Contra Costa Clean Water Program

Marsh Creek Stressor and Source Identification Study

Work Plan

July 2018

Submitted to

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

Submitted by

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

and

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

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Acronyms and Abbreviations

AFDW	ash free dry weight
BASMAA	Bay Area Stormwater Management Agencies Association
BOD	biochemical oxygen demand
Brentwood	City of Brentwood
CCCWP	Contra Costa Clean Water Program
CDFW	California Department of Fish and Wildlife
CVRWQCB	Regional Water Quality Control Board, Central Valley Region
Delta	San Joaquin River Delta
DO	dissolved oxygen
EDD	electronic data deliverable
FOMCW	Friends of Marsh Creek Watershed
FY	fiscal year
GIS	geographic information systems
MRP	Municipal Regional Stormwater NPDES Permit
MWAT	maximum daily water temperature
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity unit
PCBs	polychlorinated biphenyl congeners
POC	pollutants of concern
ppb	parts per billion
QA/QC	quality assurance/quality control
SFRWQCB	Regional Water Quality Control Board, San Francisco Region
SSC	suspended sediment concentration
SSID	stressor and source identification
SWAMP	Surface Water Ambient Monitoring Program
TMDL	total maximum daily load
USGS	U.S. Geological Survey
WTP	wastewater treatment plant
WY	water year

EXECUTIVE SUMMARY

The stressor and source identification (SSID) study will investigate the root causes of fish kills in Marsh Creek via monitoring, data compilation and review, literature review, and modeling. This SSID work plan is the first deliverable required under Provision C.8.e.iii of the Municipal Regional Stormwater NPDES Permit (MRP) issued in 2015 by the San Francisco Bay Regional Water Quality Control Board (SFRWQCB, 2015).

The primary objective of the SSID study is to determine whether low dissolved oxygen causes fish kills in Marsh Creek and, if so, to determine the causes of the low dissolved oxygen. A primary suspected cause of low dissolved oxygen is algal growth in reaches subject to intermittent non-stormwater flows; therefore, identifying sources of non-stormwater flow is an important objective of this study. An alternate hypothesis, not necessarily exclusive of low dissolved oxygen, is that pesticide toxicity causes fish kills. Proving or disproving pesticide linkages is more complex compared to identifying low dissolved oxygen 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 for this study.

The study approach follows the results of an initial data compilation and review that was completed during Year 1 (FY 2017-2018), and used to develop this work plan. The review provides evidence strongly suggesting low dissolved oxygen is a likely cause of fish kills in Marsh Creek. Additional evidence points to growth and decay of algae during spring through fall in reaches upstream of the Brentwood wastewater treatment plant (WTP); these reaches are subject to intermittent non-stormwater flows which could influence oxygen levels in creek water.

Therefore, the study will include field monitoring with an initial focus on continuous monitoring of dissolved oxygen, as well as pH, turbidity, temperature, and conductivity at three locations: just upstream of the WTP outfall, just downstream of the WTP outfall, and at the furthest downstream location above the zone of tidal influence. This continuous monitoring approach will bracket the area where fish are attracted by the continuous flow of the WTP, and consequently where most fish kills have been observed. The continuous monitoring will allow unattended measurements in the pre-dawn hours, when dissolved oxygen levels are generally lowest, and enable for the first time a pairing of real-time dissolved oxygen and other data with a fish kill event, should one occur during the study.

Additional water quality monitoring will focus on sources of biochemical oxygen demand (BOD) and pesticides. Production of BOD is thought to occur in the creek above the WTP because of pools of water which form between check dams due to intermittent non-stormwater flows. Water levels, flows, and BOD will be measured periodically in reaches upstream of the WTP to characterize the typical and extreme BOD loads in the creek. Together with the continuous monitoring data and WTP effluent monitoring data, creek BOD loads can be used to develop a water quality model which will help us understand whether BOD loads from the reaches of the creek upstream of the WTP could explain lethal dissolved oxygen sags in the reaches where fish kills have been observed.

Pesticides monitoring will be performed in conjunction with source identification of non-stormwater flows, and opportunistically in the event of a fish kill. Non-stormwater flow source identification will rely on a combination of desktop analysis of maps and aerial photos, site walks, and deployment of continuous water level sensors at locations of suspected intermittent flows. Significant sources of flow will be sampled for BOD, pesticides, and other constituents.

The entire study is expected to cost no more than $450,000 over four years. Study preparations in Year 1 (FY 2017-2018, currently under way) are expected to cost $50,000. Implementation of the study in Year 2 (FY 2018-2019) will cost up to $200,000. Should the study continue into Years 3 and 4, effort would be limited to $100,000 each year. A significant factor affecting the length of the study is whether substantial fish mortality occurs while continuous dissolved oxygen sensors are operating. If an event occurs and lethally low levels of dissolved oxygen are documented, the study could be curtailed soon after identifying the most likely causes of low dissolved oxygen. At the other extreme, the study would be terminated if no fish kill events occur within the four years, and the findings would necessarily be less conclusive.

Section 1 of this work plan provides an introduction and background, summarizing the problem statement, regulatory and environmental setting, the history of fish kills events and understanding of flow and dissolved oxygen conditions prior to the events, and relevant monitoring projects in the watershed. Section 2 develops available background information into a conceptual model with associated management hypotheses to be tested by work plan implementation. Section 3 presents the Phase I (February 2018-June 2019) implementation approach. Section 4 presents the Phase II (July 2019-June 2020) implementation approach. Section 5 summarizes quality assurance and quality control procedures. Section 6 presents an overview of the data management and reporting plan. Cited references are listed in Section 7.

1. INTRODUCTION AND BACKGROUND

Thoughtful response to serious environmental effects shows the commitment of the Contra Costa Clean Water Program (CCCWP) to managing water quality in urban drainages. This work plan, which addresses recurrent fish kills in Marsh Creek, fulfills Step 1 of Provision C.8.e.iii of the Municipal Regional Stormwater NPDES Permit (MRP) issued by the San Francisco Bay Regional Water Quality Control Board (SFRWQCB, 2015), which requires development of a stressor and source identification (SSID) study work plan to address potential sources and causes of water quality impairment.

1.1 Problem Statement

According to the Central Valley Regional Water Quality Control Board (CVRWQCB, 2017), nine documented fish kills occurred in Marsh Creek over the past twelve years[1]. These events are often associated with intermittent dry season flows or storm events with varying antecedent dry periods. The most recent event occurred in October 2017 and killed more than 500 fish, including Chinook salmon. CCCWP decided to implement an SSID study to investigate the potential causes of these occurrences. The scope of this work plan is to identify root causes of fish kills in Marsh Creek via monitoring, data compilation, literature review, and modeling.

1.2 Environmental Setting

According to the Contra Costa County Watershed Atlas (Contra Costa Community Development Department, 2003), Marsh Creek watershed is the second largest watershed in Contra Costa County, totaling 60,066 acres of urban, agricultural, and open space land uses. The creek flows 34.6 miles from its headwaters in the Mount Diablo foothills to the San Joaquin River Delta at Big Break (Figure 1). The Marsh Creek Reservoir interrupts the flow from the upper watershed at 24.4 miles downstream of the headwaters. This study will investigate the lower watershed only, from the reservoir to the Delta, because under typical hydrologic conditions flow from the upper watershed does not reach the lower watershed.

Tributaries entering the middle portion of the main stem near and within Brentwood include Dry Creek (5.8 miles), Sand Creek (18.7 miles), and Deer Creek (9 miles). Marsh Creek runs through unincorporated county property, as well as the cities of Brentwood and Oakley, and through agricultural areas (Contra Costa County Community Development Department, 2003). Flood control assets in the creek are owned and maintained by the Contra Costa Flood Control and Water Conservation District.

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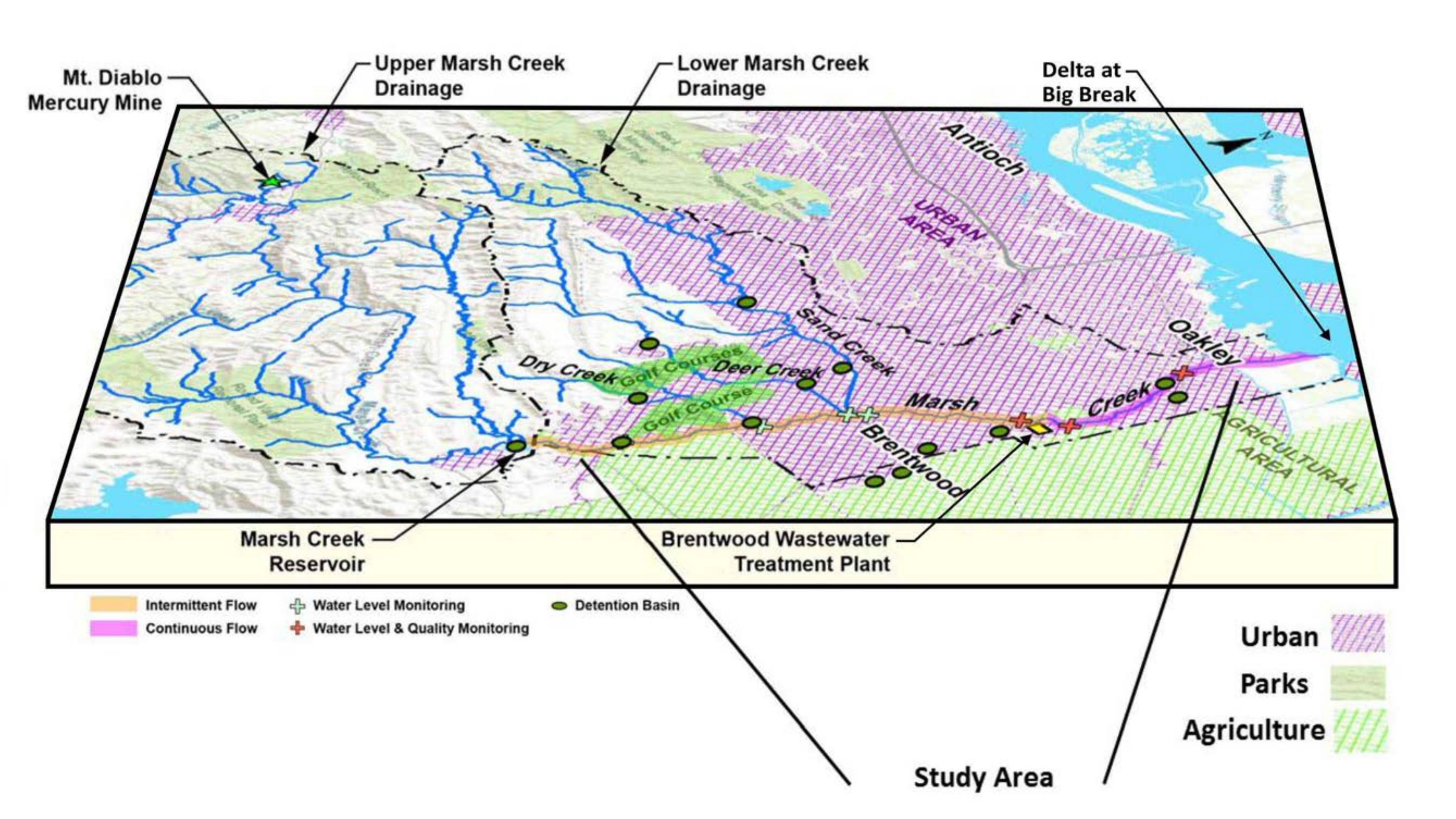
[1] The approximate dates on which CVRWQCB staff believe nine fish kills occurred are listed in a letter dated November 9, 2017 from Elizabeth Lee and Andrew Alevogt (CVRWQCB) and Gustavo Vina (City of Brentwood). Additional details on seven of the nine events were provided to CCCWP by Friends of Marsh Creek Watershed (FOMCW, 2016). The summary by FOMCW notes corroborating observations by staff of the East Bay Regional Parks, the CVRWQCB, and the California Department of Fish and Wildlife (CDFW). According to information provided by FOMCW, staff from either the CVRWQCB and/or the CDFW investigated and validated at least five of the nine fish kills cited in the CVRWQCB letter of November 9, 2017.

Figure 1. Map of Study Area Showing Relevant Watershed Features and Monitoring Locations



During most of the summer, streamflow in the creek is generally low, but rarely dry. 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. Groundwater around Marsh Creek in Brentwood is typically shallow, with depths of approximately 10 to 30 feet below ground surface (The Planning Center, 1993).

The Brentwood wastewater treatment plant (WTP), located approximately 3.5 miles south 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. The treatment plant has a design capacity of 5 million gallons per day (mgd); present actual flows are more typically in the range of 2 to 3 mgd, depending in part on recycled water consumption by irrigators.

The WTP creates a relatively constant body of flowing water in Marsh Creek downstream of its outfall. In the region below the WTP, Marsh Creek flow, following urban rhythms, shows daily cycles. Flow rates tend to peak mid-day, following peaks in early morning residential usage, and are at minimum in the pre-dawn hours. Upstream of the WTP outfall, flows are more intermittent, resulting from more intermittent activities. In addition to the Brentwood WTP, 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, and residential irrigation are all potential sources of non-stormwater flow into Marsh Creek.

Recreational access trails, including bike trails, are located along the banks of Marsh Creek, allowing unrestricted public access. Marsh Creek is identified as an important biological resource and habitat. The Central Valley Basin Plan (CVRWQCB, 2016) lists the following beneficial uses for Marsh Creek:

- Water contact recreation
- Water non-contact recreation
- Warm water fisheries habitat
- Wildlife habitat
- Rare, threatened, or endangered species

Historical accounts are not clear as to the historical importance of Marsh Creek as a salmonid habitat. Remains of salmonids have been found at pre-European archeological sites in the area, but it is unknown whether the fish were caught in Marsh Creek or the Delta. Surveys performed by the California Department of Fish and Wildlife (CDFW; formerly the California Department of Fish and Game) in 1942, 1975, 1981 and 1996 did not yield evidence of salmonids. On the other hand, volunteers working with the Natural Heritage Institute and Friends of Marsh Creek Watershed (FOMCW) have regularly observed and documented adult and juvenile Chinook salmon in Marsh Creek going back to 2001 (FOMCW, 2010). It is important to note that the Brentwood WTP came online in the 2002 time frame, establishing a continuous source of high quality flow in lower Marsh Creek below the WTP. This may have created habitat and passage, enabling Chinook salmon to migrate into the area and spawn.

1.3 Regulatory Setting

On November 9, 2017, the Central Valley Regional Water Quality Control Board (CVRWQCB, 2017) issued a Water Code Section 13267 Order for Technical and Monitoring Reports to the City of Brentwood (Brentwood) in relation to historic fish kills. Pursuant to this order, Brentwood was directed to develop a plan for storm event sampling to occur during the first rain event and any other rain event of the water year forecasted for at least 0.10 inch in a 24-hour period and preceded by at least 30 days of dry weather. Brentwood is responding to the CVRWQCB Water Code Section 13267 Order independently of this SSID study.

This SSID study implements a more holistic approach to the potential causes of fish kills, broadening the narrower scope of the November 2017 Water Code Section 13267 Order. The MRP requires SSID studies from CCCWP, as a countywide program, to address known water quality impairments. This project is an ideal candidate as an SSID study, not only because of the visibility of the issue, but also because investigating the various potential causes will yield information of general benefit to countywide Permittees and to regulatory agencies on factors affecting urban creek health.

The CVRWQCB adopted total maximum daily loads (TMDLs) for pyrethroid pesticides in specific waterbodies of the Central Valley (Resolution R5-2017-0057). California Department of Fish and Wildlife (CDFW) provided evidence suggesting pyrethroid pesticides may be involved as causative factors in the Marsh Creek fish kills (CDFW, 2016).

1.4 History of Fish Kills

According to the CVRWQCB, nine documented fish kills have occurred in Marsh Creek over the last twelve years. The most recent event occurred on or about October 23, 2017. Table 1 shows the approximate dates of the fish kill occurrences, as cited by the CVRWQCB (2017), along with the number of dry weather days antecedent to each fish kill.

As shown in Figure 2, four of the nine fish kills occurred within two weeks after a rain event, which may indicate a potential role of stormwater flows in those instances. Weekly receiving water monitoring data provided by the Brentwood WTP provide additional information. In three of the four events associated with antecedent rain, dissolved oxygen concentrations upstream of the Brentwood WTP outfall were depressed compared to downstream of the outfall. The shaded rows in Table 1 highlight events where dissolved oxygen was low at the upstream receiving water monitoring location and a rainfall event occurred within a few days of the event. Thus, a combination of antecedent stagnant, low dissolved oxygen conditions upstream of the WTP discharge, followed by a flushing of the stagnant water into the reach downstream of the WTP during rainfall events, is potentially implicated as a cause of at least some of the observed fish kills.

The timing of the other five events suggests non-stormwater flows may play a potential role in causing fish kills (Figure 3). All five events occurring under non-storm conditions were associated with some fluctuation in the stage or flow recorded at the stream gauge just upstream of the WTP outfall[2]. Low dissolved oxygen was recorded at the upstream receiving water monitoring station prior to one of the five non-storm events (on 9/5/2007).

The absence of measured low dissolved oxygen in the upstream receiving water station prior to five of the nine events does not rule out low dissolved oxygen as a root cause in those five events. The receiving water monitoring at Brentwood WTP occurs once a week; samples are typically collected during business (daylight) hours. As discussed in Section 2, daily dissolved oxygen cycles in Marsh Creek reach a low point in the pre-dawn hours. It is entirely possible that, although low dissolved oxygen was a root cause in most or all the prior fish kill events, acceptable dissolved oxygen levels were subsequently measured during daylight hours only because of the natural daily dissolved oxygen cycle.

Marsh Creek fish kill events typically occurred during spring or late summer to early fall. To date, none occurred between November and February. Air temperatures prior to these events ranged from nightly lows in in the 50s and 60s (Fahrenheit) to daytime highs in the 70s and 80s. None of the events was associated with unusually hot weather for the area. WTP operations were normal prior to all events, as evidenced by steady effluent flows and turbidity, concentrations of biochemical oxygen demand (BOD), and ammonia that met effluent limitations. None of the other receiving water parameters (pH, temperature, conductivity) stood out as unusual prior to events[3].

1.5 Monitoring Projects in the Marsh Creek Watershed

This section summarizes the relevant monitoring in Marsh Creek or its tributaries. The first subsection summarizes monitoring conducted by CCCWP. The second subsection summarizes monitoring conducted by other parties. The data sources reviewed are not the entire universe of monitoring within the Marsh Creek watershed but are the ones most relevant to understanding potential causes of fish kills. Relevant information from the data sources listed below was mined during development of the work plan to build on a foundation of lessons learned.

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[2] The gauge, designated MBW by the California Data Exchange Center, had a verified rating curve until 2013, and so historic data recorded flow in units of cubic feet per second. Stage data at MBW after 2013 are not associated with a verified rating curve and are therefore reported as stage height in units of feet.

[3] Receiving water and effluent monitoring data were provided by Brentwood to CCCWP. The downstream receiving water location monitored by Brentwood is 300 feet downstream from the Brentwood WTP outfall, close to the nearest downstream monitoring location proposed for this study and shown in Figure 1. The upstream location monitored by Brentwood is 100 feet upstream from the Brentwood WTP outfall, between the outfall and the nearest upstream location proposed for this study and shown in Figure 1.

Table 1. Dates of Marsh Creek Fish Kills, Antecedent DO Conditions and Antecedent Dry Days

Fish Kill Date	Low DO Upstream 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

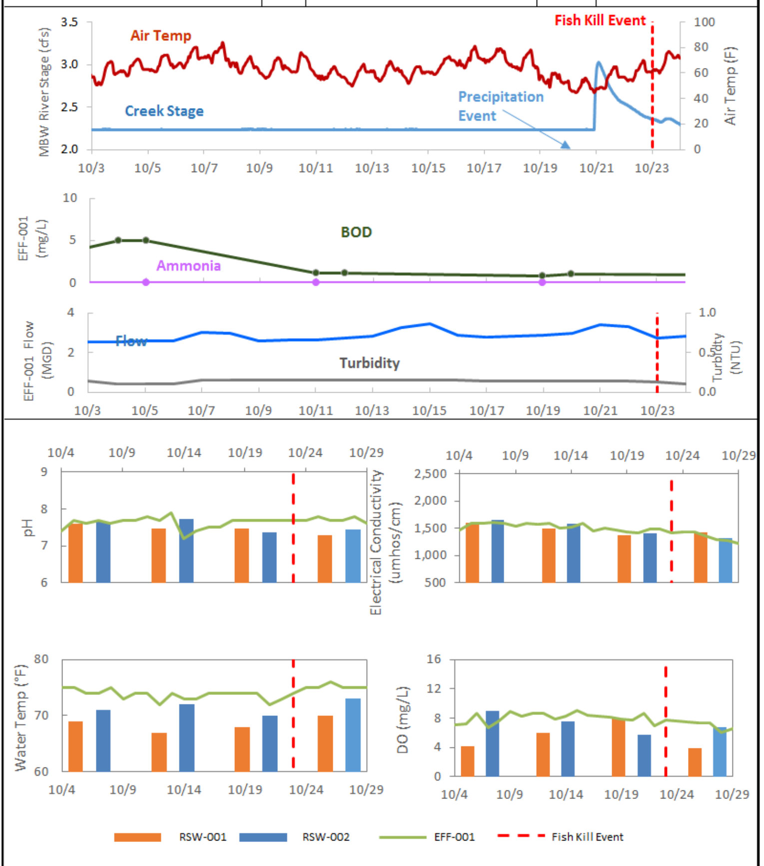
Source: CDEC, Brentwood Corp Yard (BTD); *http://cdec.water.ca.gov/cdecstation2* (accessed 01/29/18). Dissolved oxygen conditions as reported by the Brentwood WTP through its weekly receiving water monitoring program.

Shaded rows highlight events where dissolved oxygen was low at the upstream receiving water monitoring location <u>and</u> a rainfall event occurred within two weeks of the event.

*Note: The rain gauge at BTD recorded 0.5 inches on 5/23/2016; 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 5/23/2018. The precipitation event recorded on 5/23/2016 at BTD is considered a data error.

Figure 2. Water Quality and Weather Profile of Marsh Creek Two Weeks Prior to Fish Kills with Antecedent Rain Events

Marsh Creek Fish Kill Summary Report				
Date	10/23/17	**Location of Fish Kill**	Unknown	
Deceased Species	Largemouth bass, sunfish & chinook	**No. of Deceased**	"500" - Mercury News (10/27/17)	
WEATHER				
No. of Antecedant Dry Days (MAC Station)	3	**Precipitation Accumulation 14 Days Prior to Fish Kill (in)**	0.1	

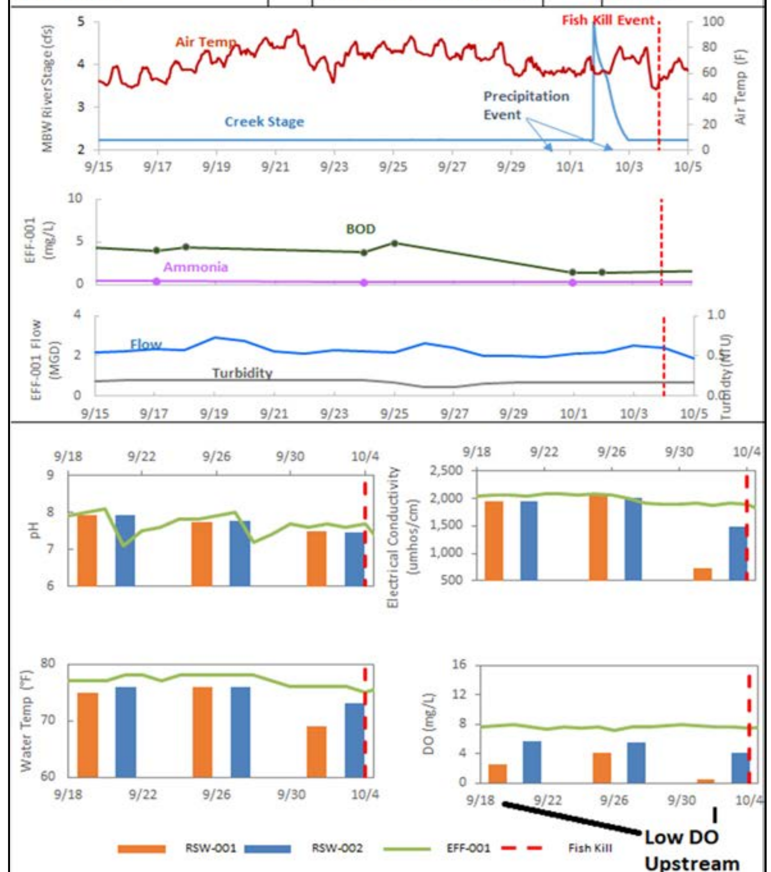


RSW-001 = upstream receiving water

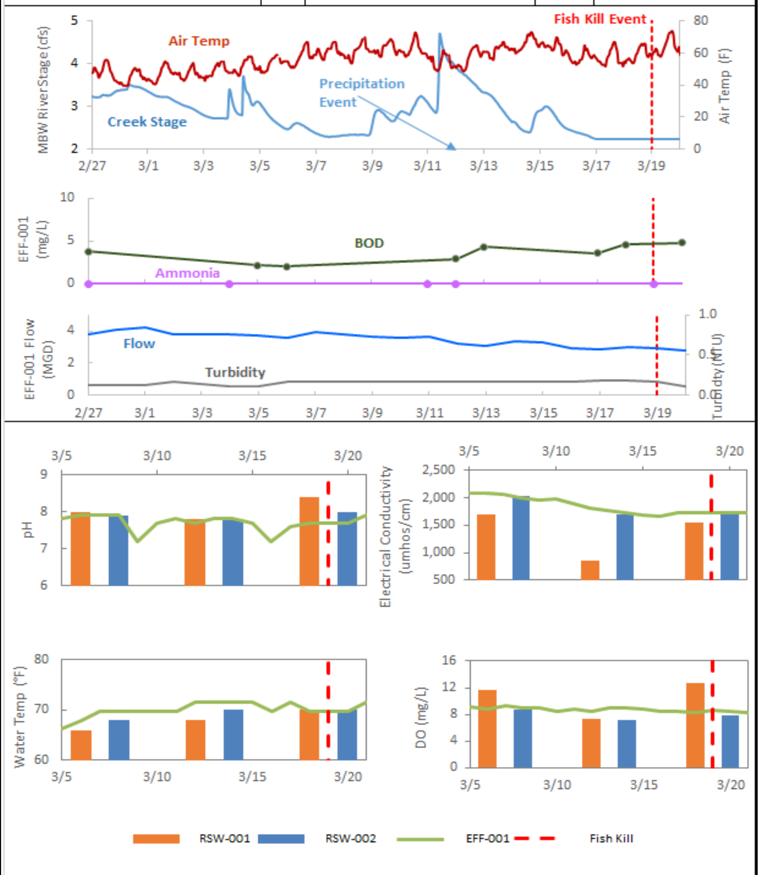
RSW-002 = downstream receiving water

EFF-001= WTP Outfall

Marsh Creek Fish Kill Summary Report				
Date	10/04/15	**Location of Fish Kill**	Between Delta Road and Sunset Road	
Carcas Description	Extensive mucus, bloody gills	**No. of Deceased**	"Hundreds of fish" - East County Times (10/6/15)	
WEATHER				
No. of Antecedant Dry Days (MAC Station)	1	**Precipitation Accumulation 14 Days Prior to Fish Kill (in)**	0.34	First rain event of WY 15-16



Marsh Creek Fish Kill Summary Report				
Date	03/19/15	**Location of Fish Kill**	Unknown	
Carcas Description	Unknown	**No. of Deceased**	Unknown	
WEATHER				
No. of Antecedant Dry Days (MAC Station)	8	**Precipitation Accumulation 14 Days Prior to Fish Kill (in)**	0.15	



RSW-001 = upstream receiving water

RSW-002 = downstream receiving water

EFF-001 = WTP outfall

Marsh Creek Fish Kill Summary Report				
Date	09/27/14	**Location of Fish Kill**	Above Delta Road going all the way downstream past Creekside Park in Oakley	
Carcas Description	Unknown	**No. of Deceased**	100 dead fish	
WEATHER				
No. of Antecedant Dry Days (MAC Station)	2	**Precipitation Accumulation 14 Days Prior to Fish Kill (in)**	0.22	First rain event of WY 14-15

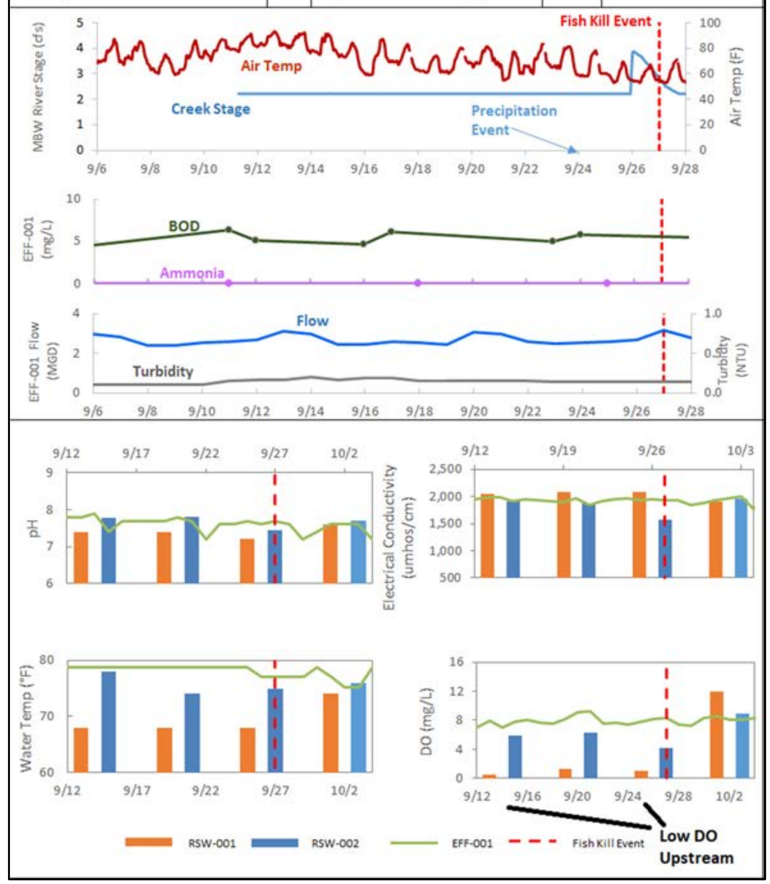
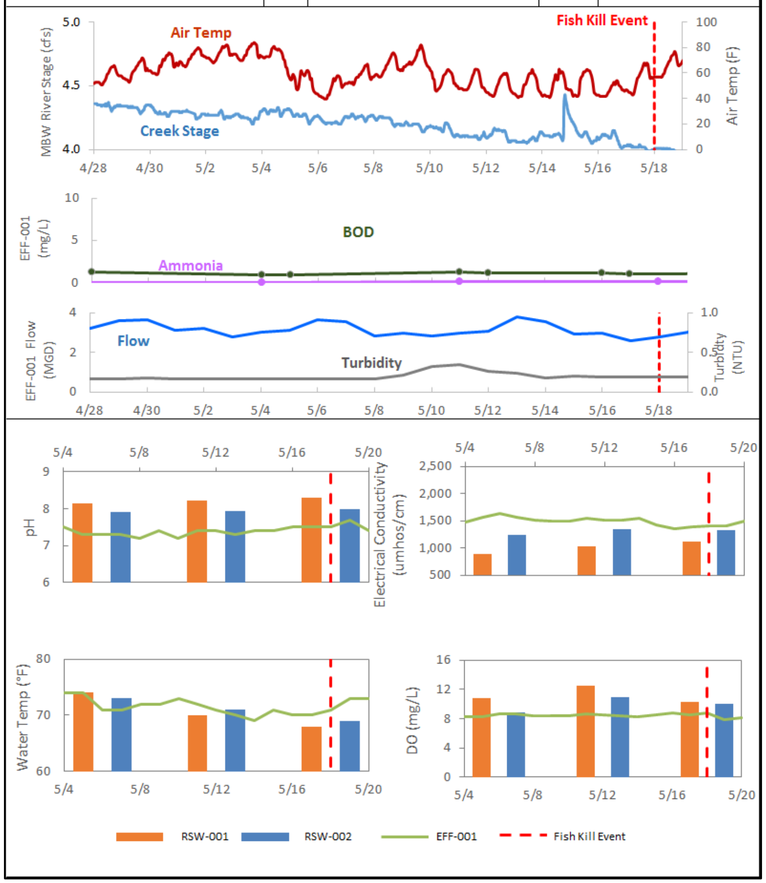


Figure 3. Water Quality and Weather Profiles of Marsh Creek Two Weeks Prior to Fish Kill Events with No Antecedent Rainfall

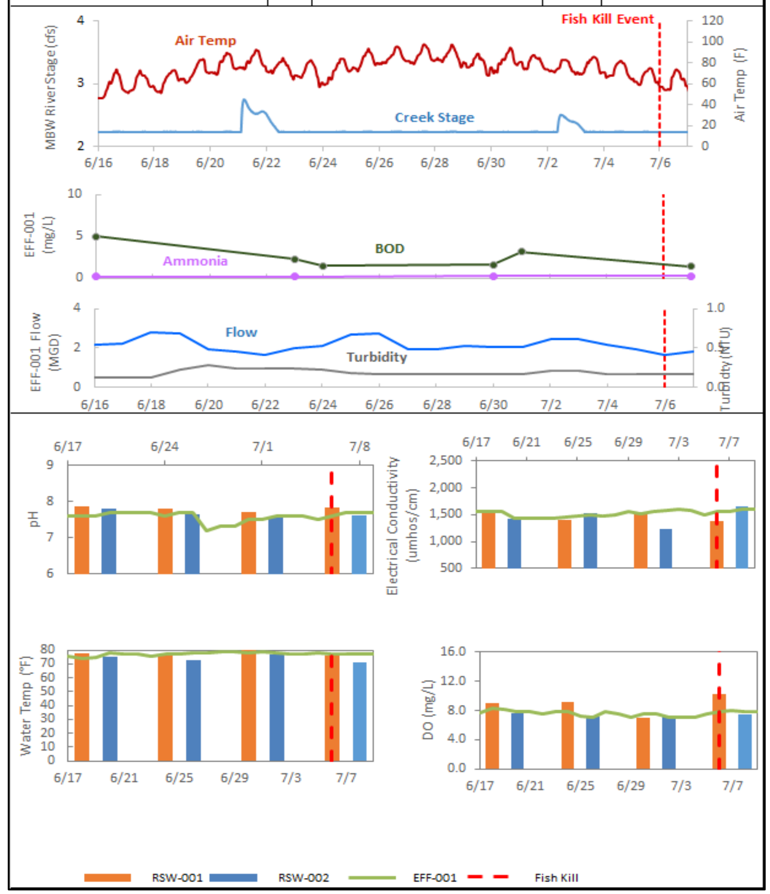
Marsh Creek Fish Kill Summary Report

Date	05/18/17	**Location of Fish Kill**		Unknown
Carcas Description	Unknown	**No. of Deceased**		Unknown
WEATHER				
No. of Antecedant Dry Days (MAC Station)	17	**Precipitation Accumulation 14 Days Prior to Fish Kill (in)**	0	



Marsh Creek Fish Kill Summary Report

Date	07/16/16	**Location of Fish Kill**		Brentwood near the Wastewater Treatment Plant
Carcas Description	Unknown	**No. of Deceased**		Hundreds of fish were reportedly dead
WEATHER				
No. of Antecedant Dry Days (MAC Station)	60	**Precipitation Accumulation 14 Days Prior to Fish Kill (in)**	0	

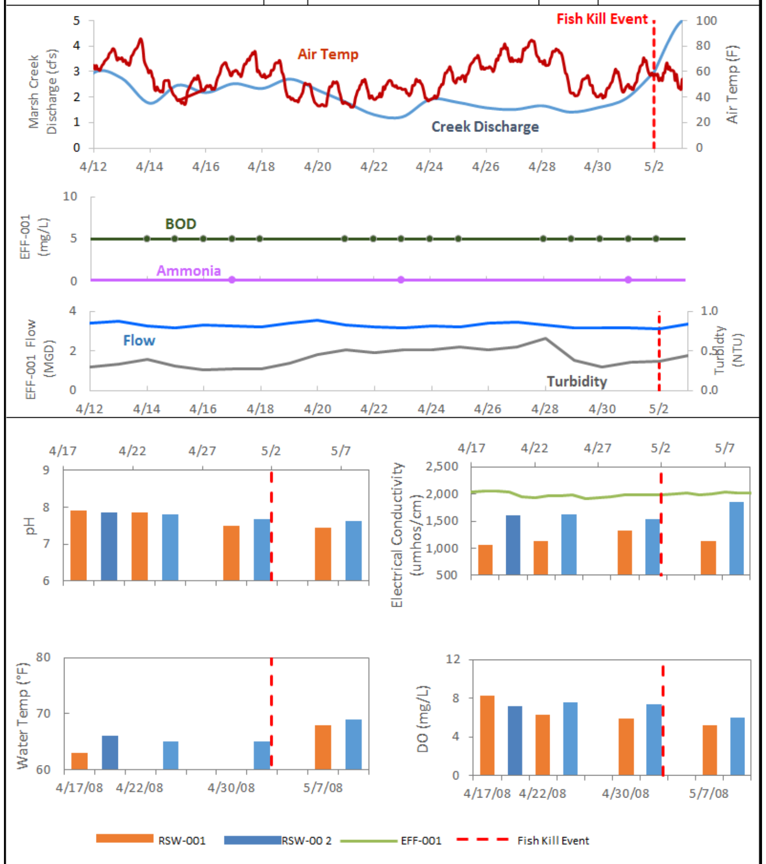


RSW-001 = upstream receiving water

RSW-002 = downstream receiving water

EFF-001= WTP outfall

Marsh Creek Fish Kill Summary Report				
Date	05/02/08	**Location of Fish Kill**	From the Brentwood WWTP to just downstream of Delta Road	
Carcas Description	Unknown	**No. of Deceased**	Unknown	
WEATHER				
No. of Antecedant Dry Days (MAC Station)	36	**Precipitation Accumulation 14 Days Prior to Fish Kill (in)**	0	

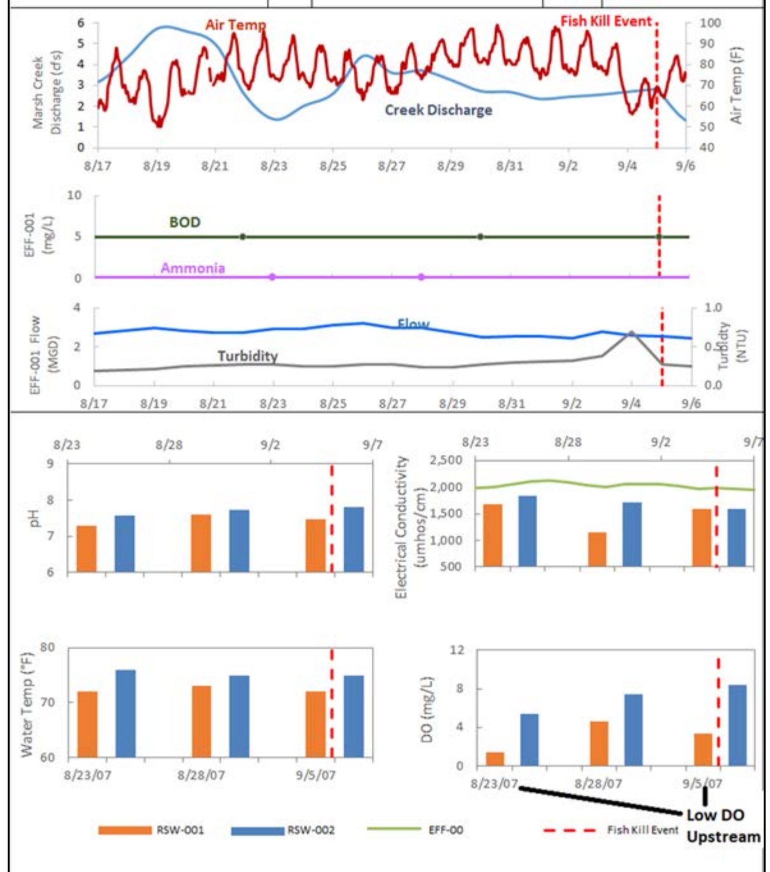


RSW-001 = upstream receiving water

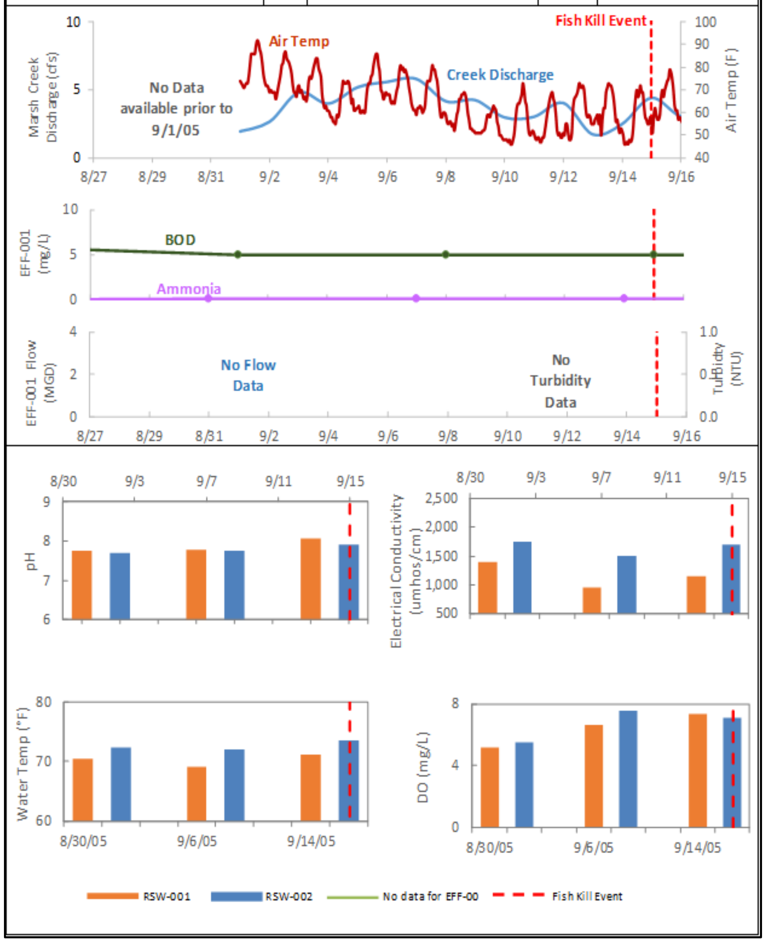
RSW-002 = downstream receiving water

EFF-001= WTP outfall

Marsh Creek Fish Kill Summary Report				
Date	09/05/07	**Location of Fish Kill**	Downstream of shared ECCID and Brentwood stormdrain pripe (near Sand Creek Road) to the WWTP outfall.	
Carcas Description	Unknown	**No. of Deceased**	Unknown	
WEATHER				
No. of Antecedant Dry Days (MAC Station)	123	**Precipitation Accumulation 14 Days Prior to Fish Kill (in)**	0	



Marsh Creek Fish Kill Summary Report			
Date	09/15/05	**Location of Fish Kill**	Unknown
Carcas Description	Unknown	**No. of Deceased**	*"Thousands of dead fish"*
WEATHER			
No. of Antecedant Dry Days (MAC Station)	117	**Precipitation Accumulation 14 Days Prior to Fish Kill (in)**	0



RSW-001 = upstream receiving water

RSW-002 = downstream receiving water

EFF-001= WTP outfall

1.5.1 Relevant Marsh Creek Monitoring Conducted by CCCWP

In compliance with the MRP and prior stormwater permits, CCCWP performed several types of monitoring in the Marsh Creek Watershed: stormwater pollutants of concern (POC) monitoring, creek status bioassessment and related water quality monitoring, creek status pesticides and toxicity monitoring, targeted continuous water quality monitoring, and an SSID study focused on pesticide-caused toxicity.

The stormwater POC monitoring commenced in water year (WY) 2011-2012 and continued through two and a half storm seasons (through the spring of 2014), at a location just above the Marsh Creek fish ladder adjacent to the U.S. Geological Survey (USGS) gauging station (see section 1.5.2). Monitoring included the collection of rainfall and stage data, as well as the measurement of turbidity, metals, mercury, methylmercury, PCBs, PAHs, nutrients, suspended sediments, total organic carbon, pesticides, and toxicity in composite and grab samples representing the storm event. A sonde was deployed to provide a continuous record of stage, turbidity, temperature, pH, conductivity, and dissolved oxygen during and between storm events. The sonde was also deployed for two 2-week periods in May and August of 2012 to provide data on dry weather water quality conditions.

Creek status monitoring included bioassessments, physical habitat characterizations, and grab samples to measure nutrients and other water quality parameters in Marsh Creek and its tributaries (e.g., Dry Creek). This monitoring was conducted annually in the Marsh Creek watershed from 2002 to 2009. In 2012, bioassessment monitoring in the eastern county drainages resumed as part of the MRP Regional Monitoring Coalition and continues to the present. The current bioassessment monitoring approach implements a random stratified sampling design, in contrast to the fixed station monitoring performed from 2002 to 2009. This means that, in any given year, Marsh Creek itself may or may not be monitored; however, Marsh Creek and its tributaries would be monitored at least once during a five-year permit term.

During the implementation of MRP 1.0 (SFRWQCB, 2009), pesticides and toxicity monitoring revealed elevated pesticide levels and toxicity in samples collected within the Marsh Creek watershed. In response, the CCCWP Permittees conducted an SSID study addressing the sources and causes of water and sediment toxicity to aquatic organisms (*Hyalella azteca*). That study identified pyrethroid pesticides as a likely cause of water and sediment toxicity. Those results are consistent with statewide studies documenting the prevalence of pyrethroid-related toxicity in urban drainages.

1.5.2 Relevant Marsh Creek Monitoring Conducted by Other Parties

Beginning October 1, 2000, the USGS operated a stream level gauge at Marsh Creek (CCCWP, 2014). The gauge is located 400 meters upstream of the Brentwood WTP outfall to Marsh Creek, just above the fish ladder at the drop structure. Data collection by USGS at this site was discontinued after September 30, 2013 due to budget reductions. The Contra Costa County Flood Control District now operates this gauge, but it does not currently have an updated rating curve which allows conversion of stage data to flow data.

The Brentwood WTP regularly conducts effluent and receiving water monitoring in compliance with its permit. In addition, rain gauges are located nearby at the Brentwood WTP and Marsh Creek Reservoir. A water level gauge at Marsh Creek Reservoir provides information as to whether flows from the upper watershed reach the lower watershed. Data from the WTP effluent and receiving water monitoring program are summarized, along with Marsh Creek flow/stage data and weather information, in Figures 2 and 3.

The Friends of Marsh Creek Watershed (FOMCW) is a community organization with a mission to "protect, conserve, and restore Marsh Creek and its tributaries, and to inspire appreciation and conservation of the Marsh Creek Watershed." (FOMCW, 2018). According to their "2015 State of the Creek Report," volunteers and staff collected water quality data from seven sites on a weekly basis, in areas downstream of Marsh Creek reservoir. The focus of the monitoring is areas where fish kills have been observed. A case narrative describing the history of fish kills and associated monitoring results and observations was provided by FOMC to CCCWP (FOMCW, 2016).

2. CONCEPTUAL MODEL AND MANAGEMENT HYPOTHESES

A conceptual model helps organize available information to define how relevant factors affect the problem at hand and identifies the most significant data gaps to be addressed through monitoring. The conceptual model for fish kills in Marsh Creek begins with the assumption that the most common cause of fish kills is hypoxia – the fish do not have enough oxygen to survive. Development of this simple conceptual model proceeds by addressing two basic questions:

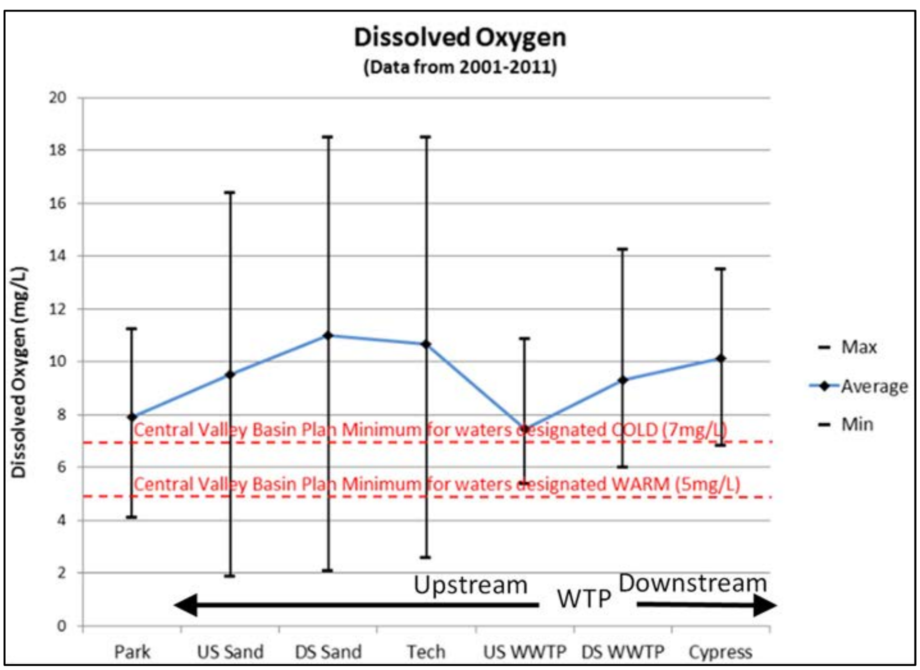
- Is there evidence for low dissolved oxygen in Marsh Creek?
- Is there evidence that other factors, in addition to or instead of low dissolved oxygen, may be contributing to fish kills?

The following subsections present evidence and information gaps related to dissolved oxygen, pesticides, and other potential causes of fish kills.

2.1 Low Dissolved Oxygen as a Potential Cause

The FOMCW reported low dissolved oxygen in Marsh Creek years ago based on a decade worth of volunteer monitoring sponsored by CCCWP (FOMCW, 2011). Their data (Figure 4) showed average dissolved oxygen was lower just upstream of the WTP compared to downstream, and dissolved oxygen was much more variable upstream of the WTP in the reaches designated as “intermittent flow” (see Figure 1). At the time, Tom Lindemuth of FOMCW hypothesized that excessive algal blooms in the stream affected dissolved oxygen levels.

Figure 4. Dissolved Oxygen in Marsh Creek, 2001-2011



Source: Friends of Marsh Creek Watershed (2011)

Other CCCWP monitoring data confirm prior findings of low dissolved oxygen upstream of the WTP and provide comparative evidence between creeks supporting the hypothesis that excessive algal blooms in Marsh Creek affect the magnitude of daily dissolved oxygen shifts (Figure 5). Dissolved oxygen was monitored at three other creeks, in addition to Marsh Creek. The magnitude of daily dissolved oxygen swings is clearly higher at Marsh Creek compared to Walnut Creek, San Pablo Creek, and Pinole Creek. The ash free dry weight (AFDW) content of the benthic substrate is also highest at Marsh Creek. AFDW provides a quantitative measure of the amount of organic carbon per unit of surface area in a creek bed. The creek with the highest organic content concentration on the substrate (Marsh Creek) also has the greatest magnitude of daily dissolved oxygen swings, consistent with algal blooms causing the daily dissolved oxygen swings in Marsh Creek.

The daily cycling of dissolved oxygen is likely driven by photosynthesis, as evidenced by the associated cycling of pH with dissolved oxygen (Figure 6). The looping shape in Figure 6 results from photosynthetic release of dissolved oxygen concurrent with uptake of CO_2 from creek water (which raises pH by decreasing carbonic acid). This is a known process in eutrophic lakes (Talling, 1976). In the late afternoon, when algae and aquatic macrophytes shift from photosynthesis to metabolism, dissolved oxygen is consumed, and CO_2 is released, driving down pH concurrently with dissolved oxygen concentrations.

The excessive algal blooms appear to be most prevalent in the reaches upstream of the WTP, where flows are more intermittent compared to downstream. The small area represented in the close-up view of the outfall in Figure 7 is consistent with upstream and downstream trends. Upstream of the WTP, in the reaches of intermittent flow, dense algal blooms between check dams are visible all the way to the reservoir. Upstream of the reservoir, the reaches of Marsh Creek which can be seen from Google Earth (there is more tree cover upstream of the reservoir) do not exhibit visible algae mats, and the AFDW ranged from 4,400 to 5,300 mg/m^3, much less than the 17,000 to 40,000 mg/m^3 observed in the algae-impacted reaches of intermittent flow between the reservoir and the WTP. Downstream of the WTP, satellite views show no signs of visible algae all the way to the mouth of Marsh Creek at Big Break.

In summary, low dissolved oxygen is known to occur upstream of the WTP. The daily swings of dissolved oxygen reach a low point in the pre-dawn hours due to the cycle of photosynthesis and metabolism in waters dense with algae. Dissolved oxygen levels did not reach lethally low levels during the comparatively brief periods that CCCWP performed continuous stormwater monitoring in Marsh Creek upstream of the WTP. The main data gap linking these observations to fish kills is a longer record of continuous monitoring of water levels, dissolved oxygen, and other continuous water quality parameters to show dissolved oxygen levels in the pre-dawn hours should a fish kill event occur during the study. Demonstrating a link, should one exist, between a fish kill event and flows of stagnant water having high BOD and consequent lethally low dissolved oxygen would essentially conclude this aspect of the investigation.

Figure 5. Comparison of the Magnitude of Dissolved Oxygen Cycles and Ash Free Dry Weight (AFDW) Among Four Contra Costa County Creeks

Figure 6. Cycling of Dissolved Oxygen and pH in Marsh Creek, May and August 2012

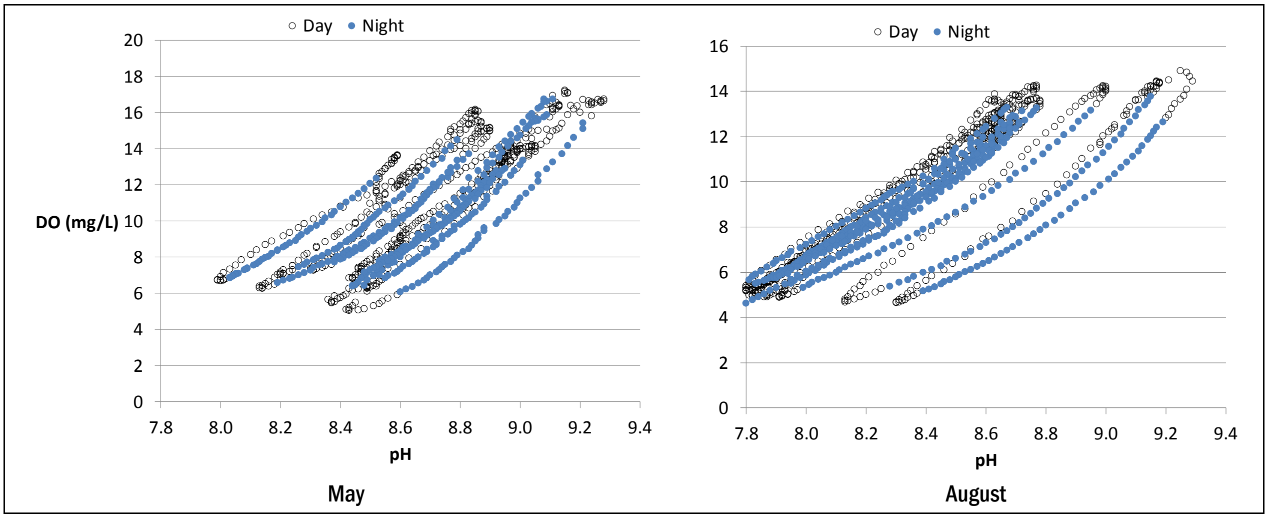


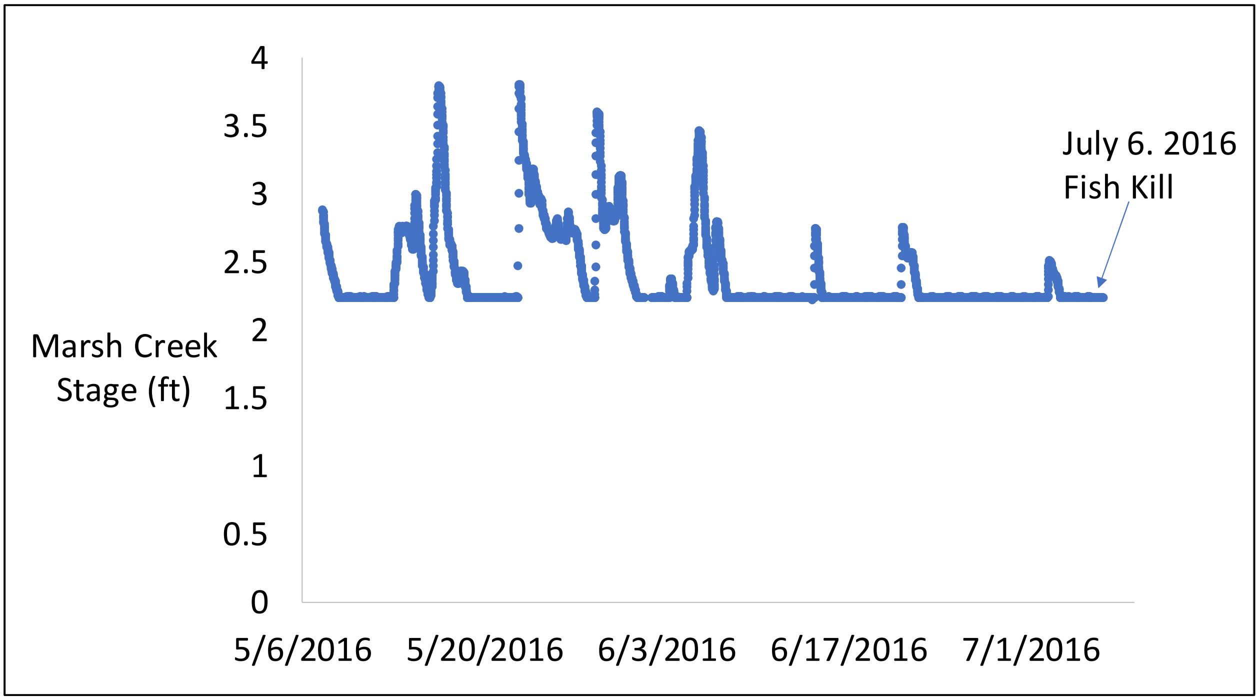
Figure 7. Visible Unattached Algae in Marsh Creek as Seen from the Ground and Above

2.2 Episodic Non-stormwater Flow as a Potential Cause

During CCCWP monitoring in the Marsh Creek watershed in the 2011-2014 time-frame, contractors observed a pattern of episodic non-stormwater flows in Marsh Creek. An example of this pattern, using data from the continuous monitoring gauge upstream of the WTP, is shown in Figure 8. In the data shown below, and consistent with CCCWP monitoring results from 2011 to 2014, a spike in flow occurs about once every two weeks. The flow spikes observed by CCCWP were measured upstream of the WTP and therefore could not have been caused by variable flow from the WTP.

Review of rainfall data shows precipitation does not explain the episodic flow spikes. From the typical summertime pattern shown in Figure 8, there appears to be either some storage that is filled and released, or an intermittent activity such as irrigation or flushing of groundwater wells or other water supply assets. The releases appear to occur in diminishing amounts as the summer season ensues. In the context of excessive algae, eutrophication, and low dissolved oxygen, dry weather discharges to the reach of intermittent flow may be contributing to the problem by creating stagnant pools between check dams where algae can bloom.

Figure 8. Flow in Marsh Creek Upstream of the WTP Prior to the July 6, 2016 Fish Kill



In addition to creating ponded stagnant water, episodic non-stormwater flows can potentially contribute to either direct or indirect causes of fish kills. An example of a direct effect would be if discharges themselves were from a stagnant water source (as opposed to stagnating in-channel), releasing sulfides, ammonia, and BOD. Another example of a direct effect would be discharges of water having unhealthy concentrations of pollutants, such as pesticides.

Indirect effects of flows could be either physical or chemical in nature. As an example of an indirect physical effect, episodic flows can cause fish kills due to stranding. There is constant flow downstream of the WTP outfall, and the flow is dominated by high quality treated water of relatively constant composition. In contrast, upstream of the WTP, flows are more erratic and result from non-stormwater urban runoff, groundwater seepage due to irrigation, and direct runoff from agricultural and golf course irrigation. A sudden, temporary increase in flow from upstream of the WTP could create fish passage, which lures fish upstream in search of new habitats, followed by stranding in less favorable habitats as the flow drops off again.

A fish ladder was installed in 2010 just upstream of the Brentwood WTP outfall. Volunteer monitors previously observed salmon in Marsh Creek upstream of this fish ladder (FOMCW, 2015). CCCWP monitoring crews observed individual stranded fish near the stormwater monitoring station, which is just upstream of the fish ladder (Figure 9).

Figure 9. Adult Chinook Salmon Stranded Between Check Dams in Marsh Creek at the POC Loads Monitoring Station, December 6, 2011

Another potential indirect effect is the increase of turbidity during episodic non-stormwater flow spikes. Increased turbidity can be a problem by itself due to gill clogging by sediments and can also be a potential exposure route for pollutants, such as pesticides. Pyrethroid pesticides are extremely hydrophobic and are typically bound to particulates in natural waters, which tend to accumulate in sediments. Rather than the direct effect of discharge containing high levels of pesticides, an indirect effect could occur if the episodic flow spikes resuspend toxic sediments already present in the creek, increasing exposure from pesticides to fish and other aquatic organisms. Evidence for pesticides as a cause is discussed in the next subsection.

In summary, episodic non-stormwater flow spikes are known to occur in Marsh Creek. A key data gap is identifying the origins of the non-stormwater flow spikes. Another key gap is the composition of the presumed discharge leading to the flow spikes. A third gap is understanding the significance of pollutants in the presumed discharge vs. resuspension of in-stream pollutants.

A careful review of historic monitoring data available through CCCWP, the County Flood Control and Water Conservation District, and the California Department of Water Resources' California Data Exchange Network (CEDEN) will be performed as part of this study to better define the historic patterns. Additionally, water level sensors will be deployed to attempt to pinpoint the origins of dry weather discharges. Water level monitoring will be augmented with visual inspections by contracted field staff, and a review of storm drain assets using county geographic information systems (GIS) layers, culminating in a map and inventory of stormwater outfalls and documented sources of flow.

2.3 Pesticide Toxicity as a Potential Cause

CCCWP has been assessing sources and causes of frequently observed toxicity to the amphipod *Hyalella azteca* in Marsh Creek and its tributaries (Table 2) over several years. The weight of evidence suggests toxicity to *H. azteca* in the investigated waterbodies is caused by pyrethroid pesticides (CCCWP, 2015). Concurrent testing did not show toxic effects on fathead minnows, so there is not a clear line of evidence linking pesticide toxicity to fish kills from any of the CCCWP investigations.

Table 2. Summary of Toxicity Test Results from Marsh Creek and its Tributaries

Sample Date	Station	Creek	Matrix	Sample Type	Percent Survival *Hyalella azteca*	Percent Survival Fathead Minnow
03/15/12	544R00025	Dry Creek*	water	Wet Weather	0%	100%
07/25/12	544R00025	Dry Creek*	water	Dry Season	98%	95%
	544R00025	Dry Creek*	sediment	Dry Season	60%	N/A
04/04/13	544R00025	Dry Creek*	water	Wet Weather	20%	N/A
	544R00281	Marsh	water	Wet Weather	0%	95%
07/09/13	544R00281	Marsh	water	Dry Season	98%	98%
	544R00281	Marsh	sediment	Dry Season	54%	N/A
02/06/14	544R00025DS	Dry Creek*	water	Wet Weather	12%	N/A
	544R00025US	Dry Creek*	water	Wet Weather	18%	N/A
02/27/14	544R00025DS	Dry Creek*	water	Wet Weather	6%	N/A
	544R00025US	Dry Creek*	water	Wet Weather	18%	N/A
07/22/14	544R00025DS	Dry Creek*	sediment	Dry Season	49%	N/A
	544R00025US	Dry Creek*	sediment	Dry Season	4%	N/A

* Tributary to Marsh Creek
Red "Percent Survival" indicates toxicity

The possibility that pesticides may cause fish kills in Marsh Creek was raised by the FOMCW in their narrative history of fish kills (FOMCW, 2016), as well as by the California Department of Fish and Wildlife in their investigation of the July 6, 2016 fish kill (CDFW, 2016). Much of the evidence presented is based on pesticide use in adjacent lands (i.e., the timing of algaecide applications in a nearby canal). After the July 6, 2016 fish kill, the CDFW found that composite samples of largemouth bass gill and liver tissue collected from Marsh Creek contained bifenthrin concentrations of 4 and 3 ppb, respectively. Bifenthrin is a commonly used pyrethroid pesticide. No other pyrethroid pesticides were detected in those tissue samples.

During the May 2018 bioassessment season, as this work plan was being prepared, CCCWP contractors conducting bioassessments noted dead crayfish in isolated pools in the reaches of intermittent flow, as well as a few individual dead fish. These observations were independently corroborated by FOMCW volunteer monitors conducting their own bioassessment work in the same period. The fish were thought to have died as a result of stranding in isolated pools. The crayfish deaths were more puzzling, as crayfish are better adapted to oxygen-limited environments and can burrow to survive in isolated pools (Grow and Merchant, 1980). Low dissolved oxygen is not ruled out as a potential cause of crayfish death, because they do need oxygen to survive; however, because crayfish are more closely connected to sediment food chains than larger swimming fish, it is possible that sediment-associated pesticides which affect *Hyalella azteca* could also affect crayfish.

The relative toxicity of one example pesticide, permethrin, to larger fish, crayfish, and highly sensitive amphipods puts the question of pesticide toxicity to crayfish into context (Table 3). The toxicity of permethrin to larger fish is about an order of magnitude less than the toxicity to crayfish. Permethrin toxicity to crayfish, in turn, is approximately an order of magnitude less compared to amphipods. Thus, while we have evidence that pyrethroids such as permethrin are present in Marsh Creek water and sediments at levels lethal to amphipods, crayfish are more tolerant by about thirty-fold (based on permethrin toxicity), and so the evidence that pesticides could explain crayfish mortality is less clear-cut – it cannot be ruled out at this point, but neither is there strong evidence in support of pesticides causing crayfish mortality.

Table 3. Toxicity of Permethrin to Larger Fish, Crayfish and Amphipods

Species	LC 50 (µg/L)
Larger Fish (e.g., Lahontan cutthroat trout, *Oncorhynchus clarki henshawi;* rainbow trout, *Oncorhynchus mykiss;* fathead minnow, *Pimephales promelas*)	1.6-9.4
Crayfish, *Orconectes immunis*	0.21
Amphipods, *Hyalella azteca*	0.007

Reference: Fojut et al., 2015

A significant information gap is the direct link between fish tissue pesticide concentrations and toxic effects in larger aquatic organisms, such as crayfish and large-mouth bass. For example, tissue effect level information is needed to interpret the tissue bifenthrin concentrations reported by CDFW following the July 6, 2016 fish kill. Information on tissue concentrations of pesticides found in fish tissues from more pristine waterbodies would also help explain whether the reported values indicate a potential link between pesticides and fish kills. This type of information will initially be developed through literature review and coordination with wildlife resource agencies. If fish kills occur during this study, opportunistic fish and/or crayfish samples may be provided to CDFW for tissue analysis of pesticides, if CDFW is willing to partner by providing laboratory analysis of tissues. Any other planned collection of fish samples and analysis of tissues to Marsh Creek would be deferred to potential future studies.

Source identification of potential pollutants is another information gap. If specific pesticides (i.e., bifenthrin) are implicated as likely causes of fish kills, then corrective measures would rely on source identification. Known usage is one existing approach to source identification. CCCWP prepared a summary of recent pesticide usage as part of the pesticide toxicity SSID study conducted under MRP 1.0 (CCCWP, 2015). This report will be referred to in preparation of the Year 1 report and updated in the future if new pesticide uses are indicated by monitoring data or new information from the Contra Costa County Agricultural Commission.

Monitoring can potentially refine the source identification by evaluating which catchments or discharge points contribute water or sediments with elevated concentrations of pesticides. CCCWP is monitoring during WY 2018 for toxicity and pesticides in Marsh Creek and the West Branch of Alamo Creek in compliance with Provision C.8.g of the MRP. This work includes wet weather water sampling and dry weather water and sediment sampling, as well as follow-up testing if toxicity is detected. Per requirements of the MRP, the analyte list includes a new pesticide, imidacloprid. Results from this separate requirement of Provision C.8.g of the MRP will be included in the Year 1 report of the SSID study of Marsh Creek fish kills.

In addition to the pesticide and toxicity monitoring separately required under Provision C.8.g of the MRP, the SSID study will add three dry weather samples for pesticides and other constituents (e.g., BOD, sulfides, ammonia). Two of those dry weather samples will opportunistically target flowing outfalls which contribute significant amounts of dry weather flow. The third will be held in reserve, to sample the creek water for pesticides in the event of a fish kill.

2.4 Swings in pH as a Potential Cause

The data presented in Section 1.6.1 also implicate pH swings as another potential cause of fish kills. The main effect of pH on larger organisms would likely be an indirect effect by increasing the toxicity of constituents present in water. For example, ammonia toxicity is highly dependent on both temperature and pH. At 25 °C, a pH swing from 8 to 9 can cause the water quality criteria for ammonia to decrease approximately six-fold (USEPA, 2013; Table 2).

Table 4. Variation of Acute and Chronic Water Quality Criteria for Ammonia with pH

pH	Acute (1 hour) Criterion (mg/L)	Chronic (30 day average) Criterion (mg/L)
pH = 8.0	2.6	0.56
pH = 9.0	0.41	0.11

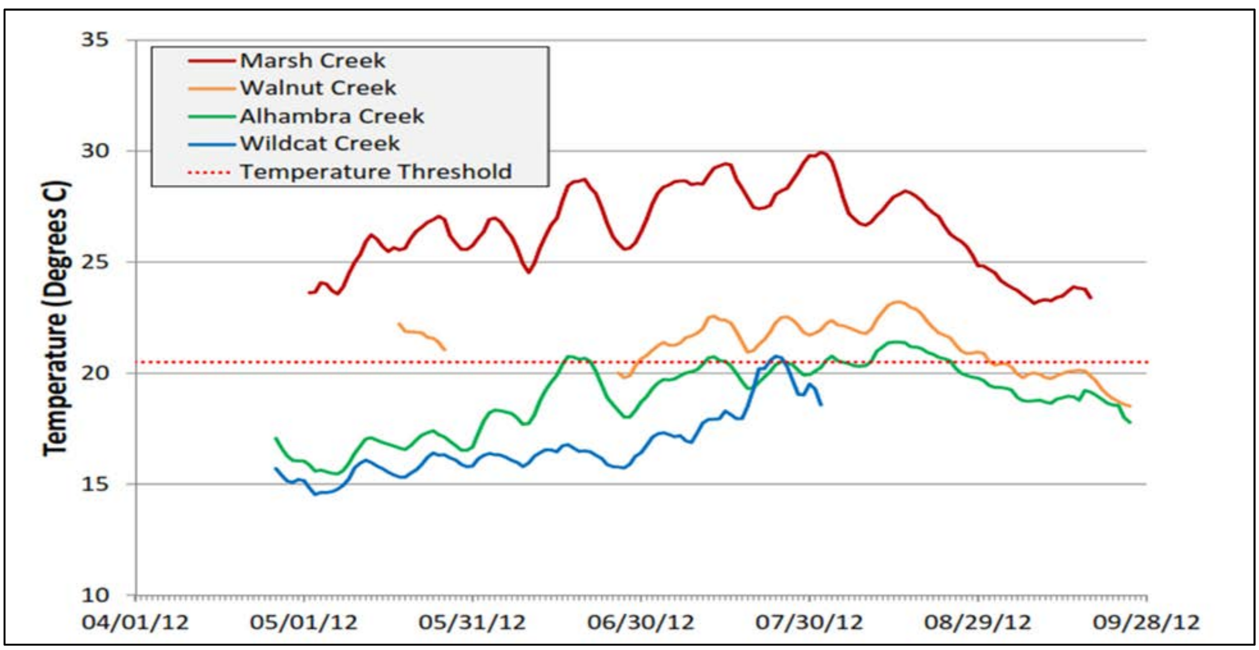
As with dissolved oxygen, spatial and temporal data gaps for pH are best addressed through continuous monitoring upstream and downstream of the WTP. Additionally, measurements of constituents which vary in toxicity depending on pH is important to this aspect of the work plan. Ammonia monitoring is the most important parameter for assessing the potential impact of pH swings. Dissolved metal monitoring could also be considered; however, the most sensitive organisms to acute metals toxicity are generally smaller, one-celled organisms. A literature review of metals toxicity to fish as affected by pH and comparison to existing monitoring data will likely be sufficient to resolve metals as a data gap.

2.5 Temperature as a Potential Cause

Marsh Creek was the warmest creek of the four major creeks monitored by CCCWP for temperature in the summer of 2012 (Figure 10). Thus, temperature is also a potential cause of fish kills. The effect of temperature can be direct or indirect. Indirect effects would generally manifest as making fish sluggish and lethargic, and therefore less able to swim away to seek refuge from low dissolved oxygen. Temperature also affects the in-stream availability of dissolved oxygen, as DO is less soluble at higher temperatures.

As with dissolved oxygen and pH, the data gaps for temperature are both spatial and temporal, and are best addressed through deployment of continuous monitoring devices upstream and downstream of the WTP outfall. The monitoring devices will also address spatial gaps in the understanding of temperature. The relatively high Marsh Creek temperatures (see Figure 10) result in part from the fact that temperature sensors were placed in isolated pools located upstream of the WTP that have very slow, intermittent replenishment rates. Temperature profiles downstream of the WTP in the reach with more constant flow may reveal healthier temperatures in that section of Marsh Creek.

Figure 10. Seven-Day Average Maximum Daily Water Temperature (MWAT) Data Collected Using HOBOs® at Four Sites in Marsh, Walnut, Alhambra, and Wildcat Creeks



2.6 Conceptual Model Summary and Management Hypotheses

Management hypotheses help translate the conceptual model and data gaps into monitoring scope. A summary of the conceptual model helps frame the hypotheses listed in Table 5. The conceptual model includes the assumption that low dissolved oxygen is the most common cause of fish kills, but there are other potential causative factors in Marsh Creek which are not exclusive of low dissolved oxygen.

Daily oscillations of dissolved oxygen and pH are known to occur upstream of the WTP discharge. Swings in pH could also play a role in fish kills by causing an increase in the toxicity of ambient ammonia levels. Temperature is another variable water quality factor which may play a role in fish kills. The daily variation of water quality both upstream and downstream of the WTP represent data gaps that will be addressed through monitoring in this study.

Pesticides are known to affect the viability of amphipods (*Hyalella azteca*) in the Marsh creek watershed. Toxicity tests on fish, on the other hand, have not shown toxicity to date. The causes of mortality to crayfish recently observed are unknown – potential causes include low dissolved oxygen, pesticides in sediments, temperature, or some yet unidentified cause. Although crayfish mortality is technically outside the scope of this study, crayfish are indicator organisms for conditions which are also potentially unhealthy to fish, and therefore will be considered, as feasible, in this study.

The management hypotheses presented in Table 5 are organized in order of priority for investigation. In Phase I of this study (spring of 2018 through spring of 2019), the work will focus on 1) evaluating the link between low dissolved oxygen and fish mortality; 2) further investigation of the role of algal blooms and dry weather discharges in creating and transporting sources of BOD downstream; 3) identifying sources of dry weather flow; and 4) further investigation of pesticides concentrations and effects in conjunction with monitoring required in Provision C.8.g of the MRP. Dry weather flow investigations also set the stage for focused pesticide source investigation.

The top two most significant sources of dry weather flow will be opportunistically sampled for chemical constituents, including pesticides, during the summer of 2018. To the extent practicable, water will be sampled for pesticides immediately following a fish kill event, should one occur during this study. In addition to opportunistic sampling of dry weather flows, CCCWP will continue to monitor toxicity and pesticides during wet weather and dry weather, following the requirements of Provision C.8.g of the MRP. Monitoring for pesticides and pesticide-caused toxicity is a countywide priority, and so CCCWP will shift monitoring for pesticides and toxicity away from Marsh Creek once the watershed has been sufficiently investigated.

As a third action to address pesticides, CCCWP will coordinate with CDFW and FOMCW to determine whether the two parties are interested in evaluating pesticide concentrations in fish and crayfish tissues. CCCWP would not perform this work directly, but rather encourage FOMCW volunteers to partner with CDFW to opportunistically collect and submit dead fish and crayfish for analysis by CDFW following an incident. CCCWP would encourage both parties to concurrently seek reference biological samples of fish or cray fish that have not perished and/or come from other, less developed watersheds. Should the CDFW and FOMCW choose to pursue such an investigation, CCCWP would consider including results in the Year 1 report if they result from thoughtful monitoring design and are technically reviewed for accuracy and relevance to the study. Preliminary discussions with CDFW and FOMCW indicate an interest in such a collaborative approach.

Table 5. Management Hypotheses and Associated Monitoring Approaches for Actions to be Initiated During Work Plan Development, Beginning February 2018

Hypotheses	Evaluation Approach	Schedule or Status
Low dissolved oxygen causes fish kills	Compile historic WTP effluent and receiving water monitoring Review and summarize time of day and antecedent weather for historic fish kills	Completed during work plan development
	Perform continuous monitoring of dissolved oxygen, pH, conductivity, turbidity, and temperature at three locations upstream and downstream of the WTP	Two of three sensors installed as of April 2018. Third sensor to be installed July 2018.
Low dissolved oxygen upstream of the WTP is caused by excessive algal blooms	Compare algal abundance, ash free dry weight, and magnitude of dissolved oxygen swings among Contra Costa County creeks	Completed during work plan development
Episodic non-stormwater flows are the result of agricultural irrigation, golf course irrigation, residential irrigation, or maintenance flushing of potable water systems.	Perform continuous monitoring of water levels at several locations within the watershed using sondes and HOBOs (Figure 1)	Water level sensors installed as of April 2018
	Issue email alerts when non-stormwater flows increase in the creek commence	Email alerts are being sent as of April 2018
	Develop a map and inventory of storm drain outfalls Opportunistically dispatch inspectors to identify and potentially sample sources of flow	To commence July, 2018
Stagnant water is flushed from upstream of the WTP to the lower creek during episodic dry weather flow spikes and first flush rain events	Collect water samples for BOD, sulfides, total organic carbon, and total suspended solids during dry weather base flow conditions, during dry weather flow surges, and during first flush storm events.	To commence July, 2018
Flushing of stagnant water from upstream of the WTP can cause lethally low dissolved oxygen downstream	Develop a simple WASP-8 water quality model to determine BOD loads needed to explain observed sags in dissolved oxygen. Compared modeled BOD loads to monitored loads.	To commence July, 2018
Non-stormwater discharges contain elevated levels of BOD and / or pesticides	Opportunistically dispatch inspectors to sample sources of flow	To commence July, 2018
Pesticides cause fish kills	Continue to monitor toxicity and pesticides in Marsh Creek in compliance with Provision C.8.g	Commenced January 2018
	Collect an opportunistic sample for pesticides and toxicity as soon as practicably possible immediately following a fish kill event	To commence July, 2018
Pesticides cause crayfish kills	Coordinate with CDFW to find out if they would partner to provide analysis of pesticides in fish and crayfish tissues	Begin discussion with CDFW in July, 2018
Daily pH peaks cause ammonia toxicity to increase, causing or contributing to mortality	Review data on ammonia toxicity vs. pH for affected species, compare to ambient conditions	To commence July, 2018
Daily temperature peaks in isolated pools cause or contribute to fish and/or crayfish mortality	Continuous monitoring of temperature, comparison of conditions at the time of a mortality event to stressful and lethal thresholds	To commence July, 2018

3. PHASE I IMPLEMENTATION (FEBRUARY 2018-JUNE 2019)

Phase I implementation began in February of 2018 with the procurement of equipment necessary to establish continuous water quality monitoring stations on Marsh Creek. Monitoring stations were installed in April and May 2018 and consisted of two types: multiparameter sonde stations and water level/temperature stations. As low dissolved oxygen is strongly suspected as a cause of fish kills, the multiparameter sonde monitoring stations continuously measure and record dissolved oxygen concentration (every two minutes). Additionally, other water quality parameters which may be associated with low dissolved oxygen are measured and recorded continuously, including temperature and pH. Because non-stormwater flows are implicated as a possible cause or contributing factor of fish kills, continuous water level monitoring is included at all stream stations. The locations, characteristics and operational details of the monitoring stations are described in the subsections below.

Pesticides and toxicity monitoring continues during WY 2018 at selected sites in the Marsh Creek watershed, in accordance with Provision C.8.g of the MRP.

3.1 Establishment of Monitoring Stations on Marsh Creek

Phase I implementation consists of the establishment of seven monitoring stations along Marsh Creek (Figure 11). Three of the stations are instrumented with multi-parameter sondes and are capable of automatic and remote-operated water sample collection. Two of these stations are in Brentwood, just above and below the WTP, and the third station is in Oakley near observed fish kills. The remaining four stations are instrumented with water level and temperature recorders and are located below the Marsh Creek Reservoir and immediately below the confluences of Sand Creek, Deer Creek, and Dry Creek. Encroachment permits were obtained from the East Bay Regional Park District prior to installation of each monitoring station.

Table 6 provides a summary of continuous monitoring station locations, water quality measurement parameters and equipment installed onsite.

The primary purpose of establishing these monitoring stations is to collect continuous time-series data which may help to identify potential stressors to fish (e.g., low dissolved oxygen), and to help determine the source(s) of non-storm increases in flow rate which have been documented within portions of Marsh Creek in the recent past. Additionally, two of the monitoring stations (544R04613 and M2) are equipped with autosamplers and can be used to automatically collect water samples for laboratory analysis of BOD, pesticides, and other constituents during storm and non-storm flow events.

Figure 11. Continuous Water Quality Monitoring Station Locations on Marsh Creek

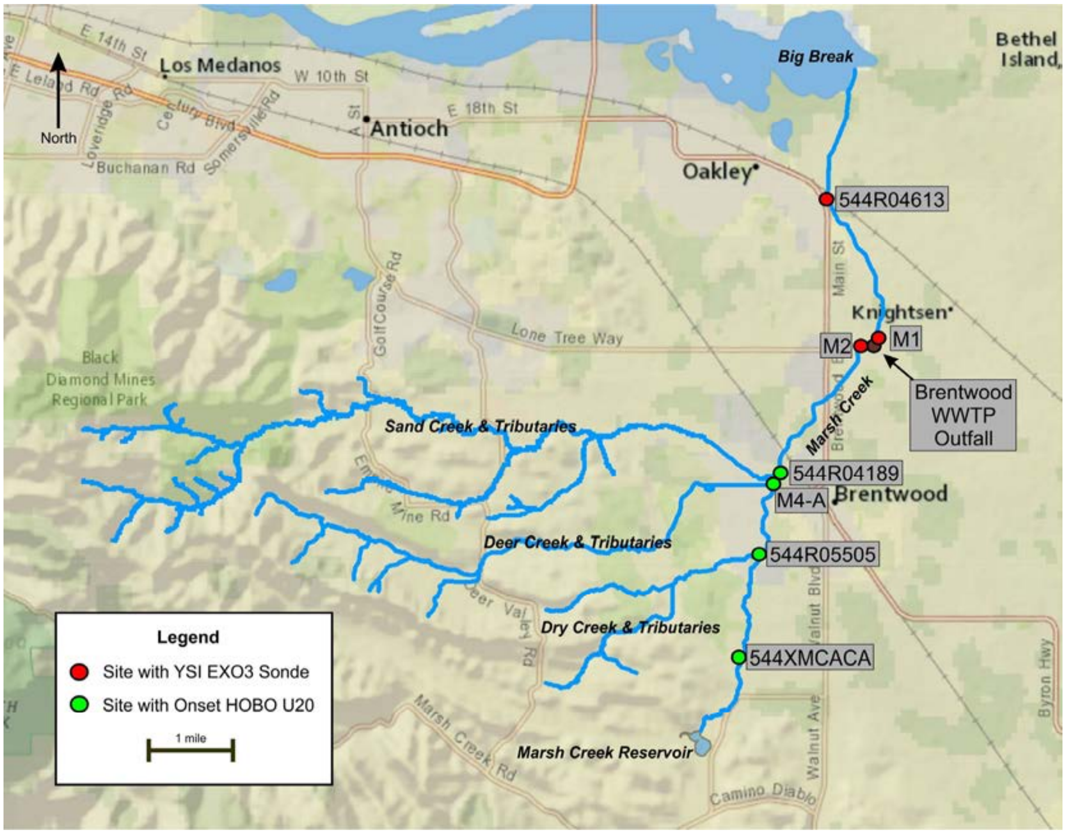


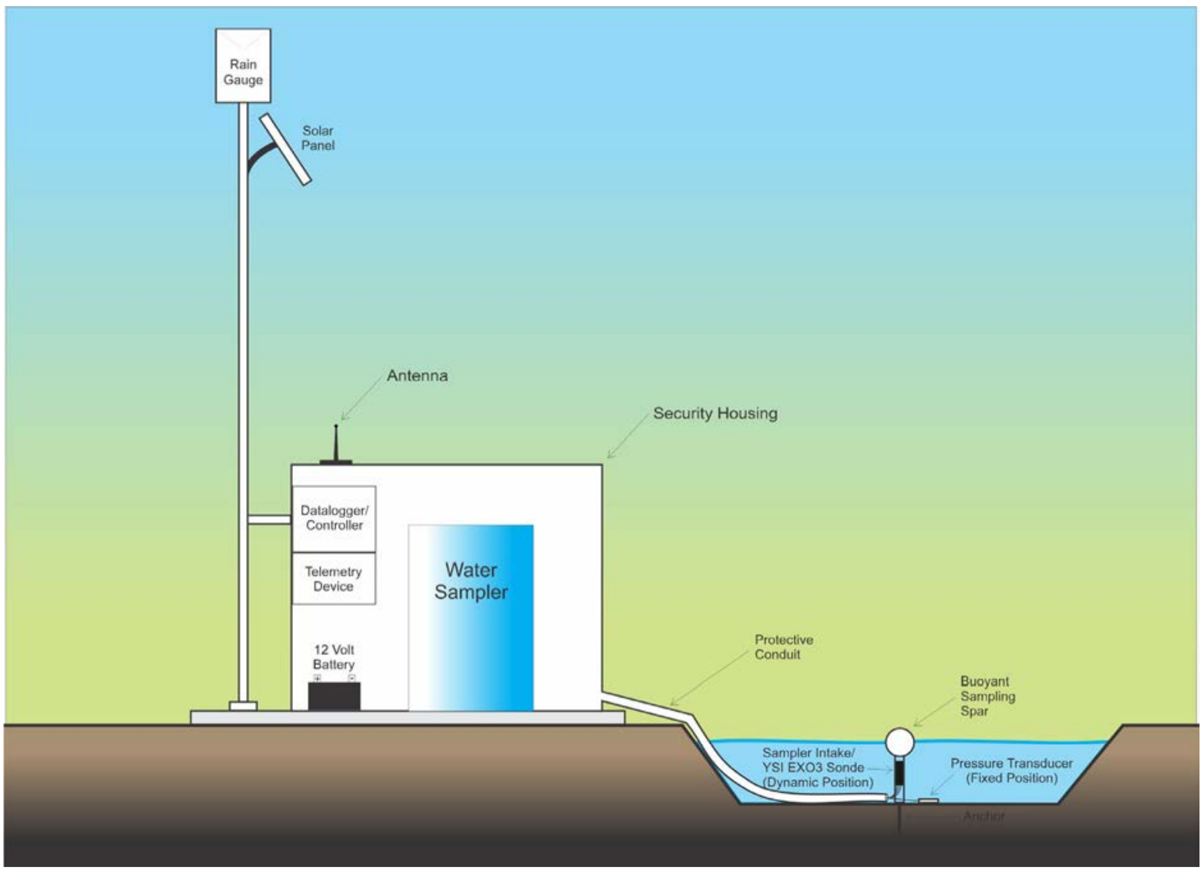
Table 6. Station Designation, Location, and Installed Equipment/Measurement Parameters

Station ID	Latitude	Longitude	Installed Equipment/Measurement Parameters								
			Water Depth	Water Temperature	Conductivity	pH	Dissolved Oxygen	Turbidity	Rain Gauge	Auto Sampler	Telemetry
544R04613	37° 59.420'	-121° 41.751'	X	X	X	X	X	X		X	X
M1	37° 57.837'	-121° 41.017'	X	X	X	X	X	X			X
M2	37° 57.754'	-121° 41.275'	X	X	X	X	X	X	X	X	X
544R04189	37° 56.323'	-121° 42.414'	X	X							
M4-A	37° 56.202'	-121° 42.523'	X	X							
544R05505	37° 55.400'	-121° 42.728'	X	X							
544XMCACA	37° 54.093'	-121° 43.104'	X	X							

3.2 Multi-Parameter Sonde Monitoring Stations with Telemetry

Three multi-parameter monitoring stations (544R04613, M1 and M2) are instrumented with YSI EXO3™ sondes, telemetry hardware and other equipment (see Table 6). Each of these stations consists of a steel security enclosure to house the above-water electronics (datalogger, cellular modem/antennae, battery, and solar charging unit). Each enclosure is securely mounted to a small concrete pad. PVC conduit protects the power/data cables and sampler intake tubing from the top of the bank to the sonde unit, pressure transducer and sampler intake points in the stream. Within its dynamically buoyant spar housing, the sonde and sampler intake tubing are double anchored to the stream bed. Figure 12 depicts the typical monitoring station configuration.

Figure 12. Typical Configuration of Multiparameter Sonde Monitoring Station



Equipment control, sensor interrogation, and data storage is managed by an onsite programmable logic controller/datalogger. These units are tasked with automatic data interrogation, data pushing to an offsite server, and instantaneous alarm notifications (via text and e-mail) when water depth or water quality triggers are met. Alarm notifications are currently set for dissolved oxygen values below 4.0 mg/L, turbidity values above 75 NTUs, and sudden increases in water level relative to a preceding three-hour average.

The sonde stations operate autonomously but require periodic sensor calibration and servicing. Although the sondes have an automatic wiper mechanism which activates every four hours to keep the sensors free of biological growth, the units are cleaned, calibrated, and serviced approximately every 60 days. Servicing and calibration includes the following:

- Independent measurements of water properties with a portable sonde unit to assist in data correction due to sensor drift, if needed
- Inspection of the anchor system, conduit, and buoyant housing, with repairs made as necessary
- Field calibration of sensors, per manufacturer's specifications
- Removal of biological growth from all in-stream components
- Inspection of electronic equipment in the security enclosure, refreshment of desiccant, and replacement of batteries, as necessary

In the event daily scheduled downloads from a sonde cease unexpectedly or downloaded data indicate a pressing need for servicing (e.g., unexpected sensor drift or failure), as-needed maintenance may become necessary. Whenever practicable, maintenance activities will be deferred until the next scheduled site visit to reduce the need for unscheduled maintenance visits. Sonde data will be automatically downloaded to a database on a daily schedule. Simple plots of sensor output will be viewed regularly to look for sensor drift/failure, which might trigger a maintenance visit.

Table 7 lists the sensor specification of the YSI EXO3 sonde.

Table 7. YSI EXO3™ Sonde Sensor Specifications

Sensor	Sensor Type	Units	Accuracy	Resolution
Temperature	Thermistor	°Celsius	±0.01 °C	0.001 °C
Conductivity	4-electrode nickel cell	micro Siemens/cm	±0.001mS/cm	0.0001 to 0.01 mS/cm
pH	Glass combination electrode	pH units	±0.1 pH units	0.01 pH units
Dissolved Oxygen	Optical	mg/L	±0.1 mg/L	0.01 mg/L
Turbidity	Optical, 90° side scatter	Formazan nephelometric units	±0.3 FNU	0.01 FNU

3.3 Water Level and Temperature Monitoring Stations

Four water level and temperature monitoring stations (544R04189, M4-A, 544R05505 and 544XMCACA) are instrumented with Onset HOBO™ U20 water level data loggers. These monitoring stations are installed on Marsh Creek upstream of the sonde stations and at locations which may help identify the source(s) of non-storm flow event documented in the recent past. A HOBO™ U20 is a small, internally powered, internally recording water level and temperature probe. There is no surface component to the HOBO™ U20 station; the entire installation is underwater. Each HOBO™ U20 is housed in a short piece of PVC pipe and is anchored to the stream bed with stout metal rods.

The HOBO™ U20 water level and temperature recorders have internal data storage and power; therefore, they must be serviced periodically to download data and replace batteries. The stations will be serviced on the same schedule as the sonde stations (i.e., once every 60 days). As with the sondes, the HOBO™ U20 sensors, housings and anchors will be inspected, cleaned, and repaired or replaced as necessary.

As water level data are collected and more is learned about where non-storm flow are found, the monitoring stations may be relocated to focus areas within Marsh Creek and/or its tributaries to better assess flow sources. Amendments to CCCWP's encroachment permits may be necessary prior to the relocation of any monitoring station.

3.4 Development of a Flow Rating Curve

Concurrent with station installation and maintenance activities, wadable stream ratings will be performed by field crews. Over time, these data should provide a rough relationship between water depth and flow rate at each monitoring station. To establish a flow rating curve, a wide range of flows should be measured in a stream section not subject to changing channel geometry or upstream or downstream blockages of flow. Marsh Creek is generally not affected by flow blockages or changing channel geometry; therefore, no obvious impediments exist to the development of flow rating curves over time.

Stream flow measurements will be made with a handheld stream stadia rod and a Marsh McBirney Flo-Mate™ handheld flow meter, per USGS-approved methods (USGS, 2010). The flow rating curves will be used to compute and add flow estimates to the time series data sets for each of the monitoring stations.

3.5 Develop Outfall Map and Inventory

Outfalls discharging to Marsh Creek between the reservoir and the most downstream station (544R04613) will be inventoried and mapped. The process will begin with searching Contra Costa County GIS layers for known storm drain asset locations, sizes, and drainages. A visual inspection will be conducted by walking the creek with a hand-held GPS to confirm locations and condition of outfalls. The inventory will be used, along with flow and water level measurements along the length of the creek, to document which outfalls or tributaries appear to contribute the most to dry weather discharges. This process will be used to prioritize the locations for opportunistic sampling.

3.6 Water and Sediment Sampling

Water and sediment sampling will include work performed under Provision C.8.g. of the MRP, as well as additional water and/or sediment quality monitoring, to address specific needs of this SSID study. Each component is described separately below.

3.6.1 Pesticide and Toxicity Sampling Conducted under Provision C.8.g

Water samples for chemistry and toxicity will be collected once in wet weather and once in dry weather, and sediment samples will be collected once in dry weather. The test methods for water toxicity are listed in Table 8. Test methods for water and sediment chemistry are listed in Table 9. Sediment toxicity will be tested for *Hyalella azteca* and *Chironomus dilutes* following EPA Method EPA-600/R-99-064. Follow-up testing and responsive actions will be initiated, fulfilling the requirements of Provision C.8.g.iv of the MRP.

Table 8. Analytical Tests, Methods, Reporting Limits and Holding Times for Water Toxicity Testing

Test Species	Test Endpoint(s)	Units	U.S. EPA Method
Pimephales promelas (Fathead Minnow)	Larval survival and growth	Pass or Fail using TST, % Effect	EPA-821-R-02-01334 EPA 833-R-10-00335
Ceriodaphnia dubia (Freshwater Crustacean)	Survival	Pass or Fail, % Effect <25% Passes, >25% Fails	EPA-821-R-02-013 EPA 833-R-10-003
Ceriodaphnia dubia (Freshwater Crustacean)	Reproduction	Pass or Fail using TST, % Effect	EPA-821-R-02-013 EPA 833-R-10-003
Selenastrum capricornutum (Green Algae)	Growth	Pass or Fail using TST, % Effect	EPA-821-R-02-013 EPA 833-R-10-003
Hyalella azteca (Freshwater Amphipod)	Survival	Pass or Fail using TST, % Effect	EPA-821-R-02-01236 EPA 833-R-10-003
Chironomus dilutus (Midge)	Survival	Pass or Fail using TST, % Effect	EPA-821-R-02-012 EPA 833-R-10-003

Table 9. Analytical Tests, Methods, Reporting Limits and Holding Times for Water and Sediment 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
Particle Size Distribution	Sediment	Plumb, 1991	±0.1 %	1 year
Pesticides[1]	Sediment	EPA 8270M	0.33 ng/g	14 days
Total Sulfides	Sediment	SM 4500-S2	2 mg/kg	7 days
Total Organic Carbon	Sediment	SM 5310 B	±0.1 %	28 days

1 Pyrethroids, chlorpyrifos, diazinon, fipronil and degradates
BOD = biochemical oxygen demand

3.6.2 Additional Water Monitoring Addressing this Study

Three opportunistic water sampling events are planned, in addition to the regular toxicity and pesticide monitoring carried out in compliance with Provision C.8.g of the MRP. Two opportunistic monitoring events will target the most significant sources of dry weather flow to Marsh Creek. The third opportunistic monitoring event will be carried out in response to a fish kill, as soon as practicably possible after the fish kill is discovered. Chemical constituents to be monitored for the three opportunistic sampling events are listed in Table 10. In addition to the constituents in Table 10, a water sample will also be collected for fish toxicity testing (*Pimephales promelas*) following a fish kill event.

Table 10. Analytical Tests for Additional Opportunistic Water Sampling

Analyte	Matrix	Test Method	Outfall Samples	Fish Kill Event Samples	Flow Spike Samples	Base Flow Samples	Total Samples
Suspended Sediment Concentration	Water	ASTM D3977-97B	2	1	3	3	9
Pesticides	Water	EPA 8270M	2	1	0	0	3
Ammonia (low level)	Water	SM 4500 NH3 C	2	1	0	0	3
Biochemical Oxygen Demand 5-Day	Water	SM 5210B	2	1	3	3	9
Total Sulfides	Water	SM 4500-S2	2	1	0	0	3
Total Organic Carbon	Water	SM 5310 B-00/-11	2	1	0	0	3
Dissolved Organic Carbon	Water	SM 5310 B-00/-11	2	1	0	0	3

In addition to the three opportunistic outfall/fish kill sampling events described in section 3.6.2, grab sampling will be performed to characterize suspended sediment concentration (SSC) and BOD under base flow conditions and during dry weather flow spike events. Up to three additional grab samples will be collected from location M1 and analyzed for SSC and BOD. Similarly, during events where dry weather flows increase suddenly during the summer and late fall, the autosampler at M2 will be triggered up to three additional times to collect a water sample from upstream of the WTP and characterize SSC and BOD. The base flow and flow spike monitoring data will provide inputs to a water quality model used to evaluate whether BOD loads from upstream of the WTP could cause lethally low dissolved oxygen conditions.

3.7 Water Quality Modeling

A simple water quality model will be developed using the Eutrophication Module of EPA's WASP-7 water quality model. The model will evaluate conditions at M1 to determine which upstream BOD loads would cause lethally low dissolved oxygen. The modeled BOD loads will be compared to conditions characterized by grab sampling to determine if transport of BOD from the eutrophic areas upstream of the WTP could cause dissolved oxygen levels low enough to cause a fish kill.

4. PHASE II IMPLEMENTATION (JULY 2019-JUNE 2020)

The direction of Phase II implementation will depend on the findings of Phase I. This work plan will be updated following the publication of the urban creeks monitoring report in March of 2019. The general approach depending on outcomes of Phase I is briefly outlined below.

If Phase I implementation yields conclusive findings an observed fish kill event was caused by lethally low dissolved oxygen associated with the creation and release of BOD from eutrophic areas upstream of the WTP, Phase II implementation of the study would continue with dissolved oxygen monitoring and could expand the investigation and documentation of dry weather flow sources. This work would be in preparation to conclude the study and turn over responsibility for longer term dissolved oxygen monitoring and identification of solutions to dry weather discharges and eutrophic conditions to the appropriate Permittees (Brentwood, Contra Costa County Flood Control and Water Conservation District, and Unincorporated Contra Costa County).

Phase I implementation could also yield inconclusive findings regarding dissolved oxygen, such as no fish kill observed, or a fish kill observed but measured dissolved oxygen does not explain the event. In that case, Phase II implementation would continue with continuous water monitoring, and could expand the pesticide aspect of the investigation. Pesticide investigations would focus on outfall monitoring to specifically identify which catchments are the most significant pesticide sources. This source investigation would also be in preparation to conclude the investigation portion of this SSID study and prepare for appropriate implementation actions following Provision C.9 of the MRP, either by CCCWP or specific Permittees, as appropriate.

5. QUALITY ASSURANCE / QUALITY CONTROL

All data collected for this study, including field measurements, time-series records, and analytical chemical results, will conform to the latest version of the Surface Water Ambient Monitoring Program (SWAMP) protocols. In all cases, measurement quality objectives will conform to SWAMP quality control and sample handing guidelines. The following subsections summarize the quality assurance/quality control (QA/QC) procedures for the various phases of this study.

5.1 Instrument Testing, Maintenance and Calibration

Prior to the deployment of field equipment, thorough bench testing will be conducted to identify any repair or maintenance needs.

To minimize or avoid downtime of instrumentation and the resulting data loss, all field monitoring equipment will be maintained in good working order and spare equipment or common spare parts (e.g., batteries and pH probes) will be available for quick repair or replacement. Field equipment with manufacturer recommended schedules of maintenance will receive preventive servicing. After use in the field, all instrumentation will be checked for needed maintenance.

Problems that occur with field instruments will be addressed by the field activities leader and, if needed, the manufacturer. This may include cleaning, re-calibration, probe replacement and sending equipment to the manufacturer for repairs. If equipment is being repaired and a different instrument is used in the interim, this will be documented in field data sheets.

An instrument or device used in this study must be calibrated through the measurement of a standard. Instrument calibrations will be performed every two months. Calibration logs will be kept to record dates of calibration and any equipment errors or failures, battery changes, and repair notes. The logs will also contain calibration methods, schedule of inspections and calibrations, and a list of needed supplies and equipment. When a change in equipment occurs, overlapping measurements will be made using both the old and new equipment to document precision and accuracy.

5.2 Field Measurement QA/QC

For those parameters that are continuously monitored, site visit measurements will be made every two months to document instrument precision and to compare with continuous data for data quality assessment. Comparisons will include water quality field measurements using calibrated, hand-held devices compared to continuous data recorded by field sondes.

5.3 Laboratory Data QA/QC

For water and sediment subject to chemical analysis, this project will use a data quality objective process that is implemented through a QA/QC program. The elements of the QA/QC program, including required levels of precision and accuracy and tolerable levels of error, are presented in detail in the Pollutants of Concern Monitoring Quality Assurance Project Plan (CCCWP, 2016).

5.4 Time Series Data Review and Validation

All the time series data will undergo examination and will initially be reviewed for outliers – unexpected values that differ from local in-time mean values. If a data outlier is identified using standard techniques, other conditions will be reviewed from field logs and calibration logs to determine any possible significance.

Otherwise, in-situ calibration tests and comparison with calibrated hand-held devices will be used to determine if any adjustments need to be made to recorded time series data, such as offsets.

5.5 Analytical Data Verification and Validation

Data reports from the analytical laboratory will be verified immediately upon receipt to ensure the following:

- All samples were tested for the appropriate analytes, and only the appropriate analytes
- Holding times were met
- Testing methods were consistent with chain of custody documentation
- Method reporting limits were achieved
- Sample IDs are consistent with the chain of custody documents

Following verification, data will undergo a comprehensive validation process which assures that laboratory narrative reporting and data qualifiers comport with laboratory QC test results including:

- Matrix spike and matrix spike duplicate recoveries
- Surrogate spike recoveries
- Certified reference material or laboratory control spike recoveries
- Method blanks results
- Laboratory split sample (duplicate) relative percent differences
- Occurrences of matrix interference
- Required dilutions

Additionally, each signed laboratory report will be compared to its corresponding electronic data deliverable (EDD) to ensure that the two documents are congruent with each other. Should any discrepancies be found during the data verification or validation process, it may become necessary to request a revised laboratory report.

6. DATA MANAGEMENT AND REPORTING

All results of analyses, as well as field notes, will be entered into Microsoft Office software (primarily Excel) and, where appropriate, Adobe Acrobat .pdf files. Electronic and handwritten data will be managed using standard techniques such as computers, external hard drives, and file servers. Data will be managed and backed-up at a minimum of three locations: the consultant's office, the consultant's cloud-based server, and submitted to CCCWP. Hand-written data such as field sheets and logs will be filed at the consultant's office. Field data, including data from loggers, will be maintained in original form (raw data) throughout the duration of the project. Data will be entered or transferred to Excel spreadsheets in appropriate SWAMP data templates. All files will be backed up nightly to the consultant's server. At appropriate intervals, finalized data will be submitted to CCCWP.

6.1 Field Data Management

Field data and observations gathered for this monitoring program will be recorded on field data sheets which include metadata. Field-collected data will be managed using the following process:

- Data will be validated; missing and questionable data will be identified, reviewed, and corrected if necessary.
- Data sheets will be electronically scanned immediately after field measurements have been completed and saved as Adobe Acrobat PDF files.
- For final storage, data will be entered into SWAMP-format field and habitat data templates and submitted based on direction from CCCWP.

6.2 Water Quality Time Series Data Management

Two types of remote sensor package devices are deployed along Marsh Creek for this study: Onset HOBO™ U20 water level data loggers and YSI EXO3™ sondes. The former device will record water depth and water temperature, while the second records the following parameters:

- Water temperature
- Conductivity
- Specific conductance
- Hydrogen-ion concentration (pH)
- Turbidity
- Dissolved oxygen (concentration and percent saturation)

The sonde devices are each connected via cable interface to a Campbell Scientific CR-1000 series data logger. These loggers are additionally interfaced to a Campbell Scientific CS451 pressure sensor and, at site M2, a tipping rain bucket. With these sensors, the loggers will record the water quality parameters listed above for the sonde devices plus the following:

- Water depth
- Water temperature
- Rainfall (Station M2 only)

Continuous water quality measurements at the four monitoring locations equipped with Onset HOBOs™ will be downloaded onsite on a periodic basis using laptop computers (approximately every 60 days). Measurements recorded at the three stations with YSI EXO3s™ will be downloaded daily to an off-site server using wireless broadband data services over the internet or using an onsite laptop computer should the telemetry fail.

Stream flow measurements will be obtained under different flow conditions at Station M1, M2, and 544R04613 to generate flow versus stage rating curves. The rating curves will be used to compute flow from stream depth measurements. Flow measurements will be obtained in-situ using a handheld stream-stick and a Marsh McBirney Flo-Tote handheld flow meter. The flow rating curves will be used to compute and add flow estimates to the time series data sets for each of the three stations.

Once compiled, the time series data will be copied into time series data templates provided by the Marine Pollution Study Lab at Moss Landing Marine Laboratory. At this point, the files are considered to be EDDs. Both original data files and final qualified EDDs will be archived and submitted to CCCWP based upon direction.

6.3 Physical and Chemical Data Management

Water quality sampling will be performed at two sites (M2 and 544R04613) during dry weather, wet weather and immediately following any occurrence of fish kill. Time-based sampling can be initiated remotely and automatically using onsite ISCO 6712 portable samplers. Water sampling may take place at other locations within Marsh Creek, its tributaries and/or outfalls which drain to Marsh Creek.

Analytical constituents for water quality samples include:

- Field parameters (temperature, pH, conductivity, dissolved oxygen)
- Suspended sediment concentration
- Pyrethroid pesticides
- Chlorpyrifos and diazinon
- Fipronil and degradates
- Ammonia
- Biochemical oxygen demand (BOD 5-day)
- Total sulfides
- Total organic carbon
- Dissolved organic carbon

Bedded sediment sampling may take place at locations of interest within Marsh Creek and its tributaries. Analytical constituents for sediment quality sampling include:

- Particle size distribution
- Pyrethroid pesticides
- Fipronil and degradates
- Carbaryl
- Total sulfides
- Total organic carbon

Opportunistic fish tissue analysis may take place in the event of a fish kill event. Analytical constituents for fish tissue sampling include:

- Pyrethroid pesticides
- Chlorpyrifos and diazinon
- Fipronil and degradates

Project laboratories are required to supply the chemistry data in SWAMP water and sediment chemistry data templates. All project data in these files will undergo complete verification and validation with subsequent qualification. Each data file will have a demonstrated ability to be submitted successfully to the SWAMP data checker, except for lookup list errors. At this point these files will be considered to be EDDs. Both original data files and final qualified EDDs will be archived and submitted to CCCWP based upon direction.

6.4 Reporting

Per the requirements of Provision C.8.e.iii.(3)(c) of the MRP, annual status reporting of the SSID study will be submitted with the Urban Creeks Monitoring Report in March of each year. The SSID study report will detail the actions taken, problem definition, and a schedule for the study's continuation and completion. As data is acquired, the status report will describe findings and results of monitoring and outline steps for the upcoming year.

As data are received, summary results will be compiled, and analysis/interpretation will be performed. The main questions the status report will attempt to address are:

- Is there evidence for low dissolved oxygen in Marsh Creek (at levels which cause mortality to fish)?
- Is there evidence other factors, in addition to or instead of low dissolved oxygen, may be contributing to fish kills?

To address these questions, the status report will include results of the following data analysis tasks:

- Evaluate and summarize water quality time series data focusing on events which may be linked to fish kills (e.g., periods of low dissolved oxygen, occurrences of discharge events from sources yet to be determined).

- Compile physical and chemical analytical results of water and sediment sampling together with prior data for evaluation of spatial and temporal differences and patterns; present results of these comparisons graphically.
- Evaluate and summarize fish kill tissue analytical results (if tested).

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