Contra Costa Clean Water Program

Marsh Creek Stressor and Source Identification Study:

Year 2 Report

Submitted to

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

March 18, 2020

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

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.

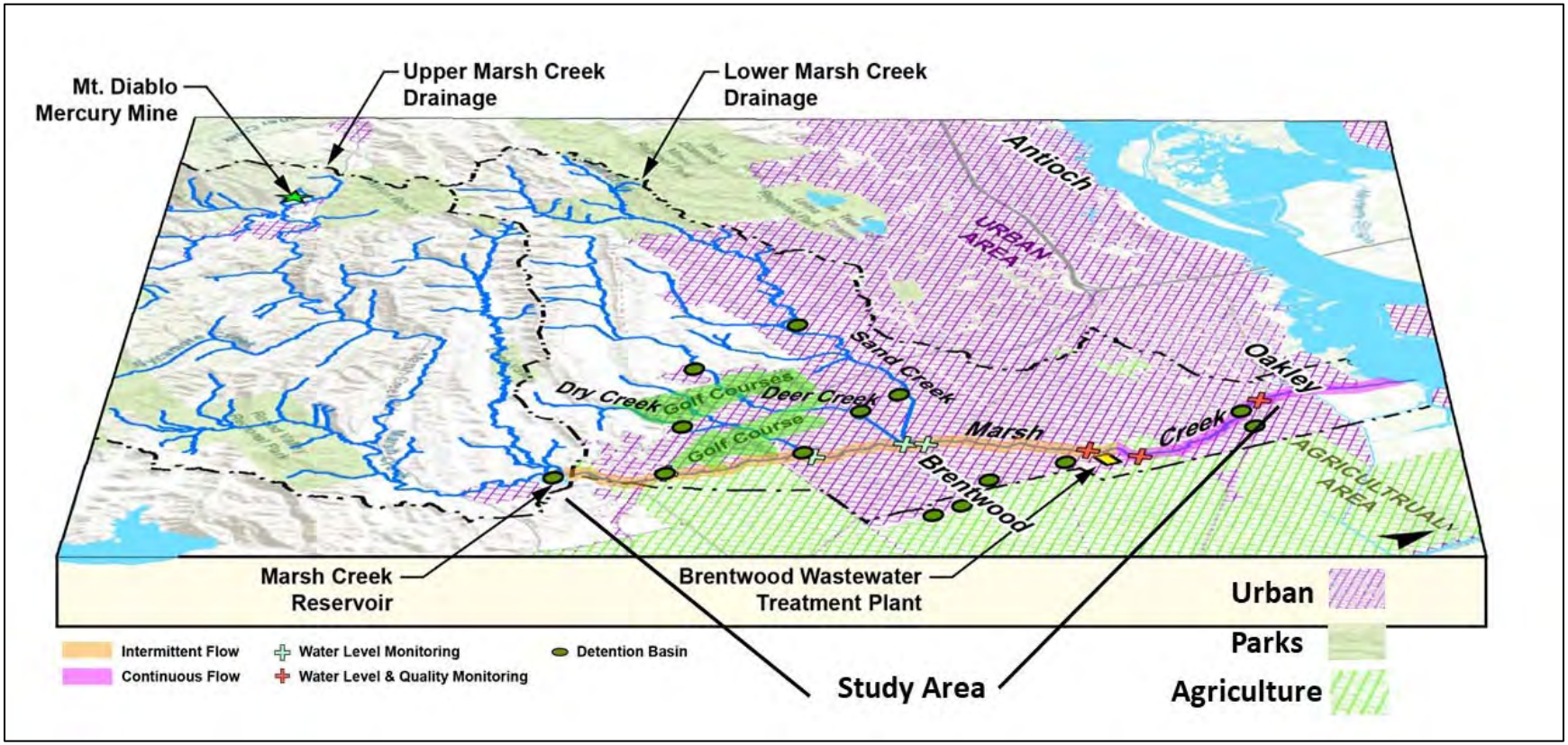
There have been 10 documented fish kills over the past 14 years in Marsh Creek, dating back to 2005 (CCCWP, 2018 and citations therein). These events are often associated with intermittent dry season flows or storm events with varying antecedent dry periods. The most recent event occurred in September 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

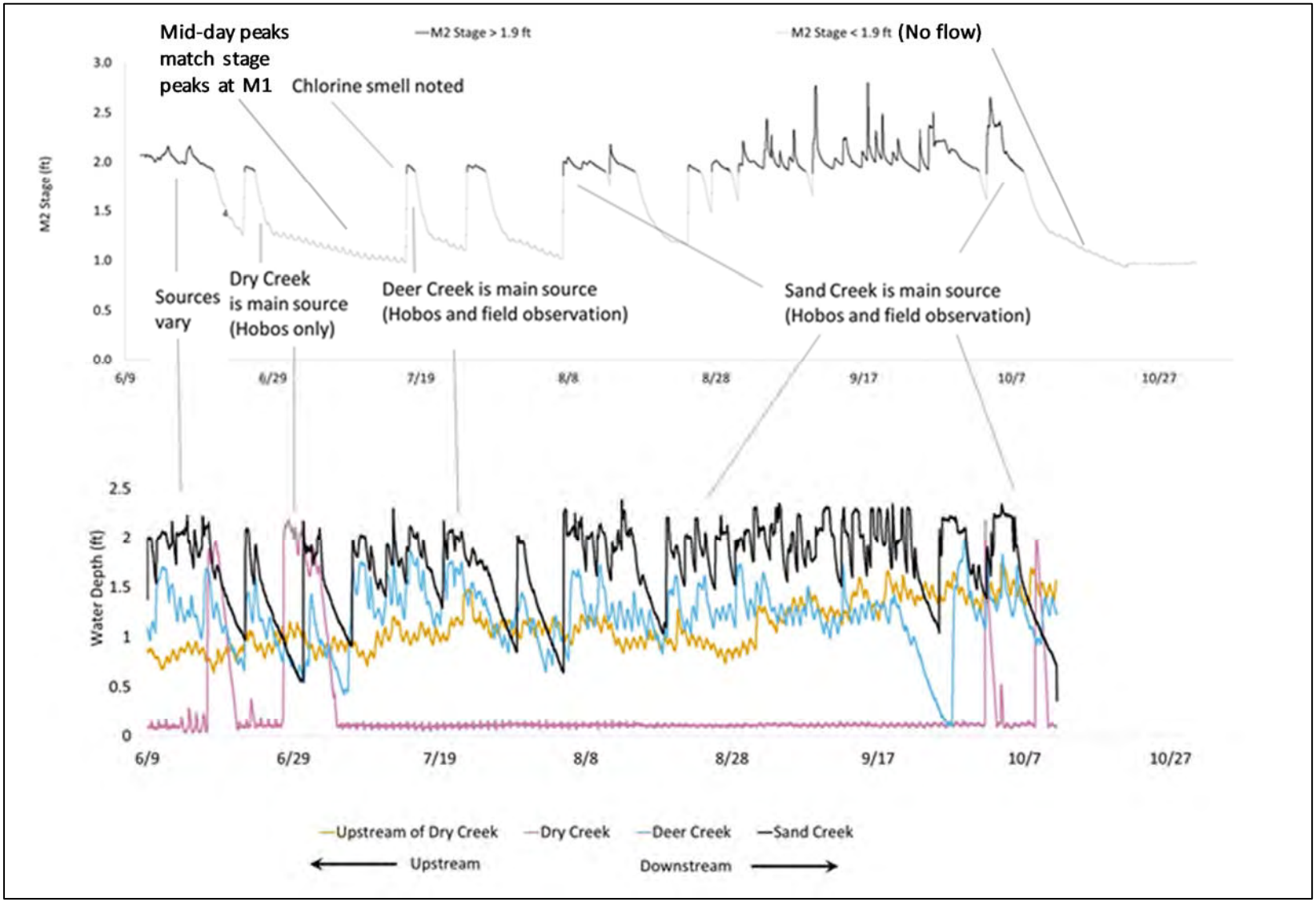
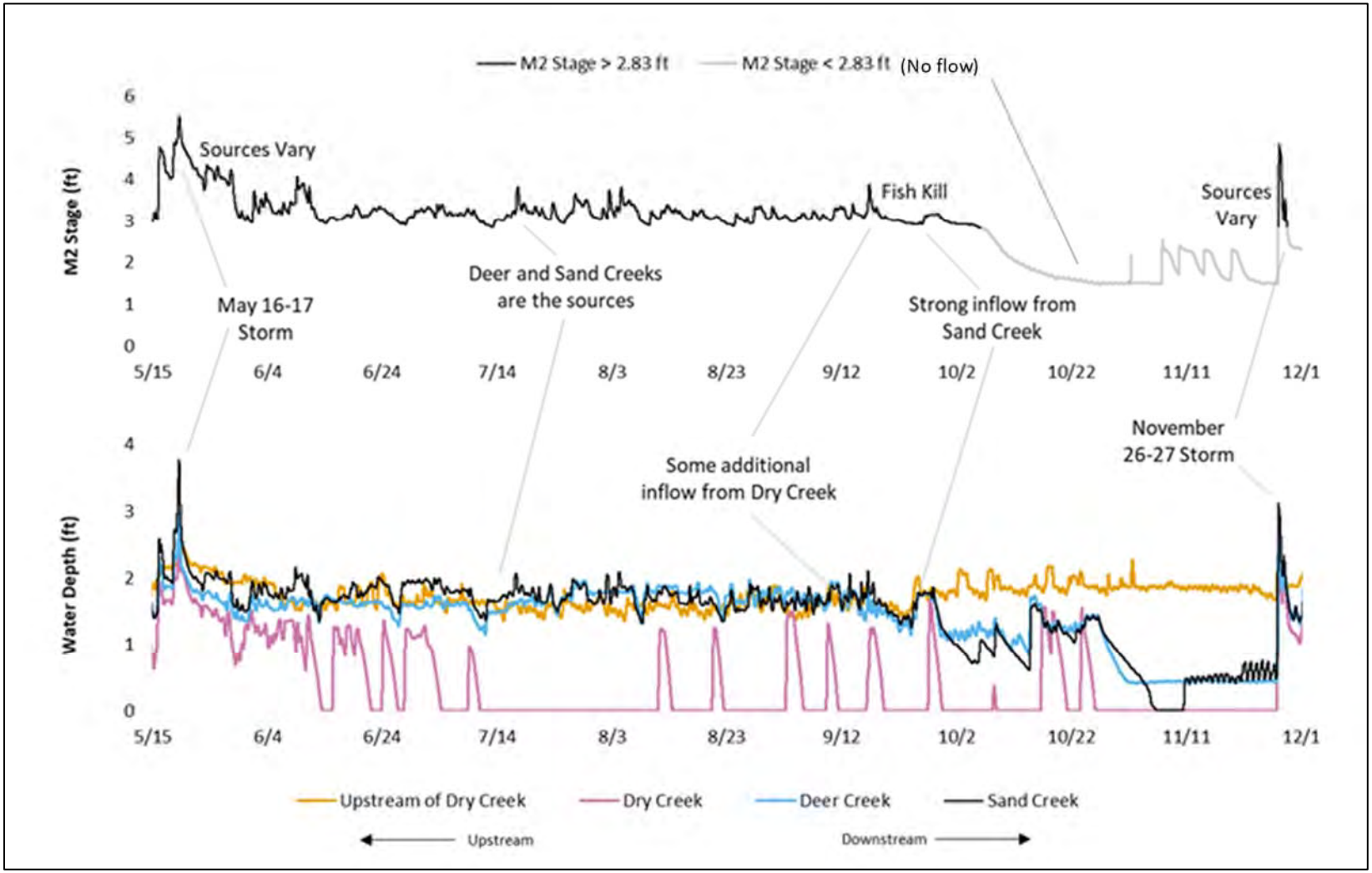


Figure 4. Stage at Station M2 and at Upstream HOBO Water Level Monitoring Stations – Year 2 Monitoring



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

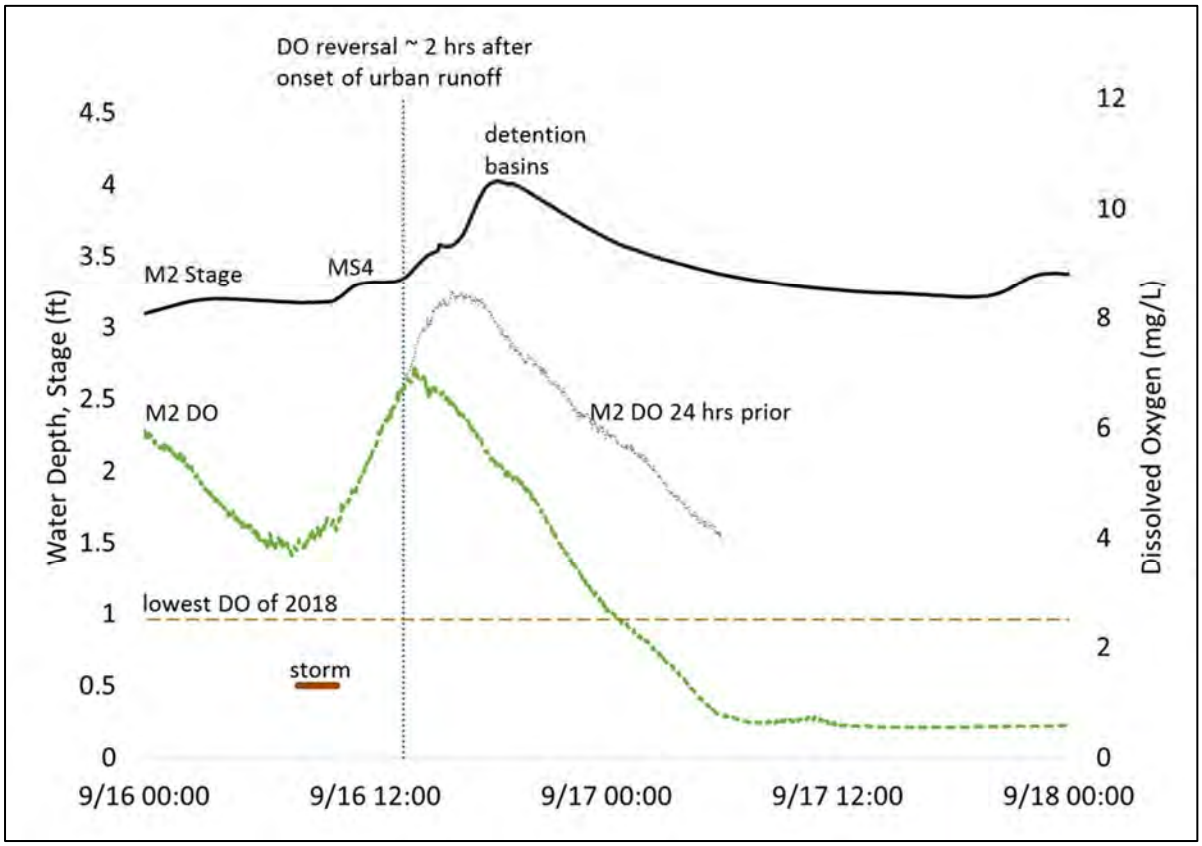
During a planned visit for another CCCWP project on Sep. 17 on Marsh Creek, the field crew was notified that a drastic drop in DO had begun at Station M2 the previous night and that they should anticipate performing a grab sample at the station due to a probable fish kill.

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.

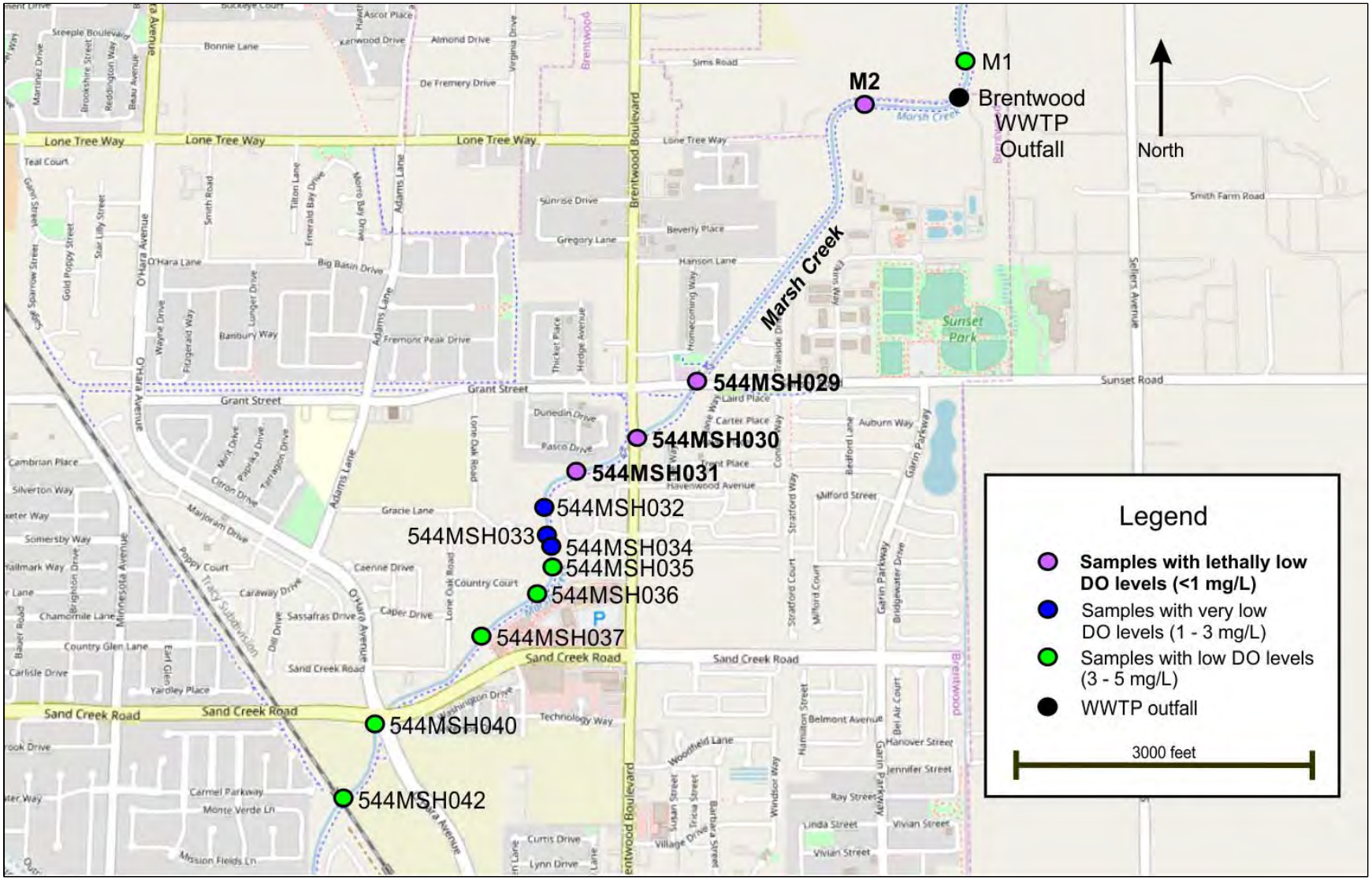
Figure 5. Marsh Creek Station M2 Stage and DO – Sep. 16-17, 2019



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.

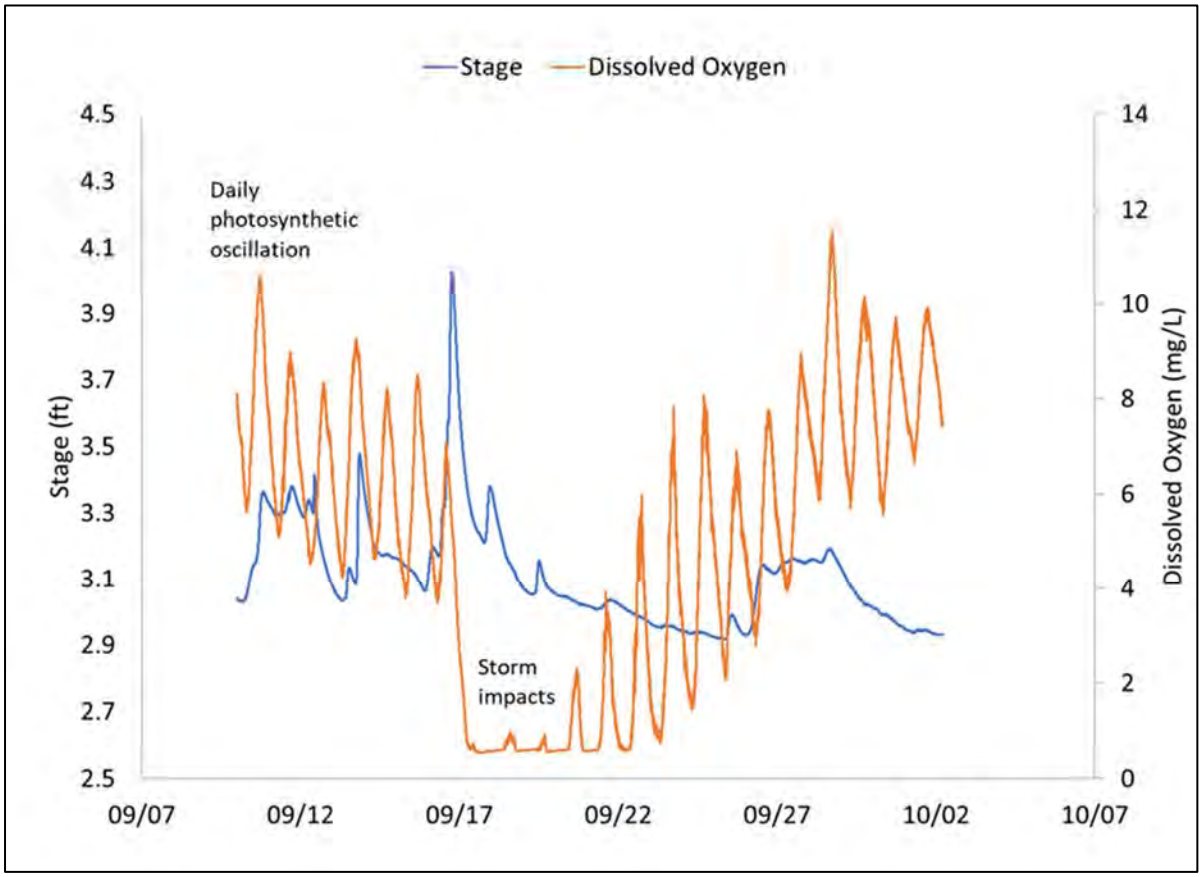
The follow-up grab sampling also provided the first insight into the benefits of WWTP flow toward ameliorating sudden DO sags. At Station M1, downstream of the WWTP, the level of DO on Sep. 18, 2019 was near or above the 5.0 mg/L objective for warm water habitat streams. Even though Marsh Creek was flowing 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

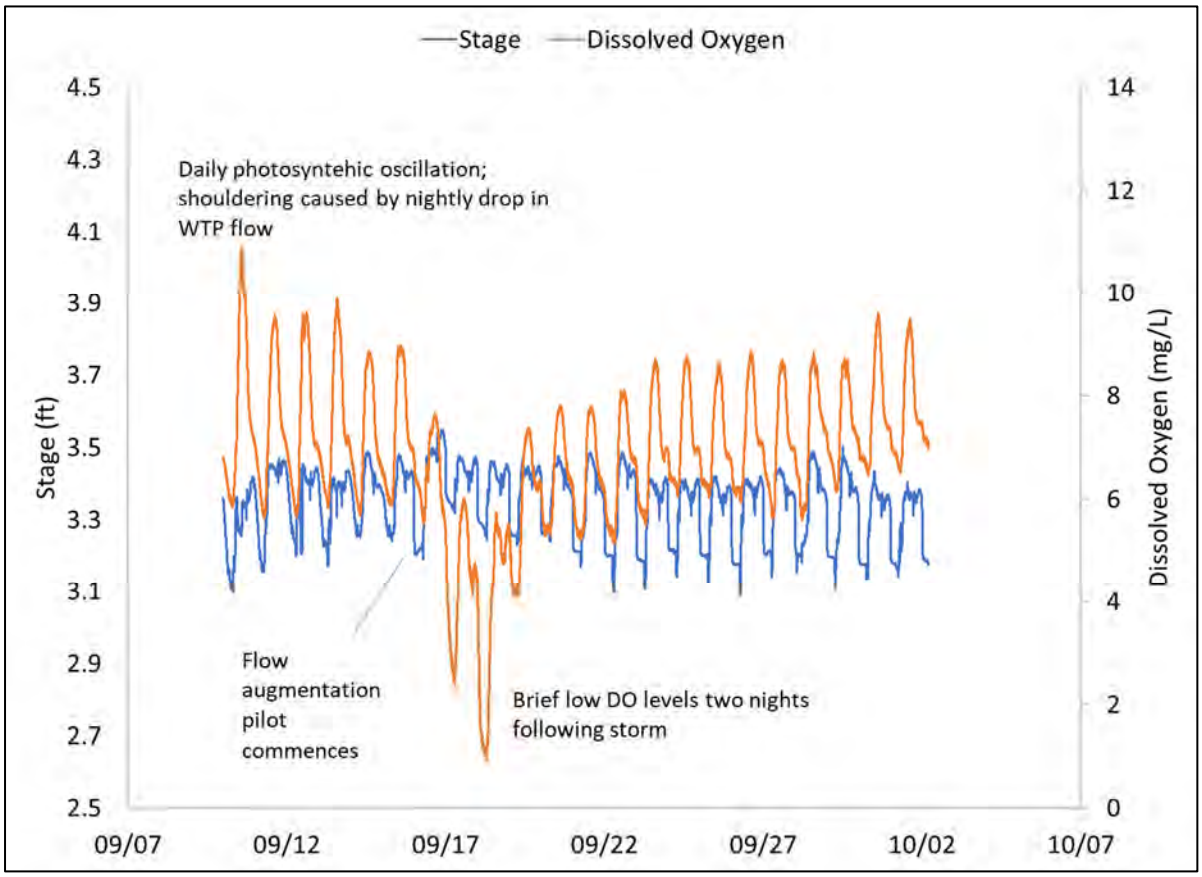
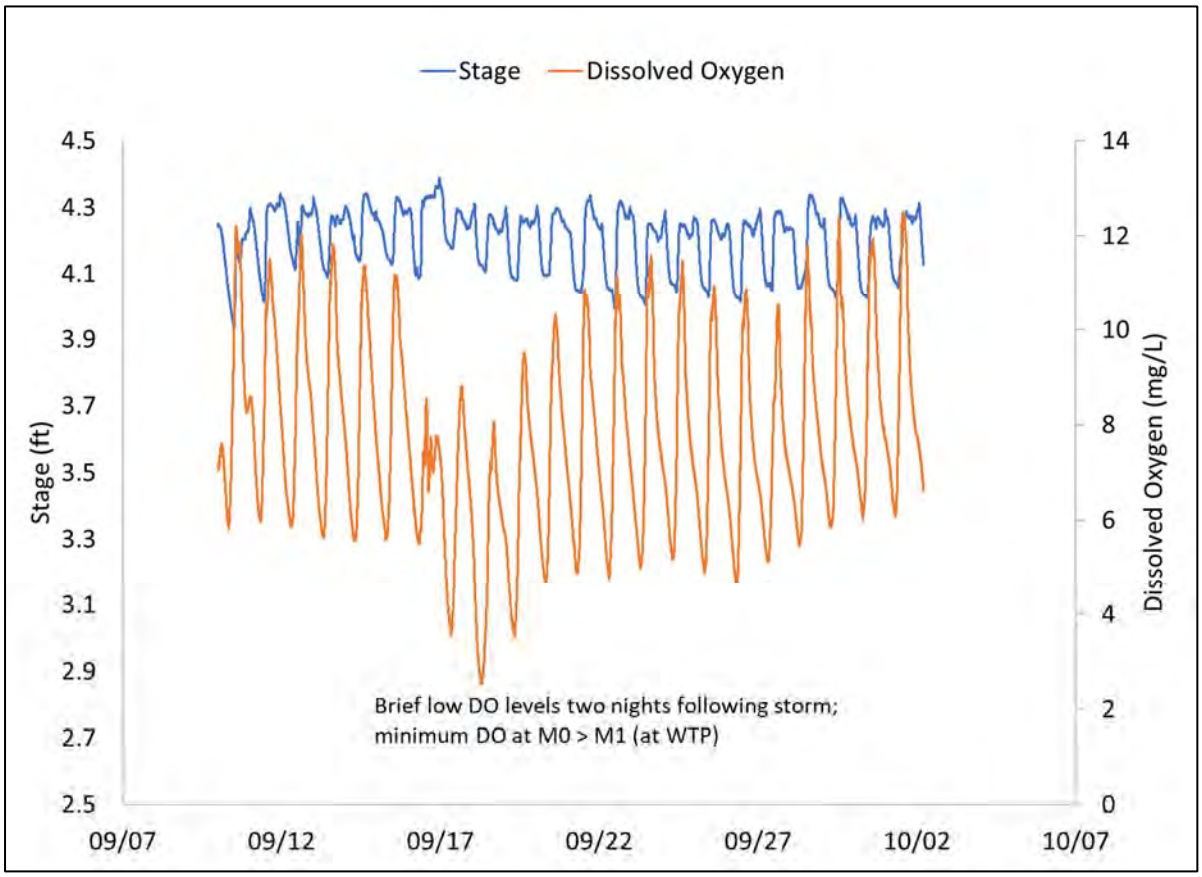


Figure 9. Marsh Creek Station M0 Stage and DO – Sep. 10-Oct. 2, 2019



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

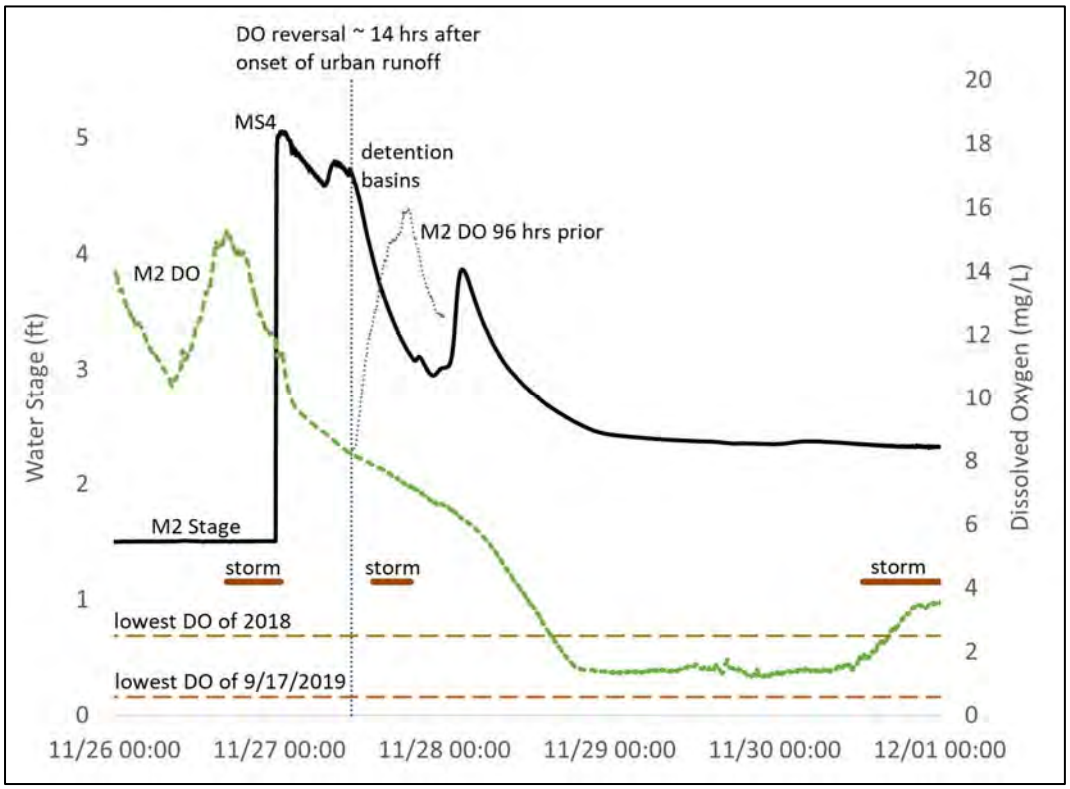


Figure 11. Marsh Creek Station M1 Stage and DO – Nov. 26-Dec. 1, 2019

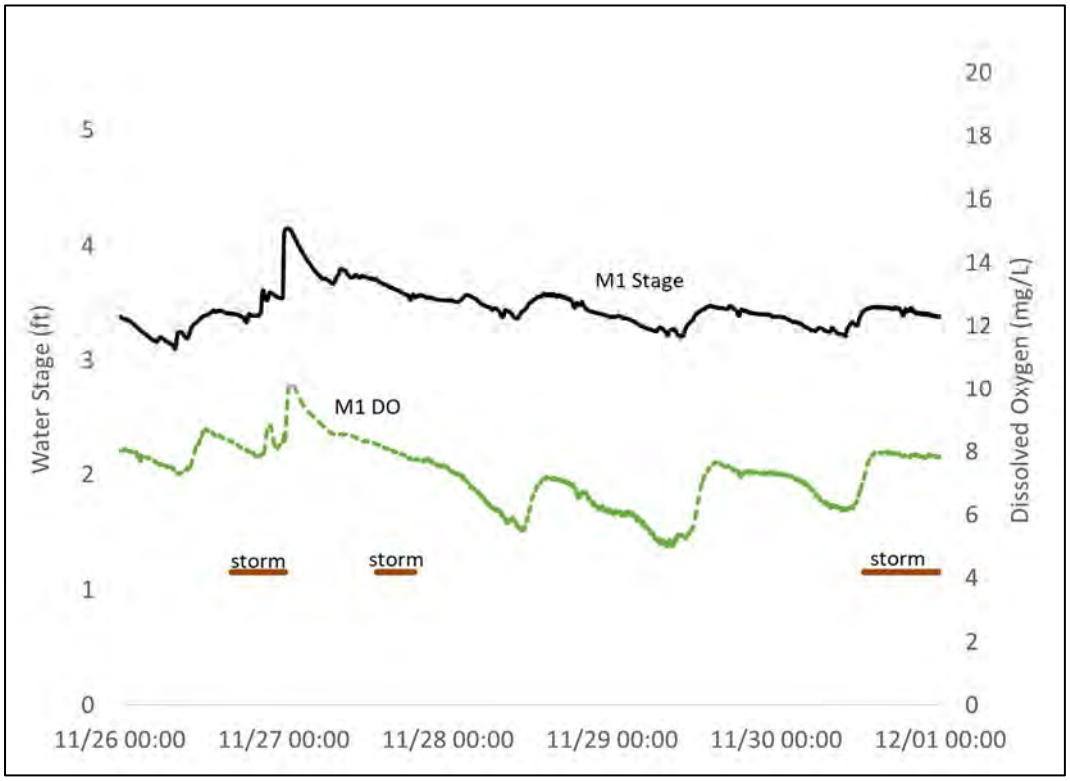
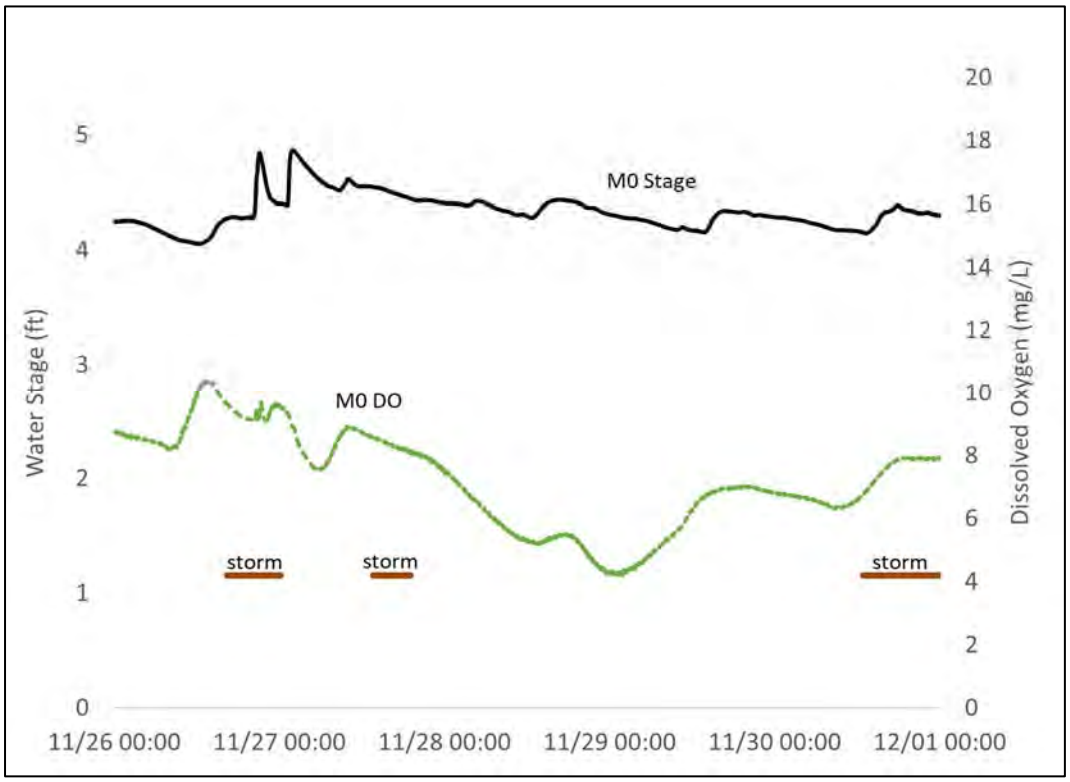


Figure 12. Marsh Creek Station M0 Stage and DO – Nov. 26-Dec. 1, 2019



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

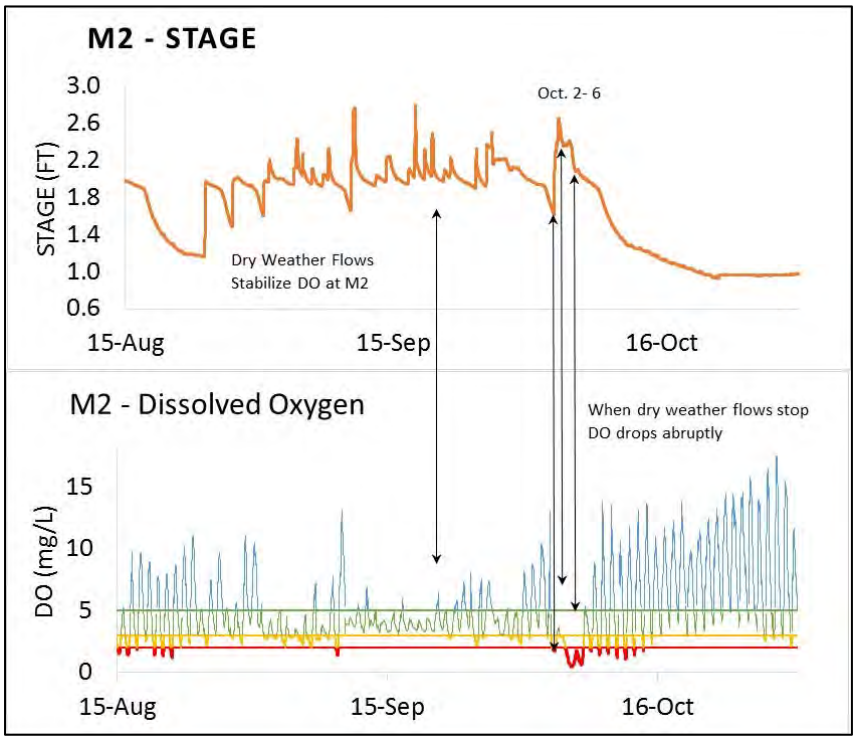
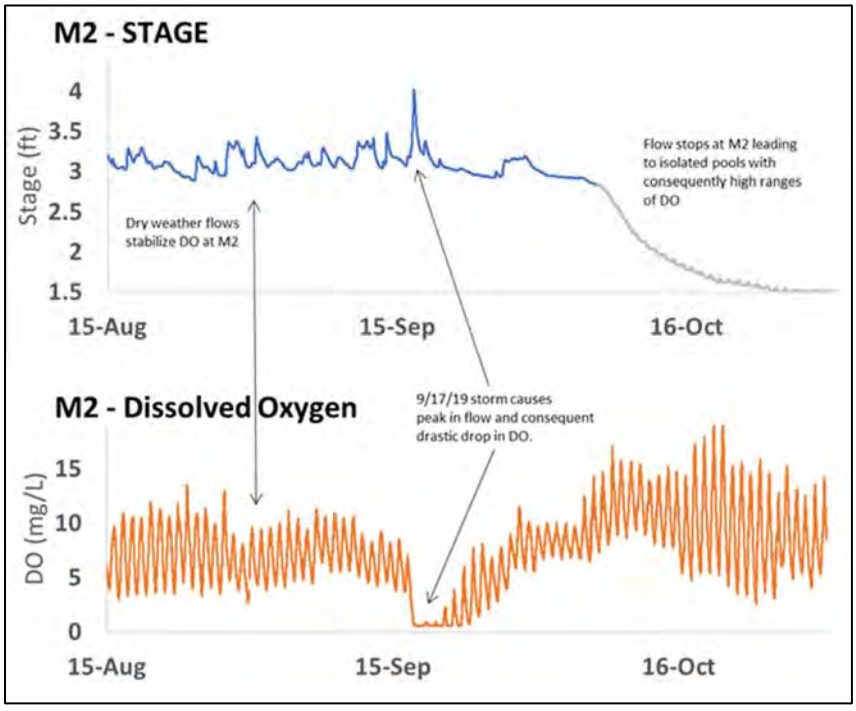


Figure 14. Comparison of Stage to DO at Station M2 – Aug. 15-Oct. 31, 2019[1]



[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.