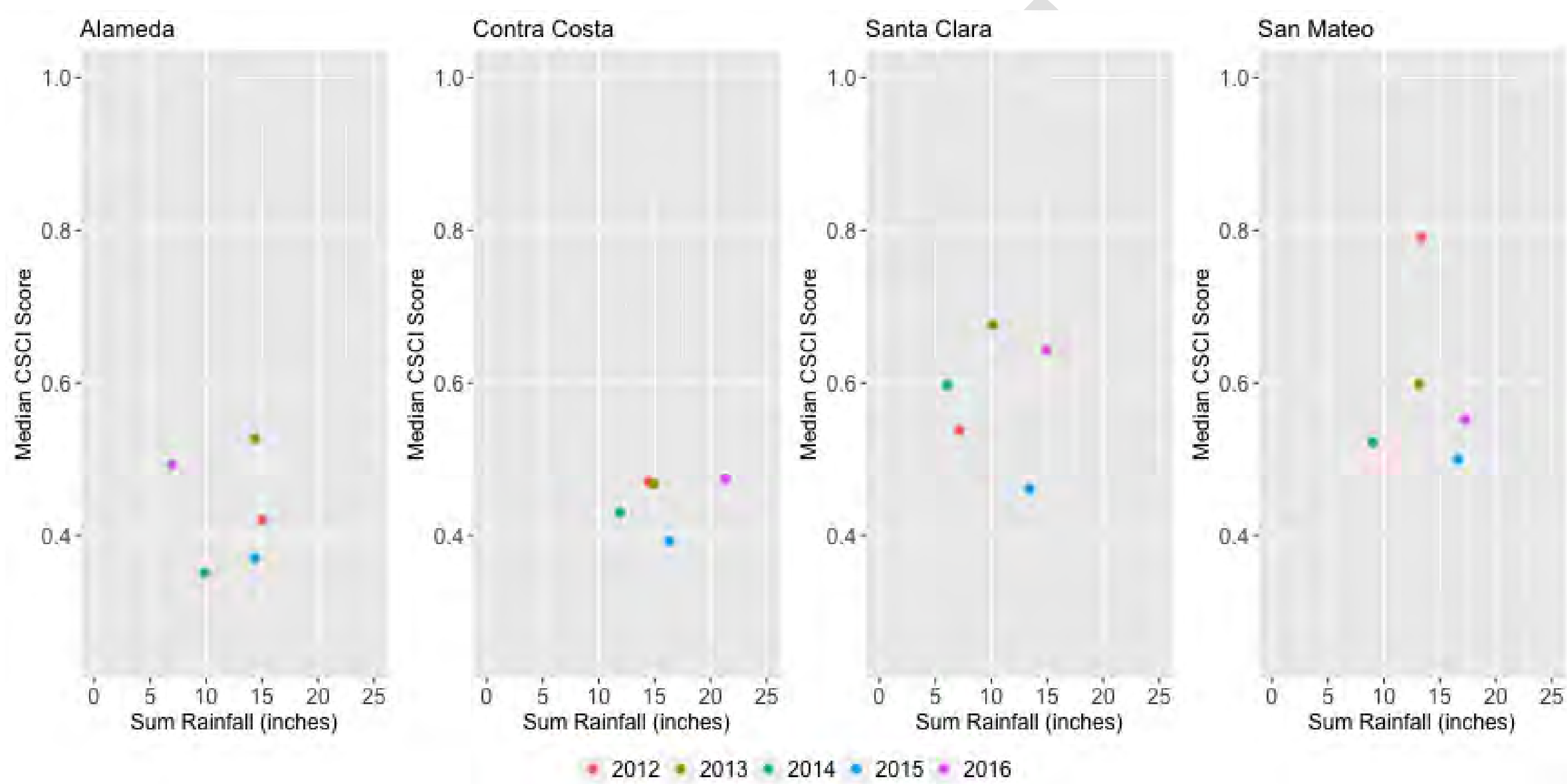

Figure 23. Relationship of accumulated annual rainfall to median CSCI score by County for each year during 2012-2016, including sites from both urban and non –urban areas

4 DISCUSSION

Study results are discussed below as they relate to the management questions and goals identified for this project.

4.1 WHAT ARE THE BIOLOGICAL CONDITIONS OF STREAMS IN THE RMC AREA?

The biological condition of streams in the RMC area was assessed using two ecological indicators: BMIs and algae. The probabilistic survey design was developed to provide an objective estimate of biological condition of sampleable streams (i.e., accessible streams with suitable flow conditions) at both the RMC area and countywide scale[6]. Results of the survey indicate that streams in the RMC area are generally in poor biological condition. As such, aquatic life uses may not be supported at a majority of sites sampled by the RMC. Two biological indicators were used to assess conditions:

- The CSCI index for benthic macroinvertebrates (BMIs) shows that 58% of streams regionwide were ranked in the lowest CSCI condition category.
- For both algae indices (D18 and S2), stream conditions regionwide appear slightly less degraded, with approximately 40% of the streams ranked in the lowest algae condition category.

These findings should be interpreted with the understanding that the survey focused on urban stream conditions. Approximately 80% of the samples (284 of 354) were collected at urban sites. As a result, the overall condition assessment represents the range of conditions found in the urban area, which is defined in the sample frame as areas classified as ”urban” in the US Census (2000) plus all areas within Census City boundaries. There was an insufficient number of non-urban samples to calculate biological conditions for the non-urban land use strata seperately, with only 2% of the sample frame sampled through 2016. In general, the biological condition assessment for the RMC area (with a focus on urban sites) was consistent with the statewide assessment of biological conditions at sites located within urban land uses (PSA 2015), which resulted in more than 90% of urban streams rated in the two lowest biological condition categories for CSCI scores.

One of the goals for the RMC monitoring design was to compare conditions of streams across counties. In general, biological conditions, based on CSCI and D18 scores, appeared better in streams located in Santa Clara and San Mateo counties, compared to other RMC counties. Higher scores in these counties may be associated with regional differences in rainfall and flow duration. For example, San Mateo and western Santa Clara county have sites in watersheds that drain the Santa Cruz mountains, which typically receive higher rainfall, in contrast to Alameda and Contra Costa counties, which primarily contain watersheds that drain the west slopes of the drier Diablo range.

[6] More samples are needed to estimate condition for non-urban land use areas and finer spatial scales (i.e., watersheds).

Santa Clara and San Mateo counties also had proportionally more non-urban sites (with higher CSCI and D18 scores) compared to other counties. CSCI scores grouped by land use class showed that all counties (except Solano) exhibit higher scores in the non-urban area. Biological condition scores at urban sites were consistently lower in all five counties, with the exception of D18, which showed regional differences (higher in San Mateo and Santa Clara counties) and overall higher scores relative to other indicators. Diatoms may respond less to habitat degradation commonly found at urban sites and provide better response to changing water quality conditions.

The use of multiple indicators provides a broad assessment of ecosystem functions. Streams that show degraded conditions for a single indicator may provide opportunities to identify the stressor and potentially implement management controls to reduce impacts. Alternatively, streams with poor conditions for both indicators (BMI and algae) may have multiple stressors that might be more challenging to remediate. Managers may also want to maintain and protect those streams that were in good biological conditions for both biological indicators.

The RMC used existing tools to assess biological condition (CSCI and SoCal Algal IBIs). These tools were also used in the regional assessments conducted by SMC, but there is still uncertainty as to how well they perform in streams within the San Francisco Bay Region.

- The CSCI is a statewide index that was developed for perennial streams; however, for the RMC project, it was used to evaluate BMI data collected in both perennial and non-perennial streams (note: the RMC assessed flow status by conducting site visits at all sites during the dry season). In addition, CSCI scores appear highly sensitive to physical habitat degradation, which occurs frequently in the many highly modified urban streams monitored by the RMC. It is not clear how well the CSCI tool can show response to stressors associated with water quality when physical habitat is the primary factor affecting the BMI community.

- For this report, the RMC evaluated algae data using SoCal Algae IBIs for diatoms (D18) and soft algae (S2). The D18 was more responsive to stressor gradients associated with water quality; however, high scores were often found in urban sites with highly degraded physical habitat. The soft algae index (S2) may not have performed well due to overall low taxa richness observed at sites throughout the RMC area. In many cases, there was insufficient number of soft algae taxa to calculate S2, resulting in data gaps. Additional testing of soft algae indices is needed to assess the utility of this indicator in the RMC area.

  The State Water Board and Southern California Coastal Water Research Project are currently developing and testing a set of statewide indices using benthic algae data as a measure of biological condition for streams in California. The statewide Algae Stream Condition Indices (ASCIs) are expected to be available in late 2018. It is anticipated that the RMC will apply the ASCIs to analyze algae data when they become available.

- The California Department of Fish and Wildlife (CDFW) has developed a statewide index for physical habitat data collected statewide using the SWAMP bioassessment protocol. The CDFW evaluated a range of physical habitat metrics for their ability to discriminate between reference and stressed sites and provide unbiased representation of waterbodies across the different ecoregions of California. The new index, referred to as Index of Physical Habitat Integrity (IPI), consists of five metrics. The IPI was not used for the stressor analysis in this report because data required to calculate metric associated with riparian canopy cover was not collected by the RMC during the first five years of bioassessments. However, three of the five metrics used in the IPI were evaluated for the stressor analysis in this report.

4.2 *WHAT STRESSORS ARE ASSOCIATED WITH BIOLOGICAL CONDITIONS?*

This question was addressed by evaluating the association between biological indicators (CSCI and D18) with stressor data through random forest and relative risk analyses. The study results indicated that each of the biological indicators responded to different types of stressors. Biological condition, based on CSCI scores, was strongly influenced by physical habitat variables, as well as land use. Condition, based on D18 scores, was moderately influenced by water quality variables and less associated with the physical or landscape variables. Since these two indicators respond to different types of stressors, they can be used in combination to assess potential causes of poor (or good) conditions.

In general, CSCI scores at urban sites were consistently low, indicating that degraded physical habitat conditions do not support healthy BMI assemblages. D18 scores at urban sites were more variable, indicating that healthy diatom assemblages potentially can occur at sites with poor habitat, but can indicate poor water quality at sites with degraded habitat.

Although results show associations between some stressors and biological condition, they do not establish causation. There are several factors that may affect the strength of the correlation between stressors and biological condition:

- Stressors are not independent of one another and may have synergistic effects on condition. For example, elevated temperatures reduce the amount of oxygen that can be dissolved in the water column and both stressors may result in adverse effects to aquatic biota.
- Potential variability of stressor concentrations over time may not be represented in a single grab sample. For example, dissolved oxygen can have a wide range of concentrations over a 24-hour period. Drops in DO concentrations typically occur in early morning hours, potentially well prior to the timing of measurements during bioassessment events.
- Many of the physical habitat variables can be highly variable throughout the sample reach. For example, a wide range of substrate grain sizes can occur within a single transect. Thus, degraded habitat conditions that may exist at selected transect(s) of the assessment reach may not be well represented in reachwide averages used as endpoints for the stressor analysis.

- Stressor impacts may be dependent on other factors (possibly not measured) for negative effects to occur. For example, elevated nutrient concentrations do not necessarily result in eutrophication (i.e., excessive plant and algal growth, reduced oxygen levels). Stream locations that have minimal exposure to sunlight, cooler water and higher flow rates may not develop eutrophic conditions, despite presence of elevated concentrations of nutrients.
- Stressors may be naturally occurring; prevalence and magnitude may vary by watershed or regionally. For example, naturally occurring nitrogen or phosphorus concentrations may be present in minimally disturbed upper watershed areas.

The development of indices that incorporate multiple stressors can lead to stronger associations with biological conditions. The State Water Resources Control Board is developing a new index to assess habitat quality (tentatively called the Index of Physical-habitat Integrity). Similar to the predictive approach used in the development of CSCI and ASCI, the IPI will be based on statistical models that account for the natural variability in stream types found throughout the state (SMC 2017). That is, sites are compared to unique benchmarks that are appropriate for local environmental conditions.

The RMC study did not evaluate the extent of stressor concentrations or levels above or below some threshold value because few thresholds have been identified for the stressors measured. For example:

- For the water quality variables collected during bioassessments, there are limited existing regulatory thresholds (e.g., Water Quality Objectives). Where WQOs do exist, they may not have thresholds that are based on associated risks to biological conditions.
- Thresholds based on reference site conditions do not exist for the RMC area because there is an insufficient amount of stressor data collected at reference sites to establish thresholds. Reference-based thresholds derived from other regions may not be representative for RMC area. Furthermore, reference-based thresholds generally result in conservative levels that may not be achievable in many streams, especially in urban streams.
- Biologically-based thresholds, primarily derived from the PSA study, were used to develop relative risk estimates for eleven stressors. Biological-based thresholds are best applied to stressors that show good dose-response to biological conditions. Thresholds can be derived by selecting distribution (e.g., 90^{th} percentile) of stressor concentrations that occur only at sites with good biological condition. In general, the relative risk for all stressors that were evaluated, with the exception of qualitative Human Disturbance Score, had similar affect to biological conditions. These results suggest that stressors are typically associated with urban stream conditions with combined effects that reduce biological conditions.

4.3 *Are Biological Conditions Changing Over Time?*

The short time frame of the survey (five years) limited the ability to detect trends. Since new sites are surveyed every year, it is expected that a much longer time period is needed to detect trends at a regional scale. The variability in biological condition observed over the five years of the current analysis may have been associated with annual variation in precipitation. Drought conditions were present during the first three years of the survey. The PSA evaluated trends for unique probabilistic sites sampled over a 13-year period and observed no trends (i.e., consistent directional change over time) (PSA 2015). Detecting trends for large geographic areas such as the Bay Area may be challenging due to regional differences in climate.

The ability to detect trends would be increased if the sample design included re-visiting sites over multiple years. Multiple surveys at individual sites would provide more site-specific detection of changing biological conditions over time. A power analysis could be used to identify the minimum number of samples needed over a specified time frame to detect trends at a site, with a specified level of confidence. The analysis could also be used to optimize the sampling program by evaluating appropriate sample sizes for detecting trends when considering expected variability in condition for different groups of sites, land use types, or management actions. For example, urban sites appear to have much lower variability in condition scores compared to non-urban sites.

4.4 EVALUATION OF MONITORING DESIGN

The information presented below is intended to guide decision making for potential revisions to procedures for implementation of the RMC Monitoring Design in the future.

4.4.1 Site Evaluations

Over the first five years of monitoring, the RMC evaluated about 25% (1455 out of 5740) of the sites in the sample frame to obtain 354 samples. Approximately 46% (873 out of 1896) of the total number of urban sites in the sample frame were evaluated during that time. Additional sites have subsequently been drawn from the sample frame and evaluated for sampling in 2017 and 2018. The number of remaining sites for evaluation in the RMC Sample Frame for each county is presented in Table 7.

Table 7. Sites Remaining in RMC Sample Frame starting 2019

<table>
<tr><th>County</th><th>Urban</th><th>Non-urban</th></tr>
<tr><td>Alameda</td><td>124</td><td>797</td></tr>
<tr><td>Contra Costa (R2)</td><td>348</td><td>307</td></tr>
<tr><td>Contra Costa (R5)</td><td>NA</td><td>331</td></tr>
<tr><td>Santa Clara</td><td>143</td><td>1189</td></tr>
<tr><td>San Mateo</td><td>67</td><td>469</td></tr>
<tr><td>Fairfield-Suisun</td><td>37</td><td rowspan="2">208</td></tr>
<tr><td>Vallejo</td><td>4</td></tr>
</table>

Based on rejection rates from previous years, the sample frame is anticipated to only last two to three years at which time the urban sites will be exhausted. Revision of the RMC monitoring design could seek to reduce the future rejection rate through re-evaluation of the sample frame to exclude areas of low management interest or regions that would not be candidates for sampling (such as due to lack of permissions or physical barriers to access). This would improve the spatial balance of samples that more closely represents the proportion of the sample frame that can be reliably assessed.

Each countywide stormwater program managed their site evaluation information independently using a standardized database. The site evaluation data were then compiled to conduct the spatial analysis needed to calculate the regional biological condition estimates presented in this report. During the compilation process, inconsistencies in procedures used to conduct site evaluation (BASMAA 2016a) were identified that affect the statistical certainty of the regional estimates. Some sites in the sample draw were skipped over (e.g., challenges in obtaining permissions from private land owners, lack of flow during period of drought) with the intention to re-evaluate the sites at a future date. The skipped sites created sampling bias that affects the spatial balance of the draw and reduces certainty in the condition estimates.

Another issue was the disproportionate sampling of non-urban sites among the counties. The RMC intended to sample twenty percent of the targeted sites each year. Some Programs had difficulty getting access to non-urban sites, or decided to focus on urban sites, resulting in a wide range in number of samples collected at non-urban sites across the counties. As a result, biological condition scores at the county scale tended to be higher in counties that sampled more non-urban sites.

4.4.2 RMC Sample Frame

Consistent with the PSA, the RMC sample design was created to probabilistically sample all streams within the RMC area, which resulted in a master list of 33% urban sites and 67% non-urban sites. However, because participating municipalities are primarily concerned with runoff from urban areas, the RMC focused sampling efforts on urban sites (80%) over non-urban sites (20%). As a result, non-urban samples are under-represented in the dataset resulting in much lower overall biological condition scores than would be expected for a spatially balanced dataset. In addition, the limited number of non-urban samples (2% sample frame assessed thru-2016) prevented statistical confidence in estimates of biological condition for non-urban land use at the regional scale.

Depending on the goals for the RMC moving forward, the RMC may want to consider developing a new sample draw that establishes a new list of sites that is weighted for specific land uses categories and Program areas of interest. Development of a revised sample frame would result in a new list of sites, associated with different length weights for each land use category. The sample draw could also include a list of sites for oversampling to maintain the spatial balance throughout any timeframe of the draw, and allow for a much longer time frame before the list is exhausted.

Re-design of the RMC sample frame could also include new strata based on developed channel classifications created by SCCWRP. The classifications are created using a statistical model that predicts likely ranges of CSCI scores based on landscape characteristics (Mazor et al. 2018). These channel classifications could be integrated as strata into the RMC sample frame to allow varying sampling efforts for urbanized streams.

4.4.3 RMC Monitoring Design

Based on evaluation of data collected during the first five years of the survey, several options to revise the RMC Monitoring Design are presented below:

1) Continue to sample new probabilistic sites
2) Re-visit probabilistic sites for a trends assessment
3) Monitor targeted sites for special studies
4) Combination of two or more of the above

Each of these options are discussed in more detail below.

Continue Sampling New Probabilistic Sites

The RMC could continue to sample new probabilistic sites from the current sample frame with the goal to establish baseline conditions over smaller spatial scales. Eventually, statistically significant datasets would be obtained to estimate biological condition for all strata previously considered (i.e., non-urban and countywide), as well as finer scales (e.g., watersheds). Smaller geographic scales of assessments may provide stronger associations between biological conditions and stressor levels. Watershed-level assessments may provide managers more opportunities to evaluate spatial patterns and temporal trends for specific watersheds.

Exclusively sampling new sites would exhaust sites in the current sample draw. It is anticipated that at the current rate of sampling (at same proportion of urban/non-urban sites), some of the Programs would run out of urban sites in two to three years. Solano County has already depleted urban sites from their sample frame. Sampling effort at new non-urban sites should be also be evaluated. Resources to conduct site evaluations (e.g., permission to access private property) are typically much higher at non-urban sites. In addition, the access to non-urban sites appears to be highly variable by county.

If this option is desired, the RMC could develop a new probabilistic sample draw with a list of sites for oversampling as described above.

Re-visit Probabilistic Sites for Trends Assessment

Re-visiting probabilistic sites previously sampled would provide trend estimates and more refined information to potentially explain causes of observed trends. The most robust trends scenario would involve sampling the same sites each year; however, given the current level-of-effort, this would only be possible at a relatively small number of sites in each county. Thus, the resulting trends assessment could only answer regional questions. Some sites could be sampled for multiple years to evaluate potential variability related to changes in precipitation; non-urban sites may be particularly sensitive to annual variation in precipitation. Integrating site re-visits into the sample design would have the advantage of extending the life of the sample frame (i.e., reduce number of new sites each year).

Targeted Studies

There are several potential objectives for conducting biological assessments at targeted sites, including:

1) Evaluate effectiveness of stream restoration/BMP implementation projects;
2) Determine source/stressor at impaired site (i.e., causal assessment);
3) Evaluate conditions in selected watersheds;
4) Study trends at minimally disturbed sites (e.g., climate change);
5) Investigate variability in biological indicator scores within sampling index period.

Targeted studies could be coordinated among RMC participants to evaluate similar objectives at regional scale or could be done independently by each Program. It is anticipated that targeted studies may require more resources with regards to site selection, data needs, detailed analyses, and reporting. However, targeted monitoring could also leverage requirements that Permittees have for other projects.

Combined Approaches

The RMC may consider implementing a combination of all the approaches described above for the future monitoring design. The SMC recommends a combination of 50% re-visit probabilistic sites (trends monitoring and 50% new probabilistic sites (ambient monitoring) until the sample frame is exhausted.

5 Conclusions and Recommendations

The following conclusions and recommendations are made based on a comprehensive analysis of a five-year dataset (i.e., WY 2012–WY 2016) from regional biological assessment survey conducted by the RMC.

5.1 Biological condition

Stream condition was assessed using three different types of indices/tools: the BMI-based CSCI and two benthic algae-based IBIs developed for Southern California (D18 and S2).

- The distribution of CSCI scores suggests the majority of streams in the RMC sample area do not support healthy biological conditions. Over half (58%) of the stream-length was in the Very Likely Altered condition class for CSCI; 74% of the sampled stream length was below the MRP trigger for CSCI scores (0.795).
- Both of the algae index scores (D18 and S2) exhibited slightly less degraded conditions compared to CSCI. Approximately 40% of the stream-length was in the Very Likely Altered condition class for D18 and S2 indices. The algal indices also had greater stream length in Likely Intact condition class (19-21%) compared to CSCI score (15%).
- Condition estimates indicate that the majority of poor scores were derived from urban sites. Approximately, 80% of urban stream length for CSCI scores, 50% for D18 scores, and 65% for S2 scores corresponded to the Very Likely Altered condition class. In contrast, less than 10% of the urban stream length for BMI or algae scores was in the Likely Intact condition (4% CSCI; 9% D18; 7% S2).
- Generally, BMI and algae scores in the non-urban area were higher than scores in the urban area for each county. Contra Costa had sites in the non-urban area with scores similar to urban sites. The low non-urban sample size precludes making any definitive comparisons; however, it was noteworthy that sites in the urban areas may receive similar or higher condition scores than sites in the non-urban area.

5.2 Stressors

Relationships between potential stressors (physical habitat and water chemistry) and biological condition (CSCI and D18 scores) were explored using statistical analyses (i.e., Random Forest models) and relative risk analyses.

- The Random Forest model performed better using CSCI scores compared to D18 scores. Validation of the final random forest models showed that the CSCI model explained 61% of the variance using eight predictor variables, while the D18 model was explained 34% of the variance using six predictors.

- The CSCI random forest model indicated that land use and physical habitat were the most influential variables on biological condition. Of the eight variables in the final model, four were landscape variables, three were habitat variables, and one was a water quality variable. Overall, the largest influence on the CSCI random forest model was percent impervious area in a 5 km radius.
- None of the nutrient variables (e.g., nitrate, total nitrogen, orthophosphate, phosphorus) correlated with CSCI scores, or were highly ranked variables in the CSCI random forest model runs.
- The random forest model for D18 indicated a different pattern to the explanatory variables compared to CSCI, with water quality variables exerting greater influence. Of the six variables in the final model, four were water quality variables (SpCond, Chloride, AFDM, Phosphorus), one was a habitat variable (PctSmalSnd), and one was a landscape variable (RdDen_1k).
- For the CSCI random forest model output, the plots of habitat and landscape variables indicate patterns of dose-response. For example, the HDI stressor variable indicated that poor condition scores are predicted when HDI exceeds a value of 2 and the variable 'percent imperviousness in 5km' exceeds 10% imperviousness.
- In the D18 random forest model output, all four of the water quality variables (i.e. SpCond, Chloride, AFDM, Phosphorus) showed general relationships. But, the variables were inconsistent in the separation of good and bad sites.
- As with CSCI, none of the nutrient variables considered in the model exhibited a significant correlation with D18 scores. Although phosphorus was ranked highly in the random forest model, no statistically significant relationship was observed.
- Eight stressor variables were selected to conduct a relative risk analyses. Six of the stressor thresholds were derived from statewide data collected for the PSA. The thresholds were based on the 90th percentile of data collected at bioassessment sites that exhibited good biological condition (i.e., CSCI scores > 0.92). Human Disturbance Index was the stressor with the greatest association (> 3.0) with poor biological conditions. The remaining seven stressors had moderate association with poor conditions, with Relative Risk values ranging between 1.26 and 1.56.

5.3 Trends

Biological condition indicator scores over five years of sampling were assessed for trends.

- There has been no obvious trend in biological index scores. In urban areas, the median score for CSCI ranged from 0.408 to 0.510, with 2016 exhibiting the highest median of the five years. D18 and S2 scores followed a similar pattern to CSCI.
- The median score for the CSCI in non-urban sites fluctuated between 0.518 and 0.931, but median scores in three of five years (2012, 2015, 2016) were based on 10 sites or less. The median score generally decreased over the first four years, then increased in 2016. The S2

scores had an opposite pattern, generally increasing over the five years of sampling. No trends were observed with D18 scores at non-urban sites.

- CSCI scores did not appear to have any association with annual rainfall totals over the five years of study.

5.4 Evaluation of the RMC Survey Design

- Approximately 30-40% of the urban sites remain in the sample draw for evaluation in 2019 and beyond. However, Solano County has already evaluated all the sites in the sample frame and will need to re-visit sites during the next sampling event. For the remaining counties, the sample frame is anticipated to last two to three years until the urban sites are exhausted.
- The RMC sample draw was initially created to equally weight sites for all strata (e.g., land use and Program areas). However, as the sampling approach focused on urban sites, length weights were recalculated. As a result, non-urban samples are under-represented in the dataset and contribute a higher proportion of stream length to the condition estimates than urban sites. Assessments of regional biological condition are much lower than would be expected for more spatially balanced draw.
- Inconsistencies in standard procedures for conducting site evaluations were identified (e.g., skipping sites in the sample draw) and may affect the statistical certainty of the regional condition assessment.

Recommendations

- The RMC should develop an approach to better manage the site evaluation data. Work may include compilation and review of the site evaluation tracking database on an annual basis to determine if SOPs (BASMAA 2016b) are being followed and take corrective action when necessary.
- The inconsistent sampling of non-urban sites across the Programs should be evaluated during the monitoring re-design process. The RMC should evaluate the need to collect data at non-urban sites and resources available to do so.

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7 APPENDICES

7.1 RANDOM FOREST ANALYSIS

Table A. Variable group, variable code, and description of response variables (condition indices) and explanatory environmental variables (landscape, habitat, and water quality) used for random forest model development.

Variable Group	Variable Code	Description
Response	CSCI	California Stream Condition Index
Response	D18	Soft algae condition score
Habitat	AvAlgCov	Mean Filamentous Algae Cover
Habitat	AvBold	Mean Boulders cover
Habitat	AvWetWd	Mean Wetted Width/Depth Ratio
Habitat	AvWoodD	Mean Woody Debris <0.3m cover
Habitat	ChanAlt	Channel Alteration Score
Habitat	EpiSub	Epifaunal Substrate Score
Habitat	FlowHab	Evenness of Flow Habitat Types
Habitat	NatShelt	Natural Shelter cover - SWAMP
Habitat	NatSub	Evenness of Natural Substrate Types
Habitat	PctBold_L	Percent Boulders - large
Habitat	PctBold_LS	Percent Boulders - large & small
Habitat	PctBold_S	Percent Boulders - small
Habitat	PctFin	Percent Fines
Habitat	PctFstH20	Percent Fast Water of Reach
Habitat	PctGra	Percent Gravel - coarse
Habitat	PctSlwH20	Percent Slow Water of Reach

Variable Group	Variable Code	Description
Habitat	PctSmalSnd	Percent Substrate Smaller than Sand (<2 mm)
Habitat	PctSnd	Percent Sand
Habitat	ShD.AqHab	Shannon Diversity (H) of Aquatic Habitat Types
Habitat	ShD.NatSub	Shannon Diversity (H) of Natural Substrate Types
Land Use	HDI	Combined Riparian Human Disturbance Index - SWAMP
Land use	PctImp	Percent Impervious Area of Reach
Land use	PctImp_1K	Percent Impervious Area in 1km
Land use	PctImp_5K	Percent Impervious Area in 5km
Land use	PctUrb	Percent Urban Area of Reach
Land use	PctUrb_1K	Percent Urban Area in 1km
Land use	PctUrb_5K	Percent Urban Area in 5km
Land use	RdCrs_5K	Number Road Crossings in 5km
Land use	RdCrs_W	Number Road Crossings in watershed
Land use	RdDen_1K	Road Density in 1km
Land use	RdDen_5K	Road Density in 5km
Land use	RdDen_W	Road Density in watershed
Land use	RoadCrs_1K	Number Road Crossings in 1km
Water Quality	AFDM.sub	Ash Free Dry Mass
Water Quality	Ammonia.sub	Ammonia
Water Quality	Chla.sub	Chlorophyll a
Water Quality	Chloride	Chloride
Water Quality	DO	Dissolved oxygen
Water Quality	Nitrate.sub	Nitrate
Water Quality	Nitrite.sub	Nitrite
Water Quality	OP.sub	Orthophosphate
Water Quality	pH	pH

Variable Group	Variable Code	Description
Water Quality	Phosphorus.sub	Phosphorus
Water Quality	Silica	Silica
Water Quality	SpCond	Specific conductivity
Water Quality	Temp	Temperature
Water Quality	TKN.sub	Total Kjeldahl Nitrogen
Water Quality	Total N	Total Nitrogen
Water Quality	UIA.sub	Unionized Ammonia

Table 1B. Model and cross-validation statistics for random forest models with CSCI and D18 scores using the final set of model variables (Table 2, Table 3)

Index	Model Dataset	Model Statistic	
CSCI	Training	R^2	0.95
	Validation	R^2	0.61
CSCI	Training	CV R^2	0.66
	Validation	CV R^2	0.52
D18	Training	R^2	0.92
	Validation	R^2	0.34
D18	Training	CV R^2	0.35
	Validation	CV R^2	0.33

Training and validation models run with the same variables, *R^2 = adjusted R-squared, CV R^2 = Cross validation R^2

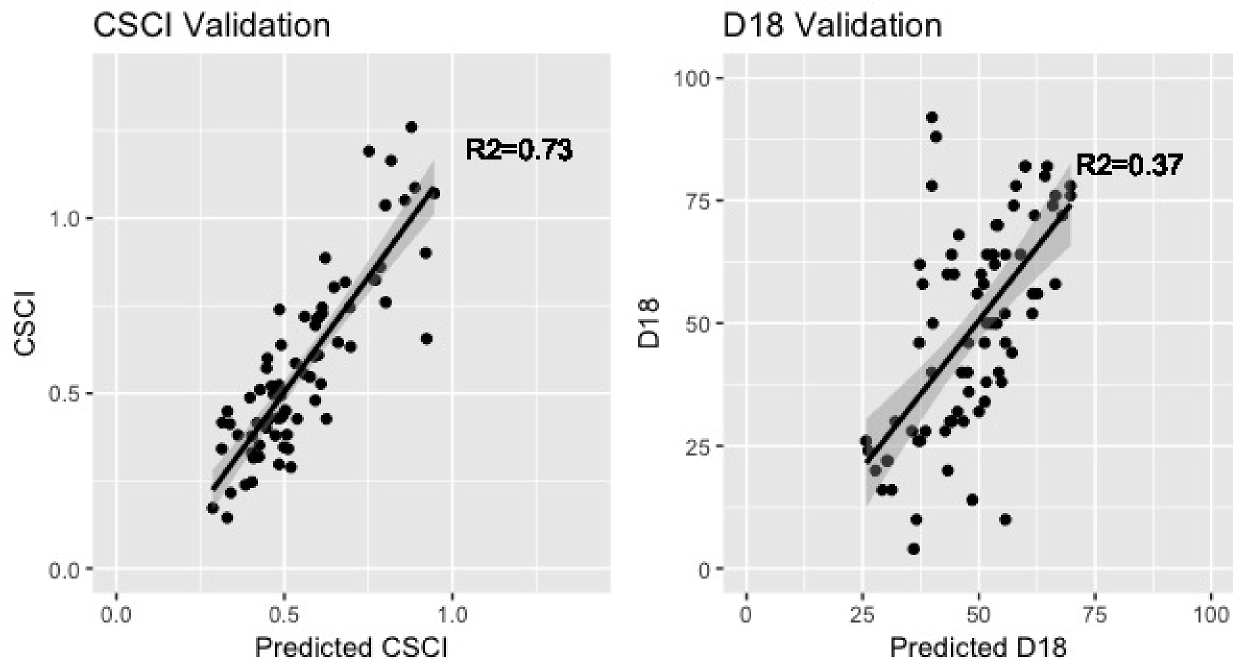

Figure A. Relationship of observed to predicted CSCI and D18 scores in the validation dataset using all 49 explanatory variables in Step 1 of the random forest trial

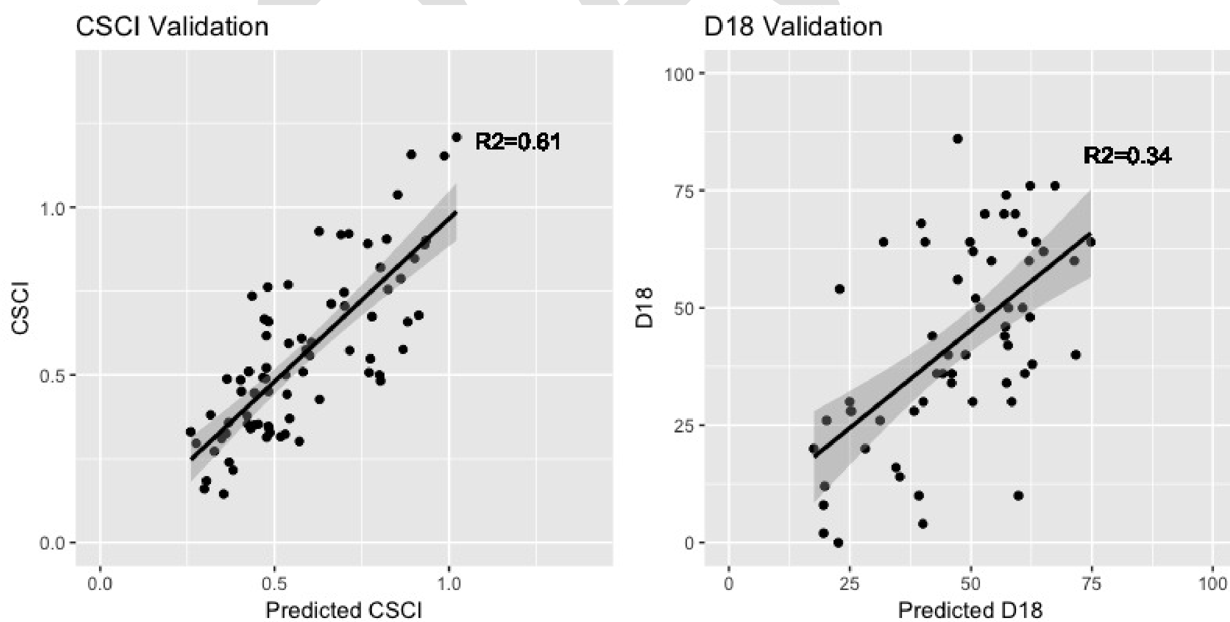

Figure B. Relationship of observed to predicted CSCI and D18 scores in the validation dataset using the final, selected list of explanatory variables in Step 2 of the random forest trial

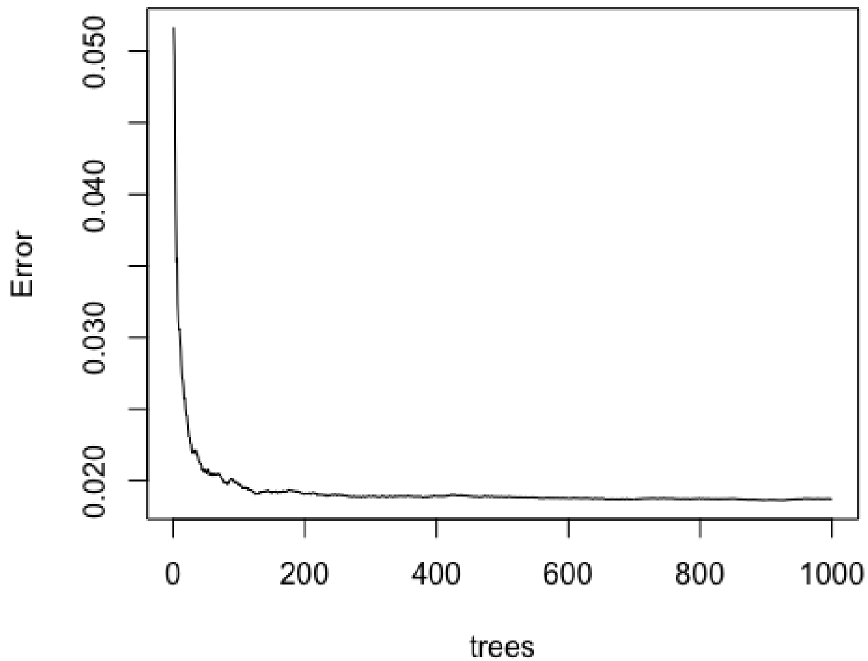

Figure C. Prediction error vs. number of trees in the CSCI model with 49 stressor variables

7.2 Partial Dependency Plots

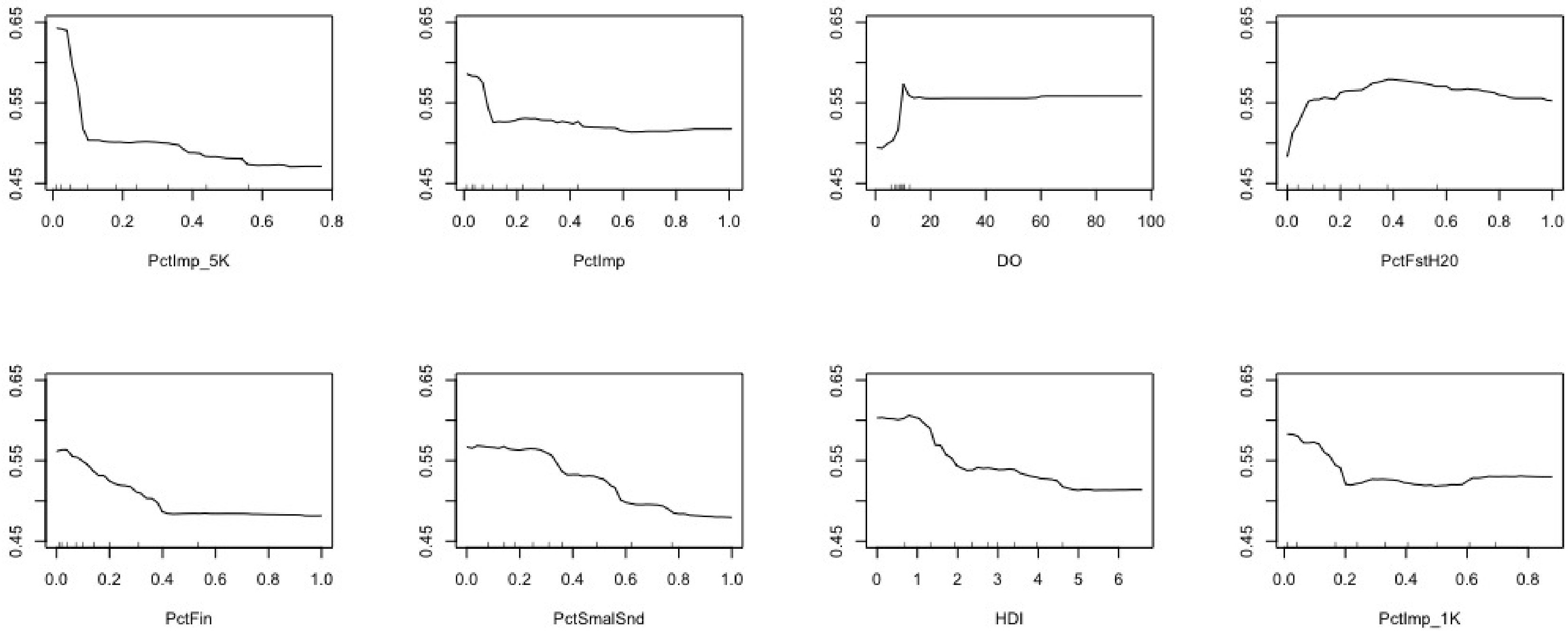

Figure A. Partial dependency plots for stressor variables in random forest model of CSCI condition. Plots show the predicted response of CSCI (y-axis) based on the effect of individual explanatory variables (x-axis) with the response of all other variables removed in the training data set.

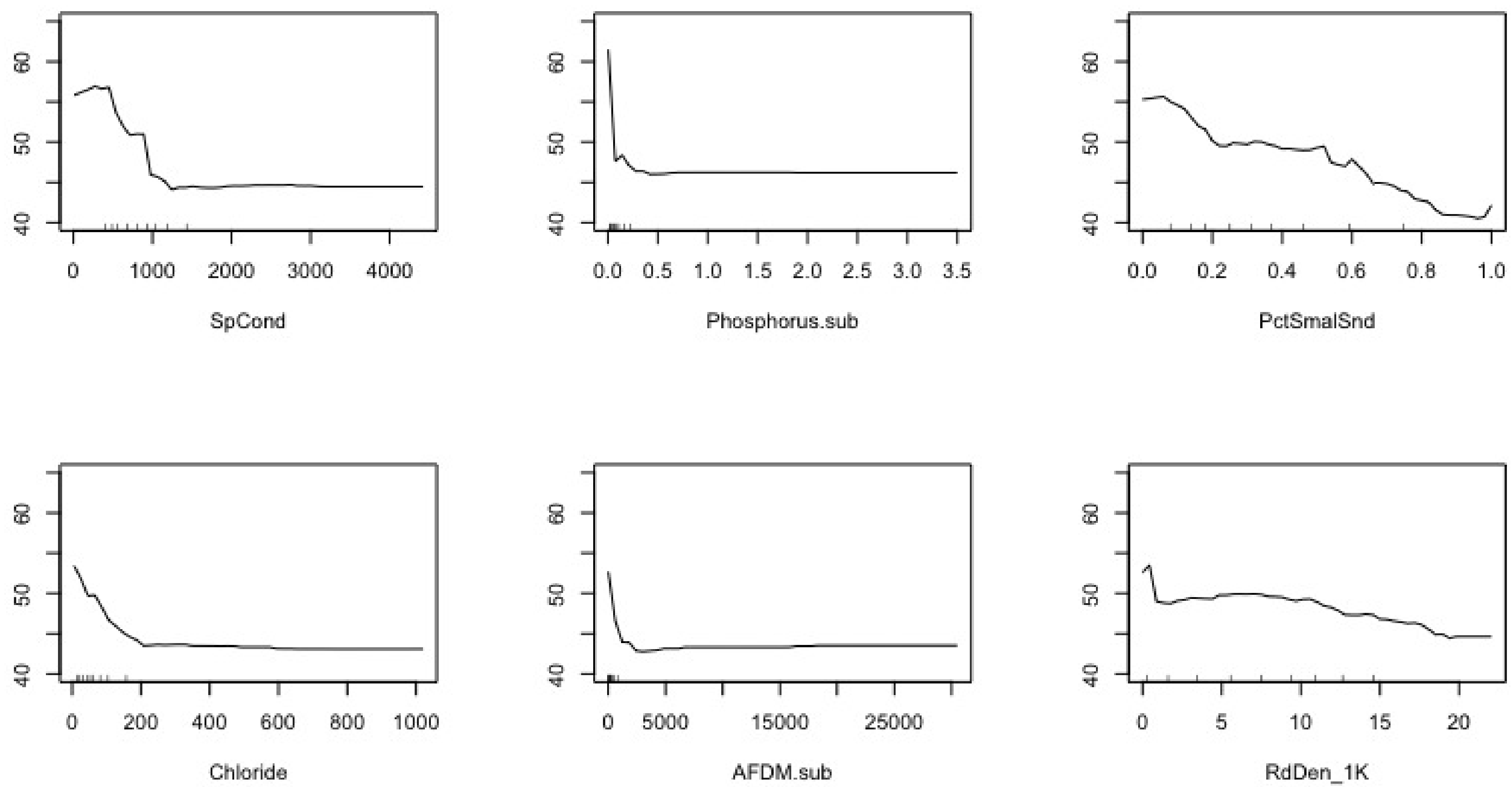

Figure B. Partial dependency plots for stressor variables in random forest model of D18 condition. Plots show the predicted response of D18 (y-axis) based on the effect of individual explanatory variables (x-axis) with the response of all other variables removed in the training data set.

7.3 CSCI-Stressor Plots

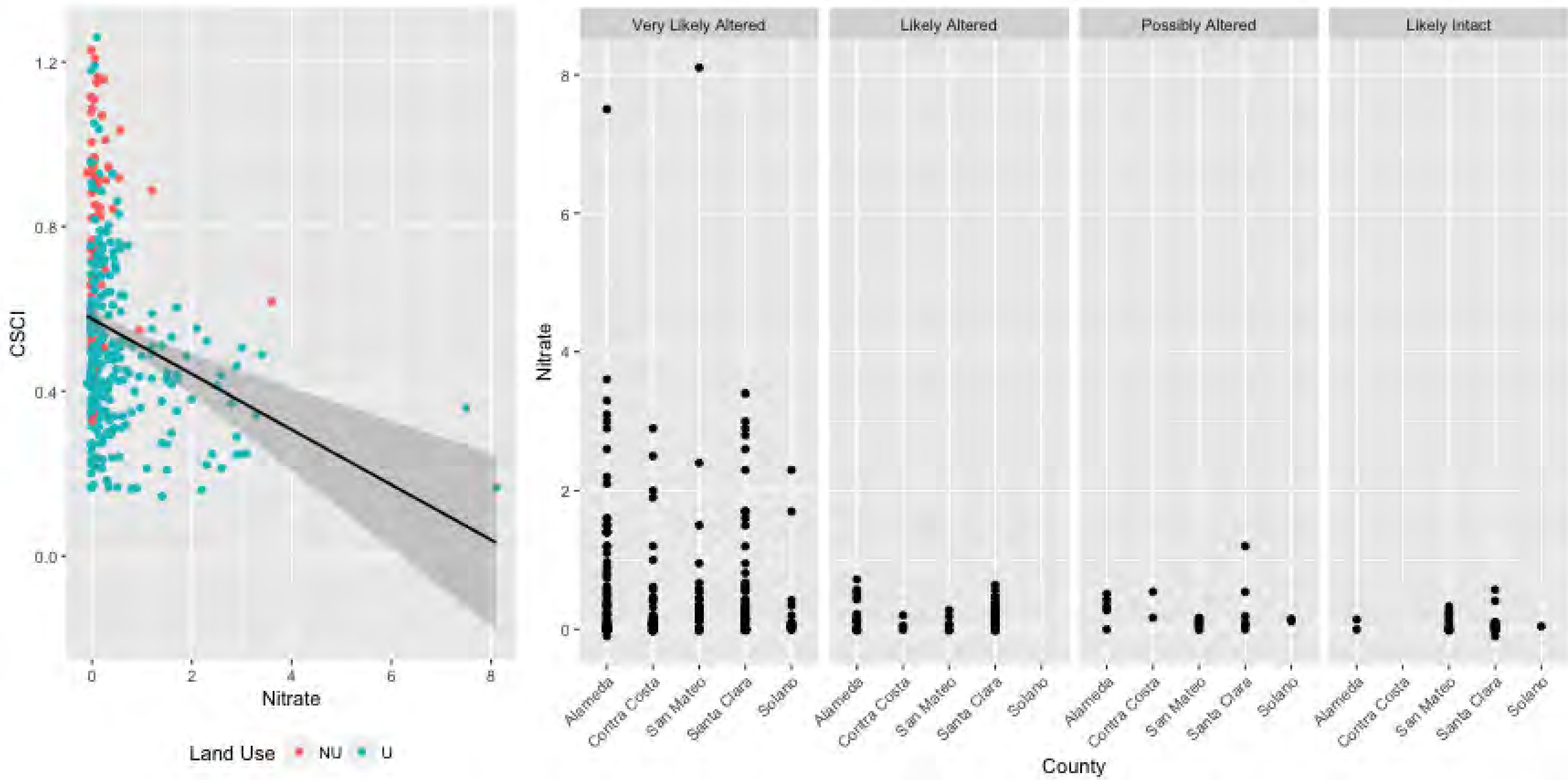

Figure A. Relationship of Nitrate concentration to CSCI scores

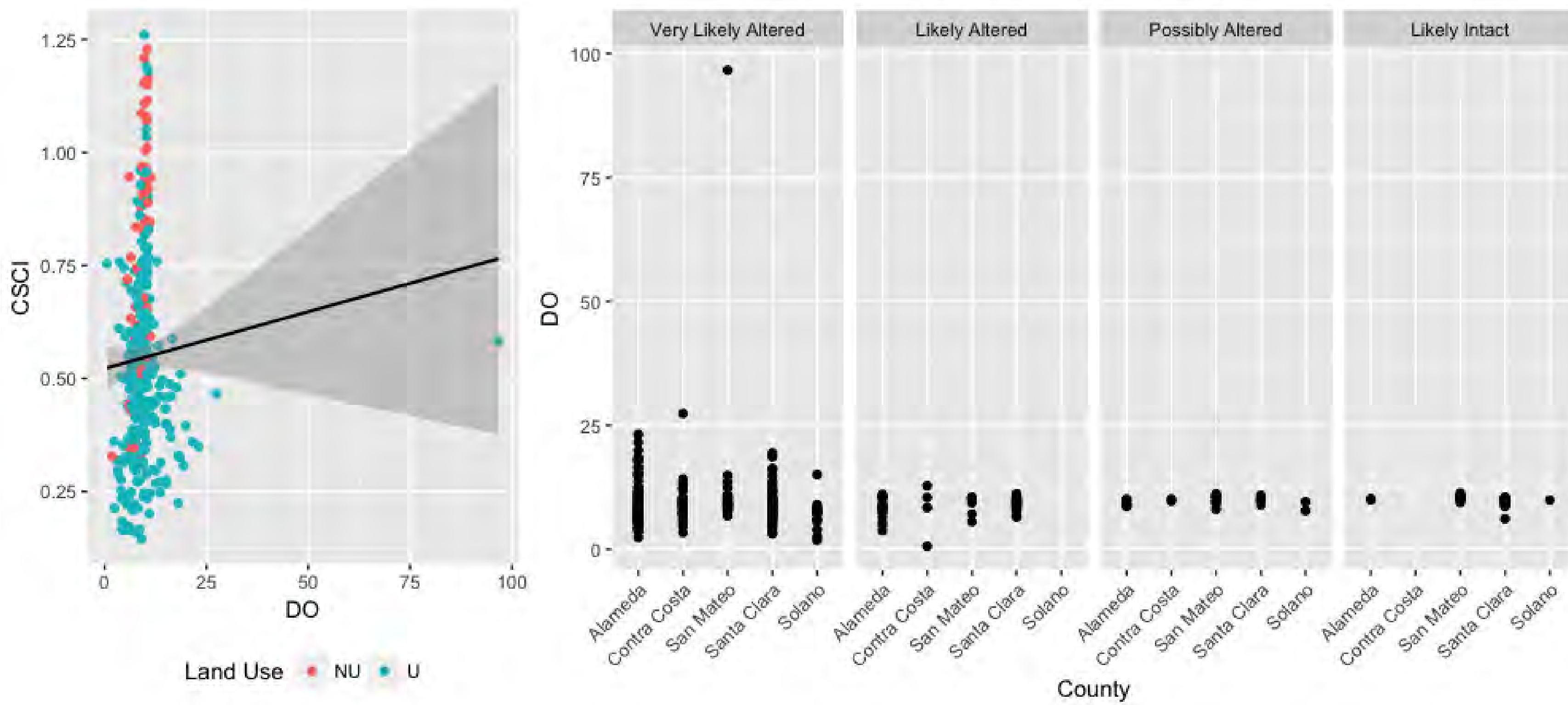

Figure B. Relationship of Dissolved Oxygen values to CSCI scores

7.4 Additional Figures

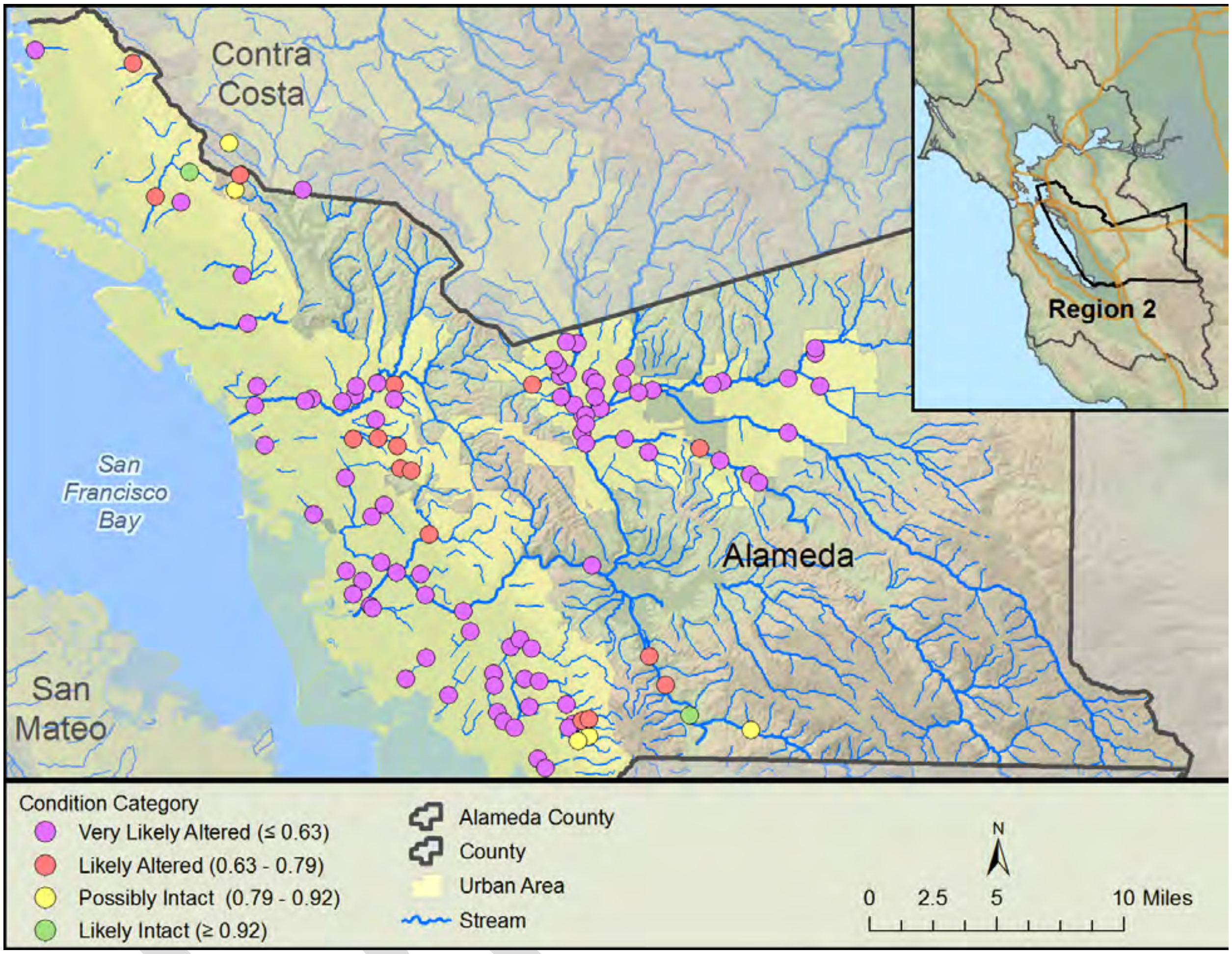

Figure A. Biological condition based on CSCI scores in Alameda County.

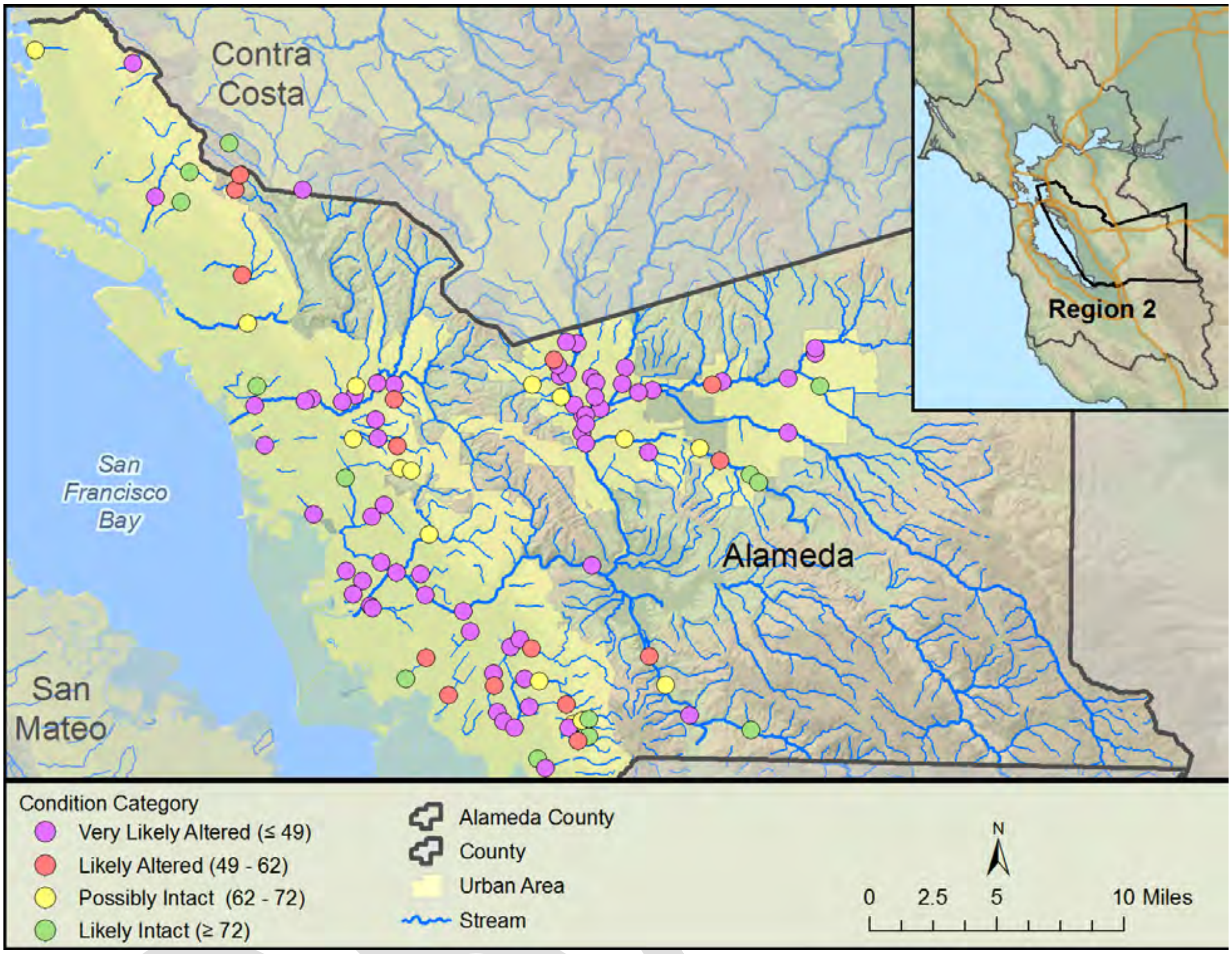

Figure B. Biological condition based on D18 scores in Alameda County.

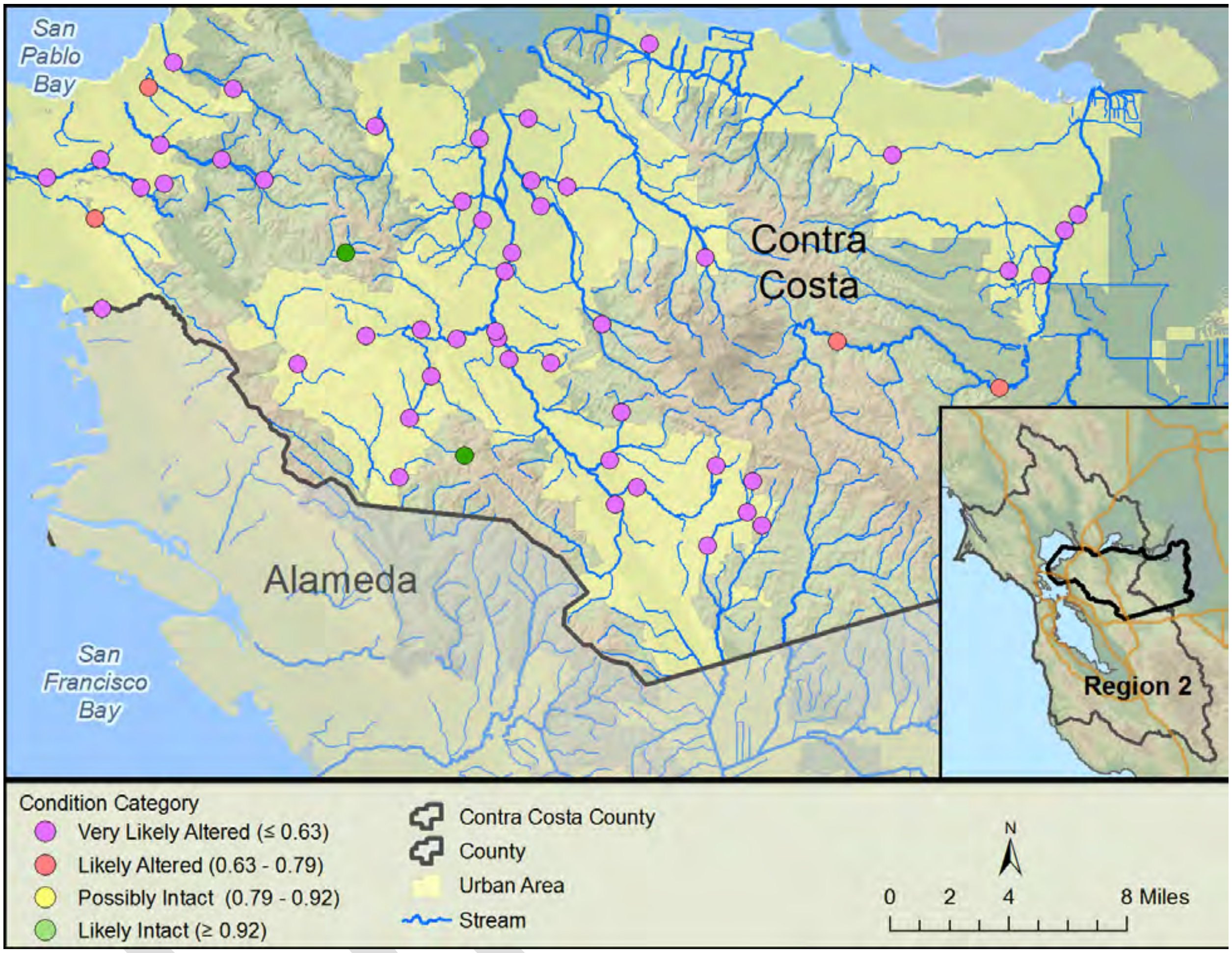

Figure C. Biological condition based on CSCI scores in Contra Costa County.

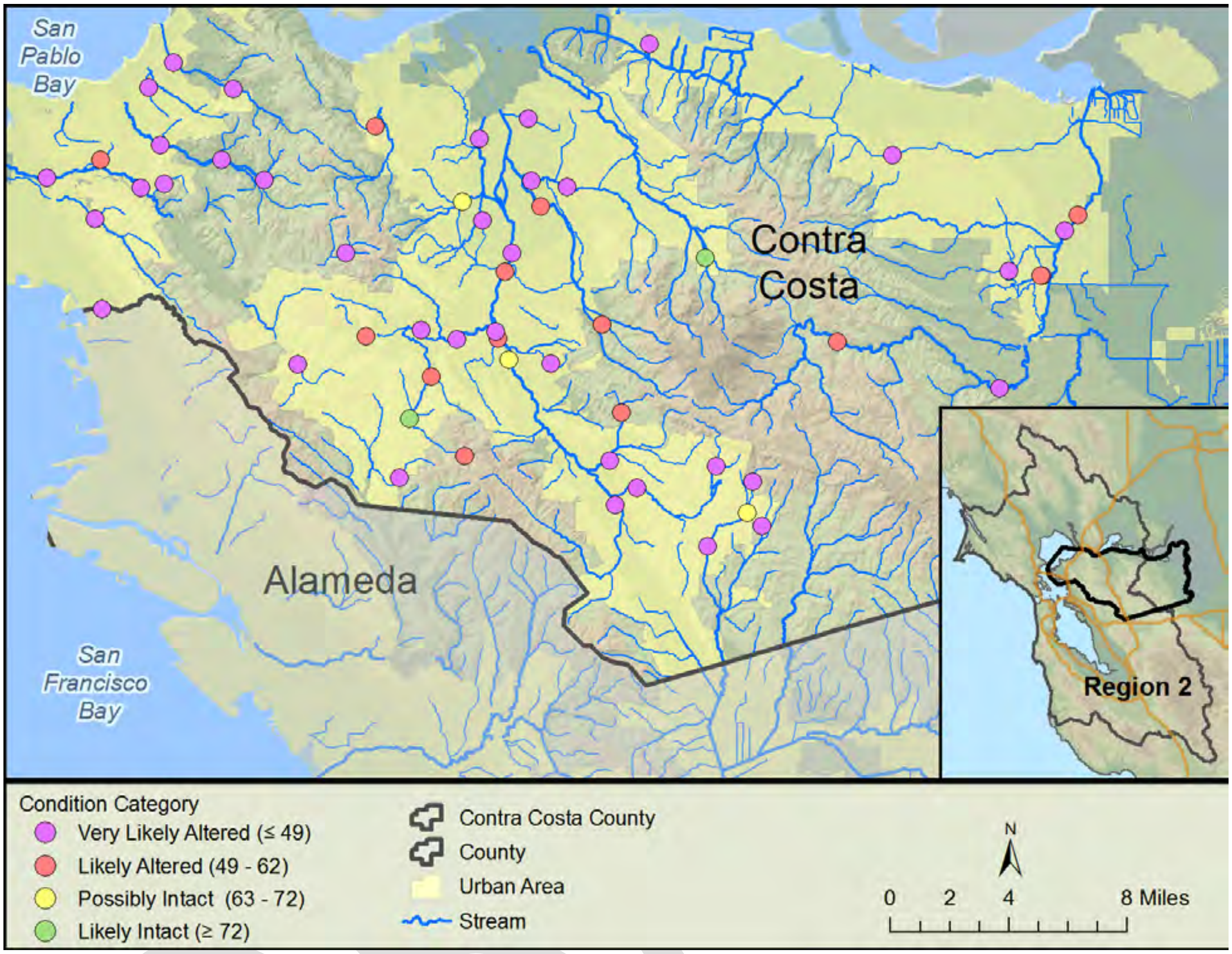

Figure D. Biological condition based on D18 scores in Contra Costa County.

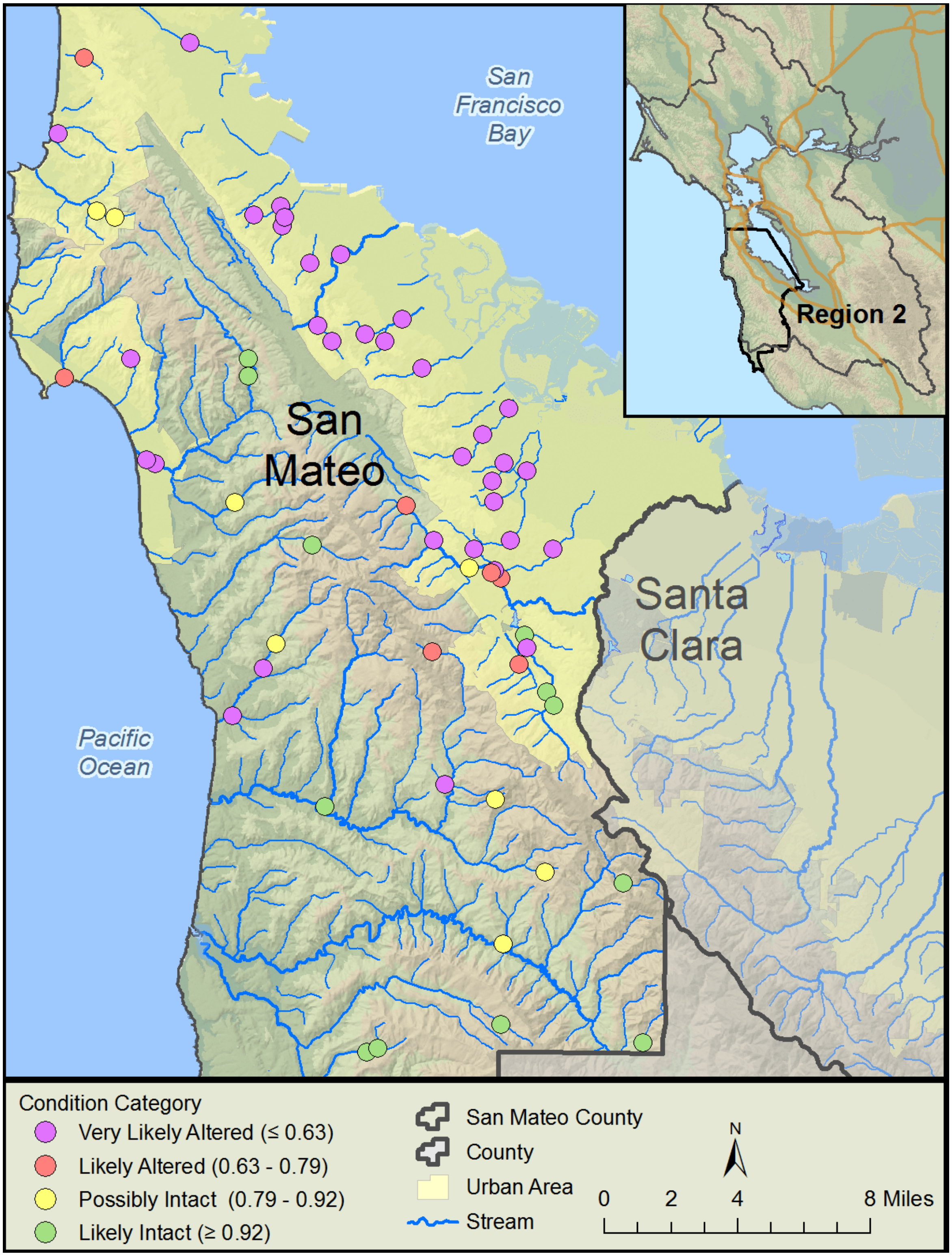

Figure E. Biological condition based on CSCI scores in San Mateo County.

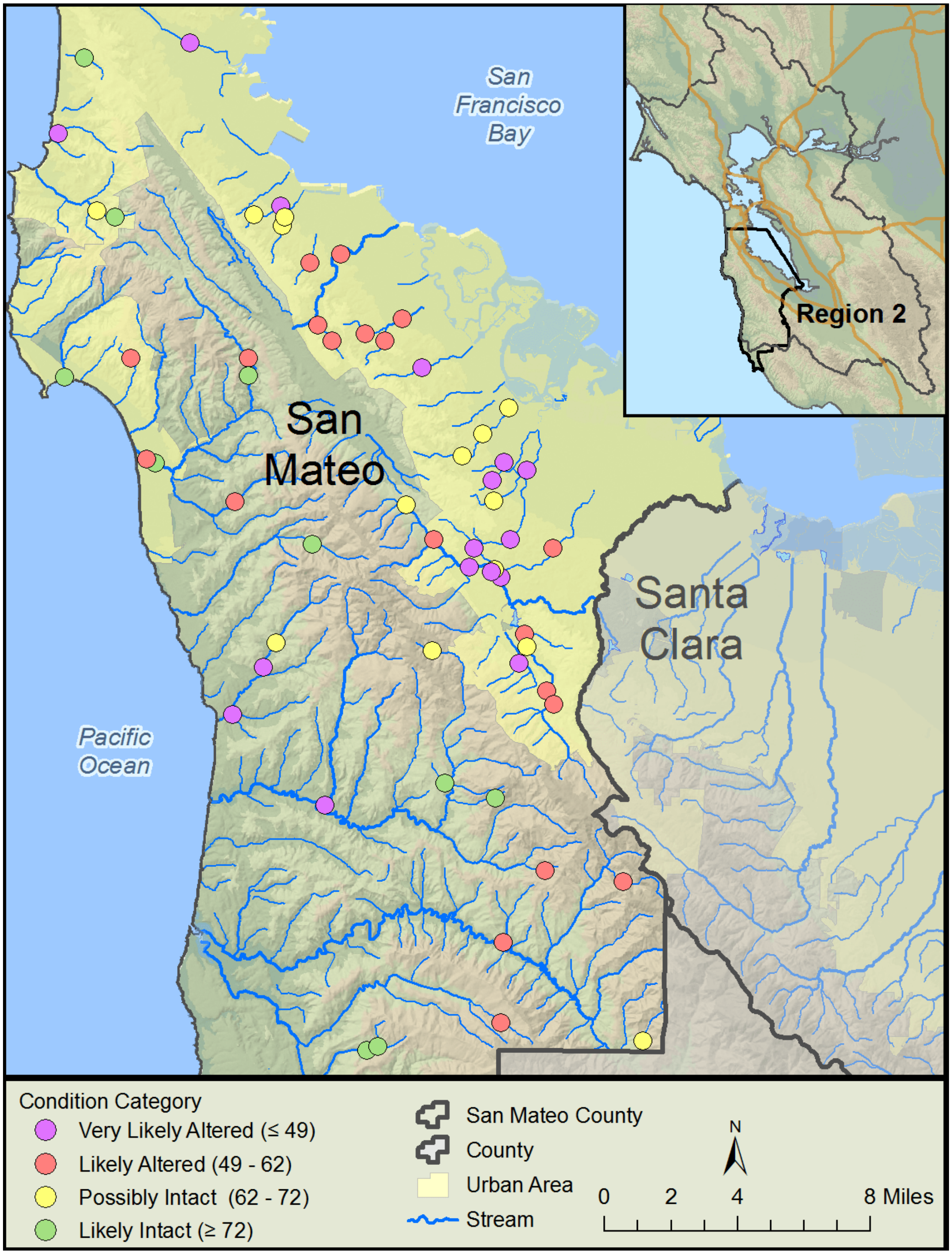

Figure F. Biological condition based on D18 scores in San Mateo County.

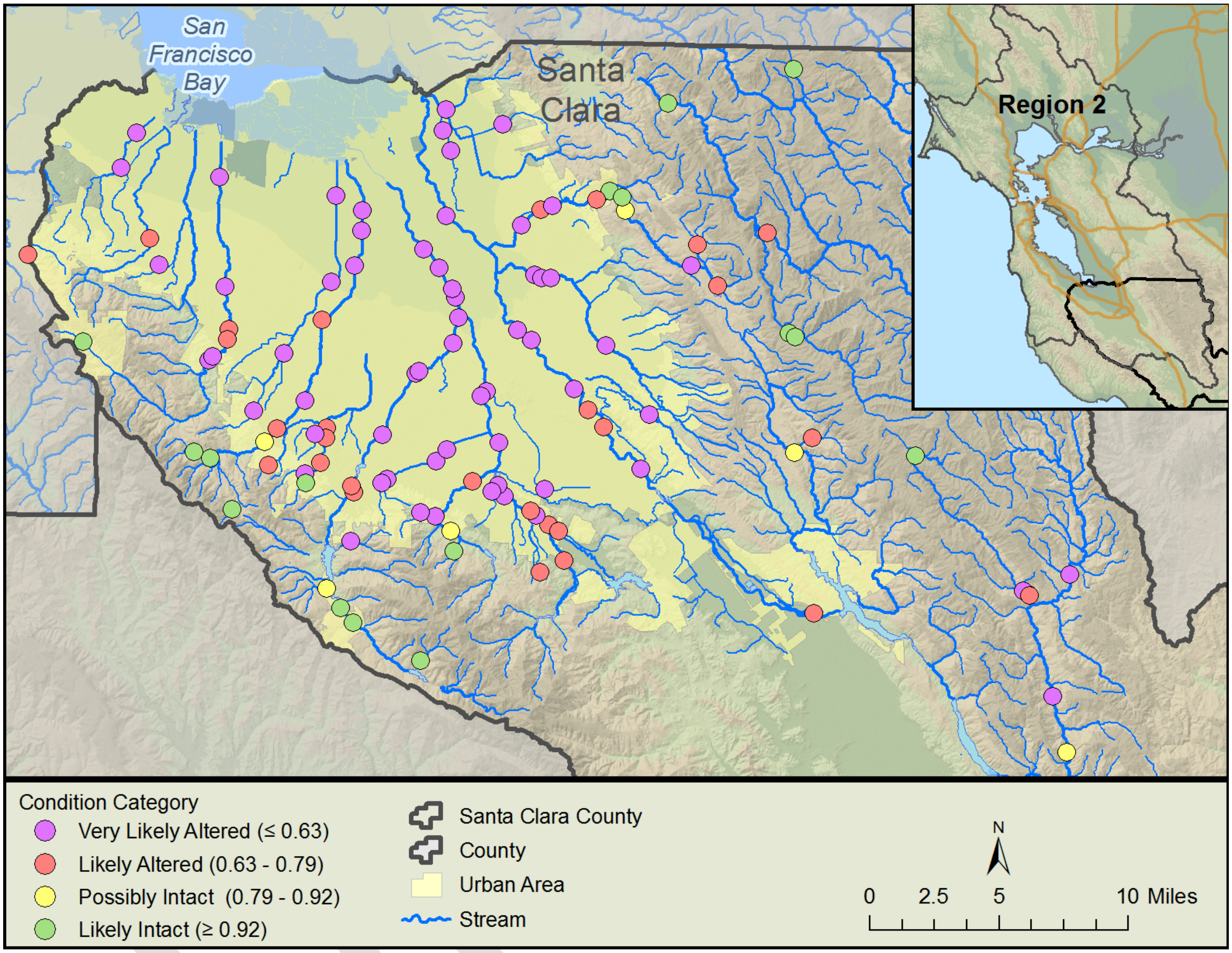

Figure G. Biological condition based on CSCI scores in Santa Clara County.

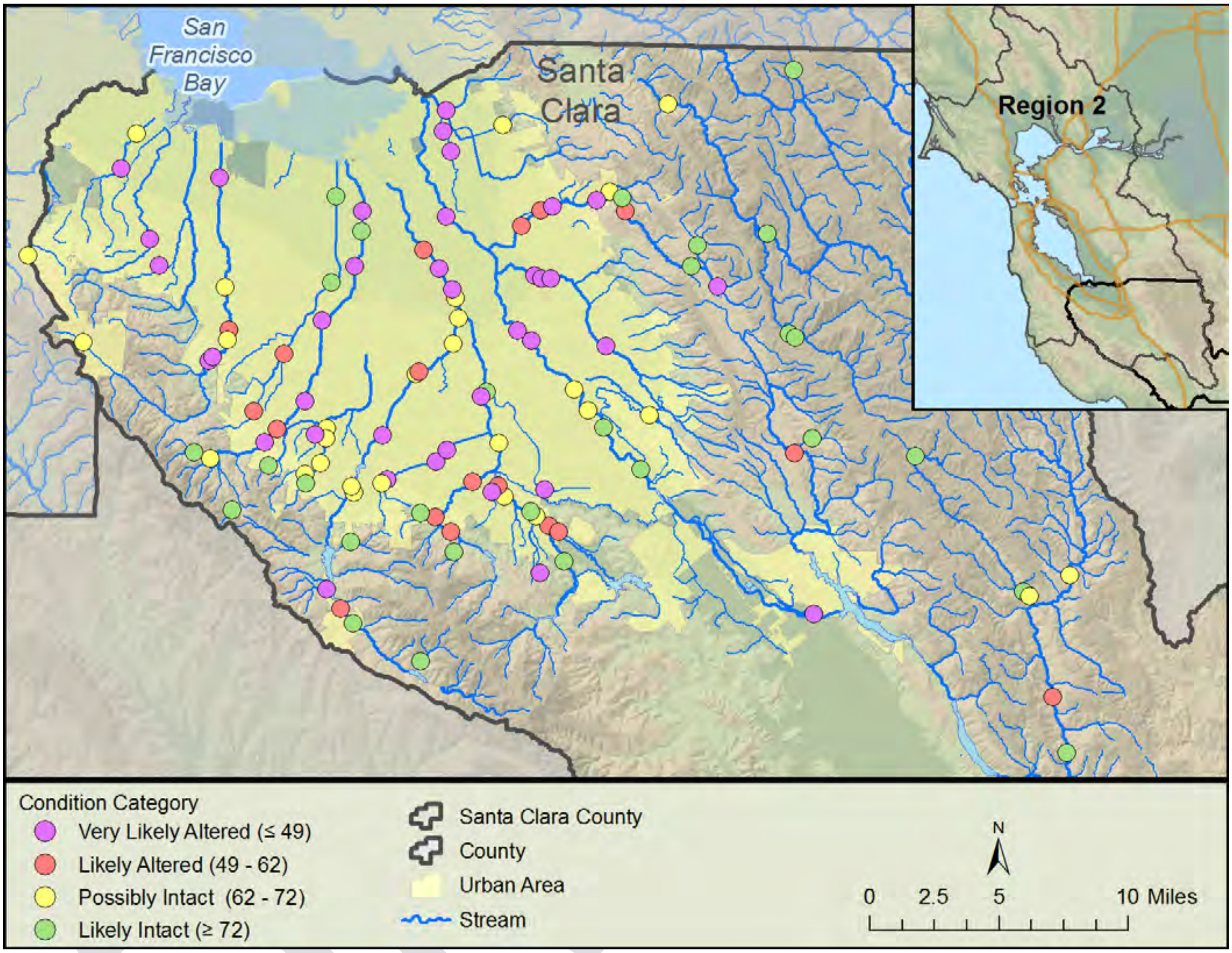

Figure H. Biological condition based on D18 scores in Santa Clara County.

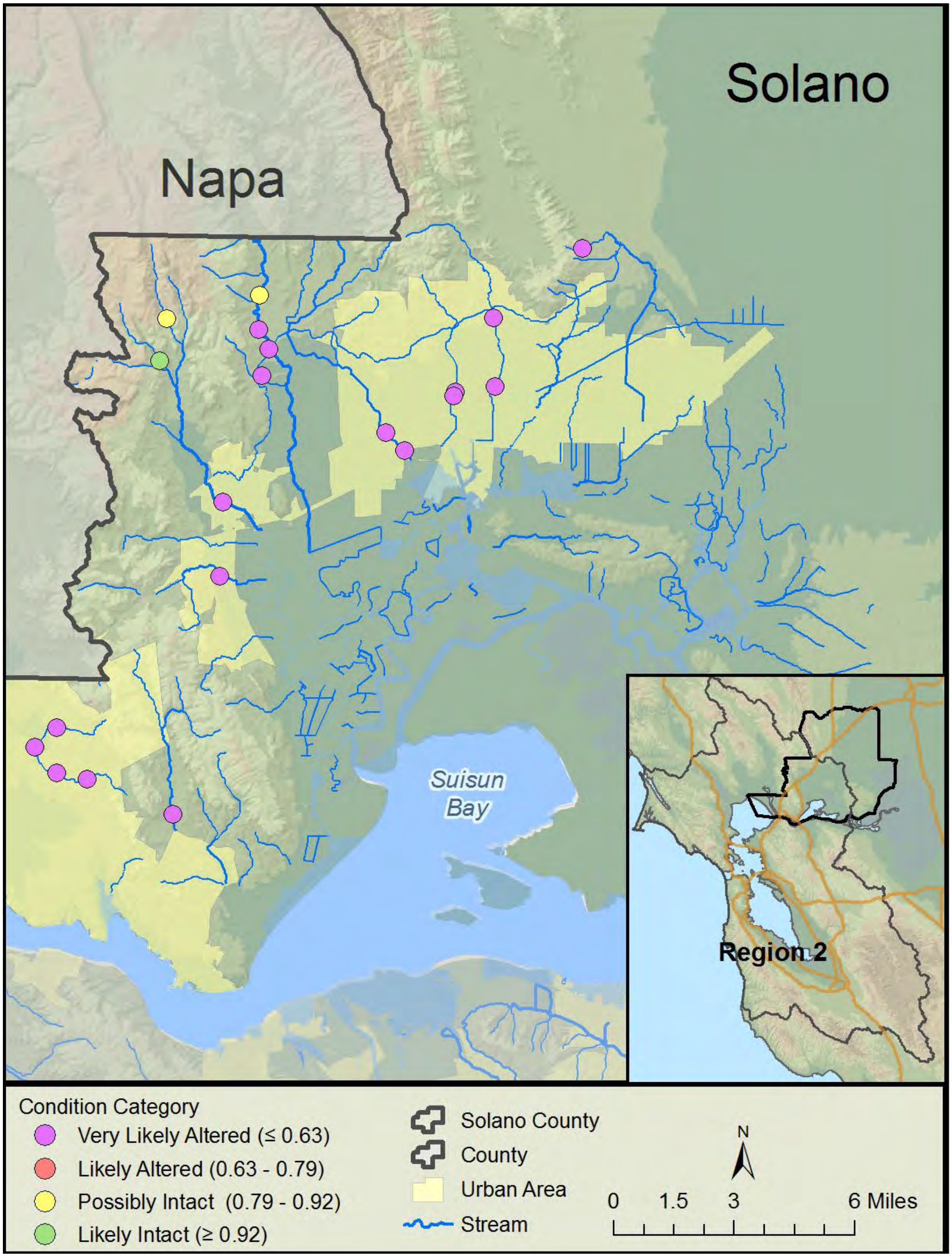

Figure I. Biological condition based on CSCI scores in Solano County.

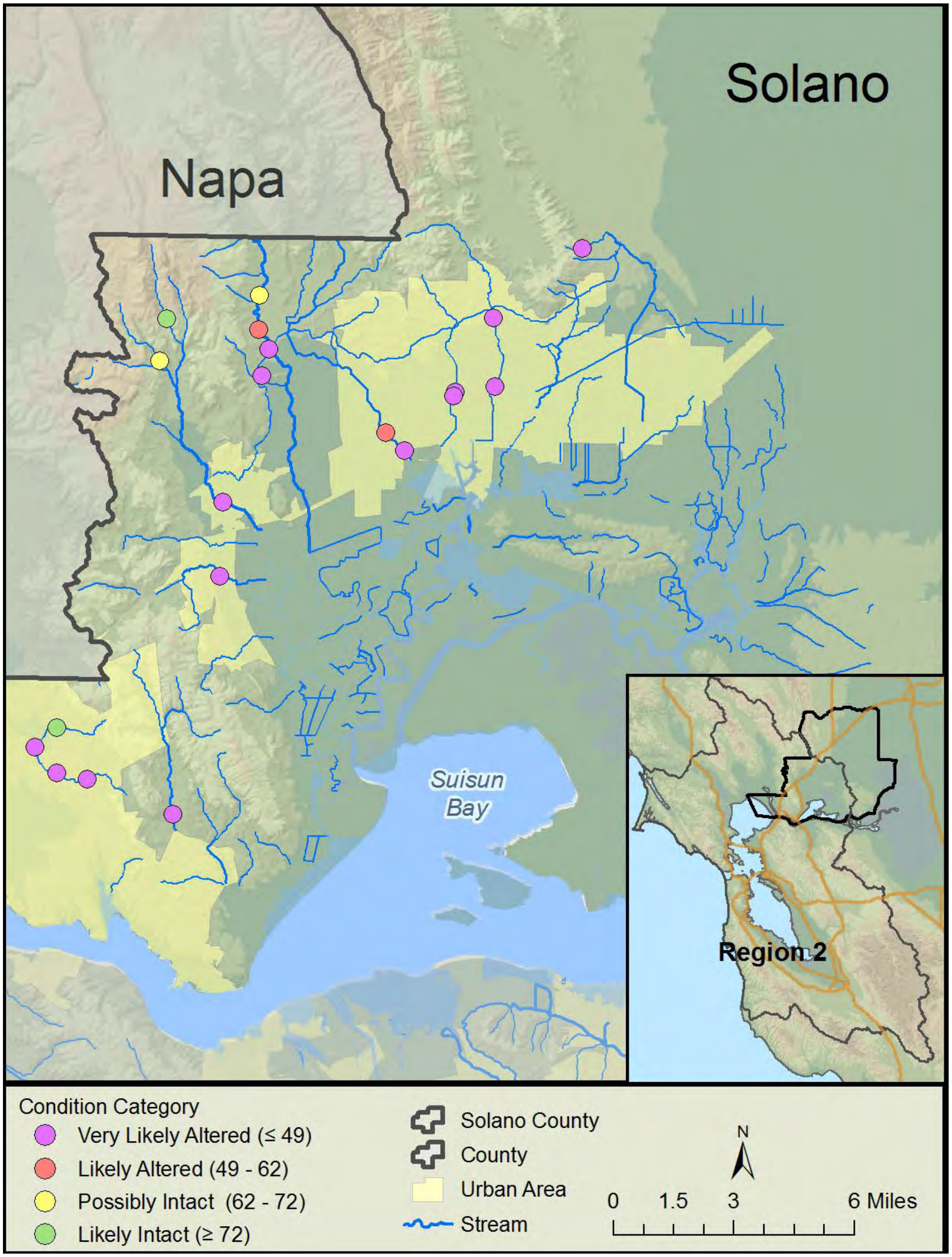

Figure J. Biological condition based on D18 scores in Solano County.

1.1. Emerging Contaminants

Emerging contaminant monitoring is being addressed through SMCWPPP's participation in the RMP. The RMP has investigated Contaminants of Emerging Concern (CECs) since 2001 and established the RMP Emerging Contaminants Work Group (ECWG) in 2006. The purpose of the ECWG is to identify CECs that might impact beneficial uses in the Bay and to develop cost-effective strategies to identify, monitor, and minimize impacts. The RMP published a CEC Strategy "living" document in 2013 and completed a full revision in 2017 (Sutton et al. 2013, Sutton and Sedlak 2015, Sutton et al. 2017) and made minor updates in 2018 (Lin et al. 2018). The CEC Strategy document guides RMP special studies on CECs using a tiered risk and management action framework.

Provision C.8.f of the MRP identifies three emerging contaminants that at a minimum must be addressed through POC monitoring: Perflourooctane Sulfonate Substances (PFOS), Perfluoroalkyl and Polyfluoroalkyl Sulfonate Substances (PFAS), and Alternative Flame Retardants (AFRs). PFAS is a broad class of chemicals used in industrial applications and consumer goods primarily for their ability to repel oil and water. PFOS are a subgroup within the PFAS umbrella and are identified in the CEC Strategy as "moderate" concern due to Bay occurrence data suggesting a high probability of a low-level effect on Bay wildlife. Other PFAS and AFRs are mostly identified as "possible" concern due to uncertainties in measured or predicted Bay concentrations or in toxicity thresholds. RMP staff recently published reports summarizing PFOS and PFAS monitoring results in the Bay (Houtz et al. 2016, Sedlak et al. 2017, Sedlak et al. 2018).[1] Organophosphate esters (OPEs), which are a class of AFRs, and are widely used in plastic and polymer additives for their flame retardant properties, have recently been elevated to "moderate" concern by the ECWG due to their presence in the Bay at levels comparable or exceeding protective thresholds, the potential for cumulative endocrine disrupting effects, lack of understanding of fate and transport and likelihood of increased use as replacement compounds (Shimabuku et al. 2019 (Draft)). Bisphenols (another class of plastic additives with endocrine-disrupting properties) have also been elevated to "moderate" concern based on recent Bay monitoring results, and in 2019, the ECWG recommended further monitoring of OPEs and bisphenols, including stormwater monitoring.

AFRs came into use following state bans and nationwide phase-outs of polybrominated diphenyl ether (PBDE) flame retardants in the early 2000's. They include many categories of compounds, including OPEs. In 2018 the RMP STLS and ECWG worked together to conduct a special study to inform ECWG's planning activities related to AFRs. The special study compiled and reviewed available data and previously developed conceptual models for PBDE to support a stormwater-related AFR conceptual model being developed by the ECWG. Organophosphate esters were prioritized for further investigation due to their increasing use, persistent character, and ubiquitous detections at concentrations exceeding PBDE concentrations in the Bay. Limited stormwater data from two watersheds in Richmond and Sunnyvale suggest that urban runoff may be an important source of these compounds. Additional monitoring and modeling was recommended in the special study, which was published in 2018 (Lin and Sutton 2018). In 2019, based on recent results from the 2017 RMP Status and Trends Water Cruise on OPE detections, and with the opportunity to advance monitoring of OPEs and other CECs via the multi-year non-targeted analysis of stormwater-related CECs initiated in 2018, the ECWG agreed to prioritize monitoring AFRs for RMP special studies. Additional funds were recommended to supplement the Emerging Contaminants Strategy in support of developing CECs conceptual models more broadly as part of the longer-term CECs Modeling Strategy.

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[1] The Emerging Contaminants Workgroup is also conducting monitoring on a number of other emerging contaminants that are not identified in the MRP. These include microplastics, ethoxylated surfactants, and fipronil.

In 2018, the RMP's ECWG initiated a multi-year special study to analyze stormwater samples collected from urban watersheds for a large suite of CECs. The list of CECs to be analyzed is based on recent work conducted in Puget Sound streams and is intended to target urban runoff constituents rather than those found in wastewater (e.g., pharmaceuticals). In addition to vehicle tire chemicals and imidacloprid (a neonicotinoid insecticide), the list includes the CECs specifically identified in Provision C.8.f of the MRP (PFOSs, PFASs, and AFRs). Pilot sampling began in 2019 in close coordination with the STLS and preliminary results were shared with the ECWG. Year-two of this three-year study was approved in 2019, with the inclusion of additional CECs, including OPEs and bisphenol A and S. The final reports and manuscripts for this study are anticipated in fall 2020.

During MRP 2.0, SMCWPPP has leveraged its participation in these RMP special studies to satisfy the POC monitoring requirement for CECs within provision C.8.f. Looking ahead to the next iteration of the MRP (MRP 3.0), SMCWPPP recommends continuing support of special studies that address data gaps and the scientific understanding of fate and transport of stormwater-related CECs in the Bay. In particular, the Program is supportive of continued coordination through the STLS to identify the appropriate watersheds and sampling sites for monitoring CECs through RMP special studies. The Program is also supportive of further developing conceptual and empirical models to better evaluate the distribution and sources of CECs of interest within a stormwater and watershed context. The Program further recommends including requirements to "conduct or cause to be conducted a special study that addresses relevant management information needs for emerging contaminants;" however, it is recommended that these requirements allow more flexibility with respect to the classes of compounds identified in the permit, allowing easier alignment with RMP special studies that may address a variety of stormwater-related CECs as the science is advanced over the coming years.

2.0 REFERENCES

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Lin, D., Sutton, R., Shimabuku, I., Sedlak, M., Wu, J., and Holleman, R. (2018). Contaminants of Emerging Concern in San Francisco Bay: A Strategy for Future Investigations 2018 Update. SFEI Contribution No. 873. San Francisco Estuary Institute, Richmond, CA.

Sedlak, M.D., Benskin, J.P., Wong, A., Grace, R., and Greig, D.J. (2017). Per and polyfluoroalkyl substances (PFASs) in San Francisco Bay wildlife: Temporal trends, exposure pathways, and notable presence of precursor compounds. Chemosphere v. 185, pp. 1217-1226.

Sedlak, M.D., Sutton, R., Wong, A., Lin, D. (2018). Per and polyfluoroalkyl substances (PFASs) in San Francisco Bay: Synthesis and Strategy. San Francisco Estuary Institute, Richmond, CA. Contribution # 867. 130 pages.

Shimabuku, Ila, Sutton, R., Chen, D., Wu, Y., Sun, J. (2019). Draft Report. Flame Retardants and plastic additives in San Francisco Bay: Targeted monitoring of organophosphate esters and bisphenols. San Francisco Estuary Institute, Richmond, CA. Contribution #925. 48 pages.

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Sutton, R., Sedlak, M., Sun, J., and Lin, D. (2017). Contaminants of Emerging Concern in San Francisco Bay: A Strategy for Future Investigations. 2017 Revision. San Francisco Estuary Institute, Richmond, CA. Contribution # 851.

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March 28, 2020

MRP PROVISION C.12.g. FATE AND TRANSPORT STUDY OF PCBS: URBAN RUNOFF IMPACT ON SAN FRANCISCO BAY MARGINS

Background

MRP Provision C.12.g requires Permittees to conduct or cause to be conducted studies concerning the fate, transport, and biological uptake of PCBs discharged from urban runoff to San Francisco Bay margin areas. The provision states: "the specific information needs include understanding the in-Bay transport of PCBs discharged in urban runoff, the sediment and food web PCBs concentrations in margin areas receiving urban runoff, the influence of urban runoff on the patterns of food web PCBs accumulation, especially in Bay margins, and the identification of drainages where urban runoff PCBs are particularly important in food web accumulation." Conceptually, advances in this type of knowledge could allow the Regional Water Board to explore revising the PCBs TMDL to incentivize implementing PCBs management actions in such drainages that drain to sensitive Bay margin areas. Prioritizing actions in these drainages could possibly facilitate reaching TMDL goals more efficiently, though establishing this type of prioritization process would involve many challenges.

Provision C.12.g. is being addressed through a multi-year project by the San Francisco Bay (Bay) Regional Monitoring Program (RMP) to identify, model, and investigate embayments along the Bay shoreline designated "Priority Margin Units" (PMUs). The project:

- Identified four PMUs for initial study that are located downstream of urban watersheds where PCBs management actions are ongoing and/or planned;
- Is developing conceptual and PCBs mass budget models for each of the four PMUs; and
- Is conducting monitoring in the PMUs to evaluate trends in pollutant levels and track responses to pollutant load reductions.

The objectives of this effort to model and investigate Bay PMUs include:

- Characterizing concentrations and the spatial distribution of PCBs in sediment and food web biota in PMUs, including establishing baseline data on PCBs concentration and loading;
- Evaluating the response of PMU receiving waters over time to load reduction efforts in the watershed, such as remediation of PCBs-contaminated properties, including tracking PCBs in sport fish as the ultimate indicator of progress in reduction of impairment; and
- Informing the review and possible revision of the PCBs TMDL and the reissuance of the MRP, both of which were initially tentatively scheduled to occur in 2020 (while the MRP reissuance process in underway and is anticipated to be completed in 2021, the status of evaluating and possibly revising the Bay PCBs TMDL remains uncertain at this time).

A general description and multi-year budget for this project is in the "PCBs" section of the RMP Multi-Year Plan, 2020 Annual Update, dated January 2020 (sfei.org/documents/2020-rmp-multi-year-plan).

The RMP PCBs Workgroup, which includes representative from BASMAA, the Regional Water Board, and other RMP stakeholders, provides oversight over the project, including reviewing and commenting on draft conceptual model reports and plans for PMU-related RMP Special Studies (e.g., PMU monitoring plans).

In accordance with MRP Provision C.12.g., Permittees submitted in their FY 2016/17 Annual Reports a workplan for meeting the above information needs, which included descriptions of studies proposed or underway and a preliminary schedule. Permittees then reported on the status of the studies in their FY 2017/18 Annual Reports. In their Integrated Monitoring Reports (IMRs), due by March 30, 2020, Permittees are required to report the findings and results of the studies completed, planned, or in progress as well as implications of the studies on potential control measures to be investigated, piloted, or implemented in future permit cycles.

The four PMUs initially selected were:

- Emeryville Crescent (Alameda County)
- San Leandro Bay (Alameda County)
- Steinberger Slough (San Mateo County)
- Richmond Harbor (Contra Costa County)

The PMU conceptual models are intended to provide a foundation for future monitoring to track responses to load reductions and may eventually help guide planning of management actions. Three of the selected embayments (all except San Leandro Bay) receive drainage from pilot watersheds that were included in BASMAA's Clean Watersheds for a Clean Bay project (basmaa.org/Clean-Watersheds-for-a-Clean-Bay-Project).

Status of PMU Conceptual Models

The following sections summarize the status of conceptual model development in each of the four PMUs.

Emeryville Crescent

A final conceptual model report (dated April 2017) is available on the San Francisco Estuary Institute (SFEI) website:

sfei.org/sites/default/files/biblio_files/Emeryville%20Crescent%20Draft%20Final%20Report%2005-02-17%20Final%20Clean_0.pdf.

The report's key finding, which was based on a simple one-box pollutant fate model and dependent on assumptions made for the model's input parameters, was that PCBs concentrations in sediment and the food web could potentially decline fairly quickly (within 10 years) in response to load reductions from the watershed.

San Leandro Bay

A conceptual model for San Leandro Bay was developed in three phases, with reports available on the SFEI website. The Phase 1 report (dated June 2017) presented analyses of watershed loading, initial retention, and long-term fate, including results of sediment sampling in 2016:

sfei.org/sites/default/files/biblio_files/Yee%20et%20al%202017%20Conceptual%20Model%20Report%20San%20Leandro%20Bay%20Phase%201.pdf.

The Phase 2 report (dated December 2017) is designated a data report and documented the methods, quality assurance, and all of the results of the 2016 field study:

sfei.org/sites/default/files/biblio_files/San%20Leandro%20Bay%20PCB%20Study%20Data%20Report%20Final.pdf

The Phase 3 report (dated November 2019) was recently completed and is available here:

sfei.org/sites/default/files/biblio_files/San%20Leandro%20Bay%20PCBs%20Phase%203%20Final%20Report%20_0.pdf

This final report incorporates all of the results of the 2016 field study, and includes additional discussion of the potential influence of contaminated sites in the watershed and the results of passive sampling by Stanford researchers. It also includes a comparative analysis of long-term fate in San Leandro Bay and the Emeryville Crescent, a section on bioaccumulation, and a concluding section with answers to the management questions that were the impetus for the work.

The report included a discussion of the results of mass budget modeling that illustrated one type of challenge encountered during the PMU conceptual modeling effort. A wetland sediment core profile at Damon Slough indicated a substantial reduction in PCBs between the 1970s and the early 2000s. The simple mass budget model developed during this study suggested continued reductions in PCBs. However, a comparison of the results of extensive sampling of San Leandro Bay surface sediment in 1998 and in 2016 suggested minimal decline in PCBs over this more recent 18 year period. This finding may suggest that continuing PCBs inputs from the watershed are greater than estimated as part of the mass budget modeling and are slowing the recovery of San Leandro Bay. It is important to note that numerous uncertainties associated with the model and its parameters influence projected system response time.

Steinberger Slough / Redwood Creek

A conceptual model for Steinberger Slough / Redwood Creek is currently under development. SFEI staff released a draft report in February 2020. Like the other conceptual models, it includes results of existing monitoring efforts in the PMU and watershed, analyses of watershed loading, development of a mass budget, and long-term fate modeling, including projected PCBs concentrations in sediment and the food web in response to load reductions from the watershed.

Richmond Harbor

Due to budget limitations and because other RMP efforts were deemed higher priority, a conceptual model for the Richmond Harbor PMU is not yet under development.

RMP Special Studies Related to PMUs

In addition to ongoing conceptual model development (as described above), and continuing technical and logistical support for the RMP PCBs Workgroup, various types of RMP Special Studies[1] related to PMUs are ongoing, including the following:

- Shiner Surfperch PCBs Monitoring in PMUs – shiner surfperch is a crucial indicator of impairment, due to its explicit inclusion as an indicator species in the TMDL, importance as a sport fish species, tendency to accumulate high concentrations, site fidelity, and other factors. The conceptual site models recommend periodic monitoring of shiner surfperch to track trends in the PMUs, and as the ultimate indicator of progress in reduction of impairment. A coordinated sampling of PCBs in shiner surfperch in PMUs is being conducted as an add-on to RMP Status and Trends (S&T) sport fish sampling. A dataset for shiner surfperch will be developed that is directly comparable across the PMUs and the five locations that are sampled in S&T monitoring.
- Stormwater Runoff PCBs Monitoring in PMUs – this study is collecting information on PCBs concentrations and particle ratios in stormwater in watersheds draining to the PMUs to better estimate current PCBs loads into the PMUs (a critical component of the PMU mass budgets) and to help track the effectiveness of PCBs controls such as remediation of PCBs-contaminated properties.
- Assess Loading and Spatial Distribution of PCBs in Steinberger Slough / Redwood Creek PMU – this study will address information gaps in the conceptual model for this area and establish baseline data for evaluating the response of these receiving waters to load reduction efforts in the watershed. Passive sampling devices (PSDs) will be deployed to assess spatial patterns in dissolved PCBs in pore water and surface water, providing information on spatial patterns in an index of current biotic exposure. In addition, analysis of depth profiles of pore water with PSDs, accompanied by bulk sediment chemistry in cores, will provide information on the chronology of loading and exposure over the past 50 years. This study is being conducted in collaboration with Stanford researchers.

Discussion

As of the end of calendar year 2019, the PMU conceptual modeling and associated special studies are continuing to progress. Four PMUs for initial study, characterization, and tracking have been identified, and conceptual models have been completed for two of the PMUs, the Emeryville Crescent and San Leandro Bay. A draft conceptual model for a third PMU, Steinberger Slough / Redwood Creek, is under development. In conjunction with the modeling, RMP Special Studies are characterizing concentrations and the spatial distribution of PCBs in sediment and food web biota in PMUs and establishing baseline data on PCBs concentration and loading, and will help evaluate the response of the PMUs to load reduction efforts in their watersheds.

The efforts to model and investigate the PMUs are generating valuable new data and knowledge that will inform future revisions of the PCBs TMDL. However, it would be premature to propose major changes to the TMDL at this time, such as revising the stormwater allocation (e.g., assigning allocations to watershed areas that vary depending upon the sensitivity of the Bay margin area to which they drain). Similarly, additional work should be completed before attempting to project any implications of the modeling and studies on potential control measures to be investigated, piloted, or implemented in

[1]These efforts are partly funded by Supplemental Environmental Projects (SEPs).

future stormwater permit cycles. BASMAA representatives will continue to participate in the RMP PCBs Workgroup to help oversee this work and guide it towards developing information that will inform implementing controls for PCBs in stormwater runoff and reducing the Bay's PCBs impairment.