APPENDIX C

SUISUN MARSH STAFF REPORT

April 11, 2018

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ESTABLISH WATER QUALITY OBJECTIVES AND A TOTAL MAXIMUM DAILY LOAD FOR DISSOLVED OXYGEN IN SUISUN MARSH AND ADD SUISUN MARSH TO SF BAY MERCURY TMDL

STAFF REPORT FOR PROPOSED BASIN PLAN AMENDMENT

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SAN FRANCISCO BAY REGION

APRIL 11, 2018

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1. INTRODUCTION

This Staff Report presents the supporting documentation for a Basin Plan amendment to establish site-specific water quality objectives and a Total Maximum Daily Load (TMDL) for dissolved oxygen (DO) in Suisun Marsh wetlands, specifically in sloughs and channels (Suisun Marsh). The Report also provides the reasoning for the proposal to extend the San Francisco Bay Mercury TMDL to Suisun Marsh, which is also impaired by mercury.

Section 303(d) of the federal Clean Water Act (CWA) requires that states identify water bodies - bays, rivers, streams, creeks, and coastal areas - that do not meet water quality standards and identify the pollutants that cause the impairment. The San Francisco Bay Regional Water Quality Control Board (Water Board) is responsible for identifying impaired surface waters and developing related TMDLs in the San Francisco Bay Region.

The Suisun Marsh wetlands are listed under CWA section 303(d) as impaired by low DO due to high organic carbon (OC). Additionally, the marsh is listed as impaired by mercury, nutrients, and salinity/TDS/chlorides (Table 1-1). This Staff Report only addresses water quality impairments due to low DO/organic enrichment and mercury. Salinity conditions in Suisun Marsh are to a great degree dependent on Delta water management regulations and decisions and affected by the overall hydrology of the Central Valley watershed (ranging from wet to critically dry). The State Water Board oversees the development and implementation of salinity objectives, and decisions regarding the need to modify the salinity objectives in the marsh will be ultimately made through the State Water Board's regulatory process as part of its revisions to the Bay–Delta Water Quality Control Plan.

Over the past two decades, low DO concentrations and fish kills have been observed in Peytonia, Boynton, Suisun, and Goodyear sloughs in Suisun Marsh (O'Rear and Moyle, 2010, Schroeter and Moyle, 2004). Fish kills were documented for the fall seasons of 1999, 2001, and 2003. In October 2004, a widespread fish kill was observed in Peytonia, Boynton, Goodyear, and Suisun sloughs (Schroeter and Moyle, 2004). In October 2009, 100% mortality of fishes was observed in Goodyear Slough (O'Rear and Moyle, 2010). The fish kills were linked to releases of low DO waters from managed wetlands. DO concentrations below 1-2 mg/L were measured in marsh sloughs when discharges from the managed wetlands occurred, which can result in mortality to some species of fish.

Because of the aforementioned low DO and mercury concerns, this TMDL is necessary to examine the water quality issue more closely, identify sources of pollutants, and specify actions that will result in the restoration of adequate DO levels in Suisun Marsh.

Improving DO levels in Suisun Marsh sloughs is a key component of maintaining the marsh's habitat value. Suisun Marsh encompases some 85,000 acres of tidal marsh, managed wetlands, and waterways in southern Solano County. It is the largest remaining wetland in San Francisco Bay and includes more than ten percent of California's remaining wetlands. The marsh provides critical wintering habitat for waterfowl on the Pacific Flyway and, because of its size and estuarine location, supports a diversity of plant communities. These provide habitats for a variety of fish and wildlife, including numerous ecologically important species (e.g., winter-run chinook salmon, delta smelt, Sacramento splittail, Ridgway's rail, California least tern, saltmarsh harvest mouse; SMPP 1997). Among them, the endangered salmonids are particularly sensitive to low DO.

Two-thirds, or about 52,000 acres, of the Suisun Marsh wetlands are managed wetlands, meaning they are diked and managed to provide seasonal wetland habitat for resident and migratory wildlife focused on better waterfowl food resources. Accordingly, water control actions and vegetation management at managed wetlands play an important role in maintaining adequate DO levels of discharge water.

In addition, large-scale efforts to restore tidal wetlands have been proposed in Suisun Marsh. Several regional ecosystem planning efforts call for extensive additional restoration and mitigation projects in the decades to come, including the Suisun Marsh Habitat Management, Preservation, and Restoration Plan, Bay Delta Conservation Plan, Bay-Delta Plan, and others. These planning efforts may ultimately result in the restoration of tidal action to at least 5,000 acres of managed wetlands in Suisun Marsh. While restoration may result in short-term localized and system-wide changes in DO, the precise effects of restoration projects have not been taken into account in this TMDL.

Table 1-1
2010 California 303(d) list of water quality limited segments

Water Body Name	Water Type	Watershed Calwater/ USGS HUC	Pollutant	First Year Listed
Suisun Marsh wetlands	Wetland, tidal	20723000/ 18050001	Organic enrichment/low dissolved oxygen	1992
Suisun Marsh wetlands	Wetland, tidal	20723000/ 18050001	Mercury	1992/2010 [1]
Suisun Marsh wetlands	Wetland, tidal	20723000/ 18050001	Nutrients	1992
Suisun Marsh wetlands	Wetland, tidal	20723000/ 18050001	Salinity/TDS/Chlorides	1992

[1] In 2010 the listing was clarified to specifically identify mercury as a source of impairment

Tidal marshes and managed wetlands are naturally rich in organic carbon and low DO due to the growth of wetland plants and their subsequent decay in these environments. The natural tendency for organic enrichment in wetland environments is exacerbated in Suisun Marsh due to wetland management activities. Flooding and draining of managed wetlands to leach salts from the soils and circulate water through the hunting season and mowing/disking of vegetation can potentially increase the release of organic carbon from wetland soils and vegetation beyond what would naturally occur. The critical periods of low DO in sloughs have been determined to be in the fall months, when managed wetland owners discharge their ponded water to the sloughs.

Other sources, such as surrounding tributaries, exchange with Suisun Bay, and discharge from the Fairfield-Suisun Sewer District wastewater treatment plant, may contribute organic carbon and nutrients to sloughs and water channels in the marsh but seem to have less direct impact on water quality in the marsh (Tetra Tech 2013a). After evaluation of the available data and common nutrient enrichment indicators, we concluded that the anthropogenic nutrient loading is not a significant contributor to low DO observed in the sloughs (Parker et al. 2015).

This report follows the findings and recommendations of the Mercury TMDL for San Francisco Bay (Bay Mercury TMDL; SFBRWQCB 2006). The previously-established elements of the Bay Mercury TMDL, including source analysis, numeric targets, linkage analysis, TMDL, load and wasteload allocations, considerations of seasonal variations, and margin of safety, and implementation plan also apply to Suisun Marsh. Actions required by the Bay Mercury TMDL are already addressing the general mercury concerns in the region, including in Suisun Marsh, by such means as source reduction and pollution prevention. However, the marsh could be also a source of methylmercury. Low DO and high organic content in the marsh favor methylation. For this reason, this TMDL proposes to address the mercury impairment by ensuring that discharges from managed wetlands maintain DO at certain levels and, therefore, reduce the potential for convertion of mercury to toxic methylmercury.

This Staff Report comprises the following main components: 1) problem statement and impairment assessment; 2) numeric targets, 3) identification of sources of organic carbon, nutrients, and mercury to the sloughs; and 4) an estimate of allowable loads of organic carbon inferred from the numeric targets of DO and linkages to fish kills and water quality problems. A brief summary of the Bay Mercury TMDL requirements and the explanation of how the mercury targets established for the Bay are also relevant in Suisun Marsh is also included. Finally, Section 12 of the Staff Report describes the implementation actions that have been completed and proposed to prevent drops in DO and our plans to monitor to determine whether the TMDL targets have been achieved.

This Staff Report has undergone external scientific peer review as required under section 57004 of the Health and Safety Code focusing on proposed DO water quality objectives for Suisun Marsh and the TMDL for DO in Suisun Marsh sloughs. The scientific basis for the TMDL for mercury in Suisun Marsh is the same as the basis for the San Francisco Bay Mercury TMDL and did not undergo scientific peer review. The Basin Plan amendment includes language for the Suisun Marsh DO objectives and TMDL and shows changes to Section 7.2.2, San Francisco Bay Mercury TMDL, in the Basin Plan appending Suisun Marsh to the list of water bodies for which the Bay Mercury TMDL applies. The Basin Plan amendment also includes some minor non-regulatory amendments to language in the Basin Plan for clarification.

Appendices A, B, and C describe the data used in the assessment, the results of the water quality analysis, and the DO simulations in selected sloughs with the HEC-RAS model. A summary of the Expert Panel recommendations on derivation of the site-specific objectives for DO is in Appendix D.

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2. WATERSHED OVERVIEW

2.1. SUISUN MARSH AREA

Suisun Marsh, located within southern Solano County, is the largest contiguous brackish water marsh remaining on the west coast (Figure 2-1). It is a part of the San Francisco Bay-Sacramento/San Joaquin River Delta estuary ecosystem and encompasses an area of 116,000 acres, including 52,000 acres of managed wetlands, 27,700 acres of upland grasses, 6,300 acres of tidal wetlands, and 30,000 acres of bays and sloughs. Figure 2-1 shows the major features of Suisun Marsh.

Starting in the 1800s, nearly all of the historic tidal marshes were diked to create grazing and farm lands. The diked areas are separated from tidal sloughs by artificial levees and water exchange is controlled by gated culverts and other water control structures. When these diked agricultural lands became less productive due to upstream water diversions, large-scale water projects, and increasing salinity in the marsh soils, many of these diked lands were converted to duck clubs. The majority of the marsh is used by over 150 private duck clubs today, which maintain diked seasonal wetlands for wintering waterfowl and hunting (Figure 2-2) as well as other resident and migratory wildlife species. In addition, some publicly owned portions of the marsh, including the Grizzly Island Wildlife Area, are managed as wetlands supporting public waterfowl hunting.

In both the historic tidal marshes and currently managed ponds, waterfowl have found wintering habitat that meets their needs for water, food, and cover (DWR 2001). At present, the marsh serves as a resting and feeding ground for millions of waterfowl migrating on the Pacific Flyway and provides essential habitat for more than 221 bird species, 45 mammal species and more than 40 fish species, including endangered species. The Marsh is critical to the survival of wintering birds on the Pacific Flyway, particularly during drought conditions, and represents a unique resource for a wide range of aquatic and wildlife species. In dry years, the marsh supports more than one-quarter of central California wintering waterfowl population.

2.1.1 Hydrology

Two major tidal sloughs connect Suisun Marsh with Grizzly Bay: Montezuma and Suisun Sloughs (Figure 2-1). The major tributary sloughs to Montezuma are Denverton and Nurse Sloughs. Cutoff Slough and Hunters Cut connect Suisun and Montezuma Sloughs. The major tributaries to Suisun Slough are Peytonia, Boynton, Cutoff, Wells, and Goodyear (Figure 8-1).

The hydrology of Suisun Marsh is affected by several factors, including Delta outflows, rainfall, tides, local creek inflow, and the Fairfield Suisun Sewer District (FSSD) Wastewater Treatment Plant discharge. The flooding and draining operations of the managed wetlands also have a strong effect on the hydrology in the sloughs.

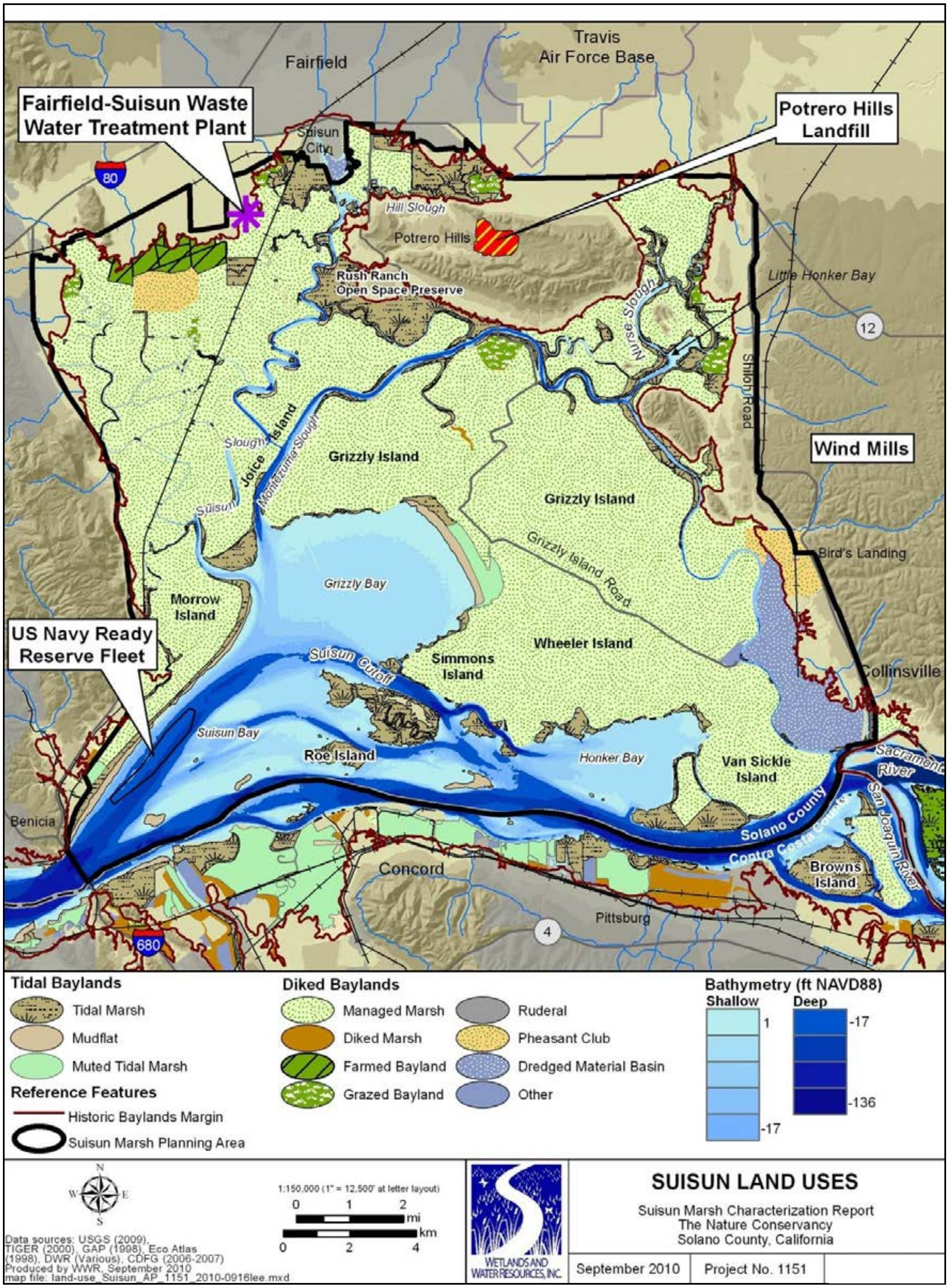
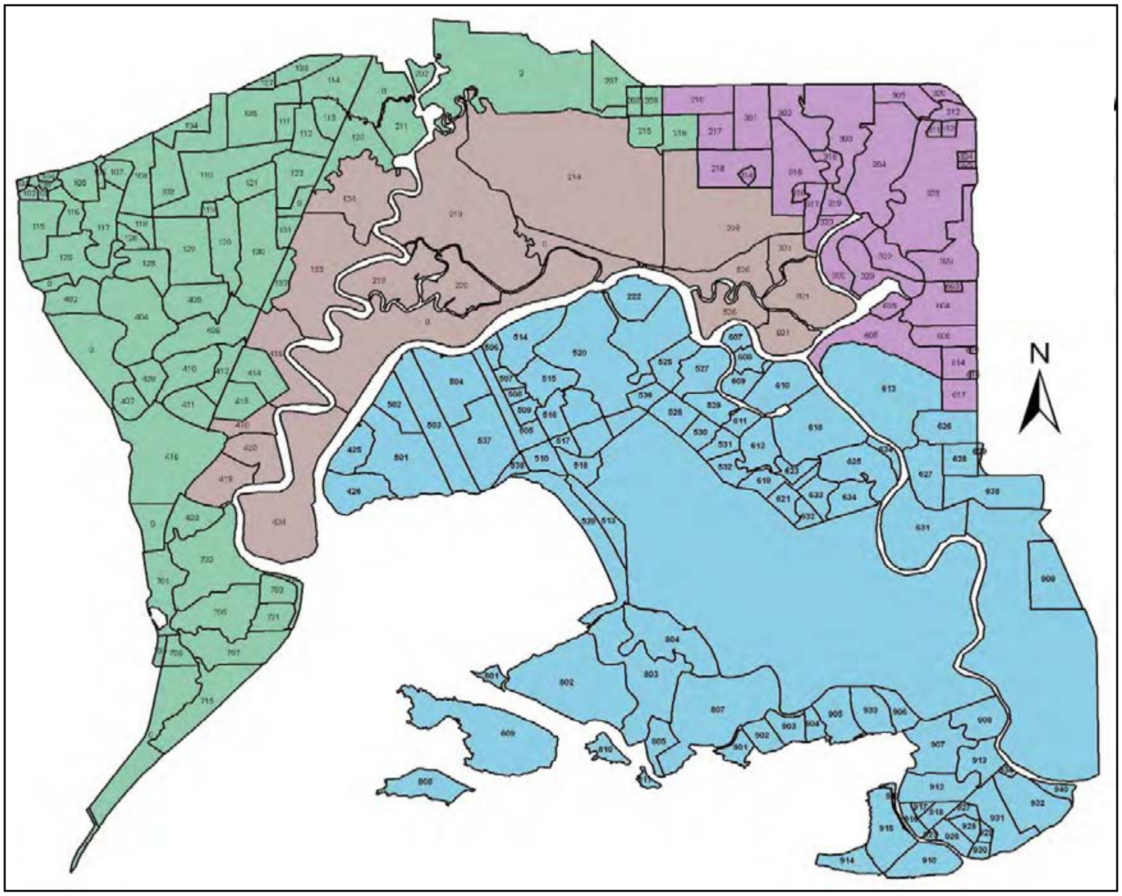


Figure 2-1 Suisun Marsh location and land uses



Colored areas represent the tidal wetland restoration regions assessed in SMP (2014)

Figure 2-2 Duck club properties (numbered) in Suisun Marsh

Tidal Exchange

Tides are the dominant driver of flows in the sloughs of Suisun Marsh. The Marsh experiences mixed semi-diurnal tides, with two daily tides of unequal height (Siegel et al. 2011). In Boynton Slough, tidal flows ranged between -800 and +1200 cfs and in Peytonia Slough, tidal flows ranged between about -700 and + 800 cfs. The variations of tidal stage depend upon three time scales of tidal processes: daily unequal high and low tides, biweekly spring-neap tidal cycle, and quarterly seasonal tides (Schureman, 1971; cited in Siegel et al. 2011).

Local Creek Inflows

Several creeks drain large, urbanized watersheds to the northern portion of Suisun Marsh, including Green Valley Creek, Suisun Creek, Ledgewood Creek, Laurel Creek, Union Creek, and Denverton Creek. (Figure 8-1). For instance, Ledgewood Creek flows along the west edge of the City of Fairfield. The creeks convey seasonal freshwater to Suisun Marsh as well as urban runoff, which could be a source of biological oxygen demand (BOD) (Siegel et al. 2011).

Fairfield-Suisun Wastewater Treatment Plant (FSSD)

The FSSD advanced secondary Wastewater Treatment Plant is located in the northwest portion of the marsh and serves more than 130,000 residential, commercial, and industrial customers, and discharges approximately 13 mgd. Approximately 90% of the plant's effluent discharges into Boynton Slough. The remainder of the discharge is recycled for landscape irrigation. A smaller discharge point exists on Ledgewood Creek in case of high effluent flows or failure of the primary discharge point to Boynton Slough.

Precipitation

Suisun Marsh receives about 25 inches of annual precipitation in comparison to tidal exchange of 4–11 inches per week, and 3–8 inches per week measured at two intensively-monitored wetlands (Siegel et al. 2011). Precipitation to Suisun Marsh is of small hydrologic influence compared to tidal exchange.

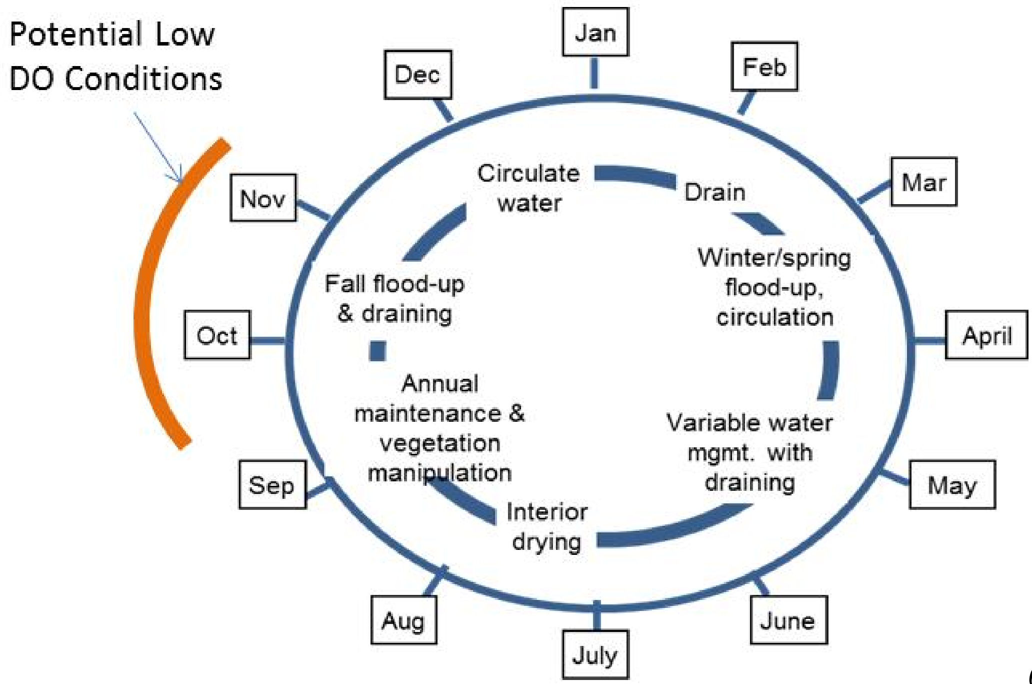
2.1.2 Role of Managed Wetlands

Managed wetlands are diked and separated from tidal sloughs by levees, with water exchange controlled by gated culverts. The primary goal of seasonal wetland management in Suisun Marsh is to provide wintering habitat for waterfowl, with a secondary goal of salinity control.

The following are the primary tools used in managed wetlands to create a habitat mosaic desired by waterfowl (Figure 2-3):

- Water management:
  - Controlled flooding and circulation of water within the wetland to maintain the desired water levels, provide additional feeding habitat and flush salts and decaying plant material.
  - Seasonal draining and drying of the wetland to promote seed germination and plant growth.
- Burning, disking, mowing and other actions to manipulate and enhance wetland vegetation, which can contribute to an organic carbon buildup.

The general wetland management cycle includes a summer period, when wetlands are left to be relatively dry, although some level of ponding may be present year-round. During the summer, vegetation is mowed or disked and the vegetation debris left in situ. Water management usually begins in early October with the "fall flood-up," when managed wetlands (or ponds) are flooded with water from the adjacent sloughs and channels (DWR 2001). When managed wetlands are flooded, vegetation in them starts to decompose, which may result in the depletion of oxygen and the production of sulfides. During the fall flood-up, water that has remained ponded in the wetland over the summer is discharged, along with the vegetation debris. Because of the decomposition of organic matter in the ponded wetland, the ponded water and the water that has initially entered during the fall flood-up, may have very low DO concentrations, or be anoxic. When this potentially anoxic water is discharged to adjoining sloughs, it may lead to a dramatic decrease in DO concentrations especially in smaller sloughs. These low DO events prevail when temperatures are high, circulation rates are low, and there is a large amount of dead broad-leafed vegetation and other organic material (DFG 2010). Although this combination of factors often occurs in fall, it can also occur throughout the winter. The water management contains several flood and drain cycles, including the major cycle in the fall and several minor cycles during late winter/spring. Complete and partial drainage of the ponds begins after the waterfowl season ends in January.



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(Modified from DFG 2010)

Figure 2-3 Conceptual representation of the typical water management cycle at a managed wetland

2.2. Beneficial Uses

Beneficial uses of water bodies help determine water quality objectives, which should be met in the water body. The beneficial uses for Suisun Marsh wetlands and the two major sloughs are shown in Table 2-1.

Table 2-1
Existing beneficial uses of water bodies in the Suisun Marsh region

	Aquatic Life Uses					Wildlife Use	Recreational Uses			
	EST	**MIGR**	**RARE**	**SPWN**	**WARM**	**WILD**	**REC1**	**REC2**	**NAV**	**COMM**
Suisun Marsh (wetland)	E	E	E	E		E	E	E		E
Suisun Slough				E	E	E	E	E	E	E
Montezuma Slough			E	E	E	E	E	E	E	E

E – existing beneficial uses

EST	estuarine habitat
MIGR	fish migration
RARE	preservation of rare and endangered species
SPWN	fish spawning
WARM	warm freshwater habitat
WILD	wildlife habitat
REC1	water contact recreation
REC2	noncontact water recreation
NAV	navigation
COMM	commercial and sport fishing

The goal of the DO TMDL is to restore and protect the most sensitive aquatic life beneficial uses (EST, MIGR, RARE, and SPWN). Since mercury concentrations in fish pose risks to human health, and are potentially hazardous to birds and mammals that consume fish, extending San Francisco Bay Mercury TMDL to Suisun Marsh aims to protect sport fishing (COMM), RARE, and WILD.

3. Problem Statement and Impairment Assessment

3.1. Water Quality Concerns

Suisun Marsh sloughs have experienced frequent low DO events and fish kills since at least 1993, when black water and dead fish were first observed. (Schroeter and Moyle 2004). The University of California at Davis (UC Davis) has monitored fish abundance in the marsh on a monthly basis since 1979 but after a reported fish kill in the fall of 1999, initiated DO monitoring as well. Since then, several fish kills and low DO events have been observed, in the fall of 2001, 2003, 2004, and 2009 (Table 3-1).

Table 3-1
Fish kills reported for sloughs within Suisun Marsh

Year	Description	Additional Information	Reference
Fall of 1999	Fish kill	Following a local pond discharge	O'Rear and Moyle, 2010
Fall of 2001	No information		Schroeter and Moyle, 2001
Summer and fall of 2003	No information		Schroeter and Moyle, 2003
October and November 2004	Large fish kills or absence of native species that are intolerant of low DO	DO levels at the time of discovery were 2.8 mg/L for three sites, and a low of 2.3 mg/L was recorded for Goodyear Slough. They were likely lower.	Stover et al. 2004
October 2009	Anoxic conditions in Goodyear Slough killed several species of fish including splittail, striped bass, and threespine stickleback.	1) Discharge of black, anoxic water from duck ponds into Goodyear Slough; 2) poor water circulation; 3) High inputs of organic materials from storms; and 4) High input of organic material at the end of the growing season	O'Rear and Moyle, 2010

The fish kills in 2004 and 2009 were the two largest and best-described events reported for Suisun Marsh. In October 2004, dead fish were seen in several sloughs, including Peytonia, Boynton, Goodyear, and Suisun Sloughs, and corresponded to low DO observed in these sloughs. The DO concentrations observed in different sloughs during the 2004 fish kill are shown in Figure 3-1 and Table 3-2. During that period, the measured DO were as low as 0.3 mg/L in Goodyear Slough and as low as 0.9 mg/L in Boynton Slough and Peytonia Slough. The reported DO levels may not directly represent the conditions that led to fish kills as they were measured after the event. Fish mortality was reported for different species, including relatively tolerant species, such as Sacramento splittail, Sacramento sucker, and carp.

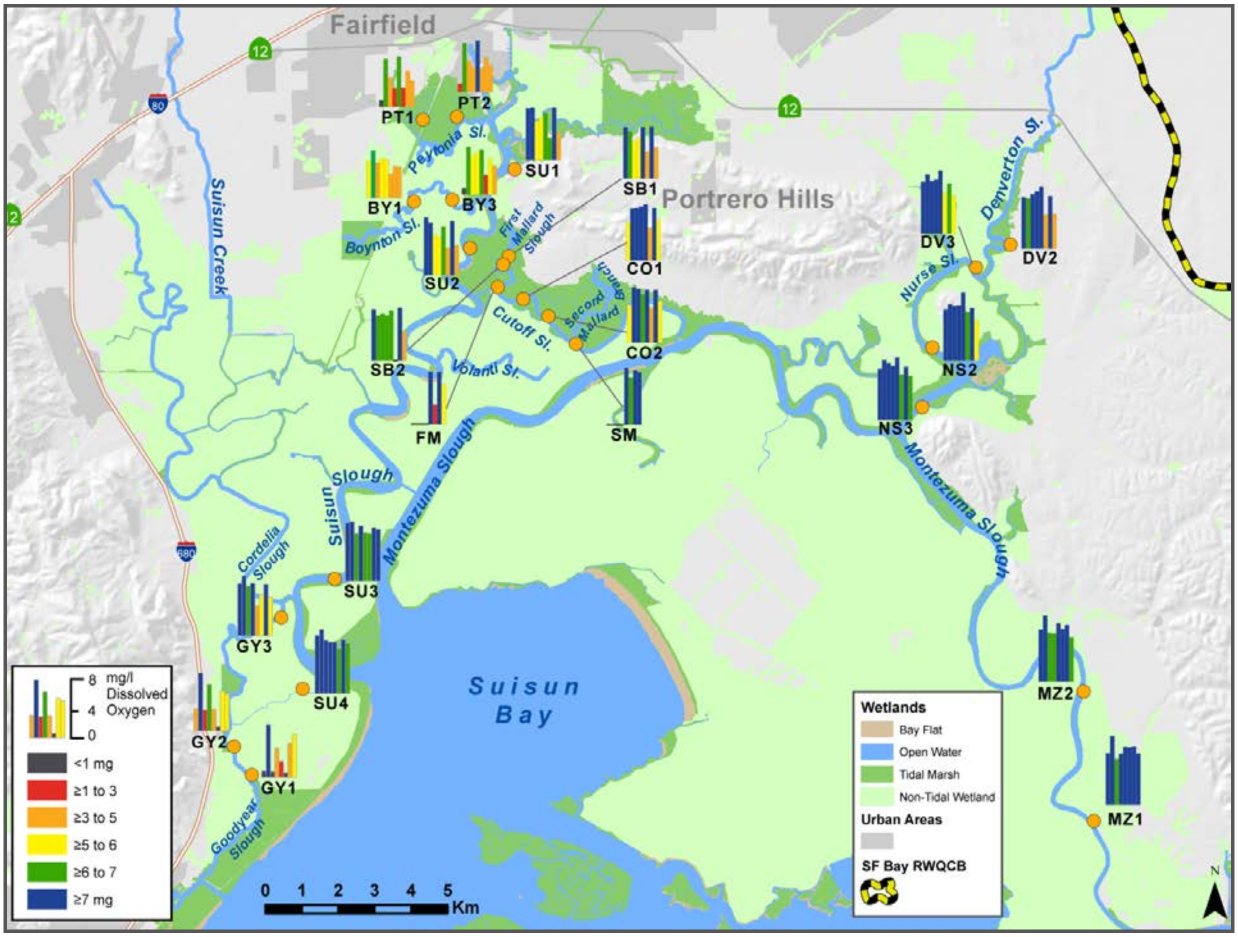
The 2009 low DO event resulted in mortality of several fish species in the upper Goodyear Slough, some of which are relatively tolerant of low DO conditions. The dead fish included bluegill, splittail, adult striped bass, threespine stickleback, and Mississippi silversides. The fish kills mostly occurred in dead-end sloughs adjacent to managed wetlands after discharge events.

Table 3-2
Dissolved oxygen concentrations observed in Suisun Marsh Sloughs in fall 2004

Date	Slough	Site	DO (mg/L)	% Saturation
10/12/2004	Boynton Slough	BY1	5.6	59.8
10/12/2004	Boynton Slough	BY3	0.9	9.3
10/12/2004	Chadbourne Slough	CHAD	4.9	62.8
10/14/2004	Cutoff Slough	CO1	5.8	62.8
10/14/2004	Cutoff Slough	CO2	5.9	65
10/13/2004	Goodyear Slough	GY1	0.3	3.2
10/13/2004	Goodyear Slough	GY2	3.2	36.7
10/13/2004	Goodyear Slough	GY3	7	77.4
10/12/2004	Peytonia Slough	PT1	0.9	9.7
10/12/2004	Peytonia Slough	PT2	1.1	10.8
10/14/2004	First Mallard	SB1	6.2	68
10/14/2004	First Mallard	SB2	6.1	66.7
10/12/2004	Sheldrake Slough	SHLD	7.6	84.9
10/12/2004	Suisun Slough	SU1	7.6	80
10/12/2004	Suisun Slough	SU2	8.2	87.2
10/13/2004	Suisun Slough	SU3	7.8	86.6
10/13/2004	Suisun Slough	SU4	7.1	78.2

Fish mortality as a result of low DO does not appear to have occurred uniformly or in all regions or sloughs within the marsh. Different regions provide distinct habitats and hydrology, and water quality in individual sloughs is a consequence of different natural and anthropogenic drivers. Low DO appears to be more of a problem in the back-end sloughs of the western part of the marsh, which have limited tidal circulation, and also have a relatively high density of duck clubs (Figure 3-1). In these smaller sloughs around the margins of Suisun Marsh, fall floodup can trap the low quality waters at the headward end of the sloughs, which reduces already-limited tidal exchange and leads to reduced DO levels in these waters (Siegel et al., 2011).

In comparison, sloughs in the eastern portion (i.e., Denverton, Nurse, and Montezuma sloughs) and lower portion of Suisun Slough (Figure 3-1), have better water quality. This is likely to result from better natural circulation, higher flows, and the relatively lower volume of managed wetland discharges.



Bars represent DO concentrations measured in grab samples in October from 2004 through 2011. Bar hights and colors indicate DO values.

Figure 3-1 Dissolved oxygen concentrations in Suisun Marsh sloughs in October 2004-2011

3.2. CAUSES OF LOW DO IN SUISUN MARSH

Low DO concentrations in the sloughs are likely to result from decomposition of organic material originating from terrestrial inputs and *in situ* production. The sloughs are naturally highly productive and accumulate large amounts of aquatic plant material and detritus, which is essential for a healthy estuarine ecosystem. Although the sloughs receive inputs from creeks that drain agricultural and urbanized areas, the operation of managed wetlands was shown to have a strong effect on the DO concentrations when hypoxic water from managed ponds was discharged into sloughs during fall and spring draining events. DO concentrations were notably higher in April, possibly due to higher wind speeds that promote mixing and re-aeration that time of the year (Siegel et al. 2011).

A conceptual model of the causes and effects of low DO in small sloughs is presented in Figure 3-2 (based on a schematic previously developed by Siegel et al. 2011). The diagram illustrates the interaction of management actions, external sources, internal processes and specific outcomes such as low DO in waters and resulting fish kills.

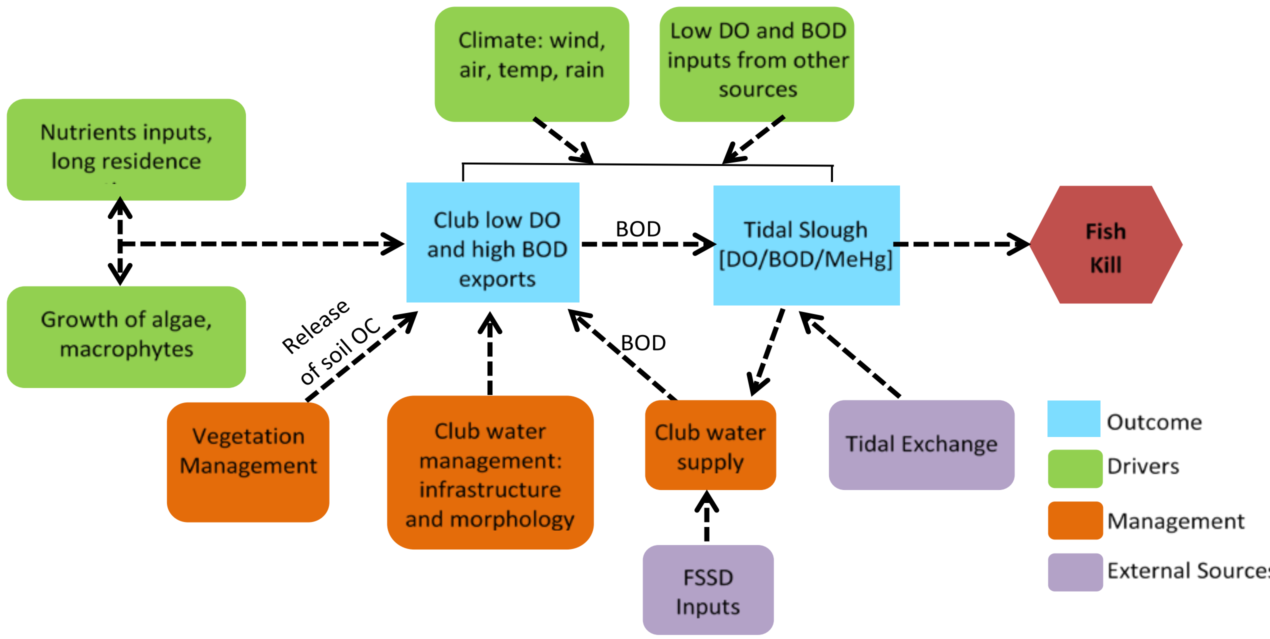


Figure 3-2 Causes of low DO in small tidal sloughs in Suisun Marsh

Aerobic bacteria need oxygen to break down organic materials present in a water body: the amount of dissolved oxygen they need is called biochemical oxygen demand (BOD). When BOD is high, DO is low because most oxygen is being used by bacteria in the decomposition process. Two types of materials that contribute to high oxygen demand, measured as BOD, are naturally present in large quantities in Suisun Marsh: organic carbon and nutrients. Potential increases in BOD result from discharges from managed wetlands and to a lesser extent storm water runoff from urbanized, agricultural, and grazed open areas and nutrient-enriched wastewater discharge from FSSD. In addition, high internal production of phytoplankton within sloughs and wetlands, wetland vegetation and decomposition of soil organic carbon within wetlands adds a considerable amount of organic carbon to the sloughs and results in naturally elevated BOD that may deplete oxygen in the water. Studies show that estuaries receiving drainage from natural wetlands and marshes may exhibit a wide range of DO, ranging from below 2 mg/L to more than 8 mg/L, while still maintaining healthy biological communities (FDEP 2013).

The western portions of Suisun Marsh are of the most concern due to a higher number of managed wetlands and limited mixing in small dead-end sloughs. The eastern parts of Suisun Marsh receive less discharge from the managed wetlands and have larger sloughs. Most of the severe low DO events and fish kills have been recorded in small sloughs in the west of Suisun Marsh. The lower Suisun Slough and Montezuma Slough are characterized by larger size, greater tidal mixing, and higher DO. A more detailed discussion of DO concentrations in sloughs is presented in Appendix B.

3.3. DO CONCENTRATIONS WITHIN MANAGED WETLANDS

DO monitoring within managed wetlands helps characterize the water quality of their discharges during drain events. In the study by Siegel et al. (2011), intensive DO monitoring was conducted for two consecutive years 2007-2008 at two managed wetlands (Wetland 123 and 112). DO was monitored at stations along the perimeter and in the interior of each managed wetland. During the fall drain events, DO concentrations at the perimeter monitoring stations were 1.5 mg/L before drainage, and dropped to near 0 mg/L, and remained at 0 mg/L for several days during drainage. DO concentrations at the interior monitoring stations mostly remained at low concentrations throughout the fall period. The managed wetlands were also drained 2–3 times during spring. During the spring drawdown events DO concentrations in the wetlands decreased to near 0 mg/L; however, they recovered in a relatively short time (Bachand et al. 2010).

3.4. Seasonal and Critically Low DO Conditions

Dissolved oxygen concentrations in western Suisun Marsh vary seasonally; however, many of the sloughs monitored have DO levels above 5 mg/L, most of the time. DO sags tend to occur in late summer and fall (mid-September through mid-November) and are linked to the water management cycle at the managed wetlands. During the managed wetland discharge season, DO in the back-end sloughs in wesatern Marsh is generally depressed (i.e., below 5 mg/L). Low DO concentrations following managed wetland discharge events can last from several days to up to a week. Figure 3-3 shows the declines in DO measured in Peytonia Slough as a result of discharge from the managed wetlands on September 26 and November 4, 2013. In September, immediately after discharge, DO dropped to below 1 mg/L for a few hours per day, however it recovered within one tidal cycle once the tide stage increased and more water was available for mixing. Although recently observed DO in sloughs receiving discharges from managed wetlands was periodically at levels that could cause fish mortality (< 2 mg/L), it did not appear to result in fish kills. Reduced frequency and loads of DO to the smaller sloughs following the changes in water management at managed wetlands might have contributed to less severe impacts on fish.

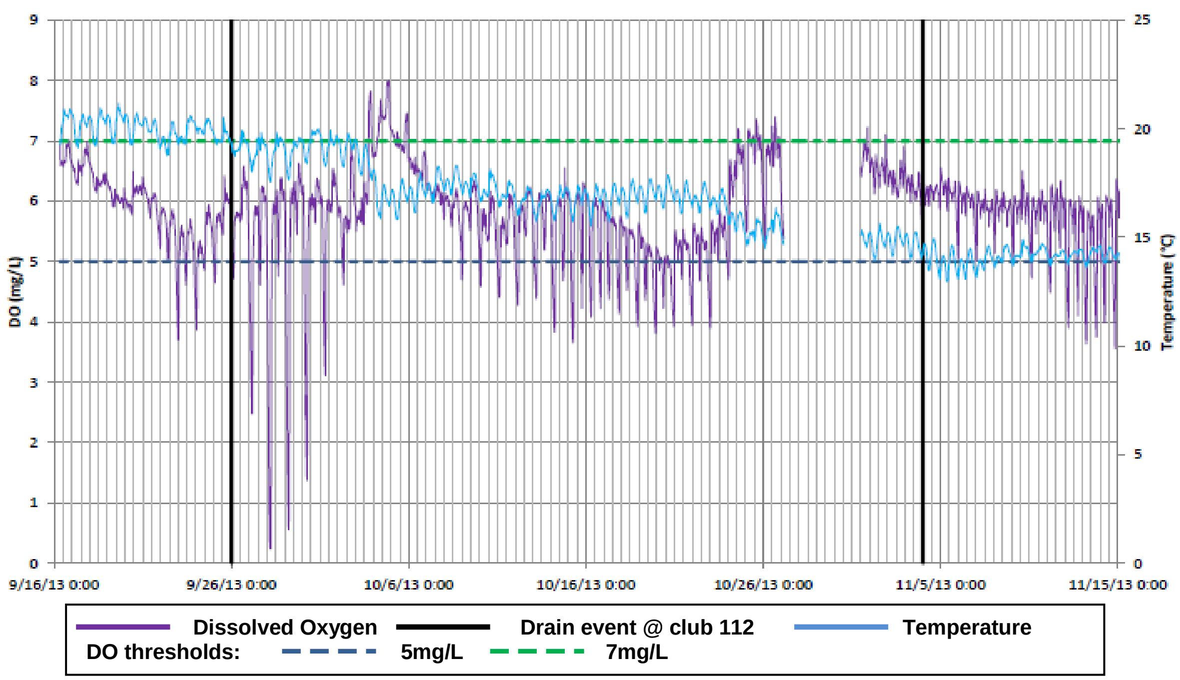


Figure 3-3 Peytonia Slough DO and temperature trends during fall discharge

Fall drain events appear to be the critical times when low DO concentrations in the managed wetland discharges can cause adverse impacts on fish and other aquatic organisms. The fall drain events usually result in longer lasting and much lower DO concentrations than the spring events. During the fall drain events the sloughs in the west are characterized by relatively low net flow and limited mixing. In spring, drain events also contribute to DO declines, however, due to higher net flow in the sloughs in the downstream direction and possibly greater mixing as a result of higher wind speeds, DO depressions in the sloughs are less severe than in the fall season.

Continuous monitoring of DO in Goodyear Slough has been conducted since August 2012 (Figure 3-4, Figure 3-5). In the fall of 2012, prior to discharge from the managed wetlands, DO concentrations in Goodyear Slough were around 7 mg/L between 08/12–10/12, and started to decrease from the middle of October, which coincided with the beginning of the drain period from the duck clubs (Figure 3-4). DO concentrations stayed low for the period of 10/12–12/12, and then started to increase from late December and stayed at around 7 mg/L from 12/12 until 01/13. During the low DO period (10/12–12/12), DO concentrations in Goodyear Slough reached as low as 1 mg/L.

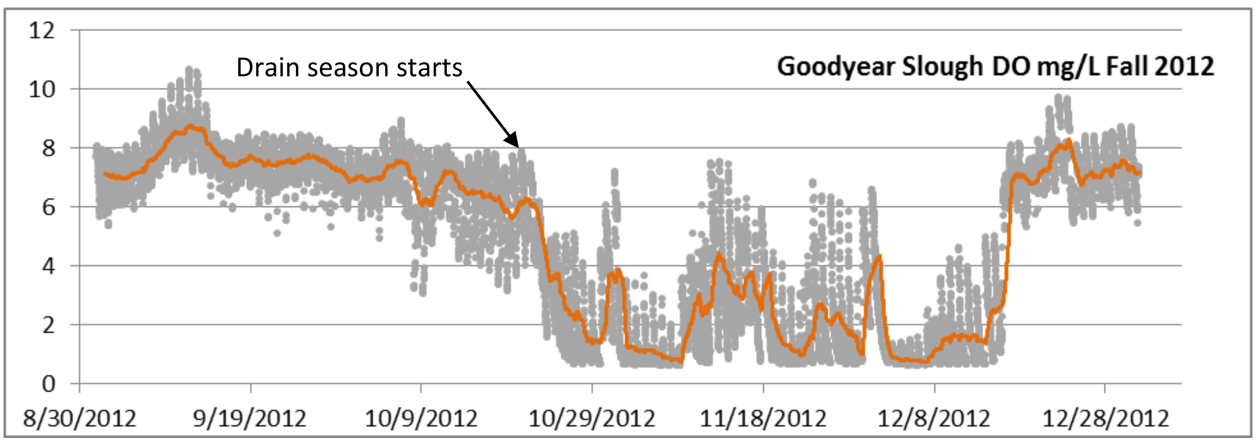


Figure 3-4 DO concentrations in Goodyear Slough during 2012 fall drain event

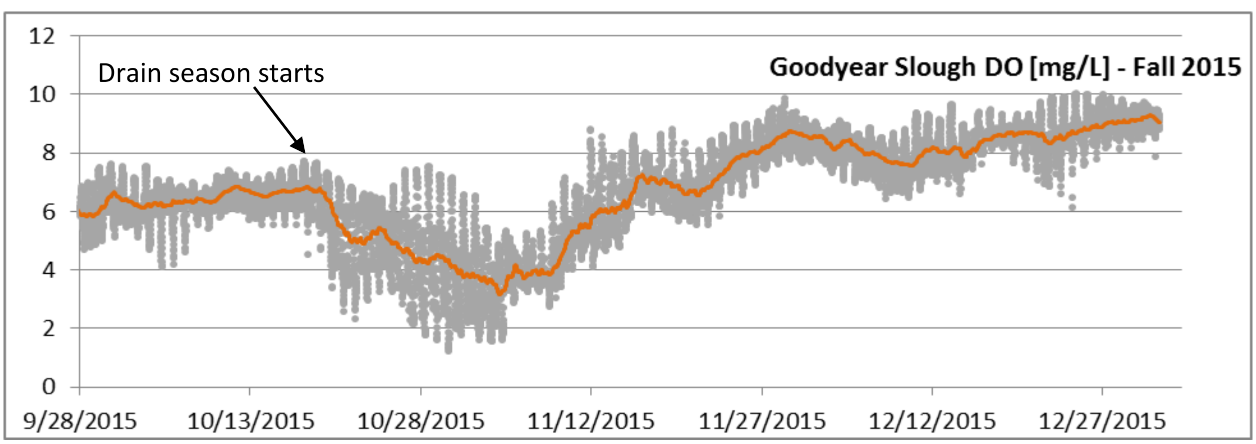
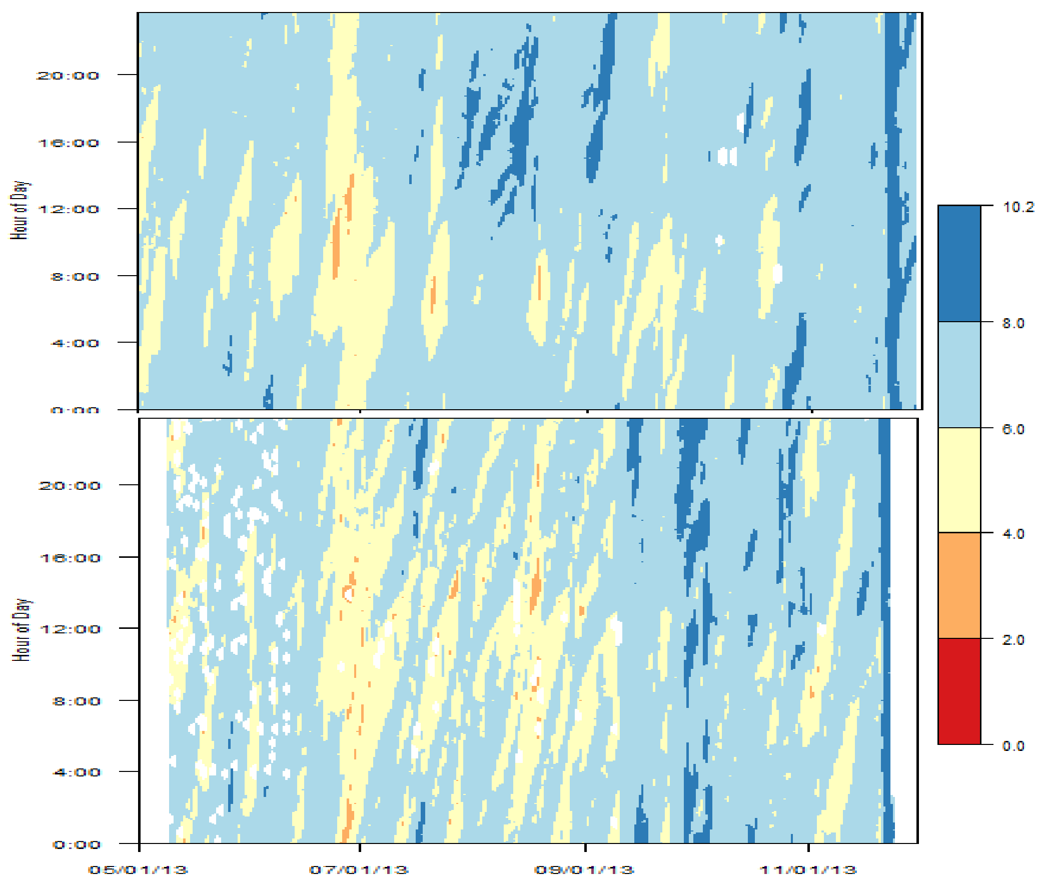


Figure 3-5 DO concentrations in Goodyear Slough during 2015 fall drain event

Recent data (2013-15) suggest that DO conditions in the sloughs have improved compared to earlier years. Trial implementation of best management practices (BMPs) at managed wetlands from 2013 onward appears to be successful at reducing impacts of their discharges on slough water quality (Figure 3-4, Figure 3-5). The employed BMPs included staggering the discharges from multiple managed wetlands, diverting discharge water to larger sloughs, and mowing vegetation early to allow for further decomposition before fall flood up. Managed wetlands that were near Peytonia and Boynton Sloughs also used a combination of water management and selective spraying to promote the growth of wetland grasses instead of broad leaf plants, which helps reduce the volume of vegetative matter and BOD load to the sloughs. In general, the overall average DO levels during the fall discharge period were higher in 2015 than in 2012 and 2007-08, and the DO depressions were much shorter.

Due to the wider slough channels, more extensive tidal mixing and lower density of managed wetlands, sloughs in the eastern part of the marsh, and especially larger sloughs such as Denverton or Montezuma Slough, maintain better DO conditions throughout the year. DO patterns in Denverton Slough also resemble those in First Mallard Slough, which is considered to be minimally impacted and representative of more natural DO conditions (Figure 3-6).



Note: DO minima (yellow/orange) in the graph often coincide with low tides.

Figure 3-6 Comparison of DO patterns in First Mallard (top) and Denverton Slough (bottom)

3.5. CONTRIBUTION OF NUTRIENTS AND NUTRIENT IMPAIRMENT ASSESSMENT

The Water Board is in the process of identifying indicators of nutrient enrichment for San Francisco Bay. Here, we considered a subset of these indicators and the data available in the marsh to evaluate, on a preliminary basis, whether or not the Suisun Marsh sloughs are impaired by nutrients. These include: pelagic and benthic chlorophyll *a* concentrations, DO concentrations, and submerged aquatic vegetation/macroalgal cover. (Parker et al. 2015). We conclude that nutrients are not the main cause of the low DO observed in the marsh sloughs and that no clearly defined impairment exists. For more information about the presence and distribution of organic carbon and BOD see Section 6 of this report.

Although excessive nutrient enrichment in wetlands is considered to be one of the primary stressors adversely affecting ecosystem functions and causing undesirable shifts in composition of plants and aquatic organisms (USEPA 2008), the indicators to distinguish nutrient impairment resulting from anthropogenic stressors versus natural conditions are difficult to quantify. Often, the interpretation of these indicators requires extensive data collected from both targeted and reference (unimpacted) wetlands, which is difficult in the complex, and constantly changing ecosystem of Suisun Marsh. Unless in excess quantities or under physical conditions conducive to increased excessive algae production, nutrients themselves usually do not adversely affect beneficial uses and water quality.

Tidal wetlands are naturally rich in nutrients (eutrophic) compared to open water areas, and have the ability to assimilate nutrient inputs, mitigating anthropogenic nutrient loads via uptake and assimilation by phytoplankton and emergent vegetation. (e.g., Fisher and Acreman 2004, Vymazal 2007). However, increasing nutrient loads from anthropogenic sources can result in severe eutrophic conditions leading to decline in water quality (Bricker et al. 2007, Chapter 8). High nutrient concentrations (eutrophic conditions) may cause undesirable biological responses such as excessive benthic algal biomass, high chlorophyll *a*, low DO, macrophyte cover, and low water clarity. use of constructed wetlands is common to improve water quality and further reduce nutrient loads downstream of industrial and municipal wastewater discharges (e.g., Fisher and Acreman 2004, Vymazal 2007).

Nutrients, defined here as different chemical forms of nitrogen (nitrate, nitrite, ammonia) and phosphorus (PO4) enter Suisun Marsh through the tributaries draining agricultural and urban areas, from the Delta, through atmospheric deposition, and via discharge from the FSSD wastewater treatment plant. Elevated nutrient concentrations can potentially result in excess growth of phytoplankton and macrophytes and the subsequent decay of these materials may result in lowering of DO and increasing turbidity in wetlands and sloughs, conditions that could harm the health of aquatic organisms including fish. A conceptual representation of the cause-and-effect relationships for nutrients in Suisun Marsh is presented in Figure 3-7 (Tetra Tech 2013a, Appendix B).

Parker et al. (2015) evaluated all available data and examined the common nutrient enrichment indicators to assess the potential for nutrient impairment in Suisun Marsh sloughs and concluded that nutrient loading does not appear to be a major driver of the impaired ecosystem health via excessive phytoplankton growth or eutrophic shifts in dissolved oxygen. Seasonal and spatial trends and nutrient-related indicators appear to be within the range likely to occur naturally in the marsh environment. Concentrations of chlorophyll *a*, which is evaluated as an indicator of overproduction of algae, fluctuate seasonally and across different sloughs but are not high in Suisun Marsh. Mean chlorophyll *a* concentrations in western sloughs varied between summer lows of 6.0 µg/L and highest values in winter reaching 13.8 µg/L. Winter chlorophyll *a* showed large variability with one sample of nearly 46 µg/L; removing this one outlier observation resulted in mean winter chlorophyll *a* of 8.7 µg/L. These levels are consistent with average winter chlorophyll *a* (mean: 7.9 and 6.2 µg/L) measured at First and Second Mallard Sloughs, which are fully tidal and are minimally impacted by anthropogenic activities compared to other areas of the marsh. In addition, western sloughs, where nutrient concentrations are highest, do not always support the highest chlorophyll *a* concentrations (Parker et al. 2015). Accordingly, although low DO is frequently detected in small back-end sloughs, and fish kills had occurred in Suisun Marsh in the past, these adverse impacts do not seem to be directly related to excessive amount of nutrients in the marsh.

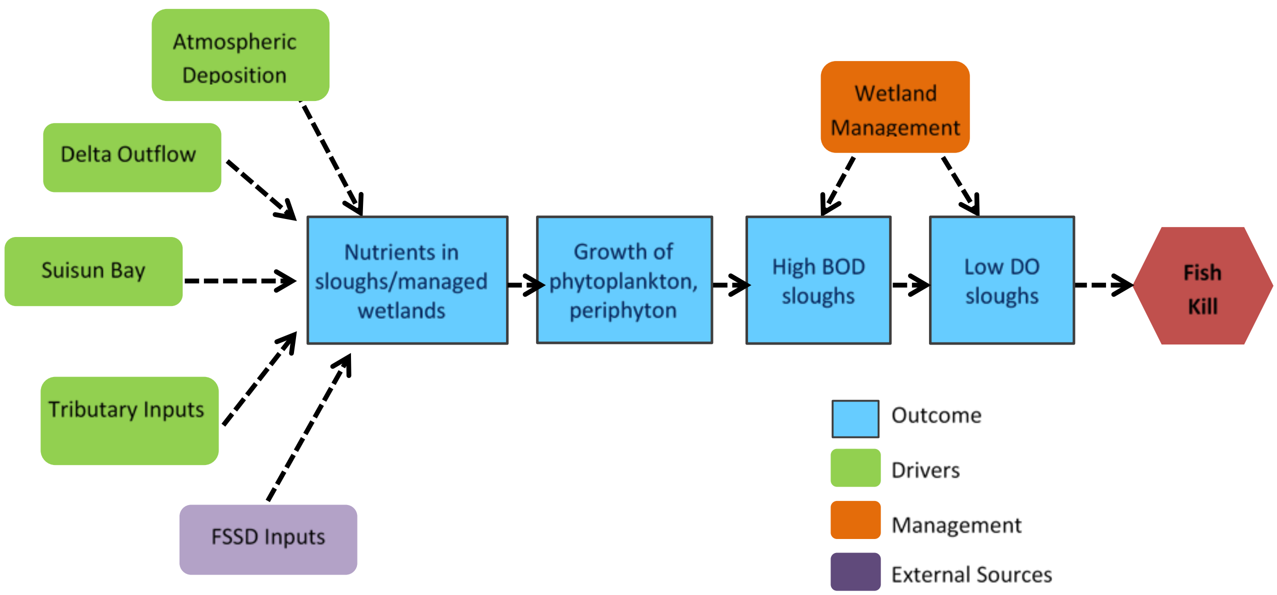


Figure 3-7 Nutrient conceptual model (cause-effect relationship) in Suisun Marsh

This assessment is based on limited data, however, it is also consistent with anecdotal information that Suisun Marsh sloughs, which support high biological productivity, can sustain phytoplankton blooms, which could inherently become a source of high BOD even without anthropogenic drivers.

3.6. Mercury Effects and Impairment Assessment

Mercury is highly toxic and can cause a number of adverse health effects in humans and wildlife. The concerns about bioaccumulation of mercury in fish, wildlife, and people that drove adoption of the San Francisco Bay Mercury TMDL (Bay Mercury TMDL) in

2006 justify extending the TMDL to Suisun Marsh. The historical and present sources of mercury to Suisun Marsh are similar, if not identical, to those in the Bay, because mercury from historic mining in the Sierras and other sources washes through the marsh on its way to the Bay. Mercury is converted to the more toxic methylmercury (methylation) principally by bacteria in sediments of aquatic ecosystems, especially near the boundary layer between oxygenated and non-oxygenated conditions. Methylmercury reaches higher concentrations with each step up the food chain – from water, to phytoplankton, to filter feeders, to small fish, to sport fish and humans, or to fish eating wildlife – in a process known as biomagnification (Figure 3-8).

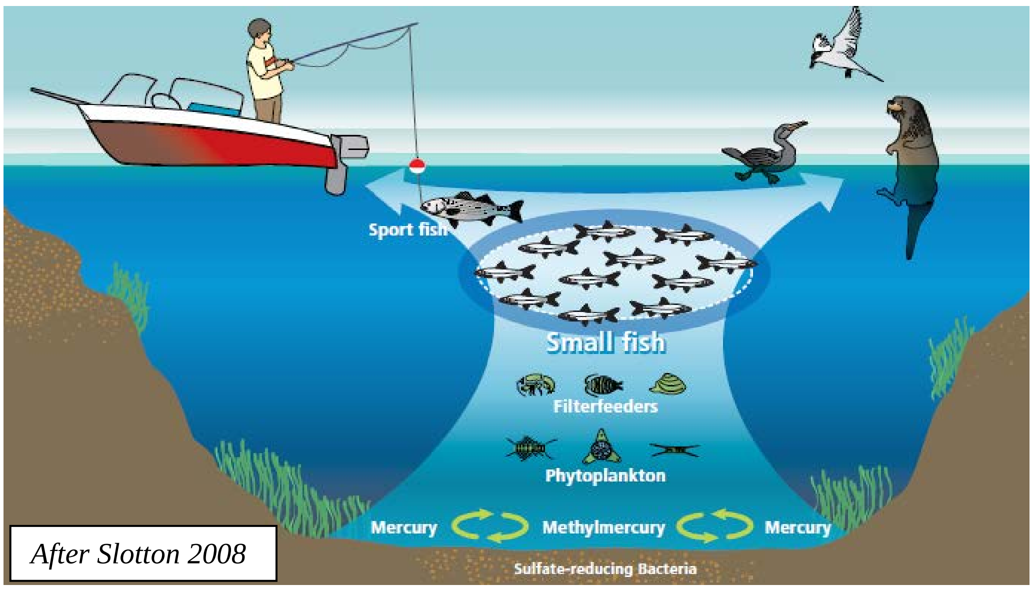


Figure 3-8 Mercury movement in the food web

The estuary has elevated mercury (Hg) concentrations in fish, sediment, and water, as compared to other North American estuaries, due to the history of Hg mining in the Coast Range mountains and the use of Hg for gold extraction in the Sierra Nevada mountains in the 19th century (Alpers et al. 2005, Heim et al. 2003, Wiener et al. 2003, Heim et al. 2008, Davis et al. 2008). Sulfate- and iron-reducing bacteria in anaerobic environments convert Hg to methylmercury (MeHg) (e.g., Gilmour et al. 1992, Yu et al. 2012).

Wetlands provide opportunities for MeHg production, or methylation, because of their wet/dry cycling, potential for elevated water temperatures, sources of labile carbon, and low redox conditions that enable sulfate and iron reducing bacteria to flourish. (St. Louis et al. 1994; Hurley et al. 1995; Rudd 1995; Gilmour et al. 1992; Yu et al. 2012).

Suisun Marsh is therefore an area of concern, because of the extensive presence of wetlands, the sources of inorganic mercury from water exchange with the Bay and Delta, and the occurrence of organic rich sediments and anoxic conditions that favor methylation. In a literature review on mercury in tidal wetlands (including managed wetlands in Suisun Marsh), it was found that these wetlands could be a significant source of methylmercury to surrounding waters (Tetra Tech 2013b).

Fish in Suisun Marsh have Hg concentrations that exceed the levels of concern for human health and wildlife. Hg concentrations in Mississippi silversides, a small fish approximately 3 inches long, were measured in Suisun Marsh in 2005-2010. All concentrations observed in silversides were consistently above 0.03 mg/kg (30 ng/g), the water quality objective for prey fish established to protect wildlife by the Bay Mercury TMDL (Figure 3-9).

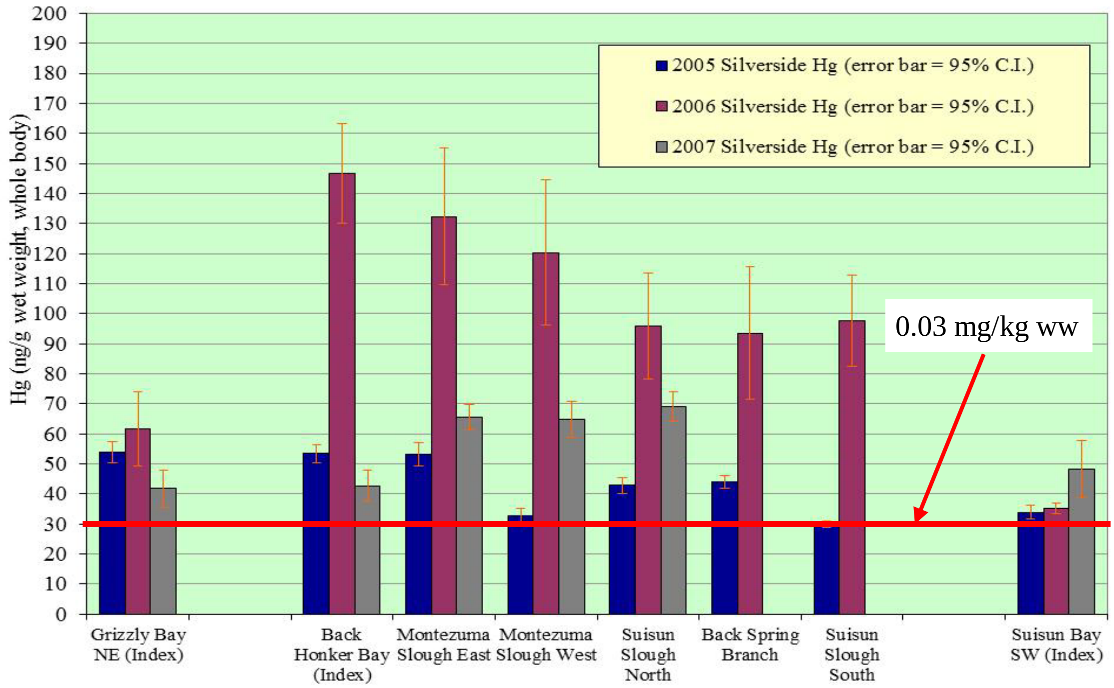


Figure 3-9 Summary of mercury in Silversides in Suisun Bay and Suisun Marsh Sloughs
(Data: Darell Slotton, UC Davis, *pers. comm.*)

Concentrations of Hg measured in silversides vary significantly across seasons and locations in the Bay. The highest concentrations are usually detected in fish caught in the South Bay (mean concentrations: ~80-260 ng/g; Greenfield et al. 2009). Although the concentrations in silversides caught in Suisun Marsh sloughs (Figure 3-9) are still above the objective, they are lower than those in the South Bay and generally comparable to the levels of Hg found in fish from managed ponds and sloughs in the Napa-Sonoma marshes (Grenier et al. 2010) and in the north Bay. The average concentrations in the 40-70 ng/g range were considered as indicative of the low-end Hg concentrations in the Napa-Sonoma region. The 1.5 to 2 fold differences in concentrations between the lowest and highest seasonal levels or differences between years observed in Suisun Marsh are also typical of the variation observed in the Napa-Sonoma marshes.

Concentrations of Hg in common sport fish (bass and white catfish) caught in Suisun Marsh sloughs in 2013 (Figure 3-10) confirm a wide-spread contamination of fish with Hg, with levels in all 10 fish exceeding the human health target of 0.2 mg/kg wet weight established for the Bay Mercury TMDL (SFBRWQCB 2006). Hg concentrations in the water column are approximately two orders of magnitude below the applicable acute water quality objective of 2.1 µg/L (Figure 3-11) which is expected because chronic exposure to elevated concentrations in the food web is more of a concern than exposure to high levels of Hg in the water column. For a more detailed discussion of the available mercury data, see Suisun Marsh Conceptual Model/Impairment Assessment Report by Tetra Tech (2013a).

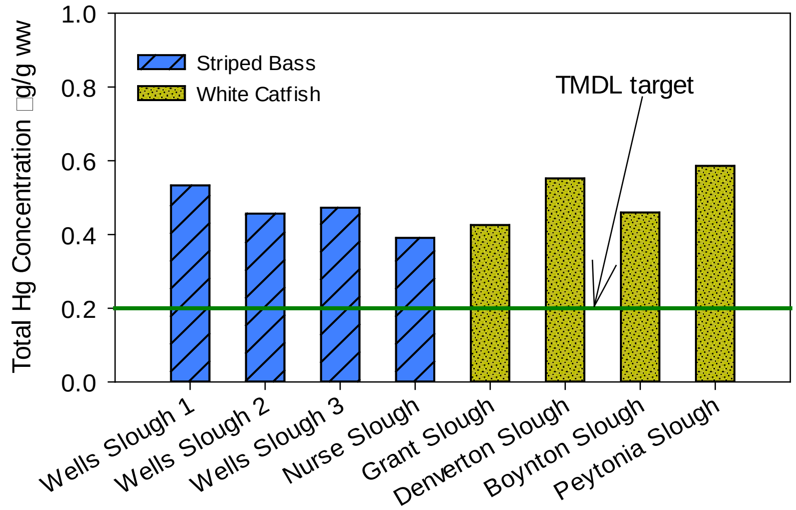


Figure 3-10 Mercury concentrations in sport fish caught in Suisun Marsh sloughs

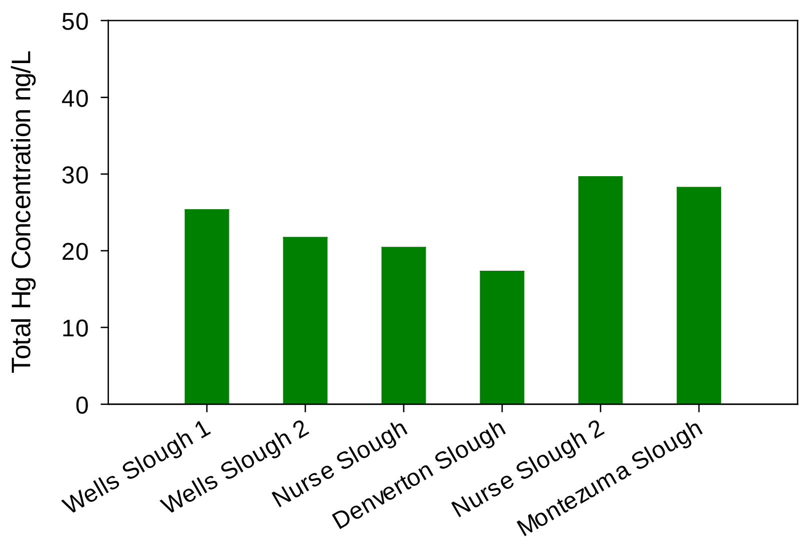


Figure 3-11 Total mercury concentrations in water column in Suisun Marsh sloughs

4. NUMERIC TARGETS: REFINEMENT OF DISSOLVED OXYGEN OBJECTIVES FOR SUISUN MARSH

4.1. RATIONALE FOR REFINING WATER QUALITY OBJECTIVES FOR SUISUN MARSH

Dissolved oxygen objectives, unlike traditional objectives for toxic substances, are often region- or waterbody-specific because the DO regime is dependent on temperature, hydrologic conditions, and natural biological processes, all of which vary geographically.

The San Francisco Bay Basin Plan identifies DO objectives for waters that are upstream of the Carquinez Bridge as being a minimum of 7.0 mg/l. It also includes a requirement that the median DO concentration for any three consecutive months shall not be less than 80 percent of the dissolved oxygen content at saturation. These water quality objectives were adopted in the 1975 Basin Plan and are generally being attained in most of the Bay's subtidal waters. The Basin Plan does not clearly address the applicability of these objectives to Marsh tidal sloughs and managed ponds as in Suisun Marsh where there is some evidence they may not be attainable.

It is also unclear whether the existing Basin Plan's DO objectives are appropriate in shallow, dynamic, biologically productive habitats like Suisun Marsh. Dissolved oxygen concentrations in shallow water habitats, such as tidal wetlands and slough networks, vary much more compared to the main water mass of San Francisco Bay and frequently exhibit concentrations less than 5.0 mg/L and less than 7.0 mg/L (Tetra Tech 2013a). The 1975 objectives do not take into account that DO concentrations in marshes and wetlands might be low due to naturally-occurring organic enrichment or due to patterns of tidal fluctuations in shallow water habitats. In addition, the objectives for the Bay, while protective of fish and other sensitive biota in San Francisco Bay did not systematically consider any species-specific requirements. Furthermore, the 1975 objectives were not derived with consideration of continuous sampling, and do not provide latitude with respect to allowable exceedances, on a temporal or spatial scale. Specifically, the objectives do not include weekly or monthly average limits representative of chronic exposures and effects of DO stress. They are expressed as instantaneous limits, which presents a challenge when interpreting data recorded continuously (measured at 15 minute intervals), which show natural daily and seasonal fluctuations. The natural pattern and the range of diel DO concentrations is affected by the level of photosynthesis and respiration. It fluctuates with temperature, salinity and pressure changes and in Suisun Marsh is further augmented by the tidal cycle. Figure 4-1 illustrates daily change in DO measured in Goodyear Slough with a YSI sonde under no discharge from duck clubs, showing DO concentrations ranging from 4 mg/L to over 8 mg/L on daily basis.

Therefore, refinement of the DO objectives was necessary to establish appropriate and attainable numeric targets for the TMDL that protect biological communities in Suisun Marsh, reflect the natural organic enrichment in the marsh, and consider the currently available scientific information and monitoring tools. Given the complexity of the task, we convened an Expert Panel of scientific and policy experts to provide advice on the development of refined objectives. The Panel included Peter Moyle (UC Davis, CA), Paul Stacey (Great Bay National Estuarine Research Reserve, NH) and Peter Tango (USGS Chesapeake Bay, MD). The proposed objectives reflect the best available science and the Expert Panel recommendations regarding fish and invertebrate responses to stress from the low DO, the level of protection needed for sensitive and endangered species, and the application of a U.S. EPA approved approach to provide scientifically-defensible DO objectives for Suisun Marsh.

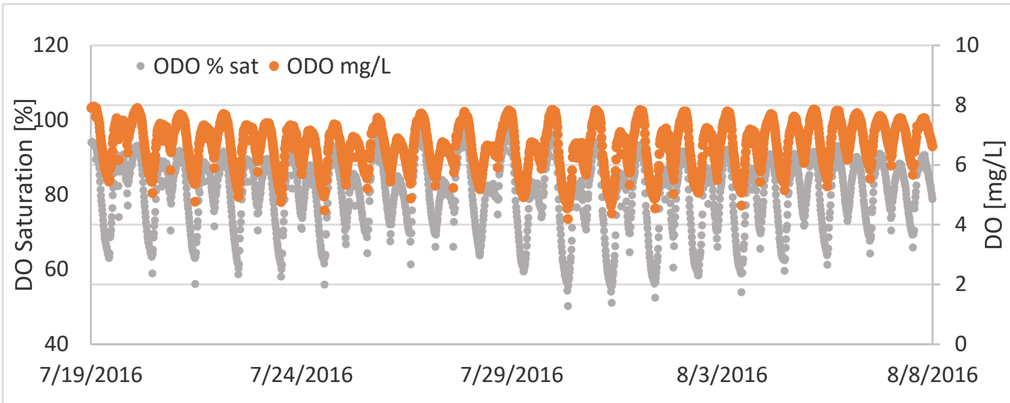


Figure 4-1 Diurnal DO fluctuations in Goodyear Slough

4.2. Derivation of DO Objectives

4.2.1 Rationale for Choosing a Method to Derive the Objectives

In the refinement of the DO objectives for Suisun Marsh we followed the approach recommended by U.S. EPA for the Virginian Province (USEPA 2000), This approach supports the derivation of region-specific DO criteria tailored to the species, habitats and DO exposure regimes of varying estuarine, coastal and marine waters. The ability to select aquatic organisms and their life stage allows the criteria to be adapted to protect species relevant to Suisun Marsh. This method provides a framework for the establishment of DO thresholds under persistent long-term exposure and episodic short-term exposure, and considers three aspects of biological health: 1) survival of juveniles and adults, 2) growth of juveniles, and 3) larval recruitment. This approach combines current understanding of biological responses to hypoxic stressors in an estuarine ecosystem, and establishes a basis for the development of site-specific DO requirements.

Since organism-level laboratory data forms the basis of the criteria calculations, the U.S. EPA approach does not address directly some of the physiological effects or behavioral responses sometimes observed in low DO waters. There is a large body of research on indirect or sublethal effects of hypoxia resulting from, for example, contracting of habitats, increased predation, or altered trophic interactions (e.g., Eby et al. 2005, Vaquer-Sunyer and Duarte 2008, Seitz et al. 2009), and also summarized in U.S. EPA (2000). We considered these ecological interactions while developing the objectives and in discussions with the Expert Panel. Many aspects of hypoxia, relevant to Suisun Marsh, have been already reviewed by McKee et al. (2011), as part of the larger effort to develop nutrient water quality objectives for the San Francisco Bay estuary of which Suisun Marsh is an integral part, and in support of setting the DO objectives for California estuaries (Sutula et al. 2012). The latter study discusses assumptions, uncertainties and an application of the Virginian Province approach to derive the DO criteria for estuaries in California. Some effects such as local acclimation and adaptation to low DO conditions (Decker et al. 2003) could result in a population that is less sensitive than predicted from laboratory studies, whereas increased predation or contracting habitats could result in under-predictions. Therefore, we concluded that the uncertainties in this method were not likely to affect the level of protection set by the criteria.

Quantifying impacts of sublethal effects on fish populations has been challenging because of the large amount of interannual variability, multiple stresses that usually exist in aquatic systems, and high recruitment variability associated with coastal species. In derivation of the criteria for the Virginian Province, the U.S. EPA, however, recognized that the established criteria were protective of the above effects because most of the observed responses occurred at levels below 2.3 mg/L. The conservative assumptions used in the modeling, together with the exposure thresholds derived from experiments under the continuous low DO conditions, make the resulting criteria protective of most indirect adverse effects.

The U.S. EPA approach represents a synthesis of knowledge regarding biological responses to hypoxic stressors in aquatic ecosystems, is consistent with the guidelines for setting the water quality criteria for other pollutants (Stephen et al. 1985), and as such provides the best available tool for setting the site-specific objectives for Suisun Marsh. Therefore, although we evaluated a variety of approaches to set site-specific dissolved oxygen objectives in Suisun Marsh, we concluded that the U.S. EPA (2000) approach relied on the best-available scientific method that incorporated past and current scientific knowledge, and also met the regulatory backing required for criteria setting. The Expert Panel also endorsed this approach. See Tetra Tech (2017) for a detailed description of this methodology and how it was applied to derive the objectives for Suisun Marsh.

4.2.2 Summary of USEPA Virginian Province Approach

The Virginian Province approach (USEPA 2000) recommends a methodology for deriving DO levels necessary to protect coastal and estuarine organisms. It was originally developed for the Cape Cod Region, and was subsequently used to derive site-specific criteria for other large estuarine systems (e.g., Chesapeake Bay or state-wide objectives in Florida). The criteria are derived from laboratory data for organisms that occur in a particular area of interest, following the general approach used to develop criteria for toxic compounds (Stephen et al. 1985). Acute effects describing lethality to 50% of test organisms (LC_{50}) and chronic effects describing the most sensitive endpoint (growth in the case of DO) are obtained from the laboratory data. Toxicity data are ranked according to genus mean acute (or chronic) values (GMAV or GMCV) from most to least sensitive to DO. The four most sensitive GMAVs for acute criteria or GMCVs for chronic criteria, and the number of genera for which acceptable data are available, are then used to determine the Final Acute Value (FAV) or Final Chronic Value (FCV). This approach considers the response to both continuous and cyclic exposures to low DO levels to derive criteria protective of at least 95% of the species likely to be present. The methodology identifies the following three main components of the criteria:

- Criterion Minimum Concentration (CMC). An estimate of the lowest concentration of DO in ambient water to which an aquatic community can be exposed briefly without resulting in an unacceptable adverse effect. This is the acute criterion.
- Criterion Continuous Concentration (CCC). An estimate of the lowest concentration of DO in ambient water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable adverse effect. This is the chronic criterion.
- Final Recruitment Curve (FRC). A function that defines the maximum allowable exposure duration at DO concentrations between the CMC and CCC necessary to prevent unacceptable reductions in seasonal larval recruitment for sensitive species. Duration of exposure must be reduced when DO concentrations decrease.

The juvenile/adult survival and growth criteria provide useful screening boundaries within which to judge the DO status of a given water body. If DO conditions are above the chronic growth criterion (CCC), then this water body would meet objectives for protection. If DO conditions are below the juvenile/adult survival criterion (CMC), then the water body would not meet the objectives for protection. When the DO conditions are between these two thresholds, then the site would require evaluation of the duration and intensity of hypoxia to determine the suitability of habitat for the larval recruitment objective, if appropriate.

4.2.3 Calculation of Acute and Chronic Thresholds for Indicator Species in Suisun Marsh

The site-specific acute and chronic DO values for Suisun Marsh were first calculated by Bailey et al. (2014) using the biological approach recommended for the Virginian Province, but with fish and invertebrate species characteristic of Suisun Bay and Suisun Marsh waters. The species list was further refined with the recommendations of the Expert Panel to focus on the species ecologically important to Suisun Marsh, both introduced and native, while species rarely encountered in the marsh were removed from considerations (Tetra Tech 2017; Table 4-1). Fish and invertebrate species representative of Suisun Marsh were then evaluated using currently available data on sensitivity to low levels of DO (i.e. hypoxia). Threatened and endangered species were also considered in the analysis, including steelhead, chinook and coho salmon, green sturgeon, and Delta smelt. It was determined that sufficient data were available for either locally-occurring species as well as for genus and family-level surrogates of local species to calculate the acute (CMC) and chronic (CCC) values for DO using the U.S. EPA procedures for deriving water quality criteria.

Table 4-1
Refined list of species to calculate DO objectives for Suisun Marsh

Species	Baily et al. 2014 List	Refined Species List (Tetra Tech 2017)
Threespine stickleback (*Gasterosteus aculeatus)*	X	X
Striped bass (*Morone saxatilis)*	X	X
American shad (*Alosa sapidissima)*	X	X
Starry flounder (*Platichthys stellatus)*	X	X
Mississippi silversides (*Menidia audens)*	X	X
White sturgeon (*Acipenser transmontanus)*	X	X
Sacramento splittail (*Pogonichthys macroelepidotus)*	X	X
Longfin smelt (*Spirinchus thaleichtys)*	X	X
Tule perch (*Hysterocarpus traski)*	X	X
Prickly sculpin (*Cottus asper)*	X	X
Staghorn sculpin (*Leptocottus armatus)*	X	X
Threadfin shad (*Dorsoma petenense)*		X
Common carp (*Cyprinus carpio)*		X
White catfish (*Ameierus catus)*		X
Yellowfin goby (*Acanthogobius flavimanus)*		X
Siberian prawn (*Exopalaemon modestus)*		X
Oriental shrimp (*Palaemon macrodactylus)*		X
Scud (*Gammarus daiberi)*		X
Opossum shrimp (*Hyperacanthomysis longirostris)*		X
Opossum shrimp (*Neomysis kadiakensis)*		X
Chinook salmon (*Oncorhynchus tshawytscha)*	X	X[1]
Rainbow trout/steelhead (*Oncorhynchus mykiss)*	X	X[1]
Pacific lamprey (*Entosphenus tridentatus)*	X	
Green sturgeon (*Acipenser medirostris)*	X	
Delta smelt (*Hypomesus transpacificus)*	X	
Longjaw mudsucker (*Gillichthys mirabilis)*	X	
Bay pipefish (*Syngnathus leptorhyncus)*	X	
California halibut (*Paralichthys californicus)*	X	
Northern anchovy (*Engraulis mordax)*	X	
Pacific herring (*Clupea pallasi)*	X	
Shiner perch (*Cymatogaster aggregate)*	X	

[1] spatially and temporally restricted

Projection of Juvenile and Adult Survival (CMC – Acute)

Based on the fish and invertebrate species identified by the Expert Panel a total of 12 data points that relate the survival of juvenile and adult organisms to low DO were used to re-calculate the acute DO threshold for Suisun Marsh. The data were ranked by species on the basis of sensitivity. The four most sensitive species were used to calculate the final acute value (FAV) and included (from most tolerant to least tolerant): striped bass, Mississippi silversides, American shad, and sturgeon. Based on the four most sensitive genus mean acute values (GMAV), the FAV calculated was 2.67 mg/L. This translated into a CMC value of 3.8 mg/L (Tetra Tech 2017).

Projection of Sublethal Effects (CCC – Chronic) Without Salmonids

For chronic effects, data from 7 species were available, with 3 data points for fish and 4 data points for other organisms. The most sensitive species for chronic effects were associated with silversides (4.33 mg/L), mud crab (4.63 mg/L), grass shrimp (4.67 mg/L) and sturgeon (4.77 mg/L). The calculated chronic DO value was 5.0 mg/L.

DO Thresholds for Protection of Salmonids

The DO criteria derived for the Virginian Province did not incorporate salmonids because the most sensitive life stages for salmonids are associated with freshwater, not brackish estuarine waters. However, salmonids are ecologically important and often use estuaries as juvenile rearing habitat and migration. Migration and estuarine habitat are beneficial uses of the marsh, so it is appropriate to consider salmonids while deriving the CMC and CCC values for Suisun Marsh, and evaluate the temporal extent to which the proposed DO objectives would be protective of salmonids using the marsh for migration (Table 2-1). Protection of embryonic and larval salmonid stages was not considered, as those life stages are only associated with spawning sites, which are located in upstream freshwater reaches of Sacramento and San Joaquin Rivers. When salmonids are included among the four most sensitive species, the calculated CCCs are 5.1 and 6.4 mg/L, depending on the chosen GMCV value and the length of the exposure period.

Based on the available data and expert opinion, these somewhat higher chronic DO concentrations apply to Montezuma, Denverton and Nurse Sloughs in order to support temporary fish passage and some extended rearing in early spring (January through April; P. Moyle, UC Davis, *pers. comm.*, Figure 4-2). The data analysis of grab samples in Montezuma and other larger sloughs suggests that DO concentrations are generally above 6 mg/L, and the highest DO concentrations are measured during spring (Figure 4-3), therefore salmonids are currently protected.

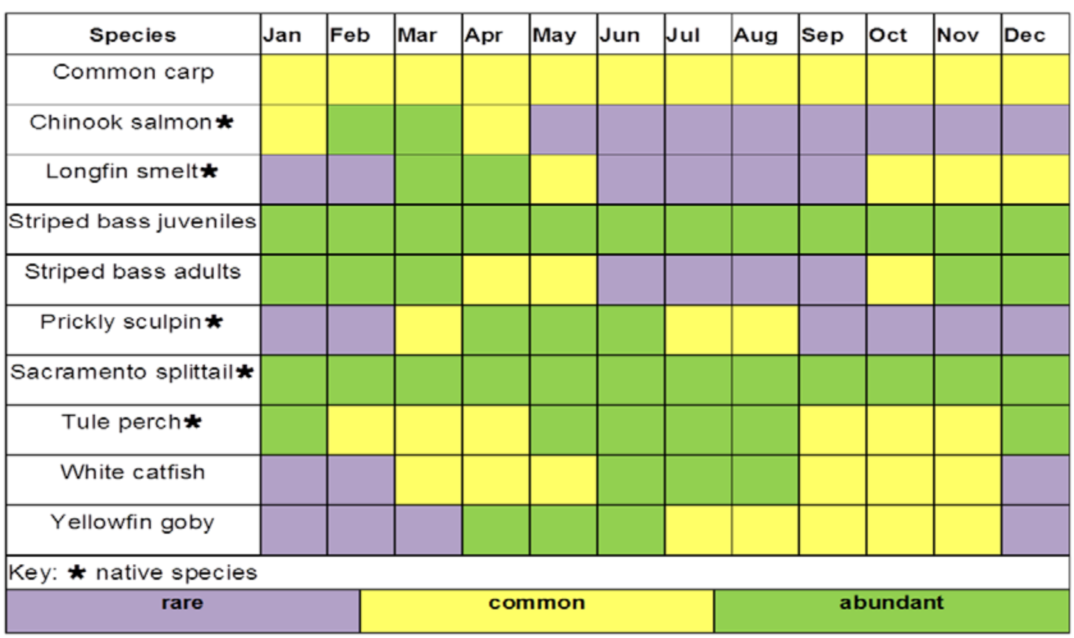
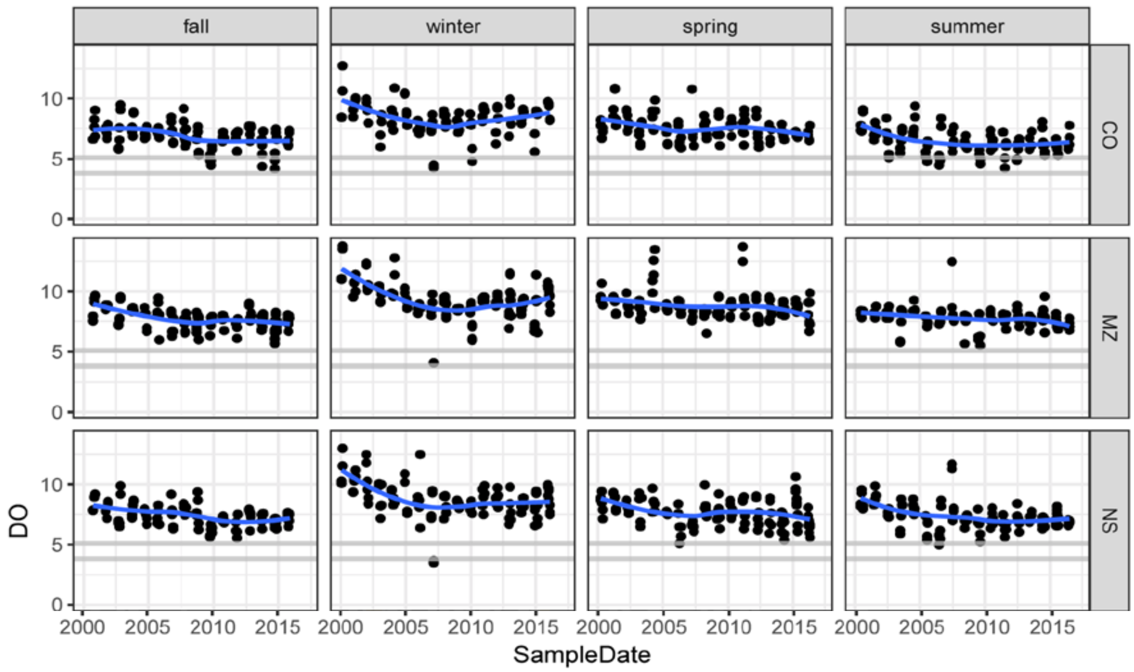


Figure 4-2 Fish species occurrences in Suisun Marsh by month

P. Moyle, UC Davis, *pers. comm.*, Tetra Tech (2017)

Figure 4-2 shows qualitatively the most common fish species found throughout the year and indicates that Chinook salmon is frequently found in Montezuma Slough and its major tributaries during January-April, and is especially prevalent in February-March.



Blue line: long-term average DO (mg/L); Tetra Tech (2017)

Figure 4-3 DO grab sample data in Cutoff (CO), Montezuma (MZ) and Nurse Slough (NS)

In its 1986 DO criteria for freshwater, U.S. EPA's recommended coldwater criterion, 6.5 mg/L, was expressed as the 30-day mean and reflected findings that DO concentrations below 3 mg/L would result in acute mortality to salmonids, while DO from 5 to 6 mg/L would have a moderate to slight impact on production. The CMC value derived for Suisun Marsh (3.8 mg/L) is higher than the U.S. EPA acute threshold for salmonids (i.e. 3 mg/L) suggesting it is reasonably protective of salmonids' survival. The recalculated CCC value with the salmonid data included in the top four sensitive species resulted in a range of DO from 5.1 to 6.4 mg/L, with the upper limit comparable to the U.S. EPA value of 6.5 mg/L, suggesting that it should be supportive of growth, i.e. offers a reasonable protection against chronic exposure in areas where salmonids might be present in Suisun Marsh. DO concentrations are generally higher in Montezuma, Nurse and Denverton sloughs, where salmonids are found during their outmigration (Figure 4-3), while the back-end sloughs where DO sags are likely to occur, are not generally considered to be suitable salmonid habitats.

4.2.4 Larval Recruitment Curve for Striped Bass

Evidence suggests that fish and other aquatic organisms can tolerate DO concentrations below the calculated CCC threshold for short periods of time and that these short excursions are unlikely to adversely affect larval recruitment in populations of exposed organisms. Based on this evidence, U.S. EPA (2000) developed a generic model to evaluate the cumulative effect of low DO between the CMC and CCC on early life stages, as larvae are more acutely sensitive to low DO than juveniles. The larval recruitment model generates a curve that describes the number of days that larva (or other sensitive life stages) of sensitive organisms can be exposed to DO concentrations below the CCC without negatively affecting the total population. A maximum acceptable reduction in seasonal recruitment due to low DO conditions was conservatively set to five percent. The model developed by U.S. EPA uses laboratory dose-response data along with data that characterizes each genus, their developmental periods, duration of sensitive life stage exposure to low DO conditions, and the proportion of population potentially exposed to a hypoxic event. The four most sensitive genera are then selected to develop the Final Recruitment Curve (FRC). The curve can then be used to evaluate how many days of low DO can be tolerated with no significant effect on recruitment. The number of acceptable days of exposure to low DO decreases as the severity of the low oxygen conditions increases. The Virginian Province FRC was generated with deliberately conservative biological parameters and may be overprotective for other areas (USEPA 2000).

A simplified model for striped bass, the only class of fish specific to Suisun Marsh with extensive DO data, was developed to evaluate the acceptable intensity and duration of low DO across the larval recruitment season (Tetra Tech 2017). Since striped bass is among the four most sensitive species used by U.S. EPA, the recruitment curve for bass in Suisun Marsh closely resembles the FRC for Virginian Province. However, as the Suisun Marsh CMC is higher (3.8 mg/L versus EPA's 2.3 mg/L) the modelled acceptable DO concentrations are more stringent. Given the DO requirements of organisms present in Suisun Marsh and their use of the marsh, the evaluation for striped bass is an appropriate approximation of DO conditions required for protection of important native species including delta smelt and Sacramento splittail (P. Moyle, UC Davis, *pers. comm.*).

4.2.5 Proposed DO Objectives and TMDL Targets

The proposed water quality objectives for DO have been developed to protect sensitive aquatic organisms in Suisun Marsh (Table 4-2). The derivation of the objectives followed the U.S. EPA guidelines (Stephen et al. 1985) and the risk-based approach of the Virginian Province saltwater criteria for estuarine and coastal waters,which reflect the DO needs of species present in the waterbody. The Virginian Province approach (USEPA 2000) is considered as the most appropriate to address protection of Suisun Marsh living resource and as a viable technical framework for setting protective DO criteria.

The approach primarily considers species representative of the Virginian Province region. However, comparisons between exposure-response relationships for the mud crab, grass shrimp and the inland silverside for northern and southern populations of each species supports the use and general applicability of the data for other regions. (USEPA 2003-Appendix C). To tailor the approach to Suisun Marsh, we asked the Expert Panel to help identify the sensitive species requirements as the laboratory-based experimental data were not available for many of the Suisun Marsh resident aquatic species. However, surrogate genera or family were commonly available. The selection of appropriate species offers a scientifically defensible approximation of DO tolerances suitable for protecting all aquatic life use. In derivation of the proposed objectives priority was given to the native and non-native ecologically important fish species. The DO requirements of threatened and endangered species were also considered and data for salmonids were included in the derivation of the objectives for specific marsh locations used by salmonids as migratory routes, and as rearing and foraging habitat during active migration. The proposed DO objectives are expressed in mg/L rather than as percent saturation because they reflect the levels of DO from laboratory experiments, which have been directly linked to adverse impacts on the aquatic organism's survival, growth and recruitment. The application of the U.S. EPA's approach in Suisun Marsh represents a comprehensive assessment of the available information, considering tolerance, exposure, and growth/recruitment factors that were appropriately applied to the representative species.

Table 4-2
TMDL DO targets for protection of aquatic life beneficial uses in Suisun Marsh

Designated Use	DO concentrations/ Duration	Protection	Time of year
All sloughs and channels	1-day mean [a] ≥3.8 mg/L (Acute - CMC)	Survival of juvenile and adult fish	Year-round
All sloughs and channels	30-day mean [b] ≥5 mg/L (Chronic – CCC)	Survival/growth of larval/juvenile and adult resident fish; protective of threatened/endangered species	Year-round
Montezuma, Nurse and Denverton Sloughs	30-day mean [b] ≥6.4 mg/L (Chronic – CCC)	Survival and growth of larval/juvenile migratory fish (salmonids); protective of threatened/endangered species	January-April

[a] estimated as daily average

[b] estimated as 30-day running average

To ensure protection of juvenile and adult resident and migratory fish against unacceptable lethal conditions we recommend DO ≥3.8 mg/L calculated as 1-day mean from continuous data. This value also protects the survival of sturgeon as laboratory data for the sensitive shortnose sturgeon suggest that it can withstand short-term exposures to low DO from 2.3 to 3.1 mg/L (Campbell and Goodman 2004). Our 1-day objective is also more stringent than the U.S. EPA value of 2.3 mg/L.

The chronic 30-day mean DO ≥5.0 mg/L will ensure survival, recruitment and growth of aquatic organisms as well as it will protect threatened and endangered species across Suisun Marsh habitats. According to the U.S. EPA methodology, exposures to DO concentrations above this level will not result in any adverse effects on growth as that value was derived by observing growth effects in the most sensitive larval and juvenile life stages. The 30-day averaging period is consistent with, and fully protects against the effects on larval recruitment greater than five percent.

The striped bass recruitment curve calculated for the conditions in Suisun Marsh indicates that DO above 4.3 mg/L for 30 days will protect against losses in larval recruitment.

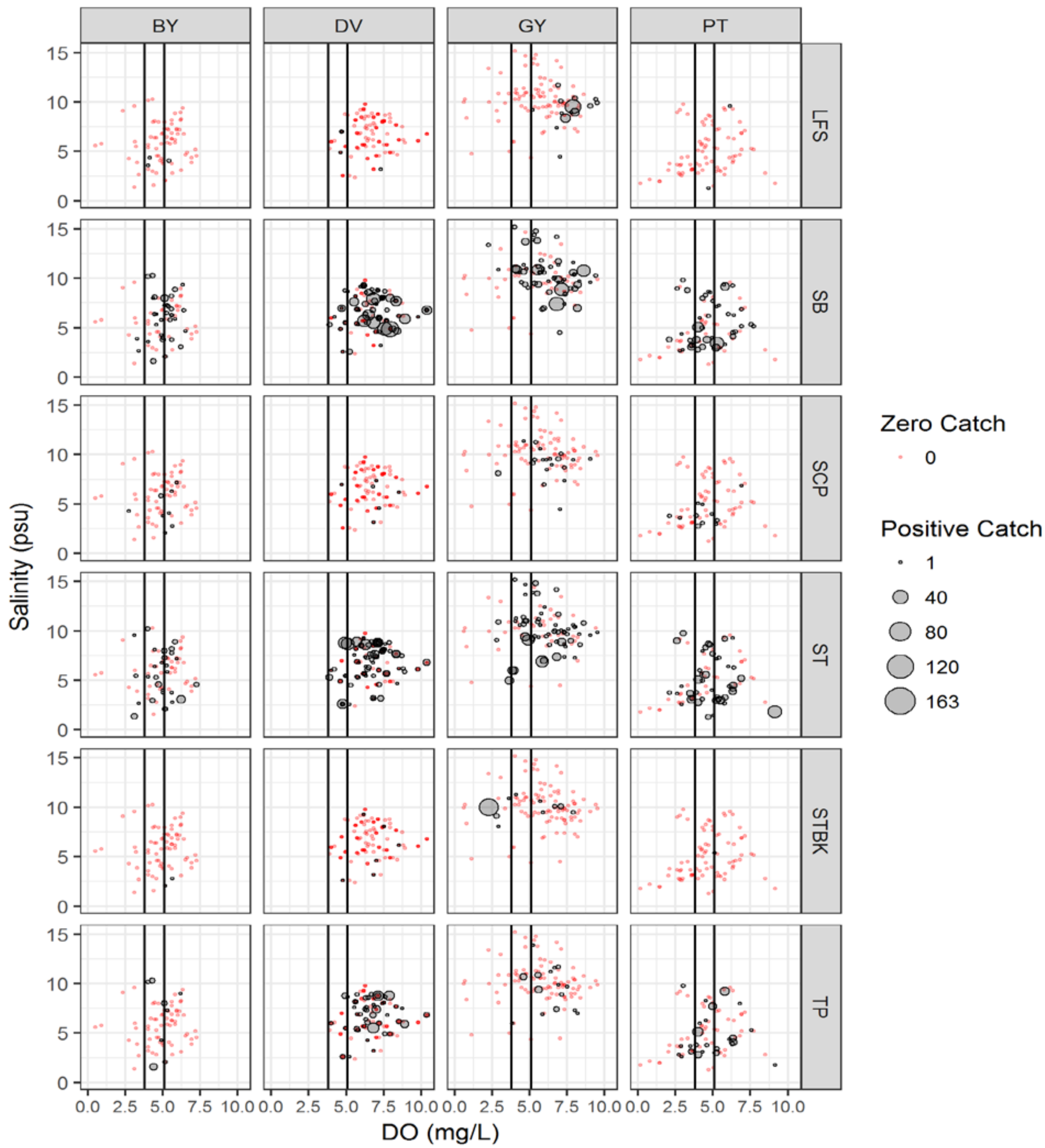
The 30-day mean DO ≥6.4 mg/L will apply from January through April in Montezuma, Nurse and Denverton Sloughs to protect listed juvenile salmonids (steelhead, Chinook). Data from the UC Davis long-term fish study tracking fish abundance and DO concentrations (O'Rear and Moyle, 2015) were evaluated to assess the spatial and temporal changes in fish presence and their use of the marsh. This study helps identify types of fish present in different habitats and sloughs throughout the year, and especially when low DO conditions are likely to occur.

In addition, the National Marine Fisheries Service (NMFS) in its biological opinion issued for the 30-year Suisun Marsh Habitat Management, Preservation, and Restoration Plan (SMP) examined the effects of the SMP on the listed and endangered species (Chinook salmon, steelhead and green sturgeon) as the only species potentially sensitive to low DO (NMFS 2013). In summary the NMFS findings included the following:

- Adults and juvenile salmonids and green sturgeon use Montezuma Slough as a secondary migratory pathway as they move downstream through the Delta and Suisun Bay to the Pacific Ocean.
- Listed juvenile salmonids use the tidal sloughs seasonally as a rearing habitat, which they enter at smolt stage, and are expected to be actively emigrating. In particular, Chinook salmon smolts may utilize major tributaries of their migratory route (Montezuma Slough), such as Nurse or Denverton Slough.
- Adult or smolt life stages of Chinook salmon and steelhead are unlikely to be found in the back-end sloughs in the west part of the marsh because these areas are beyond the migratory routes of these species.
- Additionally, the peak emigration of steelhead smolts usually occurs between March and early May, and the upstream migration of adult steelhead occurs from January through April, which coincides with high flow events. Therefore, the timing of migration combined with the low probability of fish entering the small back-end sloughs make it unlikely that steelhead will experience low DO conditions.
- Similarly, the migratory routes for green sturgeon make it unlikely for this fish to frequent the sloughs in the west part of the marsh. Green sturgeon are considered as generally tolerant of DO levels ranging from 2 to 5 mg/L.

Considering the NMFS's assessment of the effects of operation and maintenance of managed wetlands on listed and endangered species, we conclude that the proposed DO objectives are protective of all sensitive species and beneficial uses in Suisun Marsh. This conclusion is supported by the long-term observations of fish presence in different parts of the marsh and their use of the sloughs under different DO regimes (Figure 4-4).

The objectives are attained when average daily, and average monthly DO concentrations are at or above the proposed limits of 3.8 and 5.0 mg/L, respectively. Continuous data collected at regular intervals (every 15 to 60-minutes) are needed to fully evaluate whether the objectives are met. A daily average is the arithmetic average of all DO measurements collected within a 24-hour period. The 30-day (monthly) running average is the arithmetic average of daily averages for any 30 consecutive days. Each subsequent 30-day average is computed by sliding the averaging window by one day.



Proposed DO objectives (3.8 mg/L and 5.0 mg/L - dark vertical lines). Tetra Tech (2017) based on 2000-2015 fish data collected and compiled as part of the UC Davis Fish Study (O'Rear and Moyle, 2015)

Sloughs: BY - Boynton; DV - Denverton; GY - Goodyear; PT - Peytonia

Fish species: LFS - longfin smelt; SB - striped bass; SCP - prickly sculpin; ST - splittail; STBK - threespine stickleback; and TP - tule perch

Figure 4-4 DO and salinity conditions and fish abundance during October-November

4.3. Expert Panel Recommendations

The scientific advisory provided valuable insight and context for criteria setting, monitoring requirements, and allowable frequency of non-compliance. The panel also fully supports the derived thresholds for acute and chronic DO objectives proposed for Suisun Marsh sloughs (Table 4-2) and the use of the Virginian Province approach in deriving the objectives. The explanation of the findings and additional suggestions are detailed in the panel's summary of findings (Appendix D).

5. NUMERIC TARGETS: MERCURY

The statewide mercury water quality objectives approved by the State Water Board on May 2, 2017, apply to Suisun Marsh (Table 5-1). These objectives reflect the current scientific understanding of how mercury impairs humans, wildlife, and aquatic life by bioaccumulating in animal tissue. The mercury targets adopted by the Bay Mercury TMDL were established using the same assumptions and are equally protective of both human health and wildlife when compared to the statewide objectives. For example, the statewide objective for sport fish of 0.2 mg/kg in trophic level 3 or 4 fish is equal to the protection of human health target in the Bay Mercury TMDL. In addition, the statewide prey fish objective for the California Least Tern of 0.03 mg/kg similarly matches the target for protection of aquatic organisms and wildlife in the Bay Mercury TMDL. The statewide mercury objectives in Table 5-1 include two possible objectives for prey fish; the Least Tern limit is more stringent than the general prey fish limit. The Bay Mercury TMDL includes the more stringent prey fish limit, which is protective of both objectives. Therefore, when the Bay Mercury TMDL targets are met, the waterbody will also be meeting the applicable water quality objectives.

Table 5-1
Water quality objectives currently applicable in Suisun Marsh

Purpose	Limit	Description
Sport Fish Water Quality Objective	0.2 mg/kg wet weight in skinless fillet	Average mercury concentration measured in trophic level three (15-50 cm) or trophic level four fish (20-50 cm), whichever is the highest, measured in a calendar year
Prey Fish Water Quality Objective-	0.05 mg/kg wet weight in whole fish	Average mercury concentration measured in whole fish, 5–15 cm in length, measured in a calendar year
California Least Tern Prey Fish Water Quality Objective	0.03 mg/kg wet weight in whole fish	Average mercury concentration measured in whole fish, < 5 cm in length, measured April 1 to August 31

5.1. APPLICABILITY OF THE BAY TARGETS TO SUISUN MARSH

5.1.1 Derivation of the Bay Mercury Objectives

The water quality objectives and associated numeric targets adopted by the Bay Mercury TMDL reflect the primary concerns related to the presence of mercury in aquatic ecosystems, i.e., account for risks to human health from consumption of fish and protect aquatic life and wildlife that consume fish. Therefore, these objectives provide a basis to establish safe levels of mercury for Suisun Marsh.

The derivation of the fish target to protect people who consume Bay fish follows the U.S. EPA methodology to establish the national criterion for methylmercury in fish tissue (USEPA 2001) and is more stringent than the national human health criterion of 0.3 mg/kg in fish. The Bay fish target assums that people eat Bay fish more frequently and is based on the locally derived fish consumption rate of 32 g/day (CDHS&SFEI 2000). The U.S. EPA's reference dose of 0.1 µg MeHg per kg body weight per day is then applied to determine the safe mercury concentrations in fish tissue. The target to protect human health is 0.2 mg/kg average wet weight concentration measured as total mercury in five most commonly consumed Bay fish. The detailed assumptions used in derivation of the targets are discussed in the Bay TMDL Staff Report (SFBRWQCB 2006).

Compliance with the human health fish target is determined using the average mercury concentration in the edible portions of a mix of five commonly-consumed fish species (striped bass, California halibut, jacksmelt, white sturgeon, and white croaker). These five species are all carnivores in trophic levels 3 (meaning the prey species are herbivores) or 4 (meaning the prey species are carnivores) and accordingly would be expected to have bioaccumulated proportionally more mercury than species in lower trophic levels. The halibut, striped bass and white sturgeon are analyzed as muscle tissue without skin, while the white croaker is analyzed with skin, and the jacksmelt with skin and skeleton because people usually eat jacksmelt whole.

The fish target to protect fish consuming birds and wildlife was set to 0.03 mg of mercury per kg measured in small whole fish 3–5 cm in length. This fish target reflects consumption of fish less than 5 cm in length (e.g., topsmelt, jacksmelt, and northern anchovy) by California least tern based on the methodology developed by the USFWS (2003), which was also used in other TMDLs. Predatory birds with diets which depend entirely on Bay fish and aquatic organisms, have been identified as the most sensitive mercury receptors (Davis et al. 2003, Melwani et al. 2012). Therefore, the objective calculated to protect birds is also expected to protect other wildlife reliant on the Bay for food. In addition, the prey fish target coincides with the mercury thresholds considered as protective of the threatened California least tern, which, due to its status, ensures protection of rare and endangered species (USFWS 2003).

5.1.2 Rationale for Suisun Marsh Hg Targets

Sources of mercury in Suisun Marsh, located at the northeastern end of the Bay and western end of the Delta, are similar to those identified in all segments of the San Francisco estuary, and include historic mining activities, atmospheric deposition, refinery and municipal waste and urban stormwater runoff. Applying the same targets to Suisun Marsh allows for coordination of implementation actions and time schedules already in place as a result of the Bay Mercury TMDL, and is consistent with the 2017 statewide water quality standards for mercury, which also set fish tissue targets instead of sediment or water column concentrations.

The San Francisco Bay and Tomales Bay TMDLs set fish tissue targets and require direct monitoring of appropriate trophic levels and sizes of fish to evaluate compliance with the targets to protect human health and wildlife. A similar approach is appropriate for the Suisun Marsh for the following reasons:

1. Mercury in fish tissue is assumed to be composed entirely of toxic MeHg, which makes fish tissue targets more conservative and protective than water column targets.
2. Measurement of mercury in fish muscle tissue is a direct method for determining compliance with the fish target, rather than introducing uncertainty from the linkage analysis between water and fish mercury concentrations.

3. The laboratory analytical methods for total mercury in fish tissue have a lower detection limit than those for aqueous methylmercury in water.
4. The approach is consistent with the Bay Mercury TMDL and its Implementation Plan. Suisun Marsh is hydrologically connected to Suisun Bay and to San Francisco Bay.
5. The Watershed Mercury Permit (R2-2017-0041) and the Municipal Regional Permit (R2-2015-0049) already implement waste load and load allocations required by the Bay Mercury TMDL, including municipal waste and stormwater from areas adjacent to the Suisun Marsh area.

Following these recommendations, and as adopted in the Bay Mercury TMDL, the Basin Plan's 4-day average marine water quality objective (0.025 µg/L) is outdated and should be replaced in Suisun Marsh . As described in the Bay TMDL (SFBRWQCB 2006), the Basin Plan's 4-day mercury objective is based on science over three decades old (USEPA 1985). Furthermore, the Basin Plan objective reflects studies on the Eastern oyster, a low trophic level species that is not present in Suisun Marsh or San Francisco Bay.

The suspended sediment target for mercury developed for the Bay Mercury TMDL and the Tomales Bay Mercury TMDL is not considered relevant for Suisun Marsh. In San Francisco and Tomales Bays, resuspension of sediments was identified as a significant internal source of mercury, and a sediment target specifies an approach to control the overall mercury supply. In Suisun Marsh, however, resuspension of local bed sediment is a smaller source relative to contributions from upstream watersheds and tidal action Moreover, the primary concern in the marsh is methylation of inorganic mercury in wetland and slough environments, where suspended sediment mercury concentrations are not as indicative of methylation potential as other factors, such as dissolved oxygen levels. The Delta TMDL notes that over 80 percent of the total mercury input to the Delta is contributed by the Sacramento River and Yolo Bypass watersheds, and these sources are separately targeted by the load reduction actions in existing TMDLs. The newly adopted, 2017 statewide mercury standards do not include sediment concentrations, which confirms that the level of mercury in fish tissue provides a primary means to protect people and wildlife from consuming fish, which contain high levels of mercury.

5.2. PROTECTION OF HUMAN HEALTH AND WILDLIFE IN SUISUN MARSH

5.2.1 Protection of Human Health

Suisun Marsh wetlands, channels, and sloughs are popular fishing destinations and the fish consumption rate (32 g/day) of people fishing in the sloughs and the overall mix of species they consume is expected to be similar to that in the Delta and San Francisco Bay area. Indeed, the local population in the Fairfield-Suisun area may fish not only in Suisun Marsh but also in San Francisco Bay and the Delta. This fish consumption rate was used in both the Bay and Delta TMDLs and represents a consumption rate protective of 95 percent of the people who chose to eat San Francisco Bay fish on a regular basis. Selection of the higher consumption rate than the U.S EPA general population rate of 17.5 g/d (protective of 90% of population) makes the calculated target more protective of people likely to consume local fish.

The fish species and sizes used in evaluation of compliance with the targets may differ slightly but generally include a mix of commonly-consumed TL3 and TL4 fish. Each of the previously mentioned TMDLs has site-specific fish identified to comply with the targets that reflect locally available species and consumption preferences.

Fish populations in Suisun Marsh have been sampled by UC Davis for over 20 years and showed more than 50 fish species present (O'Rear and Moyle, 2015). This sampling characterized the abundance of fish species, but not tissue mercury concentrations. Fish that may be consumed by people include striped bass, black bullhead, white catfish, white croaker, and common carp. White catfish is a high trophic level (TL4), bottom feeding fish that is relatively abundant in Suisun Marsh and the Delta. This is a desirable and popular fish species because of its abundance, accessibility and size. The white catfish grows at a slow rate, which also makes this fish susceptible to mercury accumulation (Davis et al. 2000a). Largemouth bass, although common in the Delta, were caught only rarely in Suisun Marsh. Adult striped bass are not common but juvenile striped bass use the wetlands and smaller channels as a nursery (Crain and Moyle, 2011). Overall, more than 99,000 striped bass were caught during the study period to date. Since juvenile striped bass are the most frequent fish caught in the otter and midwater trawls in the sloughs and in beach seines, and bass is one of the most commonly consumed sport fish, it is a good indicator to evaluate protection of human health in Suisun Marsh and elsewhere.

We propose that the human health target of 0.2 mg/kg be measured in striped bass, the most abundant fish in Suisun Marsh. The mercury level should be expressed as an average wet weight concentration of total mercury in skinless fillets. The striped bass is already a target indicator species to evaluate human health sampled in San Francisco Bay and the target is consistent with the statewide sport fish objective of 0.2 mg/kg for waters with the Commercial and Sport Fishing use, such as Suisun Marsh sloughs.

5.2.2 Protection of Wildlife

The fish target to protect wildlife in the Delta and Bay TMDLs is 0.03 mg/kg, and may be used without modification for Suisun Marsh. A variety of small fish were found in the sloughs from 1979 through 2014 (O'Rear and Moyle, 2015), however, mercury was measured in Mississippi silversides only. This relatively small fish (average lengths of 4.4 to 7.9 cm) is considered an important indicator of wildlife exposure to MeHg in the Bay because silversides forage in shoreline marshes and shallow water habitats, which exhibit greater potential for Hg methylation (Melwani et al. 2012). The Bay TMDL used 3–5 cm fish for the fish target to protect wildlife, since the California least tern eats fish less than 5 cm. The least tern is a very sensitive species that is on the federal list of endangered species. Acordingly, this target is also the most stringent of the three statewide mercury objectives established to protect aquatic life and aquatic-dependent wildlife and is protective of all federally- and state-listed endangered species. California least terns are not common in Suisun Marsh, they have been known to breed at one location on the east side of the marsh and to forage in the bays, sloughs, tidal wetlands, and managed wetlands (USBR 2011).

Other piscivorous birds found in the marsh that feed predominantly on aquatic prey are double-crested cormorant and belted kingfisher. Since they can eat somewhat larger fish (the belted kingfisher's diet is typically <10.5 cm, and the double-crested cormorant's diet is 5–15 cm) the proposed target is protective of all piscivorous bird species, because it has been established to protect the most-sensitive species (California least tern) in the season of greatest sensitivity to mercury, which is the breeding season.

5.3. SUMMARY OF RECOMMENDATIONS

The numeric targets, which currently apply in all San Francisco Bay segments should be extended to Suisun Marsh. These include the targets for the protection of humans, aquatic organisms and piscivorous wildlife: 0.2 mg/kg (wet weight) in muscle tissue of large trophic level (TL3 or TL4) fish such as striped bass; 0.03 mg/kg (wet weight) in whole small fish (~ 50 mm in length) such as Mississippi silverside; and the existing 1-hour acute water quality objective of 2.1 µg/L.

The target for large trophic level fish is protective of humans eating 32 g/day uncooked fish per week of commonly consumed, large fish and all wildlife species that consume large fish. The small fish target is protective of birds that consume small fish. The Basin Plan 1-hour average total mercury objective of 2.1 µg/L protects against acute effects to aquatic life.

The proposed targets are shown in Table 5-2. It is implicit in this target selection that water quality objectives are met when fish mercury levels are met and the mercury concentrations in the water column do not exceed 2.1 µg/L.

These are the same targets that were adopted in other Bay-area TMDLs (e.g., San Francisco Bay, Guadalupe River, and most recently in Tomales Bay).

Table 5-2
Numeric targets for San Francisco Bay and Suisun Marsh

Purpose of Target	Target	Target Description
Protection of human health	0.2 mg/kg ww in fish tissue	Average mercury concentration measured in edible portion of TL3 and TL4 fish*
Protection of aquatic organisms and wildlife	0.03 mg/kg ww in fish	Average mercury concentration measured in whole fish, 3–5 cm in length

*Commonly consumed fish present in the sloughs and channels of Suisun Marsh such as striped bass and white catfish (TL4)

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6. SOURCE ANALYSIS: ORGANIC ENRICHMENT, DISSOLVED OXYGEN, AND NUTRIENTS

Sources contributing substances, which could potentially lower DO concentrations in Suisun Marsh sloughs were assessed for the presence of total organic carbon (TOC), biological oxygen demand (BOD) and nutrients. The relationships between these substances and low DO are explained in more detail below.

6.1. ORGANIC CARBON AND LOW DO

Because oxygen is used in decomposition of organic matter the availability, amount and type of organic material present in the sloughs and the surrounding areas could have a significant impact on lowering levels of DO. The high organic carbon concentrations in Suisun Marsh have been attributed to high levels of primary production in the interior of the marsh (Enright et al. 2009). These include primary production of macrophytes in shallow waters, attached algae in shallow calm areas such as tidal creeks, and phytoplankton production in deeper, clearer areas with intermediate residence times (e.g., small sloughs). Moreover, long water residence times, nutrient availability, and relative absence of alien clams also intensify primary production in the interior of Suisun Marsh (DFG 2008).

However, in addition to this natural, internal production, organic carbon can reach Suisun Marsh in several other natural and anthropogenic ways, including:1) tidal exchange with the Bay; 2) runoff from the surrounding watersheds; 3) wastewater treatment plant discharge; 4) managed wetland discharge; and 5) exchange with tidal marshes. Detritus from emergent tidal vegetation can also be a source of substantial amounts of organic matter in estuaries and coastal oceans (Raymond and Bauer, 2001). Adjacent uplands that remain hydrologically connected to the marsh also contribute vegetation detritus, as well as agricultural and stormwater runoff. The managed wetlands in Suisun Marsh can discharge significant amounts of organic matter as a result of soil and vegetation management activities at these sites. Finally, suspended sedimentary material containing plant material can be tidally transported from the adjacent Grizzly and Suisun Bays.

Factors such as location, primary production type, hydrology, and weather determine the sources and distribution of organic carbon. (Mueller-Solger and Bergamaschi, 2005). For instance, while tidal and managed wetland areas support vascular plant production, phytoplankton production occurs in open water areas and shallow, stagnant areas support benthic and epibenthic algal and submerged aquatic vegetation. The hydrologic connectivity of these habitats determines the dominant organic carbon sources to a particular area of the marsh. A conceptual model of sources and distribution of organic carbon is shown in Figure 6-1. A summary of BOD organic carbon loads from different sources is shown in Table 6-1.

The interactions between types of organic material present in the marsh and sloughs and DO are complex and highly variable. Downing et al. (2010) used the fluorescence index (FI) to evaluate the relative contribution of algal versus terrestrial dissolved organic matter (DOM). Algal derived materials have lower aromatic content, lower molecular weight, and higher FI compared to the more-degraded DOM from dead plants and soils of terrestrial origin. FI values in Wetland 112 and 123 ranged between 1.2 and 2, which indicates a mixture of DOM from different sources. Some increases in FI observed in Wetland 123 long after the wetland flooding might suggest that DOM was generated from algal production and leaching from vegetation in the wetland and the observed changes in DOM composition could be due to primary production within the wetland or inflow and water exchange with the adjacent slough.

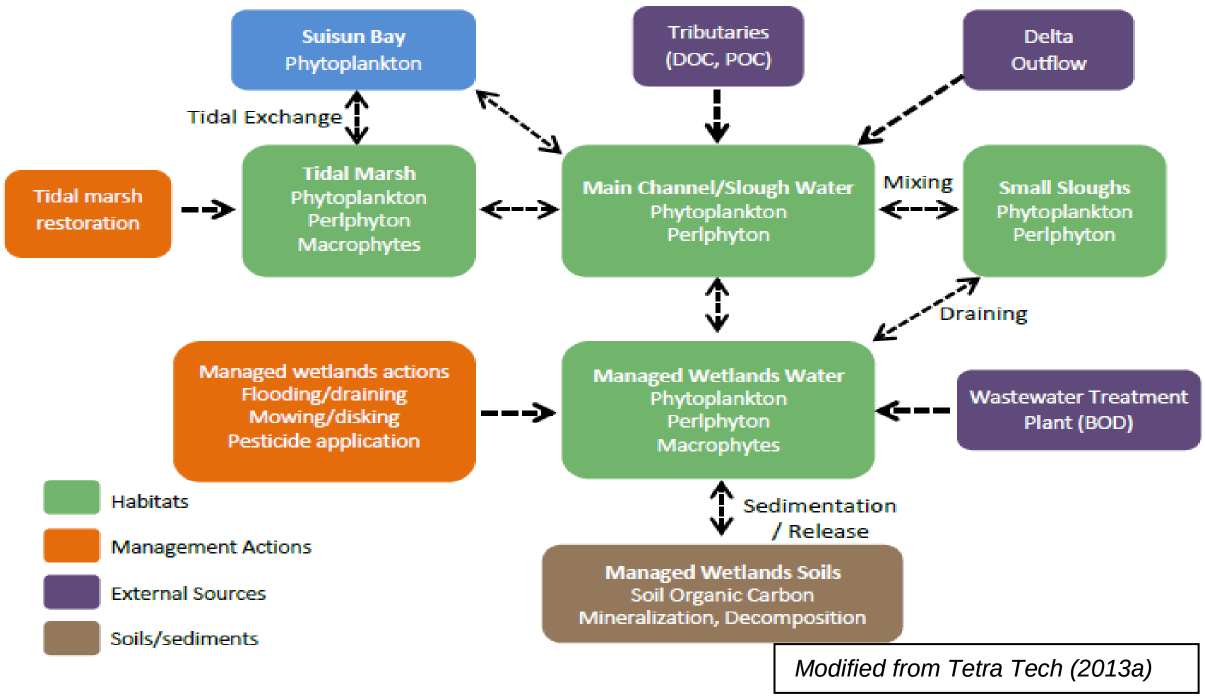


Figure 6-1 Conceptual model of sources and distribution of organic carbon in Suisun Marsh

Table 6-1
Summary of BOD and organic carbon loads from different sources

Source	BOD Loads (kg/day)	DOC Loads (kg/day)	Reference
Surrounding watersheds (stormwater)	3776	1416	Davis et al. (2000b)
FSSD treated wastewater effluent	<100	40	NPDES Permit No. CA0038024
Managed wetland discharges		1,981–8,958 during drain events	Bachand et al. 2010

6.2. Sources and Loads of Organic Carbon

6.2.1 Surrounding Watersheds

Runoff from surrounding watersheds, which contains both vegetation debris and phytoplankton, is a major external source of organic carbon to the marsh. Several creeks enter Suisun Marsh, including Valley Creek, Suisun Creek, Ledgewood Creek, Laurel Creek, Union Creek, and Denverton Creek (Figure 8-1). The creeks drain watersheds with a mix of low intensity agricultural, urban, and open space land uses. The tributary inputs of organic carbon and BOD can be estimated based on a previous study by Davis et al. (2000b). The Fairfield sub-watersheds were estimated to export a total of 3,776.5 kg/day of BOD or 1,416.2 kg/day of organic carbon at a rate of 15.7 kg/ha/yr BOD or 5.9 kg/ha/yr organic carbon (Tetra Tech 2013a).

BOD and total organic carbon (TOC) concentrations were recently sampled during two storm events and several dry weather dates in the tributaries, including Laurel Creek, Ledgewood Creek, and Suisun Creek. The concentrations of BOD and TOC measured for these sampling events are listed in Table 6-2. These concentrations along with the estimated monthly flow were used to calculate loads of BOD and TOC from tributaries to Suisun Marsh. Estimated loads of BOD based on the measured concentrations ranged from 5.7 kg/ha/yr in Suisun Creek to 13.8 kg/ha/yr in Laurel Creek; estimated loads of TOC ranged from 4.1 kg/ha/yr in Suisun Creek to 16.4 kg/ha/yr in Laurel Creek. These estimated rates of export are similar to the previous estimates by Davis et al. (2000b).

Table 6-2
Concentrations of BOD, and TOC in Suisun Marsh creeks sampled during 2013, and estimated loads

Constituents	Date	Laurel Creek upstream	Laurel Creek downstream	Ledgewood Creek upstream	Ledgewood Creek downstream	Suisun Creek upstream	Suisun Creek downstream
BOD (mg/L)	2/19/2013	8.78	4.46	7.73	6.56	4.27	3.16
	9/18/2013	ND	ND	ND	ND	ND	ND
	10/11/2013	5.84	4.82	2.54	6.5	5.96	4.28
	10/28/2013	ND	ND	ND	ND	ND	ND
	11/1/2013	6.18	2.7	ND	6.72	ND	ND
	12/10/2013	5.08	4.65	4.69	5.09	5.6	5.48
Total organic carbon (TOC, mg/L)	2/19/2013	10.1	7.66	8.73	6.18	2.47	2.33
	9/18/2013	3.11	3.07	8.78	8.69	3.6	2.83
	10/11/2013	3.13	3.01	3.59	3.7	2.4	2.4
	10/28/2013	2.58	2.6	5.3	5.67	2.5	1.97
	11/1/2013	13.1	7.6	6.6	8.2	5.9	7.5
	12/10/2013	3.5	2.4	3.69	3.63	3.27	3.19
BOD (kg/ha/yr)		13.8	7.5	11.6	10.9	7.3	5.7
TOC (kg/ha/yr)		16.4	12.3	15.0	11.7	5.3	5.2

ND – non-detect

6.2.2 Wastewater Treatment Plant Effluent

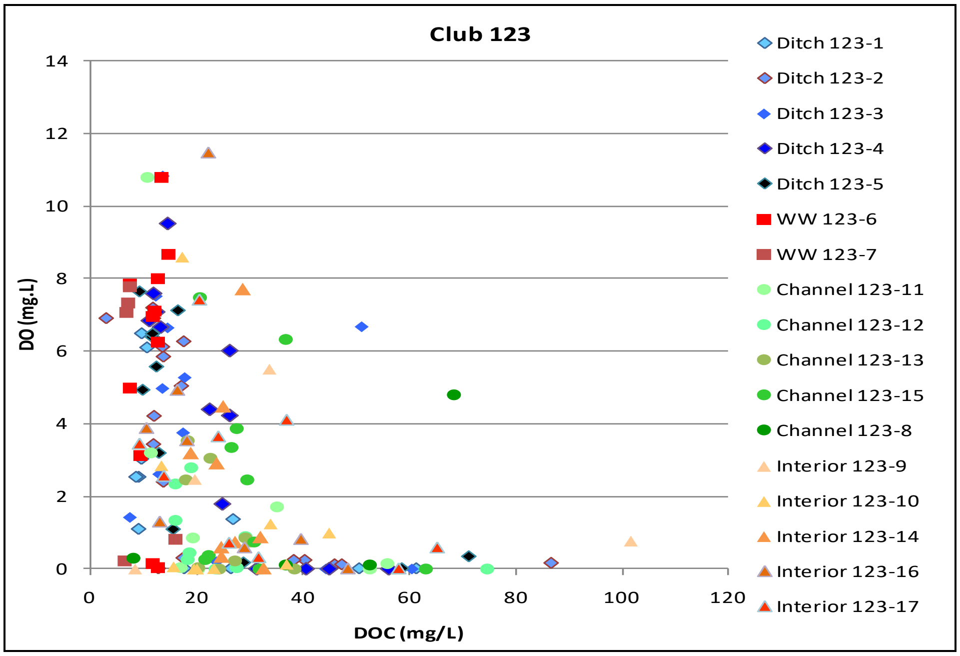
Fairfield Suisun Sewer District (FSSD) discharges a majority of its treated wastewater effluent to Boynton Slough. The plant is an advanced secondary treatment plant. NPDES Permit No. CA0038024 limits the amount of BOD in the effluent to an average monthly concentration of 10 mg/L. The plant presently treats on average up to 16.1 mgd (2000–

2002), with an average dry weather flow of 14.1 mgd. Of the treated effluent, an annual average of 14.4 mgd is discharged to Boynton and Peytonia sloughs in Suisun Marsh, and 1.7 mgd is reclaimed for agricultural irrigation. Although the maximum allowable discharge of BOD load from FSSD was approximately 900 kg/day or 346 kg/day calculated as DOC, actual discharges are usually much lower. For example, in 2012, the average daily BOD load was less than 107 kg/day (calculated DOC load of 40.1 kg/day) (NPDES discharge data).

6.2.3 Managed Wetland Discharges

Organic carbon concentrations and seasonal variability in Suisun Marsh managed wetlands and sloughs are discussed in Tetra Tech (2013a). The role of managed wetlands on dissolved organic carbon (DOC) in tidal sloughs was emphasized in the study of Bachand et al. (2010). Higher DOC concentrations were measured within managed wetlands than the adjacent sloughs. DO was consistently low in water with high DOC concentrations (Figure 6-2) and was typically below 1 mg/L when DOC concentrations exceeded 40 mg/L.

DOC concentrations in the managed wetlands increased within the first few weeks during fall wetland filling up events and then stabilized. Upon release, managed wetlands sent pulses of high DOC water to their adjacent sloughs, resulting in increased DOC concentrations in receiving waters. Based on this analysis, the managed wetlands received 468 mg/m^2 (wetland area)/tide/inch during the flood event and discharged 306 and 826 mg/m^2 (wetland area)/tide/inch at Wetland 112 and 123 during drainage events. Typically, up to 2 inches of water is imported per flood event, and 4 inches of water per tide event is discharged during drainage events. This suggests a load of DOC of 1,515 kg/day and 2,538 kg/day transported from the sloughs to the managed wetlands during flood events, and 1,981 and 8,958 kg/day transported from the wetlands to the sloughs during drainage events at Wetland 112 and Wetland 123, respectively. These data show that although the DOC concentrations and loads at managed wetlands may vary significantly from year to year, they make net positive contributions to DOC concentrations in adjacent waters.



From Downing et al. 2010

Figure 6-2 DO versus DOC concentrations at managed wetland 123

6.2.4 Tidal Marshes

Tidal marshes are productive systems that contribute organic matter to the receiving water body naturally. In a study of carbon types and bioavailability in the Delta and Suisun Marsh, tidal marsh sloughs in Suisun Marsh were found to have higher levels of dissolved organic carbon, particulate organic carbon, and phytoplankton-derived carbon than other environments in the Delta (Sobczak et al. 2002). The study suggested that the bioavailable particulate organic carbon, derived primarily from phytoplankton production, including from within the tidal marsh, forms a critical food source for pelagic fish species. Although sloughs fully surrounded by tidal marshes are not very common in Suisun Marsh, Peytonia and Boynton Sloughs both have tidal marshes connected to them. Accordingly, tidal marshes may be a significant source of dissolved organic carbon in these sloughs.

6.2.5 Load Summary

A summary of organic carbon loads from different sources is shown in Table 6-1. The load comparison shows that the managed wetlands are the largest direct source of organic carbon to the sloughs; however, a portion of this load could be attributed to natural processes.

6.3. SOURCES OF NUTRIENTS TO SUISUN MARSH

The term “nutrients” refers to nitrogen or phosphorus-containing substances, common sources of which include fertilizers, animal wastes, and both treated and untreated wastewater. However, nutrients can also enter waterways through atmospheric deposition and nitrogen fixation by microbes in the water, and through the decomposition process within wetland soils, which releases nitrogen into the water. Nutrients enter Suisun Marsh through Delta outflow, which receives nutrients from the Sacramento and San Joaquin Rivers, which both drain large urban and agricultural areas; exchange with the nutrient-rich Suisun Bay, tributary inflow that drains urban and agricultural areas, discharge from the FSSD wastewater treatment plant, atmospheric deposition, and internal releases from wetland soils. During rainy winters, stormwater runoff from tributaries may influence water quality in Suisun Marsh more significantly than during the dry season. Table 6-3 shows a summary of nutrient loads from different sources. There are limited data for phosphorus sources. However, given that N to P ratios in the water column of Suisun Marsh, which indicate nitrogen to be the limiting nutrient (Appendix B), nitrogen loads may play a more important role than phosphorus loads.

Table 6-3
Summary of nutrient loads from different sources

Sources	N loads (kg/day)	P loads (kg/day)	Reference
Surrounding Watersheds	112	103	Davis et al. (2000b)
FSSD treated wastewater effluent	1332 (970-1250)		Load estimated from average N concentrations (seasonal loads)
Atmospheric Deposition	Wet: 234 (wetlands), 82 (water surface) Dry: 156 (wetlands), 55 (water surface)		NADP for areal wet deposition and CASTNET for dry deposition rate; area of wetlands (86,000 acres) and open water (30,000 acres) used to estimate total loads

Based on the previous San Francisco Bay regional study by Davis et al. (2000b), tributary inputs from the Fairfield sub-watersheds were estimated to be 112 kg N/day and 103 kg P/day, or 0.32 kg N/ha/yr nitrate and 0.18 kg P/ha/yr phosphorus. Those estimated loads were based on modeled runoff and observed stormwater concentrations from each sub-watershed. More recently, nutrient concentrations were directly measured in Laurel Creek, Ledgewood Creek, and Suisun Creek during two storm events and several dry weather sampling events (Table 6-4). The observed nutrient concentrations for these sampling events by speciation are listed in Appendix A. The recently observed concentrations along with the estimated monthly flow were used to calculate updated loads of nutrients from tributaries to Suisun Marsh. Estimated loads from the recent sampling ranged from 1.5 kg N/ha/yr in Suisun Creek to 4.3 kg N/ha/yr in Ledgewood Creek and 0.08 kg P/ha/yr in Suisun Creek to 0.33 kg P/ha/yr in Laurel Creek. These levels are consistent with the previous estimates by Davis et al. (2000b).

The concentrations of nutrients in the FSSD wastewater treatment plant effluent are relatively low. Ammonia concentrations in the plant effluent are typically below 0.1 mg/L, although occasional spikes greater than 0.5 mg/L have also been reported. Based on the average discharge rate in 2011 and the measured average daily maximum concentration of 0.07 mg N/L, the measured ammonia load was approximately 1.75 kg N/day. Organic nitrogen concentrations in FSSD effluent normally vary from 0.05 to 1 mg/L. Nitrite and nitrate concentrations are generally at 12–33 mg/L. The estimated mean TN load from 2012–2013 is 1332 kg N/day, although the daily TN load from FSSD varies seasonally. The higher loads in March during the higher rainfall periods suggest that the higher discharge rates, not elevated nutrient concentrations in the effluent, are responsible for variations in the TN loads.

Table 6-4
Loads and concentrations of total nitrogen and phosphorus in Suisun Marsh creeks sampled during 2013

Constituents	Date	Laurel Creek upstream	Laurel Creek downstream	Ledgewood Creek upstream	Ledgewood Creek downstream	Suisun Creek upstream	Suisun Creek downstream
Total Nitrogen (mg/L)	2/19/2013	1.72	2.163	2.23	2.83	0.692	0.671
	9/18/2013	0.473	0.242	1.05	0.819	0.329	0.375
	10/11/2013	1.11	0.57	0.83	0.88	1.248	1.248
	10/28/2013	0.505	0.447	0.96	0.959	1.59	0.971
	11/1/2013					2.34	2.15
	12/10/2013	1.36	1.41	1.2	1.13	1.52	4.05
Total Phosphorus (mg/L)	2/19/2013	0.094	0.075	0.094	0.071	0.021	0.009
	9/18/2013	0.106	0.327	0.608	0.386	0.438	0.054
	10/11/2013	0.05	0.047	0.156	0.158	0.054	0.047
	10/28/2013	0.026	0.038	0.408	0.271	0.141	0.054
	11/1/2013					0.337	0.254
	12/10/2013	0.134	0.146	0.189	0.172	0.306	0.358
Total nitrogen (kg/ha/yr)		2.75	3.28	3.56	4.31	1.49	1.84
Total phosphorus (kg/ha/yr)		0.18	0.20	0.33	0.24	0.18	0.09

Atmospheric deposition, which cannot be controlled, contributes a load that may exceed the contribution from the surranding watershades. The nearest station measuring nitrogen deposition as part of the National Atmospheric Deposition Program (NADP) network is located at Davis, CA (station CA88). Total inorganic nitrogen (NH_4 + NO_3) wet deposition loads measured at this station for the last 10 years (2000–2010) averaged 2.45 kg N/ha/yr. This represents an inorganic nitrogen wet deposition load of 315.5 kg N/day to Suisun Marsh (assuming a wetland area of 86,000 acres and an open water area of 30,000 acres). Dry to wet nitrogen deposition ratios at a nearby station (YOS404) from a Clean Air Status and Trends Network (CASNET) averaged at 0.67 for the period of 2000–2008. This suggests a dry nitrogen deposition load of 210.5 kg N/day to Suisun Marsh. Using the calculations of Geiser et al. (2010) as a benchmark, nitrogen deposition in Suisun Marsh (~2.5 kg N/ha/yr) appears to be well below the critical load above which nitrogen deposition can cause ecosystem harm.

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7. SOURCES OF MERCURY (THG/MEHG) TO SUISUN MARSH

Sources of total mercury (THg) and methylmercury (MeHg) to Suisun Marsh include atmospheric deposition, tributary inputs, loads from the Delta, and discharge from the municipal wastewater treatment plant (FSSD). Tidal action from the adjacent Suisun Bay and San Francisco Bay, as well as dynamic intra-Marsh conditions, can contribute total mercury or generate methylmercury within the marsh. Data and methods used to estimate mercury loads are described in detail in the Conceptual Model/Impairment Assessment Report (Tetra Tech 2013a). Despite recent downgrading of the load estimates, the Sacramento-San Joaquin Delta is the major source of inorganic mercury to San Francisco Bay and Suisun Marsh. Other more localized sources form a very small component of the total load (Figure 7-1).

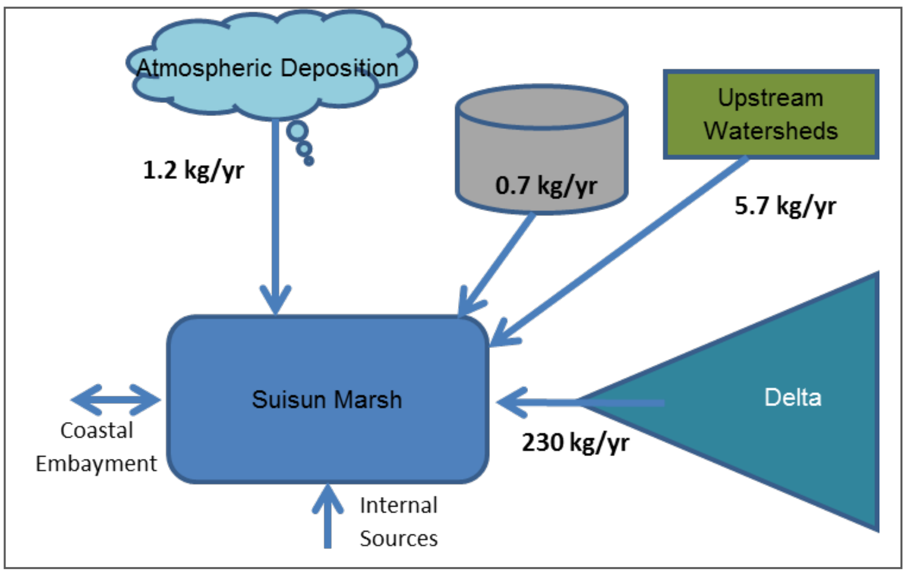

Figure 7-1 Average mercury loads to Suisun Marsh area

7.1. ATMOSPHERIC DEPOSITION

Atmospheric loads comprise mercury originating from global, regional and natural sources. Direct measurements of atmospheric deposition are sparse. Mercury concentrations in wet deposition (deposition via precipitation) were measured at three sites in the Bay–Delta region from April 2004–June 2006 (Gill 2008). Volume-weighted mercury concentrations observed at those sites were very similar, ranging from 3.7 to 4.2 ng/L. Estimated fluxes of wet deposition range from 1.5 µg/m^2/yr at Twitchell Island to 5.9 µg/m^2/yr at Pt. Reyes, depending on the precipitation amount.

Dry and wet seasonal deposition fluxes were measured at Moss Landing (Monterey County) and Woodland (Central Valley) (Table 7-1). Assuming wet deposition flux of 1.5 $\mu g/m^2/yr$ measured in close proximity to Suisun Marsh, and dry deposition flux of 1.25 $\mu g/m^2/yr$ (average of all estimates in Table 7-1), and the marsh surface area of 3.6 x 10^8 m^2, direct dry and wet annual mercury deposition is approximately 1.2 kg/yr. This is in range with the previous assessment of 1.6 kg/yr (DWR 2007).

Table 7-1
Comparison of wet and dry atmospheric deposition fluxes of mercury

Site	Period	Rainfall (cm)	[Hg] (ng/L)	Wet Deposition		Dry Deposition	
				$ng/m^2/month$	$\mu g/m^2/yr$	$ng/m^2/month$	$\mu g/m^2/yr$
Coast	Winter	50	2.5	417	5.0	33	0.40
Coast	Summer	0.75	10	25	0.30	9.2	0.11
Central Valley	Winter	20	2.5	167	2.0	92	1.1
Central Valley	Summer	0.25	10	8	0.10	283	3.4

7.2. TRIBUTARY INPUTS

Stormwater loads of mercury from small tributaries to all of San Francisco Bay was estimated to vary from 200 to 400 kg/yr (Davis et al. 2001). Scaling down this estimate to the Fairfield–Suisun area, the mercury load in urban stormwater runoff was estimated to be 3.1 kg/yr.

The overall mercury load in non-urban stormwater runoff to San Francisco Bay is 25 kg/yr. Based on projected runoff volume from Davis et al. (2000b), non-urban runoff from the Fairfield–Suisun area is estimated to contribute 1.9 kg/yr. When the size of drainage area is considered, non-urban runoff of mercury from Fairfield–Suisun is 2.6 kg/yr. The combined urban and non-urban stormwater load, therefore, can vary from 5 to 5.7 kg/yr.

7.3. LOADS FROM THE DELTA

Mercury enters the Delta in the form of contaminated sediment and contaminated runoff. The origin of much of this mercury is historical mining activities in the Coast Range and the Sierra Nevada, which used elemental mercury for gold and silver extraction (DWR 2007). Hydraulic mining for gold, which began in the 1850s and was banned in 1884, was responsible for the widespread distribution of mercury-contaminated sediment throughout the estuary including Suisun Marsh. Recent studies suggest that about 350–750 kg/yr of mercury is still being transported into the Delta from the Coast Range and the Sierra Nevada. Louie et al. (2008) estimated that more than 70% of the load entering the Delta is exported to San Francisco Bay. Average annual export of total mercury to Suisun Bay at Mallard Island varies from 198 kg/year to 361 kg/yr depending on the mix of wet and dry years used in the evaluation period that spanned from 1984 through 2006. For the most recent decade of data (1995-2006), the annual average load is estimated to be 230 kg/yr (~630 g/day). This estimate is somewhat lower than the previously projected export of 1050 g/day (~ 383 kg/yr) or the Bay Mercury TMDL estimate of 440 kg/yr.

7.4. WASTEWATER TREATMENT PLANT

FSSD is an advanced secondary treatment wastewater facility discharging treated wastewater effluent to Boynton Slough. FSSD's mercury load from 2012-2015 varied from 0.022 to 0.030 kg/yr (average 0.026 kg/yr), which is diminutive compared to other sources to the marsh. The Bay Mercury TMDL allocated 11 kg/yr of mercury for all municipal wastewater facilities discharging to the Bay, including FSSD. The combined average municipal wastewater load to the Bay for the past five years has been about 3.1 kg/yr, less than a third of the TMDL limit. This load reduction has been achieved through implementation of Bay-wide pollution prevention actions, improvements in solids removal, and intensive mercury recycling efforts.

7.5. INTERFACE WITH SAN FRANCISCO BAY

Mercury strongly adsorbs to sediment particles, so inorganic mercury historically entered Suisun Marsh channels from Suisun Bay through tidal transport, creating legacy total mercury sediment concentrations similar in magnitude to those in upper-level San Francisco Bay sediments. Today, mercury contamination and distribution throughout the Bay-Delta estuary is relatively uniform, indicating that the net mercury load to Suisun Marsh due to erosion of bottom sediments in San Francisco Bay is likely to be small, especially when compared to the riverine fluxes. The extent of these loads has not been precisely quantified but they are already captured in the TMDL mercury budget for San Francisco Bay.

The inventory of mercury in San Francisco Bay bottom sediments remains high (approximately 60,000 kg) but is expected to slowly decrease as new releases of mercury get smaller and mercury is lost via hydrologic transport to the Pacific Ocean (Yee et al. 2011). Over the last decade, the average mercury concentrations in sediments have been the lowest in Suisun Bay (~0.17 ppm), while concentrations in San Pablo Bay have been slightly higher at 0.27 ppm (SFEI 2015). These concentrations are similar to mercury found in surficial sediments (top 1 cm) in Suisun Marsh, which varied from 0.2 to 0.33 ppm (Slotton et al. 2002).

7.6. MANAGED WETLANDS

Managed wetlands, and to a lesser degree tidal wetlands, can also generate MeHg from total mercury, when anaerobic conditions exist in the water and sediment. MeHg bioaccumulates in the food web and is thus more toxic than total mercury, which is not bioavailable. The MeHg fluxes measured at an experimental study site on Grizzly Island varied from 0.007 to 0.068 g/day. When scaled up for the 52,000 acres of managed wetlands in Suisun Marsh, this translates to 0.122 to 0.46 g/day of MeHg being exported to Montezuma Slough and Grizzly Bay (Stephenson et al. 2010). These loads, however, are relatively small when compared to the load of MeHg carried by tributaries to the Delta of 16.6 g/day, and they are likely to vary significantly depending on the water management system at individual wetlands. Some data from Suisun Marsh also suggests that the MeHg flux is not unidirectional. As we learn more about mercury transformations and MeHg releases under specific conditions in Suisun Marsh, the load and flux assessments may change. However, the high temporal and spatial variability associated with the measured loads are likely to remain regardless of the amount of data being collected, because such variability is inherent in a biologically and hydrologically complex environment such as Suisun Marsh.

8. Linkage Analysis: Dissolved Oxygen and Organic Carbon

8.1. Modeling Linkages Between Organic Carbon, Nutrients and Low DO

Understanding the link between discharges from managed wetlands and changes in water quality in adjacent sloughs is essential to achieving the proposed site-specific objectives and implementing the load allocations in the TMDL. It allows for determination of the relative contribution of managed wetlands to dissolved oxygen sags, and for evaluation and testing of the effectiveness of various management options to improve water quality. Tetra Tech used the numeric hydraulic model HEC-RAS to simulate linkages between organic carbon loads from managed wetlands and DO in Suisun Marsh sloughs. The model was run for two example sloughs that experienced frequent low DO, Boynton and Peytonia sloughs, which were also continuously monitored by Siegel et al. (2011) during 2007–2008, and two other sloughs, Goodyear and Denverton sloughs, for which the continuous DO data from 2012–2013 were available (Figure 8-1). Details of model setup and the results are presented in Appendix C.

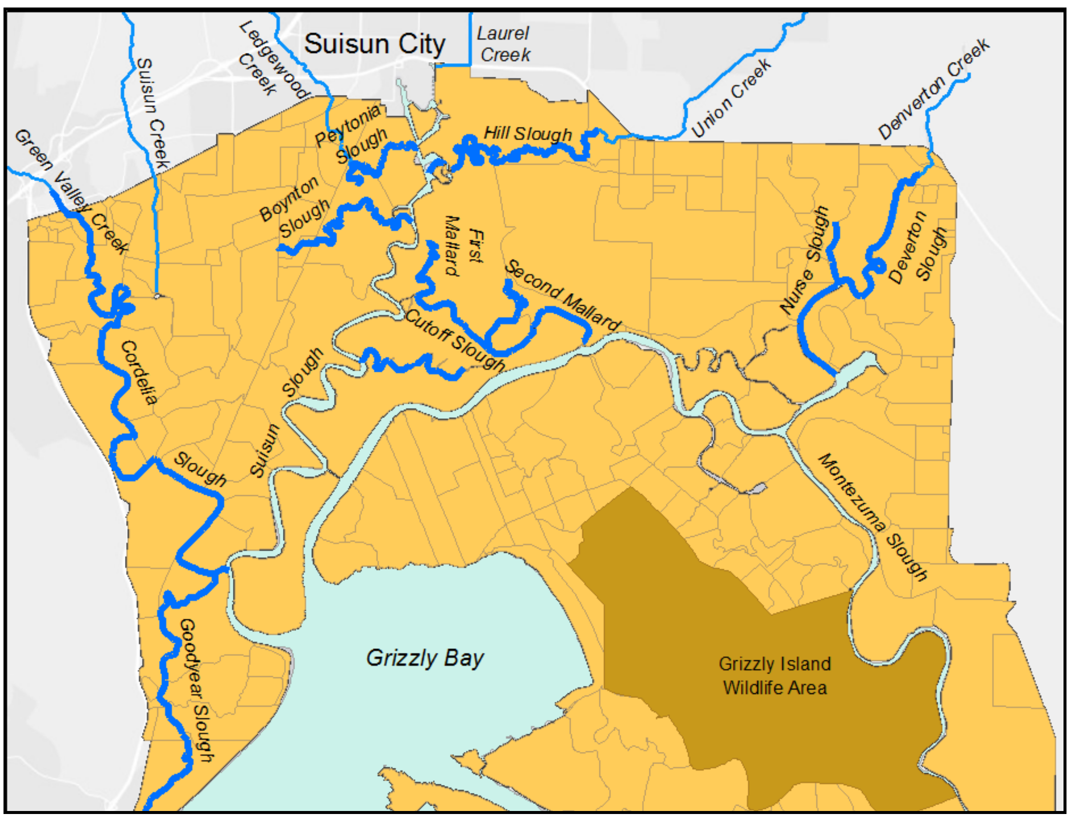

Figure 8-1 Map of major sloughs in Suisun Marsh. Among these, Boynton Slough, Peytonia Slough, Goodyear Slough, and Denverton Slough are modeled

The application of HEC-RAS provided a way to explain a dynamic linkage between DO, BOD, organic carbon, and nutrient levels. By using the model to match the observed DO levels at specific locations within Suisun Marsh, the relative contribution of different sources to the condition of concern, specifically the DO sags, can be identified and tested. The model considers each slough to be a one-dimensional channel, with tidal flows exchanging through downstream end of the slough. Upstream freshwater flows and flows from managed wetlands are considered as inputs along the channel length. Within the slough, the model describes how DO uptake occurs as a result of biological oxygen demand (BOD) by different sources as well as DO demand generated from organic carbon decomposition. Organic carbon can enter the slough as inflow from managed wetlands or may be generated internally through primary production, which is related to the levels of nutrients present. The model also simulates the effects of chemical processes like reaeration, photosynthesis and respiration, oxidation of ammonia and nitrite, and sediment oxygen demand.

In addition to simulation of managed wetland discharges, the modeling also considered the impact of decomposition of naturally-occurring organic carbon from background sources on lowering DO concentrations. Comparison of DO in the low DO-impacted sloughs (Boynton, Peytonia and Goodyear Sloughs) to the DO levels in First and Second Mallard Slough, which are minimally affected by managed wetlands, showed that the DO sags in the impacted sloughs were more severe than they would have been under the natural load of organic carbon decomposition within these environments. The additional decline in DO reflects the increased oxygen demand that the organic-rich seasonal discharges from the managed wetlands generate.

DO concentrations from the minimally impacted sites (First and Second Mallard Sloughs) also provide an opportunity to examine the level of variability in DO concentrations under unimpaired conditions. The model-simulated sources and sinks of DO in the sloughs suggest that processes that affect DO concentrations including reaeration, oxidation of BOD, photosynthesis and respiration, are generally comparable in magnitude. Conversely, oxygen consuming processes such as oxidation of ammonia, nitrite, and sediment oxygen demand seem to occur at lower rates, which suggest that nutrients are not the key factor in lowering DO in the marsh sloughs (Figure 8-2).

For each slough, a prescribed schedule of discharges from managed wetlands was used to match the observed DO sags. Managed wetland discharges were assumed to have lowest observed DO concentrations of 0.1–0.7 mg/L and high DOC concentrations (40–70 mg/L) as reported in Siegel et al. (2011). The modeled sloughs typically experienced 3 to 4 low DO events of different magnitude during fall and 1 to 2 low DO events during spring, corresponding to discharges from managed wetlands.

8.2. IMPACT OF DISCHARGE TIMING AND VOLUME ON DO

The modeling of temporal DO variations in four different sloughs under current conditions provided a basis for evaluating anticipated implementation by modifying conditions within the sloughs, such as managed wetland discharges, upstream freshwater inflows, and wastewater treatment plant flows, as well as nutrient, BOD, and DO levels in any of the inflows. These changes form the basis of the strategies proposed to achieve water quality targets in Suisun Marsh (see discussion on implementation in Section 12). Two model scenarios were tested to achieve the hypothetical DO concentration of 5 mg/L on continuous basis:

1. Reduction of managed wetland discharge volumes until achieving continuous exposure of 5 mg/L in the sloughs.
2. Discharge over a longer period without reduction in load, with the maximum allowable continuous daily discharge from managed wetlands calibrated to attain the DO exposure of 5 mg/L.

Simulations were performed separately for each slough with available data, because the hydromorphology of individual sloughs and the contributing managed wetlands influence the DO response. For both model scenarios considered, DO levels in the managed wetland discharges were conservatively assumed to be at the lowest levels, and the focus was on modifying the timing and volume of the discharge to achieve 5 mg/L DO all the time. The HEC-RAS simulations demonstrated that changes to water management at the duck club properties, and specifically reductions in discharge by 40 to 60%, could result in a significant improvement in DO conditions in the receiving slough. Similar improvements could be accomplished by allowing for discharge to occur over longer periods of time. This confirms implementation actions that improve water management, such as staggering discharges in individual sloughs, redirecting discharges to larger sloughs when possible, and coordinated release of FSSD high DO-treated effluent, provide the best opportunity to improve DO and is the most efficient use of the available resources.

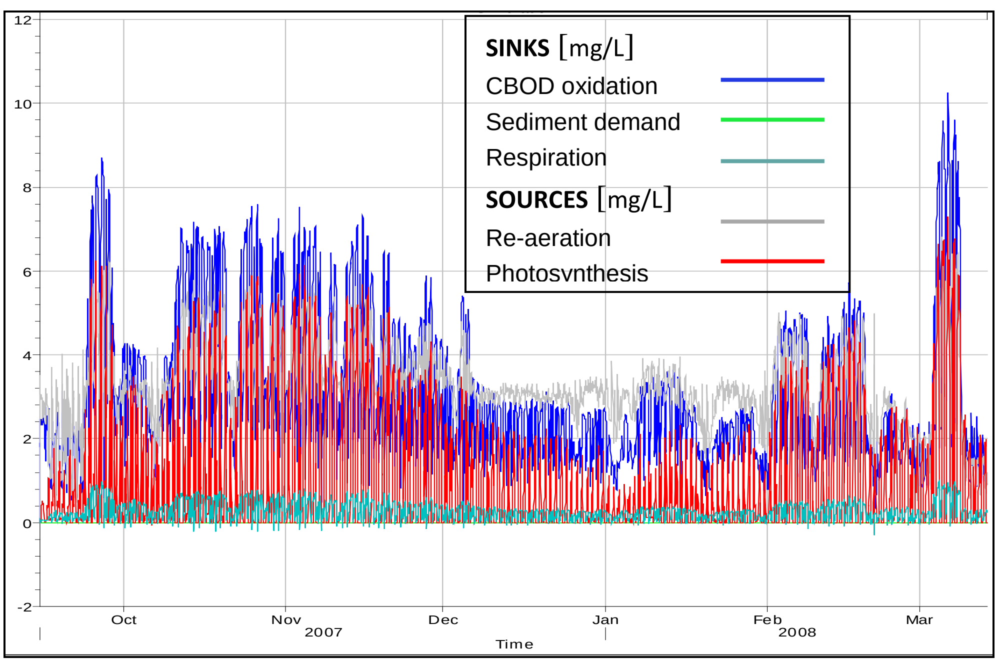

Figure 8-2 Modeled sources and sinks of DO in Boynton Slough

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9. TMDL ALLOCATIONS AND MARGIN OF SAFETY: DISSOLVED OXYGEN

9.1. DISSOLVED OXYGEN TMDL AND ALLOCATIONS

U.S. EPA's protocol for developing TMDLs defines a total maximum daily load as the allowable loadings of a specific pollutant that a water body can receive without exceeding water quality standards. For most pollutants, TMDLs are expressed as mass loadings (e.g., kilograms per year). EPA Regulations (40 CFR §130.2(i)) provide that TMDLs do not need to be expressed as mass per unit time, but may be expressed in terms of an "other appropriate measure." Dissolved oxygen concentrations are an important indicator of wetland habitat health because all aquatic organisms require some minimum level of DO to survive and prosper. Therefore, DO concentration is a relevant criterion for assessing the impact of a discharge on receiving waters, the quality of the affected receiving waters, and for the ability of the water body to support aquatic life beneficial uses.

The site-specific DO objectives derived using the U.S. EPA recommended methodology are tailored to be protective of all sensitive aquatic life beneficial uses in Suisun Marsh (Section 4 this Staff Report). The proposed TMDL is established to attain and maintain these DO objectives. The implementation actions for the TMDL are focused on the western part of Suisun Marsh bordered to the east by Suisun Slough (Figure 9-1). As discussed in Section 3, the western part of Suisun Marsh is of the most concern due to a high density of managed wetlands and limited mixing in small dead-end sloughs. That area had also experienced the most severe low DO events and fish kills in the past.

The TMDL requires the DO concentrations in the sloughs to be ≥ 3.8 mg/L, which ensures protection of juvenile and adult survival, and ≥ 5 mg/L, which protects against adverse growth effects based on a continuous exposure. Expressing the TMDL as DO concentrations in the receiving waters equal to the proposed water quality objectives provides a direct measurable target for the sources to monitor for compliance. Table 9-1 presents concentration-based load and wasteload allocations proposed for Suisun Marsh. The attainment of these allocations will ensure that conditions in the sloughs support the most sensitive aquatic life beneficial uses present. These allocations will apply year-round. All permittees and/or entities that contribute to low DO conditions are collectively responsible for meeting these allocations. Water quality monitoring data collected at selected sloughs will be used to demonstrate achievement of the allocations.

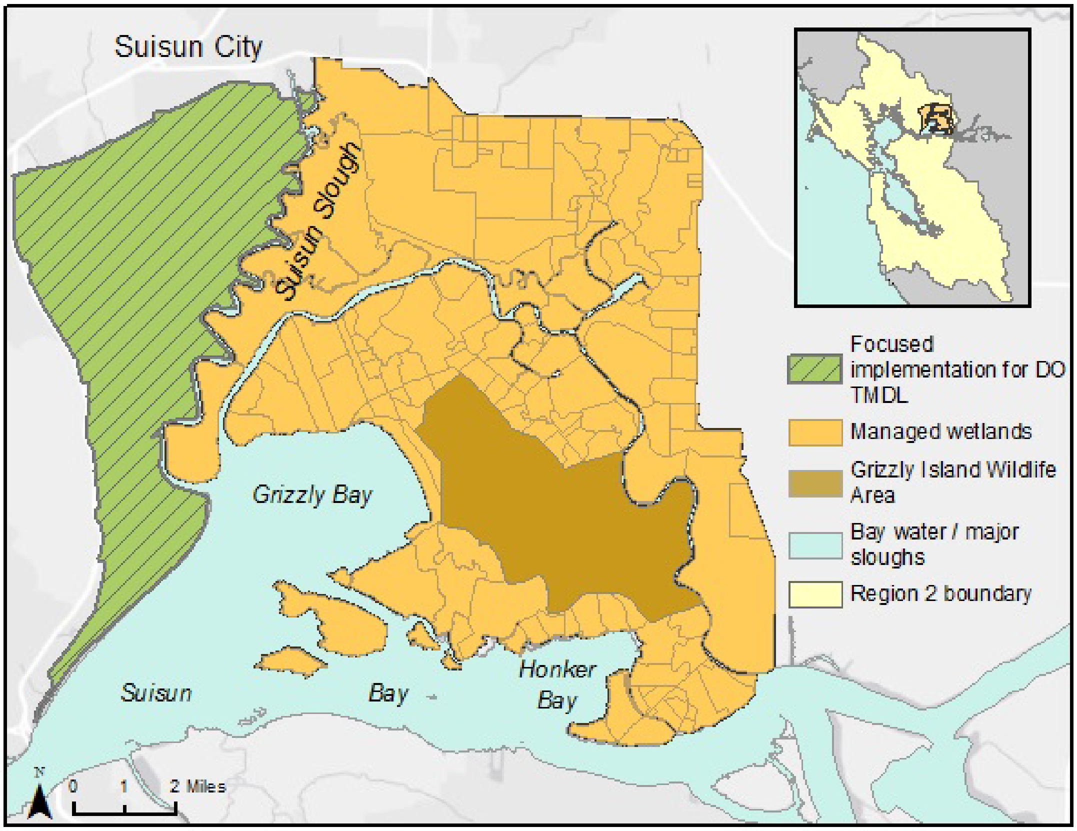

Figure 9-1 Low DO/ organic enrichment TMDL for Suisun Marsh

Table 9-1
Wasteload and load allocations for Suisun Marsh DO TMDL

Source	Allocations
	Wasteload Allocations
Fairfield-Suisun Sewer District (FSSD) NPDES Permit No. CA0038024	Discharge shall not cause DO concentrations in receiving waters to decrease below 5.0 mg/L June 1-November 15 and 7.0 mg/L during all other times of the year [a, b]
Municipal stormwater runoff in tributaries draining to Suisun Marsh NPDES Permit No. CAS612008	DO concentration in local tributaries draining urban areas and discharging to Suisun Marsh shall be ≥ 5 mg/L [b]
	Load Allocations
Managed wetlands	Discharges from managed wetlands shall not cause the DO concentrations in the sloughs to decrease below 3.8 mg/L [c] and 5 mg/L [b]

a As specified in the NPDES permit for this facility
b Expressed as 30-day running average
c Expressed as 1-day average

9.2. MARGIN OF SAFETY

Since the allocations in this TMDL are identical to the proposed water quality objectives the margin of safety for this TMDL is implicitly included. The water quality objectives take uncertainties into account, reflect conservative assumptions, and consider acceptable risks. These DO objectives were developed to protect sensitive beneficial uses, and, compliance with the objectives is expected to ensure that fish, invertebrates, and other aquatic organisms can survive and prosper in Suisun Marsh habitats.

9.3. SEASONAL VARIATIONS AND CRITICAL CONDITIONS

In developing the TMDL we considered water quality and fish data spanning more than two decades, and including the worst four consecutive dry years (2011-2015) since rainfall recordkeeping began in 1895. DO concentrations in Suisun Marsh sloughs, and especially in the western part of the marsh, tend to be lowest in the fall (October-November) when discharges from the managed wetlands combined with low freshwater inflows and limited tidal mixing result in overall decline in water quality. Meeting the DO targets under the critical flow and temperature conditions in the fall will ensure that the water quality objectives and the TMDL will be achieved at all times throughout the year.

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10. LINKAGE ANALYSIS: MERCURY

10.1. MERCURY METHYLATION IN SUISUN MARSH

As discussed in sections 3 and 5, methylmercury is more bioavailable, and consequently more toxic, to humans and aquatic life than inorganic mercury. Accordingly, limiting conversion of inorganic mercury to methylmercury (MeHg) is as important in preventing bioaccumulation as limiting discharges of mercury. Marshes and subtidal waters with low oxygen content provide conditions favoring MeHg production (e.g. Davis et al. 2012, Heim, 2003; Hurley et al. 1995, Marvin-DiPasquale et al. 2003; Slotton et al. 2002). A conceptual model of MeHg production in Suisun Marsh is shown in Figure 10-1**.** Although conditions promoting mercury transformations often occur naturally in marshes and wetlands, managed wetlands were found to have higher MeHg concentrations than other areas in Suisun Marsh. While MeHg production is not well understood, long cycles of wetting and drying, high organic carbon concentrations and low DO are known factors that promote formation of reactive Hg and increase methylation potential. According to Siegel et al. (2011), tidal marsh that receives daily tidal exchange generally does not provide the necessary inundation regime to substantially increase methylation production. Kelly et al. (1997) identified three changes in environmental conditions that stimulate mercury methylation, and are linked to the operations of managed wetlands (duck clubs) in Suisun Marsh. These are: 1) sudden death of vegetation available for decomposition and supplying a large amount of organic carbon, 2) high decomposition rate leading to an increase in anaerobic habitat, and 3) elevated temperatures often present in shallow, slow-flowing back-end sloughs. Therefore, making changes to water management in the managed wetlands and restoring portions of those wetlands to tidal action would likely contribute to lower methylation. Moreover, it would reduce incidents of dissolved oxygen depletion, prevent fish kills, and subsequently diminish MeHg impacts on aquatic life, wildlife, and humans.

Key processes affecting formation and loss of reactive inorganic mercury (Hg(II)), methylation, and demethylation in the marsh environment are summarized below. A detailed assessment of mercury cycling in Suisun Marsh, available data and potential ramifications for transformations of managed wetlands to tidal wetlands are discussed in Tetra Tech (2013a, b).

10.1.1 Formation and Loss of Reactive Hg(II)

Methylmercury concentrations in water and sediments are affected by the available pool of reactive Hg(II) ready for methylation. Different processes affect the formation and loss of reactive Hg(II) available for methylation and different forms of mercury are associated with different sources, with some being more bioavailable for methylation than the others. For example, Hg-chlorides or Hg sulfates are more bioavailable than Hg(0) and HgS. The formation of reactive Hg(II) includes dissolution of HgS by organic acids or complexation with organic carbon. This process is affected by sediment and water properties such as organic carbon concentrations, redox potential (Fe, S), pH, dissolved oxygen, salinity, and nutrients. In particular, organic carbon has been found to be important in dissolution of HgS to form reactive Hg(II).

10.1.2 Methylation and Demethylation

Alpers et al. (2008) hypothesized that the net formation of MeHg in sediment and/or water is a result of competing microbiological and abiotic reactions. Although microbiologically mediated processes tend to dominate in natural environments, the abiotic processes were also found to contribute to MeHg formation and degradation.

Methylation of Hg is carried out mainly by anaerobic sulfate- and iron-reducing bacteria at the oxic/anoxic interface in soils/sediments where these bacteria are present. Therefore, sediment and water properties that affect activity of these bacteria are important to controlling methylation. High organic carbon levels can fuel microbial activity. Reduction of sulfate and iron requires anoxic conditions, so in most situations low dissolved oxygen promotes the methylation process.

Demethylation can be carried out both biotically and abiotically. An example of abotic demethylation is photodemethylation, in which ultraviolet radiation and visible sunlight cause methylmercury to convert to inorganic mercury. Biotic demethylation can be through both oxidative pathway (to form CO_2) or through reductive pathway (by uptake of CH_4). In both cases, maintaining high levels of DO may reduce methylation potential.

10.2. ENVIRONMENTAL FACTORS CONTRIBUTING TO HIGH METHYLATION RATES IN SUISUN MARSH

10.2.1 Flooding and Drying in Managed Wetlands

Managed wetlands have higher levels of methylmercury than other types of wetland habitat, which is believed to be a product of their wetting and drying cycles. These cycles promote the formation of the reactive oxidized ionic form of mercury ($Hg(II)_R$), which methylates more easily than other forms of mercury (Alpers et al. 2008), and provide extensive oxic/anoxic surfaces for methylation in the sediment-water interface. More specifically, the drying periods replenish oxygen and lead to subsequent oxidation of Hg(0) to form reactive Hg(II); the drying also accelerates decomposition of marsh litter and conversion of reduced forms (e.g. Hg^0, sulfide, Fe^{2+}) to oxidized forms (e.g., sulfate, Fe^{3+}) (Yee et al. 2008). During the wetting periods, anoxic conditions favorable to iron- and sulfate-reducing bacteria persist in sediments, which enhances methylmercury production. Such conditions intensify natural biogeochemical processes leading to mercury methylation. For example, the low DO concentrations when the wetlands are flooded can affect the oxidation-reduction state of mercury and other elements that are commonly important in mercury cycling such as sulfur, iron, and, to a lesser extent, manganese.

In contrast, low levels of MeHg were found in open water Bay-Delta habitats, while moderate concentrations were found in habitats that flood frequently and do not fully dry, such as tidal marsh. Relatively high levels of MeHg were found in habitats that flood less frequently and are allowed to completely dry (e.g. high tidal marsh) before returning to anoxic conditions (Marvin-DiPasquale and Cox 2007). However, MeHg levels in high tidal marsh are still lower than levels in managed wetlands. (Heim et al. (2007).

The role of managed wetlands in production of methylmercury was illustrated recently in a study at managed Wetlands 112 and 123 (Bachand et al. 2010). At Wetland 123, drain events have consistently higher unfiltered MeHg concentrations (3–7 times) and higher filtered MeHg (3–20 times). Heim et al. (2007) found MeHg concentrations higher in the managed wetland interiors than on the edges, and higher concentrations in marshes than in open channel waters.

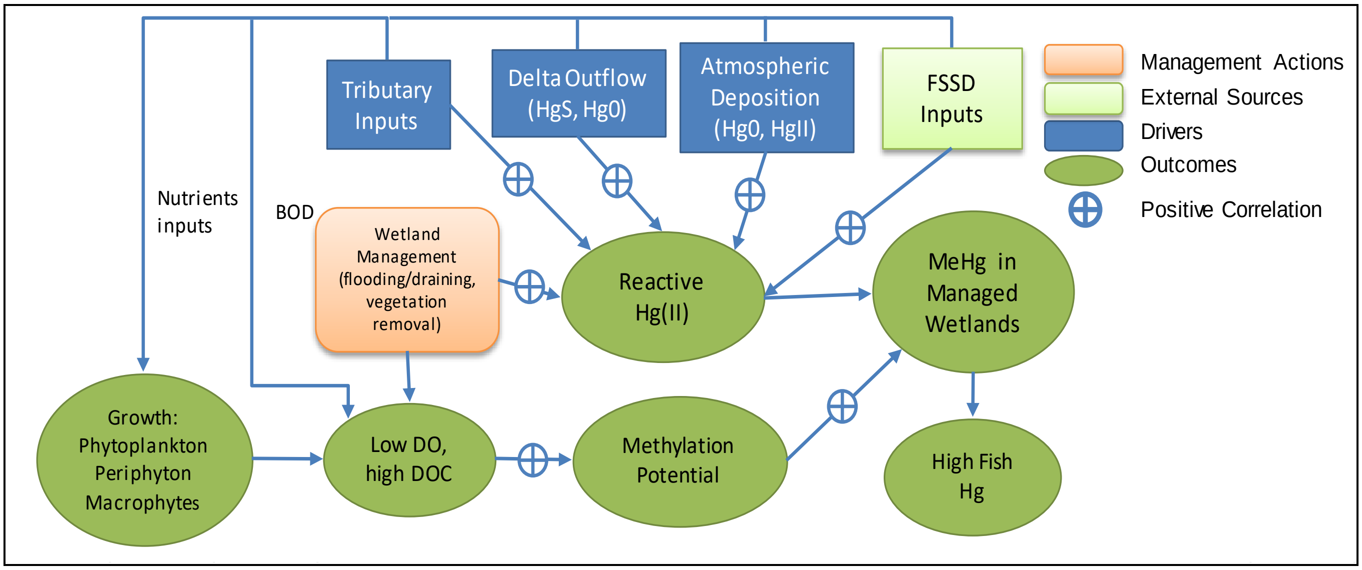


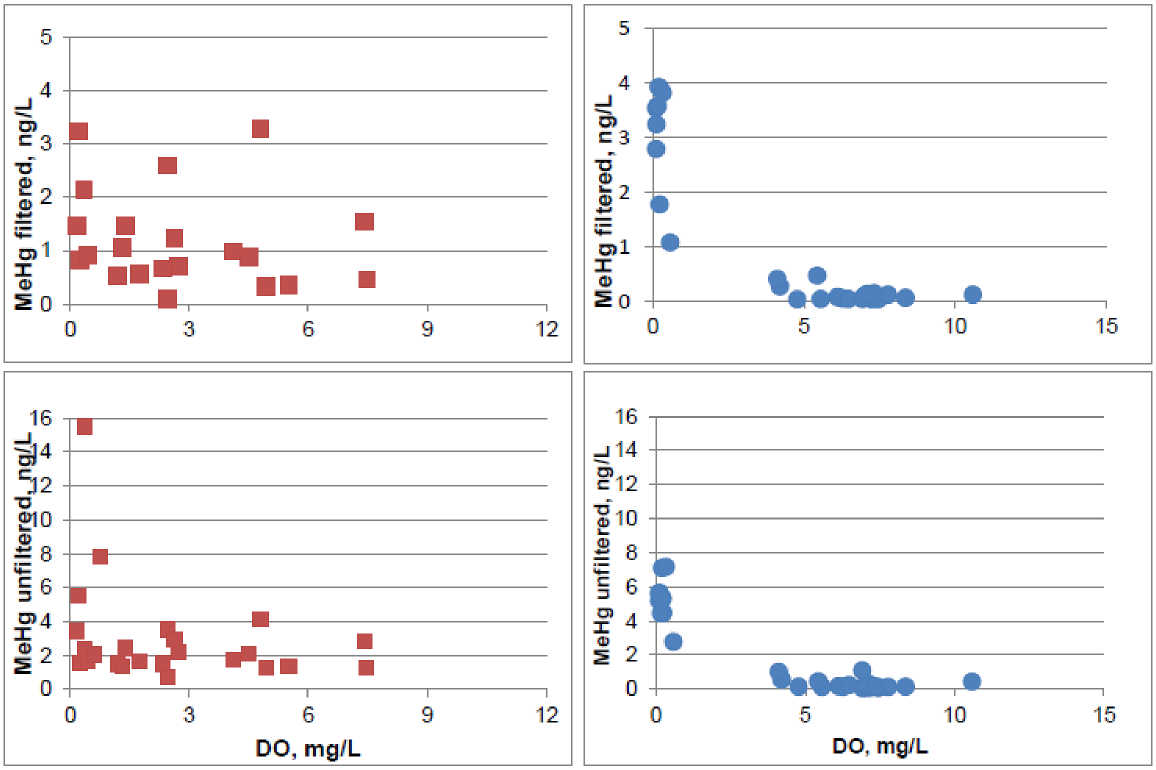
Figure 10-1 Cause-and-effect relationships of mercury in Suisun Marsh

10.2.2 High Dissolved Organic Carbon

High organic carbon in managed wetlands also contributes to high mercury methylation potential in Suisun Marsh because elevated organic carbon fuels microbial activities that are responsible for methylation.. Managed wetlands generate high levels of organic carbon because they support different types of primary production: 1) macrophytes, 2) benthic algae and 3) phytoplankton, and have soils rich in organic matter. During the recent study of Wetlands 112 and 123, Bachand et al. observed both elevated dissolved organic carbon and methylmercury concentrations within a few weeks of flooding. (Bachand et al. 2010).

10.3. DO and MeHg Production

Because of the abundance of inorganic mercury in the sediments and waters flowing into and out of Suisun Marsh, control of inorganic mercury sources beyond what is required under the Mercury TMDL is not feasible or practical. However, the clear linkage between organic carbon cycling and low DO concentrations provides a meaningful path to create conditions that do not increase or exacerbate MeHg concentrations. Specifically, as shown in Figure 10-2, both filtered and unfiltered MeHg concentrations in the managed wetlands are lower when water column DO concentrations are higher than 4 mg/L. In contrast, when near-anoxic conditions are present (< 2 mg/L), MeHg concentrations are two to four times higher than at DO levels above 4 mg/L, which can result in substantial loading of MeHg from the managed wetlands to the sloughs. Accordingly, implementation of actions to increase DO and limit anoxic conditions, are likely to simultaneously reduce MeHg levels. Thus, approaches to increase the DO levels in the slough waters to protect aquatic organisms are also directly related to potential improvement in Hg levels.



Data re-plotted from Siegel et al. 2011; left panel: interior samples, right panel: exterior samples

Figure 10-2 MeHg concentrations versus DO in filtered and unfiltered samples from managed wetlands

The large-scale conversion of managed wetlands in Suisun Marsh and the Delta to tidal marsh, planned as mitigation for the California Water Fix and other large projects, is expected to increase tidal flows throughout Marsh sloughs over the course of the next few decades. Increased tidal flows are expected to improve DO and reduce sulfide concentrations, which in turn is expected to reduce methylation potential. MeHg concentrations in tidal wetlands are up to an order of magnitude lower than those reported from diked wetlands managed for agriculture and/or waterfowl habitat (Siegel et al. 2011); accordingly, the restoration of tidal flows and circulation is expected to reduce MeHg significantly. Some level of MeHg production will still persist, as even tidal wetlands possess properties supporting methylation (Tetra Tech 2013b). However, shorter wetting and drying cycles and higher volume of water exchange (twice daily) are expected to make the tidal marshes less conducive to methylmercury production.

11. TMDL ALLOCATIONS AND MARGIN OF SAFETY: MERCURY

11.1. APPLICABILITY OF THE BAY MERCURY TMDL AND ALLOCATIONS

The San Francisco Bay TMDL, adopted in 2006, identifies the sources of mercury, prescribes the maximum load that the Bay can assimilate, and determines the load and wasteload allocations for all sources, including point and non-point sources contributing mercury to Suisun Marsh. This load allocation currently stands at 700 kg/yr expressed as total mercury (SFBRWQCB 2006). Significant load reductions are expected to be achieved through its implementation plan, which includes control actions for refineries, wastewater treatment plants, stormwater management agencies, and Central Valley watershed. These allocations and implementation plan already aim at protection of wildlife and human health related to consuming fish in San Francisco Estuary; accordingly it is appropriate to extend the allocations and implement the mercury objectives in Suisun Marsh, too.

Control actions and regulatory requirements to reduce mercury in the estuary are being implemented through the San Francisco Bay and Delta Mercury TMDLs. The Bay TMDL requires municipalities to reduce mercury loading in urban stormwater runoff by 80 kg/yr from the estimated 160 kg/yr. This is being accomplished by introducing numerous control measures such as enhanced mercury-containing light bulb and device recycling, improved operation and maintenance of stormwater infrastructure, and identification and cleanup of contaminated sites. The TMDL anticipates a 110 kg/yr reduction as a result of control measures mandated by regulatory efforts in the Central Valley to reduce the mercury loads associated with historic mercury and gold mining in the watersheds of the Sierra Nevada foothills and the Coast Range drained by the Sacramento and San Joaquin Rivers. The wastewater municipal facilities Bay-wide must also reduce their loads of Hg by about 40% to achieve an approximately 10 kg/yr reduction. The Fairfield Suisun wastewater treatment plant is among the municipal dischargers named by the Bay TMDL with assigned wasteload allocations. The average municipal wastewater load for the past five years has been about 3.1 kg/yr, less than half the final TMDL limit of 11 kg/yr.

The Bay Mercury TMDL also recognizes that wetlands may contribute substantially to methylmercury production and biological exposure to mercury within the Bay. Implementation tasks related to the wetlands focus on managing the existing wetlands and ensuring that newly constructed wetlands are designed to minimize methylmercury production and subsequent transfer to the food web. Extending the TMDL's allocations and objectives to Suisun Marsh will help ensure that tidal restoration in Suisun Marsh will not result in net increase in mercury load to the Bay.

Implementation of the Bay Mercury TMDL requiresWaste Discharge Requirements and Section 401 certifications for wetland projects to include provisions that restored wetlands be designed and operated to minimize methylmercury production, with the goal of causing no net increase in mercury or methylmercury loads to the Bay. Additionally, projects must include pre- and post-restoration monitoring to demonstrate compliance. As discussed in the Linkage Analysis (Section 10, this Report) there is a strong relationship between DO concentrations and the level of MeHg. Therefore, actions to implement the Suisun Marsh DO TMDL and maintain adequate DO levels are expected to reduce MeHg concentrations and better protect aquatic life beneficial uses in Suisun Marsh. These actions will also contribute to the overall reduction in mercury levels in San Francisco Bay, lower mercury in fish Bay-wide, and, consequently, to meeting the targets of the Mercury TMDL.

11.2. MARGIN OF SAFETY

TMDL analyses must incorporate a margin of safety to address scientific uncertainty and account for gaps in knowledge concerning the relationship between load and wasteload allocations and water quality. The Bay Mercury TMDL's targets and allocations rely on conservative assumptions about the relationship between total mercury inputs to the Bay and methylation potential. Although the water quality objectives and the Bay Mercury TMDL are written in terms of total mercury, it was assumed that all of total mercury is composed of MeHg, which are more significant to mercury concentrations in fish. This is because the ultimate goal of the TMDL is to reduce MeHg in fish tissue, thereby protecting the health of organisms that consume fish, including people. Ideally, a ratio of MeHg to total mercury could be used as a basis for the margin of safety. However, in the absence of such ratio, the conservative assumption about the amount of methylmercury provides an adequate margin of safety. An adaptive approach to implementation provides an additional margin of safety.

11.3. SEASONAL VARIATIONS AND CRITICAL CONDITIONS

Analyzing temporal patterns in water quality data helps identify critical conditions, that is, the times when the greatest deviations from the water quality objectives are likely to occur.

Mercury loads, especially tributary inputs, fluctuate because of seasonal and inter-annual variations. Winter precipitation increases sediment and total Hg inputs to the Bay through erosion, runoff and re-suspension of sediments. Most of the total Hg coming from tributaries and direct surface runoff enters the Bay during high flow events, and greater total Hg and MeHg loads are generated during wet water years. In contrast, in-situ MeHg production is typically higher during the summer months. Seasonal variations and critical conditions were considered specifically in the context of bioaccumulation and risk to wildlife. Numeric targets for prey fish reflect the bird breeding season, when birds are most sensitive to methylmercury.

In addition, seasonal and inter-annual variability in Hg loads were accounted for in the source analysis and load allocations by evaluating long-term averages of annual loads for San Francisco Bay sources and losses. Also, Implementation Plan for the Bay Mercury

TMDL, acknowledges and accommodates long-term inter-annual variability by evaluating whether sources are meeting allocations on a multi-year basis, which helps average out differences among high and low rainfall years. Potential increases in MeHg production due to activities at the managed wetlands are also considered in the proposed TMDL for low DO/organic enrichment. The monitoring programs accommodate long-term inter-annual variability by evaluating whether sources are meeting allocations on a multi-year basis.

Extending the mercury objectives to Suisun Marsh will help ensure that any increase in MeHg production due to activities at the managed wetlands will be considered in implementation of the TMDL.

11.4. ATTAINMENT OF WATER QUALITY OBJECTIVES

Although the load reductions required by the Bay Mercury TMDL are likely to be achieved by 2026, it may take as long as 100 years to achieve target concentrations in sport fish tissue. This is because the large inventory of mercury already in the Bay and the surrounding watersheds will continue to methylate, bioaccumulate, and cycle through the food chain.

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12. Suisun Marsh DO TMDL Implementation Plan

TMDL implementation plans specify management actions that may be necessary to attain compliance with a TMDL's allocations and, ultimately, restore water quality and beneficial uses. Successful implementation plans typically rely on an integrated, adaptive management approach to utilize available resources effectively and efficiently. Adaptive implementation simultaneously makes progress toward achieving water quality standards through implementing actions, while relying on monitoring and special studies to reduce uncertainty and refine future management decisions.

Suisun Marsh periodically experiences low dissolved oxygen (DO) events, which primarily occur in the smaller tidal sloughs located in the western part of the marsh furthest from Suisun Bay. Water and vegetation management at managed wetlands (duck clubs) may result in direct impacts to water quality when water is discharged from the managed wetlands into marsh sloughs. Specifically, managed wetland operations can contribute to low dissolved oxygen conditions and organic enrichment, as well as increases of mercury methylation potential. However, conditions in the marsh are complex and water quality can be also affected by management actions to improve water supply reliability, increase freshwater flows through the Delta, and to restore wetland habitat. Both anthropogenic and natural factors affect water quality, and not all factors may be controllable to the same degree by particular implementation actions. Thus, it is important to identify those actions that are more likely to be accomplished and effective. In developing the proposed implementation actions priority was given to those that were lower-cost and could be completed on-site now at managed wetlands.

This Plan focuses on three general implementation categories:

1. Actions to control sources of low DO and mercury at managed wetlands;
2. Actions to control sources of low DO and mercury originating locally and outside the marsh;
3. Actions resulting from Estuary-wide plans and policies.

In addition, the Plan outlines how the proposed implementation actions will reduce mercury risks in consumers of fish, and monitoring needed to measure progress towards attainment of numeric targets and water quality objectives. The Plan's adaptive implementation section describes methods for evaluating and adapting the TMDL as we obtain new information. Table 12-1 shows the general elements of the Implementation Plan and Table 12-2 lists the recommended best management practices (BMPs) for achieving the water quality objectives for DO in Suisun Marsh, and specifically in the western portion of the marsh, where exceedances of water quality objectives are most frequent. For detailed description of the BMPs, their expected efficiency and water quality outcomes see Siegel et al. (2011).

12.1. Implementation Actions at Managed Wetlands

12.1.1 Changes in Vegetation and Water Management at Managed Wetlands

As discussed in Sections 3 and 6, vegetation and water management at managed wetlands result in periodic discharges to marsh sloughs that carry large loads of organic material and are low in DO. A study conducted in the marsh from 2007 to 2008 identified the key processes impacting water quality and a range of BMPs expected to reduce the occurrence of DO sags, and prevent mercury methylation.(Siegel et al. 2011, Gillenwater et al. 2013). Two general categories of BMPs were recommended:

1. Hydrology Management BMPs: This category of BMPs modifies the management of duck club or slough hydrology to (a) reduce or prevent conditions that may produce low DO events, (b) restrict the amount of low DO water discharged from multiple clubs at any one time, (c) discharge water to larger, well-mixed sloughs more capable of assimilating and dispersing low DO water, and (d) change the hydrology of the receiving sloughs to improve their capacity to assimilate and disperse low DO water.

2. Carbon (Vegetation and Soil) Management BMPs**:** This category of BMPs reduces the amount of labile (with the most rapid turnover times) organic carbon present on the managed wetlands, which fuels formation of low DO conditions, by: (a) managing vegetation type, (b) eliminating or changing the schedule of mowing activities, (c) removing mowed vegetation so that it does not decompose in the ponded water, and (d) reducing soil disturbance (disking).

To be effective, BMP implementation to address low DO issues in the marsh must be coordinated at the individual slough level and involve all or most of the managed wetlands that discharge to the slough. Different sloughs will require different BMP strategies due to variations in slough hydrology, watershed characteristics, managed wetland characteristics and property infrastructure, the amount and location of tidal marsh along the slough system, and other infrastructure considerations. Certain marsh sloughs are more likely to experience low DO conditions. Sloughs at greater risk should be prioritized for more intensive water quality improvement measures. As part of the proposed TMDL, Gillenwater et al. (2013) used an index approach to identify geographic sub-areas in the marsh where the specific application of individual BMPs is likely to result in lessening the overall organic enrichment-low DO problem. The index assessment shows that implementing BMPs in the back-end sloughs in the west part of the marsh will provide the most water quality benefits because these sloughs have the least circulation and flushing.

During TMDL development, Water Board staff coordinated with the Suisun Resource Conservation District (SRCD) to initiate early implementation actions in the marsh, targeting the most affected sloughs (Table 12-2). In particular, the Water Board added conditions requiring both BMP implementation and DO monitoring in sloughs as part of the 2013 Clean Water Act Section 401 water quality certification for the US Army Corps of Engineers Regional General Permit 3 (RGP3), a 5-year permit that authorizes managed wetland operation and maintenance activities, including levee stability improvements and maintenance of water control facilities and structures in the marsh.

Most RGP3-covered activities, such as levee repairs and managed wetlands operations and mainaince activities, are conducted by individual duck clubs and coordinated by SRCD, the California Department of Fish and Wildlife (DFW), the California Department of Water Resources (DWR), and the US Bureau of Reclamation (USBR). SRCD also provides Marsh landowners with technical assistance in water control and habitat management. Early implementation continued throughout the 5-year permit term (2013-2017), which resulted in the improved water quality conditions and significantly reduced frequency of low DO. There have not been any documented fish kills since RGP3 was renewed.

The west portion of the marsh was targeted for this early implementation. The duck clubs there, with support from SRCD, have already voluntarily implemented a range of the BMPs, including the following:

- Used DO measurements to coordinate flood-up and drain events across multiple managed wetlands;
- Staggered flood-up and discharges across multiple duck clubs to avoid simultaneous discharges of low DO water to a particular slough or sloughs;
- Modified intake and discharge points to enhance water mixing in receiving sloughs;
- Cleaned and removed sediment from swales and ditches to improve internal water circulation;
- Circulated water through the managed wetlands more quickly to reduce organic enrichment;
- Maximized use of discharge from the FSSD outfall for initial flood-up of managed wetlands close to the outfall to provide higher DO inflows;
- Completed vegetation management earlier to facilitate longer decomposition prior to fall flooding, reducing organic enrichment in discharged water;
- Mechanically removed broadleaf vegetation and promoted annual grasses; and
- Coordinated water management activities at duck clubs with vector control requirements and the constraints imposed by DFW and the U.S.FWS. Specifically, coordinated diversion and intake restrictions to avoid entrainment of listed species.

The 401 Water Quality Certification for Regional General Permit 3, issued on February 14, 2018, (2018 Water Quality Certification) implements the TMDL by requiring applicants to employ water management and vegetation BMPs identified in (1) the 2007 Conceptual Model for Managed Wetlands in Suisun Marsh; (2) the 2011 Strategies for Resolving Low Oxygen and Methylmercury Events in Northern Suisun Marsh; (3) the ongoing U.S. EPA Water Quality Improvement Pilot Project; and (4) the TMDL Staff Report. Applicants are required both to describe implemented actions and the effectiveness of BMPs and to report DO monitoring results in annual reports to the Water Board.

The 2018 Water Quality Certification also requires the Goodyear Slough Outfall to be cleaned as often as necessary to maintain dissolved oxygen objectives (as determined by continuous monitoring) and no less frequently than once per year.

In addition to BMP implementation, the RGP3 authorizes the cleaning of interior ditches used for water circulation, including the Goodyear Slough outfall managed by DWR. Maintaining good flow circulation in Goodyear Slough is essential to improving DO conditions in the west portion of the marsh. DWR was responsible for conducting the cleaning of the outfall as often as necessary to maintain water circulation, and specifically should inspect and clean the outfall before the fall floodup begins at the managed wetlands. Maintaining good flow circulation in Goodyear Slough is essential to improving DO conditions in the entire Goodyear Slough complex, and will also be included in the next reissuance of the 401 certification for RGP3 activities.

12.1.2 DO Monitoring to Aid BMPs Implementation

The 401 certification for RGP 3 also requires SRCD and Marsh landowners, together with other agencies, to conduct DO monitoring in west portion of the marsh. DO monitoring starts before managed wetlands begin discharging water to sloughs and continues until mid-November, when, in general, water quality starts to improve in the sloughs receiving discharge from managed wetlands. Each year, SRCD submits to the Water Board a monitoring report describing the the results of DO monitoring, the BMPs implemented during the fall discharge period, and co-ordination details among adjacent duck clubs. The monitoring proved to be valuable in assessing the effectiveness of various BMPs and in focusing implementation in low-DO areas. Thus, reissuing the monitoring provisions will be a key implementation action of the current TMDL.

The DO monitoring completed so far was used to track and adjust the discharge schedules for selected duck clubs. For example, in order to reduce potential impacts to Boyton and Peytonia Sloughs, SRCD created a schedule of flood and drain times to stagger releases from the managed wetlands to those sloughs. In fall 2013-15, monitoring showed substantially improved DO conditions compared to previous years. While DO concentrations in the most affected sloughs still droped after the discharge started, the frequency, magnitude, and duration of DO sags decreased, suggesting that early implementation actions helped reduce DO impairment. Accordingly, the TMDL anticipates that implementation actions and monitoring should be continued, with some consideration for adaptive implementation based on the results of the monitoring.

Table 12-1
Summary of RGP3 implementation actions to meet DO objectives in Suisun Marsh sloughs

Action	Implementing Party	Timeframe
Participate in ongoing SRCD-led actions to manage and coordinate discharges into the sloughs	Landowners and land managers of managed wetlands	Ongoing
Implement on-site measures to reduce formation and discharge of low DO waters	Landowners and land managers of managed wetlands	Ongoing
Report on implementation progress of BMPs intended to prevent excessive loading of DO/organic enrichment/nutrients to the sloughs	Landowners and land managers of managed wetlands	Ongoing (annually)
Coordinate maintenance activities at the managed wetlands to prevent adverse water quality impacts	SRCD, DFW, DWR, and the USBR	Ongoing
Implement measures to ensure that water quality in marsh sloughs is protected and meets applicable	SRCD, DFW, DWR, and the	Ongoing

Action	Implementing Party	Timeframe
water quality objectives (e.g. regular maintenance and cleanup of the Goodyear Slough outfall by DWR)	USBR	
Conduct DO monitoring to assess the effectiveness of the implementation measures and document improvement in water quality conditions	Landowners, SRCD, DFW, DWR, and the USBR	Ongoing (fall monitoring)

Table 12-2
Recommended best management practices to improve water quality at managed wetlands

Best Management Practices (BMPs)	Intended Outcomes[1]
Water Management-Based BMPs: Initial Fall Flood-Up Period	
Pre-flood to shoot level, drain, immediate re-flood	Minimize initial residence time and improve DO
Pre-flood to field saturation level, drain, delayed re-flood	Improve DO
Pre-flood to field saturation level, drain, immediate re-flood	Minimize initial residence time and improve DO
Flood and hold with minimum exchange	Avoid poor WQ discharges to sloughs during sensitive periods
Delay flood-up as late as possible before hunt season	Initial flood up occurs at cooler temperatures
Reroute wetland drain events to large sloughs	Reduce BOD loading to sloughs with lower DO capacity
Stagger flood/drain events across multiple wetlands	Avoid cumulative effect of multiple low-DO discharges; spread out low DO discharges temporally
Coordinate drain events across multiple wetlands using DO- based discharge scheduling	Avoid cumulative effect of multiple low-DO discharges; base operational decisions on real-time data of slough water quality
Maximize use of FSSD water for initial flood up	Provide higher DO wetland inflows, reduce upstream slough flows
Maximize FSSD water discharge into Boynton and/or Peytonia sloughs during drain events	Dilute low DO/high DOC water in Boynton, minimize net upstream flow
Water Management-Based BMPs: Circulation Period (winter, hunting season)	
Minimize exchange between wetlands and sloughs	Avoid low DO discharges, allow photo-demethylation and wind mixing
Exchange water between wetlands and sloughs frequently	Minimize residence time in wetlands to avoid anoxic conditions and methylation
Maximize internal wetland circulation	Eliminate stagnant areas with low DO
Vegetation and Soil Management-Based BMPs	

Best Management Practices (BMPs)	Intended Outcomes[1]
Manage for wetland plants less leafy greens	Reduce labile organic matter
Mow vegetation earlier in the season	Allow longer vegetation decomposition period to improve DO conditions in discharges
Remove mowed vegetation from wetlands	Reduce labile organic matter from dead vegetation
Graze wetlands to remove unwanted vegetation	Reduce labile organic matter from dead vegetation
Reduce soil disturbance (disking) activities	Reduce soil organic matter content available for decomposition

[1] For detailed description of the BMPs, their expected efficiency and water quality outcomes see Siegel et al. (2011).

12.1.3 Funding Opportunities and Special Projects

Limited infrastructure, lack of electricity in the field, and inadequate funding by landowners may impede improvements to water management at duck clubs. Infrastructure to manage wetlands can include gates, pipes, flashboard risers, and pumps, as well as the ditch system that circulates flood water through the wetland. Upgrades to water control structures and related infrastructure (e.g. intake pipe screening), changes to the intensity of vegetation management, and changes to ditch maintenance, such as periodic excavation of material in internal ditches to improve circulation, could require expenses that some land owners may not be able to afford. Other options, such as installation of pumps, may be limited by limits to available power at the duck clubs.

Four available funding sources, described below, may help meet these needs. We are supportive of efforts by dischargers and other interested parties to seek funding for pilot-scale testing and full implementation of expanded BMPs and other changes, such as landscape modifications, changes to ongoing operations and infrastructure, and monitoring to support implementation of the TMDL. These include:

- Federal Environmental Quality Incentives Program (EQIP);
- Suisun Marsh Preservation Agreement Implementation Fund (SMPA PAI Fund),
- Water Quality, Supply, and Infrastructure Improvement Act (Proposition 1) Grant, and
- U.S. EPA Grants.

EQIP

EQIP, administered by the Natural Resource Conservation Service (NRCS), is a potential funding source to help landowners pay for BMP implementation. The EQIP program provides financial and technical assistance to land managers to help plan and implement conservation practices that address natural resource concerns, and for opportunities to improve soil, water, plant, animal, and related resources on agricultural land and non-industrial private forest land.

SMPA PAI Fund

The SMPA PAI Fund, established as part of the Suisun Marsh Habitat Management, Preservation, and Restoration Plan, provides cost share for eligible activities in managed wetlands that mitigate for the impacts of the Central Valley Project and State Water Project. Activities eligible for PAI finding include: improvements to managed wetland facilities, improvements in operational efficiency and water management capabilities. Such improvements align well with the implementation actions proposed in this TMDL.

Proposition 1 Grants

The Proposition 1 grant program provides funding to meet the California Water Action Plan objectives of more reliable water supplies, restoration of important species and habitat, and more resilient, sustainably managed water resources system that can better withstand inevitable and unforeseen pressures in the coming decades. Beginning in 2015, this grant program has funded more than $85 million in projects that will benefit the Delta over a 10-year period. The Delta Conservancy administers the Proposition 1 Ecosystem Restoration and Water Quality Grant Program, which funds planning and/or implementation projects with the objective to protect, restore, and enhance ecosystem functions, and improve water management practices to advance water quality in waterways.

EPA Grant Programs

The U.S. EPA has at least two grant programs that may be well-suited to pilot scale BMP implementation. The San Francisco Bay Area *Water Quality Improvement Fund (SFBWQIF)* has, since 2008, provided grants of approximately $800,000 to $1 million that can be used over a period of up to four years for activities that enhance aquatic habitat, and protect and restore the water quality of the San Francisco Bay and its watersheds. The SFBWQIF has invested over $44 million in 61 projects through 36 grant awards in the Bay Area to date. A project funded under this grant program is currently underway in Suisun Marsh (see section 12.1.2 below).

The federal *Clean Water Act Section 319(h)* grant program is a federally-funded nonpoint source pollution control program administered in California by the State Water Board. This program funds projects that will control non-point source discharges that impair beneficial uses and limit the effects of pollutants in those discharges. Grant applicants compete in a statewide selection process in which proposed projects are reviewed by a panel of State Water Board, Regional Water Board, and U.S. EPA staff. Funds for each project range from $250,000 to $800,000, and the applicant must fund at least 25% of the project. This grant program could fund projects that supplement early implementation funded by the U.S. EPA WQIF, and to continue ongoing efforts to implement the DO TMDL requirements in Suisun Marsh. The preliminary findings of the current study in the marsh indicate that real-time DO tracking would improve the coordination of flooding and discharging activities, and, as a result, would help prevent acute drops in slough DO. Instantaneous access to DO data measured at strategic locations in the west Marsh would provide a much-needed warning system about worsening DO conditions, and help with more effective deployment of BMPs. We support efforts to install a DO monitoring telemetry system and use of predictive models to aid water quality management at managed wetlands, and to provide regulatory feedback.

12.1.4 WQIF Project 2016-2018

During development of this TMDL, SRCD obtained U.S. EPA WQIF funding to implement a planning project in partnership with CDFW, FSSD, Delta Conservancy and others, and with support from the Water Board. The goals of this project are to:

- identify constraints, opportunities and recommendations for BMPs in Suisun Marsh that could improve water quality relative to DO and MeHg;
- build knowledge within the managed wetland landowner community, and
- develop working relationships between all stakeholders to support attaining long-term TMDL objectives.

The project continues to provide a framework for implementation of the Suisun Marsh DO TMDL, and promotes successful actions and relationships that support attaining long-term TMDL objectives. Expected environmental outcomes are reduced occurrences of low DO and MeHg production in tidal sloughs as described in Siegel et al. (2011). The project funding extends from 2016 through 2018 and information learned through the project will inform the feasibility of attainment of the TMDL and adaptive implementation.

12.1.5 Restoration of Managed Wetlands to Tidal Marsh

Suisun Marsh is targeted for extensive future tidal wetland restoration to improve water quality and ecosystem values (SMP 2014). There is evidence to suggest that the quality of water discharged from tidal wetlands is better than that from managed wetlands (Tetra Tech 2013b). This is because tidal wetlands have better circulation and shorter residence times than managed wetlands. Restoration of managed wetlands to tidal marsh, therefore, offers a means of minimizing or avoiding generation of low DO waters. Tidal restoration also alters the hydrology of the tidal sloughs to which sites are connected, leading to an increase in tidal mixing throughout the slough/wetland system, which again leads to improved water quality conditions. However, tidal wetlands could trigger mercury transformations and contribute to temporary increase in loading of mercury into adjacent sloughs.

The restoration of the 70-acre Blacklock site in northeast Suisun Marsh provides an opportunity to study the impact of the restoration on DO and mercury cycling. The project converted a diked, managed wetland with limited seasonal water exchange with Nurse Slough to tidal marsh with unrestricted daily tidal inundations. Monitoring and studies estimating changes in mercury cycling after conversion to tidal marsh are ongoing at Blacklock. The data from these studies will be used to abate potential adverse mercury effects and aid future restoration efforts in other parts of the marsh.

The Bay Mercury TMDL also recognizes that wetlands may contribute substantially to methylmercury production and biological exposure to mercury within the Bay and requires implementation tasks to ensure that restored wetlands are designed to minimize methylmercury production and subsequent transfer to the food web.

Large-scale restoration efforts in the marsh and the Sacramento-San Joaquin River Delta (Delta) are further discussed under Estuary-Wide Implementation Actions.

12.1.6 Waste Discharge Requirements

The primary regulatory tool to implement the TMDL at both managed and restored wetlands is the 401 certification issued in support of the USACE's RGP3. However the Regional Board may also issue individual Waste Discharge Requirements (WDRs) under section 13263(a) of the Water Code to individual landowners if the TMDL is not achieved via voluntary collaboration amongst landowners and compliance with the 401 certification.

Such WDRs and Section 401 water quality certifications must, at a minimum, include provisions to minimize methylmercury production and biological uptake, and result in no net increase in mercury or methylmercury loads to the Bay. Restoration projects must also include pre- and post-restoration monitoring to demonstrate compliance and to collect information that will inform future management decisions. This information will be adaptively incorporated into the implementation plan as it becomes available.

12.2. IMPLEMENTATION ACTIONS FOR SOURCES OTHER THAN MANAGED WETLANDS

Municipal and stormwater discharges contribute pollutants, including mercury, into the marsh sloughs, and are a potential conveyer of other pollutants that may affect DO (e.g., nutrients). This TMDL does not require new implementation actions because the existing regulatory programs for municipal stormwater runoff and municipal wastewater are in place, and will continue to address these other pollutants and dissolved oxygen.

12.2.1 Municipal Wastewater

Fairfield Suisun Sewer District

The wasteload allocation for FSSD will be implemented through the facility's NPDES permit (CA0038024), which already has receiving water limitations for DO and numeric effluent limits for biological oxygen demand and nutrients. The current permit specifies that the receiving water limitations have to be met in Boyton Slough and Ledgewood Creek and identifies monitoring locations to demonstrate compliance. These locations may change in the future. The permit also requires implementation of BMPs to maintain optimal treatment performance and monitoring to identify and manage controllable sources of pollutants that affect DO.

FSSD's effluent data show that 1,461 measurements out of 1,463 (99.9 percent) were ≥ 5.0 mg/L, and 1,131 (77 percent) were ≥ 7.0 mg/L (evaluated for the permit reissurance in 2015). Because FSSD already provides advanced secondary treatment, and its wastewater has high DO concentrations greater than those in the receiving waters, the requirements of the facility's NPDES permit are not expected to change to implement the TMDL. The wasteload allocation for the FSSD wastewater treatment plant will continue to be implemented as receiving water limitations (≥5.0 mg/L June 1-November 15, and ≥7.0 mg/L during all other times of the year and expressed as 30-day running average and within one foot of the surface). Staff will recommend to the Water Board that the requirement to maintan the median DO concentration for any three consecutive months at ≥ 80% of DO content at saturation not be required as this objective does not apply. FSSD's receiving water monitoring of nutrients, pH, hardness, temperature, salinity, and DO help track water quality in the receiving sloughs and will provide information to refine effluent limits in future permits. FSSD also collected nutrient data for effluent characterization required by a 13267 letter issued by the Water Board on March 2, 2012. At the next reissuance, the TMDL requirements will be included in the conditions of the reissued NPDES permit for FSSD.

Since FSSD effluent has high DO levels, routing more FSSD discharge to Boynton and Peytonia sloughs would improve DO conditions by providing flushing flows and high DO water at times when low DO water is being discharged from managed wetlands. Additionally, treated wastewater can be used directly to flood up duck clubs located in the immediate vicinity of the discharge pipeline. This would reduce the amount of water drawn from the sloughs, thereby reducing net upstream flows that had been associated with fish kills in the past. FSSD currently participates in the WQIF project, which tests the best ways to utilize treated effluent from its facility to improve DO conditions in the marsh.

Mercury Watershed Permit

Discharges of mercury from FSSD are regulated by the Mercury Watershed Permit (Order No. R2-2017-0041), which implements the San Francisco Bay Mercury TMDL wasteload allocations for industrial and municipal wastewater discharges. The numeric effluent limits, trigger actions, and other compliance requirements in FSSD’s NPDES wastewater permit reflect the targets established by the Bay Mercury TMDL, which are the same as the targets proposed for Suisun Marsh. Accordingly, extension of the Bay Mercury TMDL to Suisun Marsh would not necessitate any changes to the Watershed Permit or to the implementation actions required by FSSD under that permit.

12.2.2 Municipal Stormwater Runoff

Runoff from adjacent watersheds has been identified as a potential source of organic material and nutrients, and a potential conveyer of mercury. Actions necessary to control stormwater pollution, including actions specifically designed to control mercury discharges, are implemented through the requirements included in the Municipal Regional Stormwater NPDES permit (MRP) (Order No. R2-2015-0049). No new requirements are necessary to implement the DO TMDL. Because mercury-related requirements in the MRP are already designed to comply with the San Francisco Bay Mercury TMDL and the site-specific water quality objectives established by that TMDL, no new actions are required to attain the mercury objectives proposed for Suisun Marsh. However, a brief description of relevant stormwater controls from the MRP, which will help control both DO and mercury, appears below:

MRP permittees, including the City of Fairfield and the City of Suisun City, are responsible for implementing control measures needed to prevent or reduce pollutants in stormwater and for funding the capital, operation, and maintenance expenditures necessary to implement such measures. Both general and pollutant-specific control measures will help to achieve compliance with this TMDL.

The MRP identifies the need for collecting information on pollutants of concern in receiving waters, which include DO, nutrients, mercury and ancillary parameters such as total organic carbon in order to identify pollutant sources, loads, trends and to evaluate the effectiveness or impacts of existing management actions.

Mercury-related actions are found in section C.11 of Order No. R2-2015-0049. These actions include implementation of pollution prevention, source control, stormwater treatment, and risk reduction measures; construction of green infrastructure projects; and assessment of load reductions of mercury. In addition, MRP permittees are required to develop TMDL implementation plans demonstrating that they will comply with the Bay Mercury TMDL load allocations by 2028. MRP permittees are also required to conduct monitoring. The municipal stormwater program generates water quality data that are designed to estimate loads of mercury and other contaminants from local tributaries and stormwater conveyances, track these loads over time, and assess the success of control measures in reducing mercury discharges.

Moreover, section C.1 of the MRP, in part, states that when discharges are causing or contributing to an exceedance of the applicable water quality standard, MRP permittee(s) shall submit a report to the Water Board that describes the BMPs being implemented and additional BMPs that will be implemented to prevent or reduce the discharge of pollutants causing or contributing to the exceedance.

The actions already implemented through MRP requirements are expected to continue to improve water quality in streams discharging to Suisun Marsh and in the marsh sloughs.

12.2.3 Mercury Loading from San Francisco Bay and the Sacramento-San Joaquin River Delta

Implementation actions already required by the San Francisco Bay Mercury TMDL and the methylmercury TMDL in the Delta are helping to address local and estuary-wide mercury impairment, which is caused by mercury loads from historic mining, atmospheric deposition, and active municipal and industrial sources. Allocations, management techniques, and control strategies already required by the existing mercury TMDLs will, over time, contribute to the overall improvement of water quality conditions in the Bay and in the marsh. The major requirements called for in the Bay Mercury TMDL, which directly contribute to meeting the targets in Suisun Marsh include actions to:

- Reduce mercury loads to achieve the average total mercury reduction of 500 kg/year;
- Reduce methylmercury production and consequent risk to humans and wildlife exposed to methylmercury:
- Investigate ways to address public health impacts of mercury in San Francisco Bay/Delta fish including activities that reduce actual and potential exposure of and mitigate health impacts to those people and communities most likely to be affected by mercury;
- Conduct monitoring and focused studies to track progress and improve the scientific understanding of the system and to evaluate and report on the spatial extent, magnitude, and cause of contamination for locations where elevated mercury concentrations exist;
- Encourage actions that address multiple pollutants.

12.3. ESTUARY–WIDE IMPLEMENTATION ACTIONS

Driven by Cal WaterFix and the need for climate change resiliency, large-scale wetland ecosystem restoration projects in various areas of the Estuary, including Suisun Marsh, are in the planning stages. Several regional ecosystem planning efforts call for extensive additional restoration in the decades to come, including the Suisun Marsh Habitat Management, Preservation, and Restoration Plan (SMP), Bay Delta Conservation Plan, Bay-Delta Plan, Delta Plan, and others. These planning efforts may ultimately result in the restoration of tidal action to up to 65,000 - 100,000 acres of land. Tidal marsh restoration, together with improvements in freshwater inflows, is expected to result in a better and more diverse ecosystem, which in turn will contribute to long-term improvements in water quality, including DO conditions in Suisun Marsh. In the process, short-term localized and system-wide random changes in DO may also occur. The scope and progress of the current restoration planning efforts are summerized below:

Suisun Marsh Habitat Management, Preservation, and Restoration Plan (SMP)

The SMP, established in 2014, is a comprehensive 30-year plan designed to address the use of resources within the wetland and upland habitats in the marsh, resolve permitting issues related to ongoing and future maintenance and management activities, and balance the benefits of tidal wetland restoration with other uses in the marsh. The principals agencies involved in developing and implementation of the SMP are U.S. FWS, U.S. Department of the Interior, Bureau of Reclamation, CDFW, NMFS, and SRCD. The SMP advocates actions to improve DO concentrations in managed wetlands by eliminating or reducing discharges to smaller sloughs, increasing circulation, changing vegetation cover or implementing rapid flooding and drainage to improve aeration. All of these actions have been demonstrated to help alleviate low DO conditions in the receiving sloughs. The planned conversion of managed wetlands to tidal wetlands and increased tidal flows are expected to have a beneficial impact on water quality because it would increase levels of DO and improve overall water quality in Marsh sloughs. Over the 30-year SMP implementation period, up to 7,000 acres of diked/managed wetlands will be restored to tidal wetlands. The SMP EIS/EIR (2014) programmatically evaluates any impacts resulting from managed wetland activities and the conversion of managed wetlands to tidal habitat. The EIS/EIR also provides a detailed analysis of baseline conditions and environmental commitments and mitigation measures necessary to ensure that resources are protected and that restoration and managed wetland goals are met simultaneously.

The main goals of the SMP include:

- Preservation and enhancement of managed seasonal wetlands;
- Implementation of a comprehensive levee protection and improvement program; and
- Protection of ecosystem and drinking water quality, while restoring habitat for tidal marsh-dependent sensitive species.

Bay Delta Conservation Plan (BDCP)

As currently proposed, the BDCP establishes a framework for ecosystem restoration across the legal Delta and Suisun Marsh. It aims to create or restore a mosaic of natural communities that would be adaptable to changing conditions, sea level rise, increase native biodiversity, improve linkages between habitats, and allow natural flooding and tidal circulation to promote the regeneration of vegetation and improve water quality. It currently targets protection of at least 31,000 acres of existing natural communities and restoration or creation of more than 72,000 acres of natural communities, including at least 65,000 acres of tidally influenced wetlands. In addition, the BDCP intends to improve the Delta and Marsh ecosystems by taking actions such as:

- Protect and improve habitat linkages to promote the movement of native species;
- Prepare for future sea level rise by providing transitional areas that allow future upslope establishment of tidal wetlands;
- Allow natural flooding to promote the regeneration of vegetation and related ecosystem processes;
- Connect rivers and their floodplains to recharge groundwater, provide fish spawning and rearing habitat, and increase food supply;
- Manage the distribution and abundance of nonnative predators to reduce predation on native special-status species.

Actions advocated by BDCP, and in particular, the tidal wetland restoration, is expected to have a beneficial impact on water quality because it would increase levels of DO and improve overall water quality in Marsh sloughs.

Bay-Delta Water Quality Control Plan (Bay-Delta Plan)

The State Water Board is updating its Bay-Delta Plan, which will set water quality objectives for south Delta agriculture, and San Joaquin River flow objectives to protect fish and wildlife in the entire Estuary, and, eventually, Delta outflow objectives, Sacramento River flow objectives, Suisun Marsh salinity objectives, and potential new floodplain habitat flow objectives. The Bay-Delta Plan provides a framework for managing Suisun Marsh resources to protect the public trust and fish and wildlife beneficial uses; regulate, manage, and study pollutants in Suisun Marsh; and address development around Suisun Marsh to minimize impacts to beneficial uses and improve water quality.

Delta Plan

The Delta Plan is a long-term management plan required by the 2009 Delta Reform Act. It builds on work by DWR, DFW, and the State Water Board and encompasses water use, flood management, and habitat restoration, with a specific focus on the legal Delta and Marsh. It calls for protection, restoration, and enhancement of the ecosystem by designating six high priority locations in the Delta and Suisun Marsh to recover endangered species and rebuild salmon runs. The Delta Plan also prioritizes actions to reduce pollution, ensure improved water quality, and limit invasive species, while moving to establish a more natural pattern of water flows in the Delta, all of which will contribute to improvement of DO conditions. The Marsh is one of the Delta Plan's priority habitat restoration areas. In addition, the Delta Plan calls for coordination of efforts to implement requirements of the Bay Mercury and Delta methylmercury TMDLs. Parties identified as responsible for current methylmercury loads or proponents of projects that may increase methylmercury loading in the Delta or Suisun Marsh should participate in control studies or implement site-specific study plans that evaluate practices to minimize methylmercury discharges.

12.4. MONITORING AND COMPLIANCE

12.4.1 Mercury Monitoring to Protect Human Health and Wildlife

Considerations for compliance monitoring for the human health target of the TMDL include: extent of local angling and use for human consumption, species abundance in popular fishing areas, and factors such as sport fish trophic position and diet, which influence the extent that fish will take up and bioaccumulate mercury. For use as indicators of mercury concentrations in a given area, site fidelity whether a given fish species remains in a local region, rather than migrate to other areas, is helpful. As discussed in Chapter 5, we propose that the human health target of 0.2 mg/kg apply to striped bass, the most common sport fish caught in Suisun Marsh. The mercury level should be expressed as an average wet weight concentration of total mercury in skinless fillets. This is consistent with the 0.2 mg/kg adopted in other Bay Area mercury TMDLs, including San Francisco Bay, Tomales Bay, Guadalupe River, and Sacramento–San Joaquin Delta. The Regional Monitoring Program (RMP) measures mercury (and many other contaminants) in water, sediment, and fish tissue collected at several locations around the Bay each year. The monitoring frequency and fish sample size in Suisun Marsh should follow the monitoring protocols developed by RMP for sampling fish in San Francisco Bay.

Considerations for compliance monitoring for the wildlife target of the TMDL include: the piscivorous species of birds and other wildlife present in the marsh, the type and size ranges of fish eaten, the extent that those fish bioaccumulate mercury, and the timing of bird species' critical life-stages. Protection of wildlife should be determined using Mississippi silversides, which is an important indicator of wildlife exposure to MeHg because the fish forages in shoreline marshes and shallow water habitats, which exhibit greater potential for Hg methylation. Mercury concentrations were sampled in silversides in the marsh in the past, which provides a useful data for comparison and tracking progress on how the concentrations in biota are changing over time.

12.4.2 Current DO Monitoring to Protect Aquatic Life Beneficial Uses

Suisun Resource Conservation District (SRCD) together with DFW, DWR, USBR, and the owners and land managers of Suisun Marsh duck clubs conduct water quality monitoring focused on DO conditions in the back-end sloughs, as required by the 401 certification issued by the Water Board on February 14, 2018. The 401 certification requires the sampling frequency and spatial extend to be sufficient to determine ambient DO levels before the discharge occurs and to determine whether water quality objectives for DO in the receiving waters are met after the release of water from the managed wetlands. In addition to DO data, monitoring reports submitted by the agencies on an annual basis contain information on operation and maintenance activities at managed wetlands and the status of BMP implementation..

The Biological Opinion issued by the National Marine Fisheries Service on July 3, 2013, requires monitoring of DO concentrations during May, June and October in the western region of Suisun Marsh. This monitoring is conducted to assess the effects of drain water in receiving sloughs to ensure the continued existence and protection of the listed and sensitive species.

The Municipal Regional Stormwater Permit (MRP, Order No. R2-2015-0049) requires MRP permittees to collect information on pollutants of concern, including nutrients, mercury, DO and total organic carbon in order to identify pollutant sources, loads, trends and to evaluate the effectiveness or impacts of existing management actions. The cities of Fairfield and Suisun City conduct monitoring as required by the MRP. In particular, Provision C.8.d. calls for status creek monitoring to assess chemical, physical, and biological impacts of urban runoff on receiving waters in order to evaluate whether water quality in these streams meets all applicable numeric and narrative water quality objectives. Continuous monitoring of DO, temperature and pH is required because these parameters are fundamental to supporting aquatic life beneficial uses. The MRP specifies the reporting requirements and the monitoring frequency, duration and locations for individual MRP permittees.

12.4.3 Required Monitoring to Assess Compliance with DO Objectives and Meeting TMDL Targets

Implementing parties, and specifically, entities named in the 401 certification for the RGP3 permit, including Marsh landowners represented by SRCD, and DFW, DWR and USBR, are collectively responsible for developing monitoring plans and conducting monitoring sufficient to assess compliance with the wasteload allocations, load allocations, and DO numeric objectives established for Suisun Marsh sloughs. At a minimum this monitoring should be conducted in the fall to inform management decisions. The monitoring should include appropriate sampling frequency and periods of data collection, and must be adequate to evaluate DO on daily basis as well as 30-day running averages. DO monitoring should also be conducted at established compliance points in order to evaluate whether they are achieving the load allocation and site-specific objectives. The results will be reported the to the Water Board, including efforts to improve water quality, the BMPs implemented during the fall discharge period, and coordination details among adjacent managed wetlands, with a focus on efforts in the western Marsh.

The Water Board will collaborate with other agencies and Marsh landowners to identify opportunities to collect additional DO data in Suisun Marsh sloughs to enhance the understanding of DO variability, and the extent to which deviations from the DO objectives occur under natural and anthropogenic conditions. For example, DWR constructed several facilities in Suisun Marsh for the purpose of mitigating adverse impacts on Suisun salinity from the State Water Project and Central Valley Project, and maintains a network of monitoring sites for real-time, daily, and monthly measurements of salinity and other water quality parameters in a number of compliance and monitoring stations throughout the marsh. We are working with DWR to furnish station S-35 in Goodyear Slough with a DO sensor to collect continuous data in this location. The additional DO data will supplement focused monitoring during the fall discharge, and advance understanding of the cumulative effects of BMP implementation on the conditions in the west Marsh.

Water quality monitoring conducted by National Estuarine Research Reserve (NERR) in the First and Second Mallard sloughs, which are minimally impacted tidal sloughs, was helpful in developing the site-specific objectives. Continued data collection by NERR will assist the Water Board in evaluating potential effects of climate on the marsh, and DO background conditions.

12.5. ADAPTIVE IMPLEMENTATION

As new information becomes available through monitoring and evaluation, this Implementation Plan may be modified. Implementation of the management actions described here will be guided by feasibility, improved information, available funding, and site-specific conditions.

Accordingly, this TMDL will be implemented in phases starting with early implementation options and actions that are already being implemented under existing permits and through coordination among private and public entities. The information gained through the early implementation of BMPs at the managed wetlands in the western Marsh will be used to refine selection and deployment of BMPs in other areas of Suisun Marsh, if deemed necessary.

In particular, the DO monitoring required by the 401 certification and tools developed during the project funded by the U.S. EPA WQIF will improve our understanding of the natural and anthropogenic fluctuations in DO and better determine the conditions when impacts to fish are likely to occur. Interpretation of these data may result in improved ways to evaluate the compliance with the proposed DO objectives, and more focused deployment of BMPs.

The ongoing efforts to improve our understanding of the fate and transport of mercury in marsh environment will allow better predictions of MeHg production, which will guide tidal restoration and inform the need to adapt implementation schedules.

Further, the success of the DO and Hg TMDLs depends not only on actions implemented at managed wetlands, but to a large degree on Estuary-wide efforts. We will be assessing implementation progress and new data to determine if the quantity and quality of emerging information are sufficient to require changes to the implementation strategy. The need for special studies will be evaluated on the basis of new information collected throughout the marsh. As a result of adaptive management and monitoring, additional implementation of BMPs could be required in the west Marsh or elsewhere depending on implementation progress, or if water quality conditions decline in the eastern Marsh.

13. MINOR EDITS TO BASIN PLAN CHAPTERS 2 AND 3

Minor clarifications or corrections to Chapters 2 and 3 of the Basin Plan are proposed as part of this project. These editorial changes are intended to clarify or correct narrative passages or specific tables of the Basin Plan. These proposed non-regulatory edits do not affect or change any State or regional policy, program, or implementation plan. The types of revisions proposed, with rationale, are described below in Table 13-1. The specific changes, shown in underline-strikeout, can be found in the Basin Plan amendment.

Table 13-1
Miscellaneous editorial revisions to Basin Plan Chapters 2 and 3

Location	Description of Edit
Section 2.2.1, 2.2.2	We corrected the abbreviation for Industrial Process Supply (PROC) to match the definition in the text of Chapter 2. The abbreviation was incorrectly given as PRO in these two locations.
Section 2.2.1, 2.2.2, and Tables 2-2 and 2-3	We corrected the abbreviation for Freshwater Replenishment (FRSH) to match the definition in the text of Chapter 2. In these two Chapter 2 sections and the headers for these two tables (and footnotes for Table 2-2), the abbreviation was incorrectly given as FRESH. All instances of this abbreviation were changed to “FRSH”.
Section 2.2.2 and Table 2-2	We corrected typos in this section and table in which “Industrial Water Supply, Industrial process water supply, or Industrial service water supply” were given as the beneficial use names. “Industrial Process Supply” and ”Industrial Service Supply” are the correct names.
Table 3-3	Footnotes b and f of Table 3-3 have been updated to note that Table 3-3A contains site-specific nickel water quality objectives for South San Francisco Bay and site-specific copper water quality objectives for all segments of San Francisco Bay.
Table 3-3	Footnote k on Table 3-3 does not currently have sufficient information about the derivation of the PAH objective. The required information was available in the 1986 version of the Basin Plan, but was accidentally dropped in subsequent versions. The original footnote has been restored and appended to the current footnote k of this table to provide explanatory context for the PAH objective.
Tables 3-3 and 3-4	We updated footnotes to Tables 3.3 and 3-4 to remove the citation of the draft criteria and cite U.S. EPA’s final tributyltin criteria adopted in 2003.
Table 3-3A	We included a footnote 3 to Table 3-3A explaining that water effect ratios are already included in copper and nickel site-specific objectives as originally adopted and provided information about converting dissolved metal objectives to total metal concentrations. This is to eliminate confusion and clarify the meaning of the site-specific objectives.

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14. REGULATORY ANALYSES

The proposed Basin Plan amendment establishes site-specific objectives (SSOs) for dissolved oxygen (DO) protective of aquatic life beneficial uses, and a TMDL for low DO/organic enrichment in Suisun Marsh. This section includes the analyses required by law for the adoption of new water quality objectives and for the proposed Basin Plan amendment. It provides an overview of the Project's compliance with California Water Code requirements; peer review requirements of Health and Safety Code §57004; federal and state ant degradation policies; and with California Environmental Quality Act (CEQA).

The proposed amendment also makes non-regulatory revisions to Chapters 2 and 3 in the Basin Plan to improve clarity. Because these changes are solely a clarification of the Basin Plan, there are no potential significant environmental impacts or economic impacts associated with compliance with these revisions.

14.1. REGULATORY ANALYSES REQUIRED TO ESTABLISH NEW WATER QUALITY OBJECTIVES

For the proposed water quality objectives, this section contains the analyses required by the California Water Code (CWC §13241 and §13242), federal water quality criteria requirements (40 Code of Federal Regulations [CFR] §131.11), and state and federal anti-degradation requirements.

14.1.1 Water Code Section §13241 Analysis

Water Code section 13241 requires the Water Board to consider the following when establishing a water quality objective:

a) Past, present, and probable future beneficial uses of water;
b) Environmental characteristics of the hydrographic unit under consideration;
c) Water quality conditions that could reasonably be achieved through the coordinated control of all factors which affect water quality in the area;
d) Economic considerations;
e) Need for developing housing within the region, and
f) Need to develop and use recycled water.

The following analysis demonstrates how section 13241 requirements were considered in establishing the proposed site-specific objectives for dissolved oxygen.

Beneficial Uses

The past, present, and probable beneficial uses of Suisun Marsh are estuarine habitat, fish migration, preservation of rare and endangered species, fish spawning, wildlife habitat, water contact recreation, and non-contact water recreation (Table 2-1). In addition, the two largest sloughs in the marsh, Montezuma and Suisun sloughs, are designated as warm water fish habitat. The proposed new SSOs for DO reflect current scientific findings regarding the DO requirements of the most sensitive life stages of fish and other aquatic organisms. They have been developed using U.S. EPA-recommended methodology, and adapted to incorporate information regarding fish present and site-specific conditions in Suisun Marsh. Since the SSOs were developed to be protective of the most sensitive beneficial uses, those relevant to aquatic life, the objectives are protective of all beneficial uses listed above.

Environmental Characteristics of the Hydrographic Unit

The hydrographic unit is the whole of Suisun Marsh, but the objectives and the TMDL apply to the sloughs within the marsh as shown in Figure 2-1 and Figure 8-1. The environmental characteristics and existing conditions are discussed in Chapter 2 of this Staff Report. Chapter 4 discusses the rationale for refining the DO objectives and presents the site-specific environmental data, and steps taken to establish the SSOs for DO reflecting the fish species and conditions in the marsh.

Water Quality Conditions that Could Reasonably be Achieved

The proposed water quality objectives reflect the desired water quality conditions in Suisun Marsh sloughs such that beneficial uses will not be adversely affected by low DO. Although the recommended SSOs are lower than the existing Basin Plan objectives, they better reflect natural patterns and range of daily DO fluctuations with temperature, salinity and pressure changes, based on currently available scientific information and available monitoring tools.

The objectives also take into account naturally-occurring organic enrichment in marshes and wetlands, which periodically leads to lower DO concentrations.The new objectives were derived according to methodology established by the U.S. EPA (2000) and result in scientifically-defensible objectives for DO. The method used to calculate the chronic levels of DO required to protect aquatic organisms in Suisun Marsh is described in Chapter 4. The proposed DO objectives have been peer reviewed by the Expert Panel to ensure that these objectives offer protection of biological communities and reflect the best scientific understanding of natural marsh conditions (Appendix D).

A water quality attainment strategy developed to support the proposed TMDL and SSOs (Chapter 12), and specifically the early implementation actions (Section 12.1), and ongoing activities at managed wetlands describe coordinated efforts to control factors that may affect water quality. The strategy includes actions at managed wetlands aimed at lowering the extent and frequency of low DO events in nearby sloughs and simultaneous monitoring to improve coordination of water releases from wetlands to verify that these efforts result in meeting the proposed water quality objectives and protection of beneficial uses.

Economic Considerations

The proposed site-specific objectives for DO will be implemented through the Suisun Marsh TMDL. The goal of this analysis is to evaluate the costs of various implementation measures to improve habitat conditions for aquatic organisms and wildlife, and to minimize or avoid adverse effects of low DO concentrations in Suisun Marsh sloughs. This report’s implementation section (Section 12) describes candidate implementation measures that may be used to control potential sources of low DO.

The discussion of economic considerations or costs associated with various measures described in the implementation section is limited to those actions that are currently technically feasible and reasonably likely to be implemented. The TMDL is not prescriptive but rather provides implementing parties with a set of BMPs that could be tailored to the specific location, hydrologic conditions, or other needs. A subset of the candidate implementation measures listed in Table 12-2 is currently tested in the field as part of a project founded by the U.S. EPA's Water Quality Improvement Grant. When completed in 2018, the final recommendations of that project will provide additional information on the feasibility and costs of implementation.

Anticipating costs with precision is challenging for various reasons. Most of the actions to improve DO conditions rely on co-ordination of water management actions or might be part of the existing regulatory requirements. In addition, it should be noted that there are multiple additional benefits associated with the implementation of these strategies. These benefits include improving fish and wildlife habitat, supporting a better functioning ecosystem or enhancing recreational values of the marsh.

We consider the new costs of applying the TMDL measures to be relatively minor as most of the actions to improve DO conditions in the sloughs are either already required or are being currently implemented. To a significant extent, the proposed TMDL can be considered a tool to focus and facilitate implementation, and assist the Water Board with protection of water quality and meeting DO objectives in Suisun Marsh.

Municipal discharges: The FSSD is maintaining the optimal wastewater treatment for DO, and is currently meeting the DO targets set in the TMDL. We do not anticipate any additional costs resulting from the implementation of the TMDL other than incidental increases associated with identifying and managing controllable sources of pollutants in their service area, which may affect the receiving water quality. There could be some new costs associated with conducting or causing to conduct monitoring of water quality if conditions change.

Watershed and urban runoff: As discussed in Section 12.2.2, urban storm water runoff from Fairfield and Suisun City are regulated under conditions in the Municipal Regional Stormwater Permit (MRP). The cities of Fairfield and Suisun City have joined to form the Fairfield-Suisun Urban Runoff Management Program to operate the storm sewer system and to prevent storm water pollution associated with municipal activities. Under terms of the MRP, permittees are required to identify tasks and programs to reduce the discharge of pollutants in storm water to the maximum extent practicable in a manner designed to achieve compliance with water quality standards and objectives. Since this TMDL does not impose new requirements but rather builds upon the current efforts, we anticipate municipalities will incur no additional costs. The ongoing costs for operations and maintenance of storm water system, inspections, enforcement, staff training, public education and outreach, and effectiveness monitoring will be incurred by the permittees with or without a requirement to meet the applicable DO objectives in streams discharging to Suisun Marsh.

Managed Wetlands: Costs to implement the candidate BMPs are dependent on the extent to which BMPs have already been implemented in the marsh. For the purpose of this assessment, each BMP listed is assumed to have been implemented separately from the other BMPs. In reality, some BMPs may be implemented concurrently or might be needed only for a limited time, and therefore reduce the overall cost. Table 14-1shows a summary of potential costs for the main reasonably foreseeable TMDL implementation measures. The cost of improvements to water control structures is given in a range of expenses. Individual project costs can vary greatly based upon cost of installation, types of water control structures, mobilization, and/or construction engineering. All costs are estimated to be completed using Prevailing Wage rates. The estimates are specified mainly for structural BMPs, which should be installed at the strategic locations where its benefit is maximized and most cost-effective. Thus, these costs are generally provided as per acre of application or per lineal foot of installation. Since, the majority of the water conveyance maintenance (grading and cleaning), and improvements (drain gates installation) at managed wetlands are conducted under the SMP, the costs incurred directly as a result of the TMDL are minimal.

Table 14-1
Summary of potential cost ranges of implementation

Implementation Action	Cost (low-high)	Unit
SRCD staff resources to coordinate water management activities	Previously required no additional cost	Not applicable
Vegetation and Soil Management:		
Mowing to control green leafy vegetation	\$40 – \$50	Per acre of area treated
Selective spraying of herbicide (dry season) to control green leafy vegetation	\$150 – \$200	Per acre of area treated
Water Management BMPs (every 5 – 10 years)		
Improving existing interior water conveyance ditches (excavation):	\$6 – \$8	per lineal foot of ditch
Creation of new interior water conveyance ditches (excavation):	\$10 – \$12	per lineal foot of ditch
Creation of new interior water conveyance swales (grading):	\$4 – \$5	per lineal foot of ditch
Improving existing interior water conveyance swales (grading):	\$2 – \$3	per lineal foot of ditch
Water Management BMPs (every 15 – 20 years)		
Installation of new exterior drain gates (HDPE pipe and corrosive resistant flap gate and riser):	\$15,000-\$22,000 \$20,000-\$35,000	For 24” diameter pipe For 36” diameter pipe
Upgrading an existing Corrugate Metal Pipe (CMP) exterior drain or dual purpose structures to smooth wall HDPE pipe and corrosive resistant water control structures	\$25,000-\$45,000 \$40,000-\$55,000	For 24” diameter pipe For 36” diameter pipe

Monitoring costs.

The fall monitoring of DO prior and during the discharges from the managed wetlands is ongoing and does not represent a new cost under this TMDL. However, additional ambient monitoring may be needed to detect whether the water quality objectives have been achieved. In particular, there is limited monitoring data available for Montezuma Slough, which serves as a main migratory path for salmonids and is assigned with higher DO concentrations than those for the back-end sloughs. The specifics of this monitoring, such as the exact number of monitoring locations and sampling frequency have not yet been determined. For the purpose of a cost estimate, it is assumed that in addition to the existing water quality monitoring conducted in the northwest part of the marsh, 2 more locations will also be monitored in the reminder of the marsh. The initial capital outlay for continuous monitoring (YSI sonde, software, and deployment infrastructure) could be considerable ($10,000-$20,000). The annual ongoing costs to monitor basic water quality parameters (water temperature, pH, specific conductance and dissolved oxygen) at one location is approximately $36,000[1].

Assuming two monitoring stations and the period of data collection of approximately 6 months for each site, the annual cost for additional monitoring is estimated at $56,000 to $76,000. However, these initial and ongoing costs would presumably be offset by a reduction in costs associated with traditional discrete sampling. Reductions are expected in long-term operating costs due to reduced sampling, vehicle use (fuel and maintenance), and analysis costs as well as an opportunity to use the YSI sondes for other projects and studies. If continuous monitors are sufficiently maintained and staff are available to analyze the data collected, these instruments enhanced temporal resolution in ambient and operational data, and can help with early detection and taking action to prevent a low DO event from developing or worsening.

Need for Housing

The proposed water quality objectives would not restrict or alter the development of housing in Suisun Marsh because the marsh is not suitable for housing development.

Need to Develop and Use Recycled Water

There are no proposed restrictions on recycling of water due to dissolved oxygen. Adopting the recommended site-specific objectives will have no impact on the quality and quantity of wastewater available for recycling or reclamation in the region, and none of the alternatives considered would restrict the development or use of recycled water. The intent of the proposed water quality objectives is to improve water quality and protect beneficial uses in Suisun Marsh. Therefore, the proposed objectives are consistent with the need to develop and use recycled water.

[1] Based on the USGS data collection in Tualatin River

14.1.2 Water Code Section §13242 Analysis

Water Code section 13242 requires that when adopting water quality objectives in the Basin Plan, a program of implementation for achieving the objectives must be included. The program must include, but not be limited to:

- Description of the nature of actions necessary to achieve the objectives, including recommendations for appropriate actions by any entity, public or private;
- Schedule for the actions to be taken;
- Description of surveillance to be undertaken to determine compliance with the objectives.

In regard to the proposed site-specific objectives for DO, the Suisun Marsh TMDL project lists actions necessary to achieve the proposed water quality objectives as described in the program of implementation in Chapter 12. It sets forth appropriate actions by public and private entities, a schedule for actions to be taken, and a monitoring program to determine compliance with the proposed water quality objectives. Accordingly, in addition to meeting the requirements of EPA TMDLs, it meets the requriements of § 13242 as well.

14.1.3 Antidegradation Analysis

The recommended SSOs for DO in Suisun Marsh are consistent with the State's Antidegradation Policy, contained in the State Water Resources Control Board Resolution 68-16, and the federal antidegradation policy (40 C.F.R. § 131.12). Antidegradation policies adopted at federal and State levels are intended to maintain existing water quality at levels necessary to protect existing and future beneficial uses.

The proposed DO objectives would not result in degradation of Suisun Marsh water quality compared to the DO concentrations currently observed in minimally impacted and fully tidal sloughs representative of natural DO conditions. DO objectives, unlike traditional objectives for toxic substances are region-specific because the DO regime is dependent on temperature, hydrology, and natural biological processes, all of which vary spatially and temporally. The conditions in the marsh are significantly different from the conditions in San Francisco Bay open waters, for which the current Basin Plan objectives were developed in 1975 and which do not take into account that DO concentrations in marshes and wetlands are lower due to naturally-occurring organic enrichment and limited tidal and wind mixing. In tidal marsh environments, the high quantity of organic matter is critical for wetland accretion and providing healthy and productive habitat for estuarine beneficial uses, even if it also lowers DO. In addition, the current Basin Plan objectives do not include daily or monthly limits to prevent acute and chronic effects of DO stress, and do not require continuous measurements to evaluate whether the objectives are met or not. This is essential to fully understand the DO concentrations, which show natural daily and seasonal fluctuations. Since the proposed objectives would maintain water quality in Suisun Marsh sloughs relative to the conditions through the 2000s and improve protection of listed juvenile salmonids by requiring a higher DO of 6.4 mg/L during spring migration (January-April), no degradation of water quality would occur by approving the proposed amendment.

Approval of the site-specific objectives would not cause degradation of water quality in any downstream water bodies (e.g., San Francisco Bay). The existing beneficial uses of Suisun Marsh, and the level of water quality necessary to protect them, will be enhanced by the TMDL to implement the proposed objectives. The proposed amendment would not result in water quality lower than that prescribed in the State water quality policies.

14.2. PEER REVIEW AND SOUND SCIENTIFIC RATIONALE

14.2.1 Scientific Peer Review for DO Objectives and TMDL

Pursuant to Health & Safety Code Section 57004, Basin Plan amendments with a scientific basis must be peer reviewed. Scientific peer review ensures that regulatory decisions and initiatives are based on sound science. Scientific peer review also helps strengthen regulatory activities, establishes credibility with stakeholders, and ensures that public resources are managed effectively.

The portions of this Staff Report (Sections 3,4,6,8,9,12) that provide scientific basis for establishing the site-specific objectives for DO, and the TMDL to implement these objectives were submitted for scientific peer review through the CalEPA peer review process. Peer review comments were received and incorporated into the revised Staff Report. Peer review comment letters will be addressed in the response to comments.

14.2.2 Scientific Peer Review for Mercury Objectives and TMDL

The proposed Basin Plan amendment will extend applicability of the fish tissue-based water quality objectives for mercury from San Francisco Bay to Suisun Marsh sloughs, and establish a mercury TMDL with requirements that are the same as those of the already required and implemented by mercury TMDL for San Francisco Bay (Resolution No. R2-2004-0082). The proposed amendment does not contain new science that would require peer review. It represents an application of earlier, extensively peer reviewed work products, specifically, the 2004 San Francisco Bay TMDL, and the 2016 draft proposed rule for mercury water quality objectives and the program of implementation to amend the Water Quality Control Plan Control Plan for Inland Surface Water and Enclosed Bays and Estuaries of California.

The proposed amendment does not depart from the scientific approach of the other Basin Plan amendments from which it is derived. Therefore, additional peer review is not required.

14.3. CEQA ENVIRONMENTAL ANALYSIS

This section presents the analyses required under CEQA when the Water Board adopts a Basin Plan amendment under the Water Board’s certified regulatory program (Pub. Res. Code § 15251(g)). The Water Board is the lead agency responsible for evaluating the potential environmental impacts of Basin Plan amendments. Staff prepared the required environmental documention, which include an Environmental Checklist and a written report (this Staff Report) that disclose any potentially significant environmental impacts of the Basin Plan amendment. This Staff Report, including the CEQA Checklist and analyses, constitute a substitute environmental documentation. A scoping meeting was held on May 12, 2017 to satisfy CEQA’s recommendation to engage the public and interested stakeholders in consultation about the scope of the environmental analysis.

The State Water Board's regulations require a substitute environmental documention to include: 1) a brief project description; 2) identification of any significant or potentially significant adverse impacts of the proposed project; 3) analysis of reasonable alternatives to the project and mitigation measures to avoid or reduce any significant or potentially significant adverse environmental impacts; and 4) analysis of the reasonably foreseeable methods of compliance (Cal. Code Regs., tit. 23, § 3777, subd. (b)).

The environmental impact analysis evaluates the reasonably foreseeable environmental impacts of the implementation measures identified in the Implementation Plan (see Section 12). Specific implementation projects, such as wetland restorations or large-scale water management improvements at duck clubs may require additional CEQA analysis.

Overall, these analyses indicate that project will benefit the environment. It is not expected to have significant adverse impacts on the environment and will not cause immediate, large scale expenditures by the entities required to implement it. Although the precise implementation actions parties will use to achieve the objectives are not known at this time, the Checklist evaluates potential impacts from measures that are readily implementable, low-impact, and effective. They are generally consistent with the actions and recommendations of the 2014 Suisun Marsh Habitat Management, Preservation and Restoration Plan (SMP) and its programmatic EIS/EIR, which details and evaluates baseline conditions and the recommended managed wetlands activities (e.g., Table 2-5 in the EIS/EIR; SMP 2014) that have been initiated in Suisun Marsh, and comprises the analysis of impacts and mitigation measures. All potential adverse impacts of these activities, albeit small, had been already accounted for under the proposed mitigation measures.

These reasonable foreseeable methods of compliance with the proposed TMDL are not expected to significantly impact the environment.

Project Description and Objectives

The project would establish site-specific water quality objectives for DO in Suisun Marsh sloughs, extend water quality objectives for mercury to Suisun Marsh, establish a Total Maximum Daily Load (TMDL) and an Implementation Plan designed to achieve these objectives. The purpose of the TMDL is to achieve the narrative and numeric water quality objectives, to reduce occurrences of anthropogenically induced low DO in Suisun Marsh sloughs, reduce methylation and bioaccumulation of mercury, and thereby protect the beneficial uses of these waterbodies. The project objectives are:

- Update the Basin Plan to incorporate the site-specific water quality objectives for DO considering species-specific DO requirements and types and life stages of fish and aquatic organisms present in Suisun Marsh, and calculated based on the best available scientific information.
- Extend mercury objectives already applicable to San Francisco and Suisun Bays to Suisun Marsh;
- Protect the overall aquatic health beneficial uses and enhance its aesthetic and recreational values;

- Comply with the CWA requirement to adopt a TMDL for Section 303(d)-listed water bodies;
- Set numeric targets for DO reflecting the natural marsh conditions and protective of the most sensitive beneficial uses;
- Attain DO objectives as quickly as feasible;
- Achieve the numeric targets and attain water quality standards by maximizing use of existing regulatory tools and implementing non-structural BMPs at managed wetlands on a voluntary basis.

Reasonable Foreseeable Methods of Compliance

The TMDL Implementation Plan (Sections 12.1 through 12.4) identifies the tasks and the schedule necessary to achieve compliance with the numeric targets, which are the same as the proposed water quality objectives. The candidate water quality control measures necessary to meet the TMDL targets and a BMP effectiveness and water quality monitoring program are currently implemented in the western portion of the marsh under the U.S. EPA grant, the Suisun Marsh Managed Wetland BMP Water Quality Improvement Pilot Project. The BMPs, which modify water and vegetation management at managed wetlands, are designed to use the existing infrastructure and scheduled maintenance activities to enhance water quality and existing managed wetland values, tidal habitats, endangered species habitats, and levee integrity. All measures proposed in the TMDL are consistent with existing local, regional, and statewide regulations. The cumulative effects of potential implementation actions are also discussed in Section 13.3.4. Possible implementation actions are listed in Table 12-2.

14.3.1 Environmental Checklist

The Water Board has based its Environmental Analysis on the Checklist and sample questions found in Appendix G of the CEQA Guidelines (14 Cal. Code Regs. Appendix G). The Checklist and the discussion that follows evaluate the environmental impacts of the TMDL implementation activities listed in Table 12-2. Some TMDL implementation activities solely involve planning or assessment, and water quality monitoring. These activities are not evaluated in the Environmental Analysis because they do not result in direct or reasonably foreseeable indirect physical changes in the environment.

ENVIRONMENTAL CHECKLIST

Project Title:	Basin Plan Amendment to Establish Water Quality Objectives and Total Maximum Daily Load (TMDL) for Dissolved Oxygen/Organic Enrichment in Suisun Marsh Sloughs and to Add Suisun Marsh to San Francisco Bay Mercury TMDL
2. Lead Agency Name and Address:	California Regional Water Quality Control Board San Francisco Bay Region 1515 Clay Street, Suite 1400 Oakland, California 94612
3. Contact Person and Phone:	Barbara Baginska, (510) 622-2474
4. Project Locations:	Suisun Marsh, California
5. Project Sponsor's Name & Address:	California Regional Water Quality Control Board San Francisco Bay Region 1515 Clay Street, Suite 1400 Oakland, California 94612
6. General Plan Designation:	Not Applicable
7. Zoning:	Not Applicable

8. Description of Project:

The project is a Basin Plan amendment to revise the existing water quality objectives for dissolved oxygen in Suisun Marsh sloughs, the provisions to implement these objectives, to establish a concentration-based TMDL for dissolved oxygen/organic enrichment, and to extend the San Francisco Bay Mercury TMDL to Suisun Marsh.

9. Surrounding Land Uses and Setting:

Suisun Marsh is a mosaic of tidal, seasonal and managed wetland habitat at the center of the San Francisco Bay-Delta Estuary. The Marsh is bounded to the west, north and east by hills and to the south by Suisun, Grizzly, and Honker Bays. Montezuma Slough, the largest slough in the marsh, runs from east to west between the Sacramento-San Joaquin Delta and Suisun Bay. Major sloughs draining to Montezuma Slough are Denverton and Nurse sloughs. The second largest slough in the area is Suisun Slough, which divides the marsh into eastern and western portions. Tributaries to Suisun Slough include Cordelia, Goodyear, and several small dead-end sloughs in the northwestern portion of the marsh (Figure 8-1). The managed wetlands of Suisun Marsh are managed specifically for nesting and wintering waterfowl and, together with the tidal marshes, provide important habitat for resident and migratory waterfowl and shorebirds, and other native and special-status wildlife. Urban and agricultural areas are found adjacent to the marsh.

10. Other public agencies whose approval is required:

The State Water Board, the California Office of Administrative Law, and the U.S. EPA must approve the Basin Plan amendment following adoption by the Water Board.

11. Have California Native American tribes traditionally and culturally affiliated with the project area requested consultation pursuant to Public Resources Code section 21080.3.1? If so, has consultation begun?

California Native American tribes in the project area were informed about the project but did not request consultation pursuant to Public Resources Code section 21080.3.1.

ENVIRONMENTAL FACTORS POTENTIALLY AFFECTED:

We have determined that the project would not have any significant adverse impacts on the environment; hence, there are no physical, biological, social and/or economic factors that might be affected by the proposed project. Please see Section 14.3.3 for additional explanation.

☐	Aesthetics	☐	Agriculture and Forestry	☐	Air Quality
☐	Biological Resources	☐	Cultural Resources	☐	Geology/Soils
☐	Greenhouse Gas Emissions	☐	Hazards and Hazardous Materials	☐	Hydrology/Water Quality
☐	Land Use/Planning	☐	Mineral Resources	☐	Noise
☐	Population/Housing	☐	Public Services	☐	Recreation
☐	Transportation/Traffic	☐	Tribal Cultural Resources	☐	Utilities/Service Systems
☐	Mandatory Findings of Significance				

This checklist identifies physical, biological, social and economic factors that might be affected by the proposed project. In many cases, studies performed in connection with the project indicate no impacts. A NO IMPACT answer in the last column reflects this determination. A clarifying discussion is included either following the applicable section of the checklist or is within the body of the document itself. The words "significant" and "significance" used throughout the following checklist are related to CEQA. The questions in this form are intended to encourage the thoughtful assessment of impacts and do not represent thresholds of significance.

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
I. AESTHETICS: Would the project:				
a) Have a substantial adverse effect on a scenic vista?	☐	☐	☐	☒
b) Substantially damage scenic resources, including, but not limited to, trees, rock outcroppings, and historic buildings within a state scenic highway?	☐	☐	☐	☒
c) Substantially degrade the existing visual character or quality of the site and its surroundings?	☐	☐	☐	☒
d) Create a new source of substantial light or glare which would adversely affect day or nighttime views in the area?	☐	☐	☐	☒
II. AGRICULTURE AND FOREST RESOURCES: In determining whether impacts to agricultural resources are significant environmental effects, lead agencies may refer to the California Agricultural Land Evaluation and Site Assessment Model (1997) prepared by the California Dept. of Conservation as an optional model to use in assessing impacts on agriculture and farmland. In determining whether impacts to forest resources, including timberland, are significant environmental effects, lead agencies may refer to information compiled by the California Department of Forestry and Fire Protection regarding the state's inventory of forest land, including the Forest and Range Assessment Project and the Forest Legacy Assessment Project; and the forest carbon measurement methodology provided in Forest Protocols adopted by the California Air Resources Board. Would the project:				
a) Convert Prime Farmland, Unique Farmland, or Farmland of Statewide Importance (Farmland), as shown on the maps prepared pursuant to the Farmland Mapping and Monitoring Program of the California Resources Agency, to non-agricultural use?	☐	☐	☐	☒
b) Conflict with existing zoning for agricultural use, or a Williamson Act contract?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
c) Conflict with existing zoning for, or cause rezoning of, forest land (as defined in Public Resources Code section 12220(g)), timberland (as defined by Public Resources Code section 4526), or timberland zoned Timberland Production (as defined by Government Code section 51104(g))?	☐	☐	☐	☒
d) Result in the loss of forest land or conversion of forest land to non-forest use?	☐	☐	☐	☒
e) Involve other changes in the existing environment which, due to their location or nature, could result in conversion of Farmland, to non-agricultural use or conversion of forest land to non-forest use?	☐	☐	☐	☒
III. AIR QUALITY: Where available, the significance criteria established by the applicable air quality management or air pollution control district may be relied upon to make the following determinations. Would the project:				
a) Conflict with or obstruct implementation of the applicable air quality plan?	☐	☐	☐	☒
b) Violate any air quality standard or contribute substantially to an existing or projected air quality violation?	☐	☐	☐	☒
c) Result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non- attainment under an applicable federal or state ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors)?	☐	☐	☐	☒
d) Expose sensitive receptors to substantial pollutant concentrations?	☐	☐	☐	☒
e) Create objectionable odors affecting a substantial number of people?	☐	☐	☐	☒
IV. BIOLOGICAL RESOURCES: Would the project:				
a) Have a substantial adverse effect, either directly or through habitat modifications, on any species identified as a candidate, sensitive, or special status species in local or regional plans, policies, or regulations, or by the California Department of Fish and Game or U.S. Fish and Wildlife Service?	☐	☐	☐	☒
b) Have a substantial adverse effect on any riparian habitat or other sensitive natural community identified in local or regional plans, policies, regulations or by the California Department of Fish and Game or US Fish and Wildlife Service?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
c) Have a substantial adverse effect on federally protected wetlands as defined by Section 404 of the Clean Water Act (including, but not limited to, marsh, vernal pool, coastal, etc.) through direct removal, filling, hydrological interruption, or other means?	☐	☐	☐	☒
d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites?	☐	☐	☐	☒
e) Conflict with any local policies or ordinances protecting biological resources, such as a tree preservation policy or ordinance?	☐	☐	☐	☒
f) Conflict with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved local, regional, or state habitat conservation plan?	☐	☐	☐	☒
V. CULTURAL RESOURCES: Would the project:				
a) Cause a substantial adverse change in the significance of a historical resource as defined in §15064.5?	☐	☐	☐	☒
b) Cause a substantial adverse change in the significance of an archaeological resource pursuant to §15064.5?	☐	☐	☐	☒
c) Directly or indirectly destroy a unique paleontological resource or site or unique geologic feature?	☐	☐	☐	☒
d) Disturb any human remains, including those interred outside of dedicated cemeteries?	☐	☐	☐	☒
VI. GEOLOGY AND SOILS: Would the project:				
a) Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:	☐	☐	☐	☒
i) Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault? Refer to Division of Mines and Geology Special Publication 42?	☐	☐	☐	☒
ii) Strong seismic ground shaking?	☐	☐	☐	☒
iii) Seismic-related ground failure, including liquefaction?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
iv) Landslides?	☐	☐	☐	☒
b) Result in substantial soil erosion or the loss of topsoil?	☐	☐	☐	☒
c) Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse?	☐	☐	☐	☒
d) Be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property?	☐	☐	☐	☒
e) Have soils incapable of adequately supporting the use of septic tanks or alternative waste water disposal systems where sewers are not available for the disposal of waste water?	☐	☐	☐	☒
VII. GREENHOUSE GAS EMISSIONS: Would the project:				
a) Generate greenhouse gas emissions, either directly or indirectly, that may have a significant impact on the environment?	☐	☐	☐	☒
b) Conflict with an applicable plan, policy or regulation adopted for the purpose of reducing the emissions of greenhouse gases?	☐	☐	☐	☒
VIII. HAZARDS AND HAZARDOUS MATERIALS: Would the project:				
a) Create a significant hazard to the public or the environment through the routine transport, use, or disposal of hazardous materials?	☐	☐	☐	☒
b) Create a significant hazard to the public or the environment through reasonably foreseeable upset and accident conditions involving the release of hazardous materials into the environment?	☐	☐	☐	☒
c) Emit hazardous emissions or handle hazardous or acutely hazardous materials, substances, or waste within one-quarter mile of an existing or proposed school?	☐	☐	☐	☒
d) Be located on a site which is included on a list of hazardous materials sites compiled pursuant to Government Code Section 65962.5 and, as a result, would it create a significant hazard to the public or the environment?	☐	☐	☐	☒
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project result in a safety hazard for people residing or working in the project area?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
f) For a project within the vicinity of a private airstrip, would the project result in a safety hazard for people residing or working in the project area?	☐	☐	☐	☒
g) Impair implementation of or physically interfere with an adopted emergency response plan or emergency evacuation plan?	☐	☐	☐	☒
h) Expose people or structures to a significant risk of loss, injury or death involving wildland fires, including where wildlands are adjacent to urbanized areas or where residences are intermixed with wildlands?	☐	☐	☐	☒

IX. HYDROLOGY AND WATER QUALITY: Would the project:

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
a) Violate any water quality standards or waste discharge requirements?	☐	☐	☐	☒
b) Substantially deplete groundwater supplies or interfere substantially with groundwater recharge such that there would be a net deficit in aquifer volume or a lowering of the local groundwater table level (e.g., the production rate of pre-existing nearby wells would drop to a level which would not support existing land uses or planned uses for which permits have been granted)?	☐	☐	☐	☒
c) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, in a manner which would result in substantial erosion or siltation on- or off-site?	☐	☐	☐	☒
d) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, or substantially increase the rate or amount of surface runoff in a manner which would result in flooding on- or off-site?	☐	☐	☐	☒
e) Create or contribute runoff water which would exceed the capacity of existing or planned stormwater drainage systems or provide substantial additional sources of polluted runoff?	☐	☐	☐	☒
f) Otherwise substantially degrade water quality?	☐	☐	☐	☒
g) Place housing within a 100-year flood hazard area as mapped on a federal Flood Hazard Boundary or Flood Insurance Rate Map or other flood hazard delineation map?	☐	☐	☐	☒
h) Place within a 100-year flood hazard area structures which would impede or redirect flood flows?	☐	☐	☐	☒
i) Expose people or structures to a significant risk of loss, injury or death involving flooding, including flooding as a result of the failure of a levee or dam?	☐	☐	☐	☒
j) Inundation by seiche, tsunami, or mudflow	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
X. LAND USE AND PLANNING: Would the project:				
a) Physically divide an established community?	☐	☐	☐	☒
b)Conflict with any applicable land use plan, policy, or regulation of an agency with jurisdiction over the project (including, but not limited to the general plan, specific plan, local coastal program, or zoning ordinance) adopted for the purpose of avoiding or mitigating an environmental effect?	☐	☐	☐	☒
c) Conflict with any applicable habitat conservation plan or natural community conservation plan?	☐	☐	☐	☒
XI. MINERAL RESOURCES: Would the project:				
a) Result in the loss of availability of a known mineral resource that would be of value to the region and the residents of the state?	☐	☐	☐	☒
b) Result in the loss of availability of a locally-important mineral resource recovery site delineated on a local general plan, specific plan or other land use plan?	☐	☐	☐	☒
XII. NOISE: Would the project result in:				
a) Exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies?	☐	☐	☐	☒
b) Exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels?	☐	☐	☐	☒
c) A substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☐	☐	☒
d) A substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☐	☐	☒
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project expose people residing or working in the project area to excessive noise levels?	☐	☐	☐	☒
f) For a project within the vicinity of a private airstrip, would the project expose people residing or working in the project area to excessive noise levels?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
XIII. POPULATION AND HOUSING: Would the project:				
a) Induce substantial population growth in an area, either directly (for example, by proposing new homes and businesses) or indirectly (for example, through extension of roads or other infrastructure)?	☐	☐	☐	☒
b) Displace substantial numbers of existing housing, necessitating the construction of replacement housing elsewhere?	☐	☐	☐	☒
c) Displace substantial numbers of people, necessitating the construction of replacement housing elsewhere?	☐	☐	☐	☒
XIV. PUBLIC SERVICES:				
a) Would the project result in substantial adverse physical impacts associated with the provision of new or physically altered governmental facilities, need for new or physically altered governmental facilities, the construction of which could cause significant environmental impacts, in order to maintain acceptable service ratios, response times or other performance objectives for any of the public services:				
Fire protection?	☐	☐	☐	☒
Police protection?	☐	☐	☐	☒
Schools?	☐	☐	☐	☒
Parks?	☐	☐	☐	☒
Other public facilities?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
XV. RECREATION:				
a) Would the project increase the use of existing neighborhood and regional parks or other recreational facilities such that substantial physical deterioration of the facility would occur or be accelerated?	☐	☐	☐	☒
b) Does the project include recreational facilities or require the construction or expansion of recreational facilities which might have an adverse physical effect on the environment?	☐	☐	☐	☒
XVI. TRANSPORTATION/TRAFFIC: Would the project:				
a) Conflict with an applicable plan, ordinance or policy establishing measures of effectiveness for the performance of the circulation system, taking into account all modes of transportation including mass transit and non-motorized travel and relevant components of the circulation system, including but not limited to intersections, streets, highways and freeways, pedestrian and bicycle paths, and mass transit?	☐	☐	☐	☒
b) Conflict with an applicable congestion management program, including, but not limited to level of service standards and travel demand measures, or other standards established by the county congestion management agency for designated roads or highways?	☐	☐	☐	☒
c) Result in a change in air traffic patterns, including either an increase in traffic levels or a change in location that results in substantial safety risks?	☐	☐	☐	☒
d) Substantially increase hazards due to a design feature (e.g., sharp curves or dangerous intersections) or incompatible uses (e.g., farm equipment)?	☐	☐	☐	☒
e) Result in inadequate emergency access?	☐	☐	☐	☒
f) Conflict with adopted policies, plans or programs regarding public transit, bicycle, or pedestrian facilities, or otherwise decrease the performance or safety of such facilities?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation Incorporated	Less Than Significant Impact	No Impact
XVII. TRIBAL CULTURAL RESOURCES: Would the project cause a substantial adverse change in the significance of a tribal cultural resource, defined in Public Resources Code section 21074 as either a site, feature, place, cultural landscape that is geographically defined in terms of the size and scope of the landscape, sacred place, or object with cultural value to a California Native American tribe, and that is:				
a) Listed or eligible for listing in the California Register of Historical Resources, or in a local register of historical resources as defined in Public Resources Code section 5020.1(k), or	☐	☐	☐	☒
b) A resource determined by the lead agency, in its discretion and supported by substantial evidence, to be significant pursuant to criteria set forth in subdivision (c) of Public Resources Code Section 5024.1. In applying the criteria set forth in subdivision (c) of Public Resource Code Section 5024.1, the lead agency shall consider the significance of the resource to a California Native American tribe.	☐	☐	☐	☒
XVIII. UTILITIES AND SERVICE SYSTEMS: Would the project:				
a) Exceed wastewater treatment requirements of the applicable Regional Water Quality Control Board?	☐	☐	☐	☒
b) Require or result in the construction of new water or wastewater treatment facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?	☐	☐	☐	☒
c) Require or result in the construction of new storm water drainage facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?	☐	☐	☐	☒
d) Have sufficient water supplies available to serve the project from existing entitlements and resources, or are new or expanded entitlements needed?	☐	☐	☐	☒
e) Result in a determination by the wastewater treatment provider which serves or may serve the project that it has adequate capacity to serve the project's projected demand in addition to the provider's existing commitments?	☐	☐	☐	☒
f) Be served by a landfill with sufficient permitted capacity to accommodate the project's solid waste disposal needs?	☐	☐	☐	☒
g) Comply with federal, state, and local statutes and regulations related to solid waste?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
XIX. MANDATORY FINDINGS OF SIGNIFICANCE				
a) Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, substantially reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of California history or prehistory?	☐	☐	☐	☒
b) Does the project have impacts that are individually limited, but cumulatively considerable? ("Cumulatively considerable" means that the incremental effects of a project are considerable when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects)?	☐	☐	☐	☒
c) Does the project have environmental effects which will cause substantial adverse effects on human beings, either directly or indirectly?	☐	☐	☐	☒

14.3.2 Environmental Checklist Discussion

The analysis of potential environmental impacts is based on the foreseeable methods of compliance available to improve dissolved oxygen conditions in Suisun Marsh sloughs, and the level of significance is based on the current conditions.

The proposed project will not have any significant adverse impacts on the environment. The proposed site-specific objectives are fully protective of the most sensitive beneficial uses, as fully explained throughout the Staff Report and the TMDL, which implements the objectives.

The managed wetland activities related to the improvements, maintenance and repairs of levees, and to construction, cleaning and maintenance of pipes, water structures and interior ditches, could also contribute to improving water quality despite the fact that they may result in short-term minor impacts. However, these activities have not been identified as direct candidate control measures in the Implementation Plan, and are not evaluated as part of this analysis because they represent activities already considered by the environmental analysis conducted for the SMP EIS/EIR.

An explanation for each box checked on the Environmental Checklist is provided below:

I. Aesthetics

Physical changes to the aesthetic environment as a result of the Basin Plan amendment are expected to be minimal, such as changes to management of vegetation, or temporary, as well as limited to the interior areas of the managed wetlands. Such actions would not degrade the existing visual character or quality of the marsh or its surroundings and would not create any new source of light or glare. Actions or projects implemented would not occur near a designated state scenic highway, and, therefore, would not result in adverse aesthetic impacts to state scenic highways.

II. Agriculture and Forest Resources

The proposed Basin Plan amendment and implementation actions would not result in any changes to agricultural resources and would not contribute to conversion of farmland to non-agricultural use since there is no row crop agriculture in Suisun Marsh. It would not affect agricultural zoning or any Williamson Act contract, and would not have any adverse impact in this regard because Suisun Marsh is zoned as marsh.

III. Air Quality

The proposed Basin Plan amendment will not have adverse impacts on air quality because it will not cause any change in population or employment, ongoing traffic-related emissions, or require any large-scale contruction. The Basin Plan amendment would not conflict with applicable air quality plans. It would not expose sensitive receptors to ongoing pollutant emissions and therefore would not pose health risks nor create objectionable odors.

IV. Biological Resources

The amendment is designed to protect and enhance biological resources, including aquatic organisms, wildlife and rare and endangered species. Although the proposed site--specific water quality objectives for dissolved oxygen are lower than those established for the tidal waters of San Francisco Bay (upstream of Carquinez Bridge) water quality and hydrologic conditions in the sloughs in Suisun Marsh naturally have lower DO levels than open, tidal waters of Suisun Bay. The DO objectives were derived to protect all ecologically relevant species present in Suisun Marsh, including threatened and endangered species like salmonids and green sturgeon. Compliance with the DO objectives will have the added benefit of limiting mercury methylation, which will reduce health risks for fish, wildlife, and humans. Accordingly, the proposed Basin Plan amendment will not degrade the quality of the environment, substantially reduce fish or wildlife habitat, cause fish or wildlife populations to drop below self-sustaining levels, or threaten to eliminate a plant or animal community.

The recommended BMPs to improve DO conditions are predominantly non-structural BMPs, and therefore they would not have a substantial adverse effect, either directly or indirectly, on any species listed as a candidate, sensitive, or special status species in local or regional plans, policies, or regulations, or identified by the CDFW or USFWS. Implementation of the proposed action would not result in the physical alteration of a natural environment such that there would be any adverse effects on federally-or State-listed species. The proposed action would not conflict with any Habitat Conservation Plans, Natural Community Conservation Programs, or local policies designed to protect biological resources. The project would not result in a depletion of biodiversity in aquatic and riparian habitats near the project area.

V. Cultural Resources

This proposed Basin Plan amendment is not expected to have an impact on cultural resources, because implementation actions would not involve construction in areas with known cultural resources, changes to, or demolition of historic structures.

Likely TMDL implementation actions by municipalities to control mercury or manage DO, such as creation of green infrastructure or placement of stormwater treatment structures, would include only minor construction in existing roadways and stormwater facilities and would not require changes to historic buildings or structures.

VI. Geology and Soils

Implementation of best management practices as recommended under the proposed Implementation Plan, and as necessary to comply with the water quality objectives and the TMDL targets, would not require construction of habitable structures or lead to an increase in population. Therefore, implementation actions would not create or increase any human safety risks related to fault rupture, seismic ground-shaking, ground failure, or landslides. The activities would be limited to the interior areas of managed wetlands, which are flat, and would not result in soil erosion or instability. These activities would be limited by both volume and geographic location, thus minimizing any potential risks even further. There would be no impacts from septic tanks or alternative wastewater disposal systems from the project.

VII. Greenhouse Gas Emissions

This proposed Basin Plan amendment is not expected to generate significant greenhouse gas emissions, because it would not result in any construction projects or otherwise cause direct or indirect change in the environment. Implementation of non-structural vegetation and water management BMPs may result in incidental GHG emissions.

VIII. Hazards and Hazardous Materials

The proposed establishment of site-specific DO objectives and extension of the Mercury TMDL to Suisun Marsh is designed to improve water quality in the marsh, specifically to minimize exposure of humans and wildlife to harmful methylmercury. Anticipated implementation actions to increase dissolved oxygen are also expected to reduce mercury methylation and thereby reduce bioaccumulation of mercury in fish, wildlife, and humans. Control actions by Fairfield, Suisun City, and the Fairfield-Suisun Sanitary District to reduce mercury levels in discharges are already required by the Mercury Watershed Permit (R2-2017-0041) and by the Municipal Stormwater Permit; therefore, implementation of this TMDL is not expected to increase transport, use, disposal, handling, or emissions of hazardous materials. The project would not interfere with any emergency response plans or emergency evacuation plans, and would not affect the potential for wildland fires or expose people or structures to an increased risk from wildland fires.

Although there is one site within Suisun Marsh of approximately 0.3 acres identified on the hazardous waste and substance material sites list, implementation of this TMDL will not affect this site, which is capped with concrete and surrounded by a chain-linked fence. Accordingly, this project to create a Suisun Marsh TMDL will have no impact relating to hazardous materials.

IX. Hydrology and Water Quality

This project is intended to improve water quality in Suisun Marsh sloughs and enhance fish and wildlife habitat. The proposed TMDL and the revised DO objectives will have beneficial impact on water quality, as changes to water management at the managed wetlands will minimize occurrences of low DO conditions in the adjacent sloughs, which, in turn, will ensure that sloughs meet water quality objectives, and that beneficial uses are protected and restored. The implementation actions listed in Table 12-2 would not result in violations of water quality standards or waste discharge requirements.

The candidate non-structural BMPs would not affect groundwater supplies, substantially alter the existing drainage pattern, contribute additional runoff or interfere with the conveyance of urban storm water. Suisun Marsh is designated as a resource conservation area and managed specifically for nesting wintering waterfowl, and to provide habitat for a variety of resident and migratory waterfowl, shorebirds and other native and special-status species. Therefore, no new housing would be considered or constructed because of this project. The Implementation Plan encourages early implementation of the readily available, low-cost, non-structural BMPs, which have already demonstrated a positive effect on the environment and water quality.

X. Land Use and Planning

The Basin Plan amendment regulates water quality, would not result result in development of any structures or physical facilities, and would therefore not physically divide an established community. Long-term implementation actions could include conversion of managed wetlands to tidal marsh; however, any such proposed conversions would be completed in accordance with the Bay-Delta Conservation Plan, the Suisun Marsh Protection Plan, applicable Habitat Conservation Plans or Natural Community Conservation Plans, as well as local, State, and federal land use policies. Actions are all in line with the Suisun Marsh Restoration Plan.

XI. Mineral Resources

No mineral resources would be affected by the proposed action.

XII. Noise

The Basin Plan amendment regulates water quality and would not directly cause any change or increase in noise levels.

XIII. Population and Housing

The Basin Plan amendment will not have any impact on housing and will not affect the population of Suisun Marsh. The project will not induce growth through such means as construction of new housing or businesses, or by extending roads or infrastructure. Suisun Marsh is designated as a resource conservation area, therefore, no new housing would be considered because of the project. The very limited housing that exists in

Suisun Marsh and its population would not be displaced and no replacement housing would be necessary.

XIV. Public Services

The Basin Plan amendment would not affect populations or involve construction or substantial alteration of government facilities. The Basin Plan amendment would not affect service ratios, response times, or other performance objectives for any public services, including fire protection, police protection, schools, or parks.

XV. Recreation

The Basin Plan amendment regulates water quality and would not directly affect recreational activities. Implementation of vegetation and water management BMPs at duck clubs is not expected to have any effect on the duck hunting experience. By improving water quality, the proposed project would enhance and protect the environmental value and recreational resources of Suisun Marsh. In particular, ensuring higher DO levels will help sport fish populations thrive, while reducing mercury methylation will help reduce exposure of recreational and subsistence fishers to mercury.

XVI. Transportation / Traffic

The Basin Plan amendment would not increase population or provide employment, it would not affect transportation facilities or generate any additional traffic. Nor would the proposed action change any policy, plan, or program.

XVII. Tribal Cultural Resources

Implementation of the Basin Plan amendment is not expected to affect or change any Tribal cultural resources because it will not involve construction, development, or other changes to the marsh landscape. Implementation will not affect sites listed on the state or federal register of historic places. Pursuant to AB 52, the Water Board notified Tribal organizations affiliated with Solano County of the project, but received no requests for consultations.

XVIII. Utilities and Service Systems

Since the Basin Plan amendment would not affect water demands or supplies, the project would not exceed wastewater treatment requirements or result in construction or expansion of the wastewater treatment facilities or stormwater drainage facilities. The proposed Basin Plan amendment would have no impacts on utilities or service systems.

XIX. Mandatory Findings of Significance

The proposed Basin Plan amendment is intended to restore and enhance water quality and protect biological resources, including fish, wildlife, and rare and endangered species in Suisun Marsh. The proposed DO objectives and the TMDL are designed specifically to benefit fish and wildlife species by increasing DO levels in the sloughs, and by preventing occurrences of low DO conditions, which in the past had led to fish kills. The DO objectives were derived to protect sensitive species and life stages present in Suisun Marsh including threatened and endangered species such as salmonids. In addition, actions to raise DO are also expected to limit mercury methylation, thereby reducing mercury bioaccumulating in fish and wildlife. Therefore, the proposed water quality objectives and Implementation Plan will protect all beneficial uses of the marsh and will not degrade the quality of the environment, substantially reduce fish or wildlife habitat, cause fish or wildlife population to drop below self-sustaining levels or threaten to eliminate a plant or animal community.

Moreover, the TMDL's monitoring provisions and the Water Board's adaptive management approach to implementation provide additional safeguards and guarantees that future implementation of the Basin Plan amendment will be carried out in ways that enhance, and do not degrade, the quality of the environment in the marsh.

Furthermore, the project does not have impacts that are individually limited, but cumulatively considerable. In fact, coordination of implementation of BMPs among multiple duck clubs will reduce, rather than increase, the impacts of low dissolved oxygen.

The Basin Plan amendment will not adversely affect people, either directly or indirectly. To the contrary, achievement of water quality objectives is expected to support healthy fish populations, reduce bioaccumulation of mercury in sportfish, and enhance aesthetic attributes and recreational opportunities within the marsh sloughs. All of these effects will benefit people using the marsh for recreation orr subsistence directly.

14.3.3 Potential Cumulative Impacts

This Basin Plan amendment is specifically designed to improve DO conditions and envance habitat values and beneficial uses in the marsh sloughs. The cumulative impact here is the overall positive change in the environment from coordinated actions to improve water quality in the marsh. As shown in the Environmental Checklist, there are no potentially significant environmental impacts from the implementation of this Basin Plan amendment, and the project is consistent with the SMP and its programmatic EIS/EIR (SMP 2014), where the regional and cumulative impacts have already been adequately addressed.

For this reason, the adoption of the Basin Plan amendment does not require further evaluation of cumulative effects.

14.4. CONSIDERATION OF ALTERNATIVES

As explained in this report, the proposed project would not result in any significant adverse impacts on the environment and would not cause any reasonably foreseeable indirect physical changes; therefore, alternatives beyond the No Project alternative are not explored.

Though an alternative analysis is not needed to lessen or mitigate impacts, we provide a discussion of the No Project alternative to illustrate that the proposed project would be environmentally beneficial.

Alternative: No Project

Under this alternative, the Water Board would not amend the Basin Plan to establish the following: revised water quality objectives for DO in Suisun Marsh sloughs, a TMDL designed to achieve these objectives, and an Implementation Plan. The purpose of the TMDL is to achieve DO objectives, prevent fish kills and reduce occurrences of anthropogenically induced low DO in Suisun Marsh sloughs, thereby protecting beneficial uses of these waterbodies. The No Project alternative would not meet the project objective to update the Basin Plan to incorporate the site-specific water quality objectives for DO representing the best available scientific information. Nor would it increase the likelihood of water quality protection or restoration of the impaired beneficial uses in Suisun Marsh sloughs. The inaccuracies in the existing DO objectives would not be corrected, and fish kills might continue to occur.

The implementation would also be limited to actions from responsible parties engaged in land use activities that are currently covered by State or Regional Water Board permits. The No Project approach would potentially allow some dischargers to continue to engage in activities that discharge low DO waters without a regulatory oversight, which, in turn, will likely result in the non-attainment of water quality standards. In addition, federal and state implementation grants and other funding sources are typically only available for projects located in watersheds that have an approved TMDL or some other effective watershed-scale management plan in place.

The No Project alternative would not set targets, and it would not ensure that monitoring would continue to demonstrate the achievement of those targets. It would potentially result in economic impacts of unnecessary enforcement, or lead to significant burden of developing a large number (over a hundred) of individual permits to help control water quality in the sloughs.

Thus, the No Project alternative would not meet the objective to ensure ongoing protection of existing water quality, prevent fish kills or low DO induced recruitment impacts to aquatic organisms in Suisun Marsh.

Preferred Alternative

The proposed Basin Plan amendment meets all the project objectives and will not result in any significant adverse environmental impacts. The alternative does not meet all the project objectives and is not environmentally superior. Therefore, the proposed Basin Plan amendment is the preferred alternative.

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APPENDIX A: SUMMARY OF DATA USED IN THE REPORT

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1. DO Concentrations in Suisun Marsh								
Site	**Location**	**Record Period**	**Frequency**	**Mean**	**SD**	**Min**	**Max**	**Source**
NZ032	Montezuma Slough, 2nd bend from mouth	1999–2007	Monthly	8.30	0.89	6.7	11.2	P. Moyle
MZ1	Montezuma Slough at Roaring	2000–2011	Monthly	4.34	3.55	0.1	13.8	P. Moyle
MZ2	Montezuma Slough at boat ramp	2000–2011	Monthly	4.47	3.51	0.1	13.55	P. Moyle
SU1	Suisun Slough seining beach	2000–2011	Monthly	4.28	3.75	0.3	75.9	P. Moyle
SU2	Suisun Slough- below Boynton Slough	2000–2011	Monthly	4.43	2.75	0.1	11	P. Moyle
SU3	Suisun Slough – above Cordelia Slough	2000–2011	Monthly	6.24	3.51	0.2	13.9	P. Moyle
SU4	Suisun Slough – below Cordelia Slough	2000–2011	Monthly	6.4	3.6	0.2	14.8	P. Moyle
S42	Suisun Slough 300’ south of Volanti Slough	1978–1985	Monthly	7.90	0.82	5.6	10	P. Moyle
GY1	Goodyear Slough – upper	2000–2011	Monthly	6.21	3	0.1	16	P. Moyle
GY2	Goodyear Slough - middle	2000–2011	Monthly	6.19	3.02	0.1	14	P. Moyle
GY3	Goodyear Slough – lower	2000–2011	Monthly	6.19	3.42	0.1	13.5	P. Moyle
BY1	Boynton Slough - upper	2000–2011	Monthly	3.29	2.53	0.1	11.2	P. Moyle
BY3	Boynton Slough – lower	2000–2011	Monthly	3.81	2.62	0.1	10.2	P. Moyle
PT1	Peytonia Slough – upper	2000–2011	Monthly	3.46	2.65	0.1	10.5	P. Moyle
PT2	Peytonia Slough – middle	2000–2011	Monthly	3.75	2.67	0.1	10.64	P. Moyle
CO1	Cutoff Slough –site 1	2000–2011	Monthly	7.38	1.36	4.30	10.90	P. Moyle
CO2	Cutoff Slough – site 2	2000–2011	Monthly	7.52	1.35	4.50	12.75	P. Moyle
DV2	Denverton Slough – middle	2000–2011	Monthly	7.13	1.54	3.50	11.80	P. Moyle
DV3	Denverton Slough - lower	2000–2011	Monthly	7.16	1.35	3.40	11.50	P. Moyle
NS2	Nurse Slough – middle	2000–2011	Monthly	7.90	1.37	3.50	11.80	P. Moyle
NS3	Nurse Slough – lower	2000–2011	Monthly	8.08	1.37	3.70	13.00	P. Moyle
SB1	Spring Branch – upper	2000–2011	Monthly	6.78	1.44	0.62	10.60	P. Moyle
SB2	Spring Branch – middle	2000–2011	Monthly	6.91	1.28	1.40	10.36	P. Moyle

2. FSSD Receiving Water Data					
Station	**Location**	**Record Period**	**Frequency**	**Parameters**	**Source**
C-1(RW1)	Boynton Slough, about 100 feet downstream from the discharge outfall	2005–2010	Seasonal	Temperature, DO, pH, secchi disk, salinity, turbidity, PO4, NO3, TKN, NH3, unionized NH3, organic N, chlorophyll a	FSSD receiving water study
C-2 (RW2)	Boynton Slough, about 100 feet downstream from Southern Pacific Railroad crossing	2005–2010	Seasonal		FSSD receiving water study
C-3 (RW3)	Boynton Slough, 1800 feet downstream from discharge outfall	2005–2010	Seasonal		FSSD receiving water study
C-4 (RW4)	Boynton Slough, in the mouth where it enters Suisun Slough	2005–2010	Seasonal		FSSD receiving water study
C-5 (RW5)	Mouth of Sheldrake Slough as it enters Suisun Slough	2005–2010	Seasonal		FSSD receiving water study
C-6 (RW6)	Peytonia Slough, in the mouth where it enters Suisun Slough	2005–2010	Seasonal		FSSD receiving water study
CR1 (RW7)	Peytonia Slough, about 100 feet downstream from railroad crossing	2005–2010	Seasonal		FSSD receiving water study
CR2 (RW8)	Chadbourne Slough, about 100 feet downstream from railroad crossing	2005–2010	Seasonal		FSSD receiving water study

3. Intensive DO monitoring in Sloughs					
Station	**Location**	**Record Period**	**Frequency**	**Parameters**	
PS-CWQ-1	Peytonia Slough	09/07–12/08	15 min	Intensive (15min) DO monitoring data	Siegel et al. 2011
BS-CWQ	Boynton Slough	09/07–12/08	15 min	Intensive (15min) DO monitoring data	Siegel et al. 2011
	Goodyear Slough	08/12–02/13	15 min	DO, temperature, specific conductivity, pH	Regional Water Board, 2013
	Denverton Slough	08/12–02/13	15 min	DO, temperature, specific conductivity, pH	Regional Water Board, 2013
	First Mallard Slough	05/08 – 05/14	15 min	DO	NOAA NERRS
	Second Mallard Slough	05/08-05/14	15 min	DO	NOAA NERRS

APPENDIX B: ASSESSMENT OF WATER QUALITY DATA: DISSOLVED OXYGEN AND NUTRIENTS

Prepared by Tetra Tech Inc., 2015

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Assessment of Water Quality Data: Dissolved Oxygen and Nutrients - *Prepared by Tetra Tech Inc., 2015*

DISSOLVED OXYGEN

Dissolved oxygen (DO) concentrations across Suisun Marsh are compared to the existing Basin Plan water quality objectives (Table B-1). For the present evaluation, larger sloughs in Suisun Marsh could be considered as tidal waters upstream of Carquinez Strait, and, therefore, the currently-applicable water quality standard for DO in the Basin Plan is 7 mg/L. However, it is recognized that the specific water quality impairments occur not in large, tidally-mixed open-water areas, but in small, poorly-mixed slough channels. The latter may require a different DO target, reflecting the natural mixing characteristics of these waters and their beneficial uses. An alternative DO target may be developed by evaluating reference sloughs with contributing watersheds in relatively natural conditions, and by evaluating the physiological requirements of organisms that are present in Suisun Marsh. This document presents an overview of DO levels in minimally impacted sloughs for comparison against all other locations in Suisun Marsh. Additional work, not presented here, is being performed by the Water Board to better define the DO requirements from a physiological standpoint. Together, both the reference and physiological approaches, as well the current Basin Plan requirements, will be used to define future DO targets for Suisun Marsh.

Table B-1
Existing Basin Plan water quality objectives for dissolved oxygen

Tidal Waters	DO [mg/L]	DO [% saturation][1]
Downstream of Carquinez Bridge	5.0 mg/L minimum	80%
Upstream of Carquinez Bridge (Suisun Marsh)	7. 0 mg/L minimum	80%

[1] median dissolved oxygen concentration for any three consecutive months

Dissolved Oxygen at Grab Sample Locations

Observed DO data were mainly collected by UC Davis in the fish study (P. Moyle, personal communication) and by the Bay Area Delta and Tributaries system compliance monitoring at stations in Montezuma Slough, Suisun Slough, Goodyear Slough, Boynton Slough, and Peytonia Slough. Locations of these monitoring stations are shown in Figure B-1.

DO concentrations observed at stations in Montezuma Slough are meeting the water quality objective of 7 mg/L most of the time, with only a few exceptions (about 8% of the time). Percent dissolved oxygen saturation in Montezuma Slough is occasionally lower than the 80% saturation (for about 20% of the time; Figure B-2; Table B-2). When compared to the 80% saturation criterion, a median value over every three-month period was calculated based on the bi-weekly data. Three stations in Suisun Slough (SU3, SU4, and SU42) showed DO concentrations above the criterion of 7 mg/L most of the time (Table B-2). DO concentrations in the upper reach of Suisun Slough (SU1 and SU2 below Boynton Slough) were below 7 mg/L nearly half of the time and were largely below the saturation objective (in excess of 80% of measurements) (Figure B-3). Percent DO saturation at SU3 and SU4 was mostly above 80% saturation with only a few exceptions.

DO concentrations measured at tributary sloughs showed exceedances of DO objectives for a significant percent of time, particularly in the upper and middle sections of Goodyear Slough (Figure B-4). Low DO concentrations usually occurred in late summer and fall months.

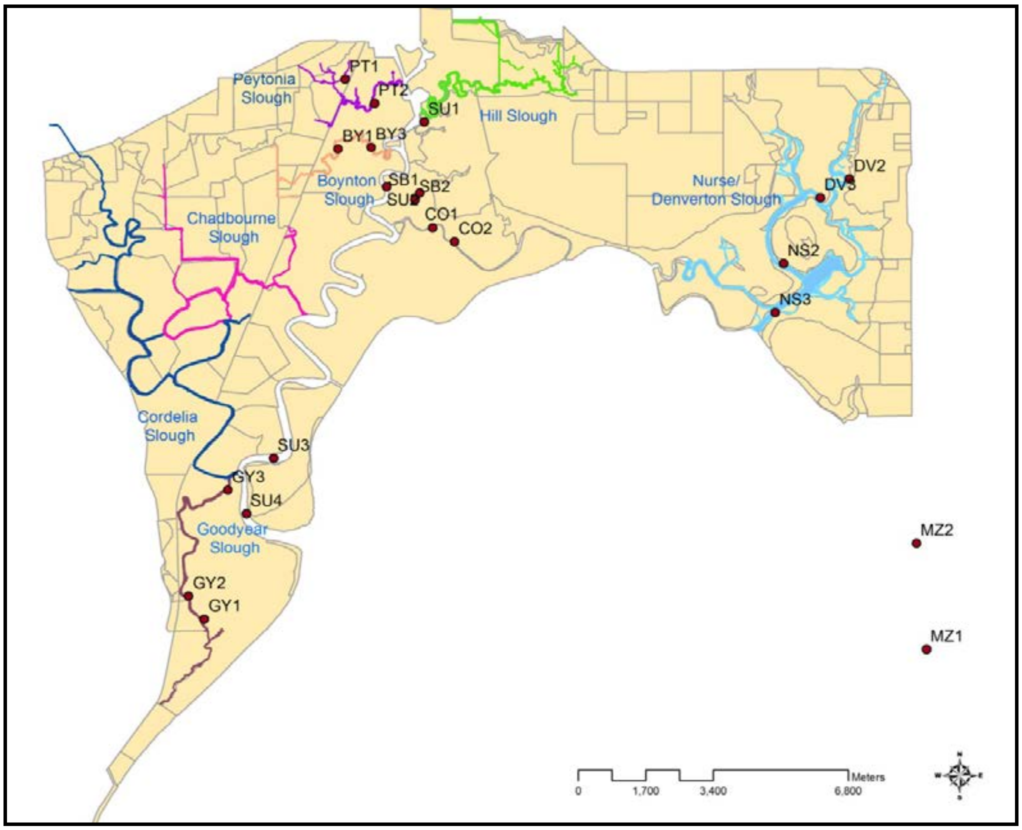
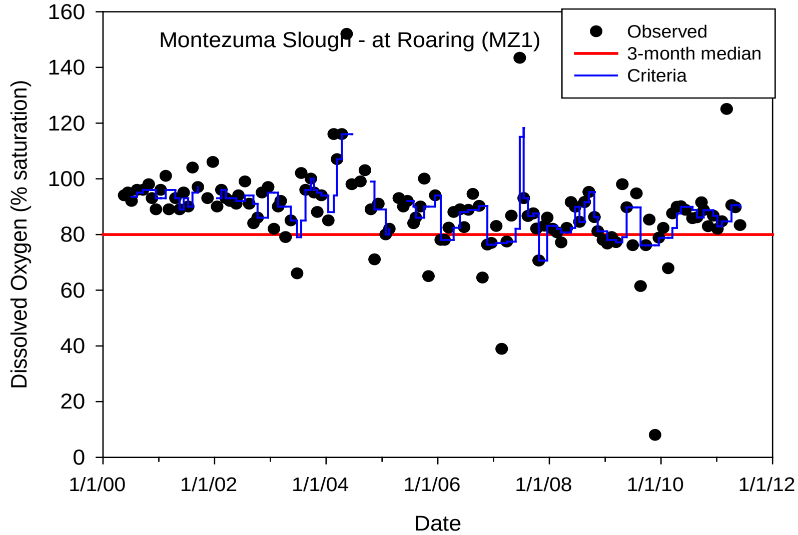


Figure B-1 Monitoring locations for DO, salinity and specific conductance

PT: Peytonia Slough, BY: Boynton Slough, GY: Goodyear Slough, CO: Cutoff Slough, SB: First Mallard, DV: Denverton Slough, NS: Nurse Slough, MZ: Montezuma Slough, SU: Suisun Slough



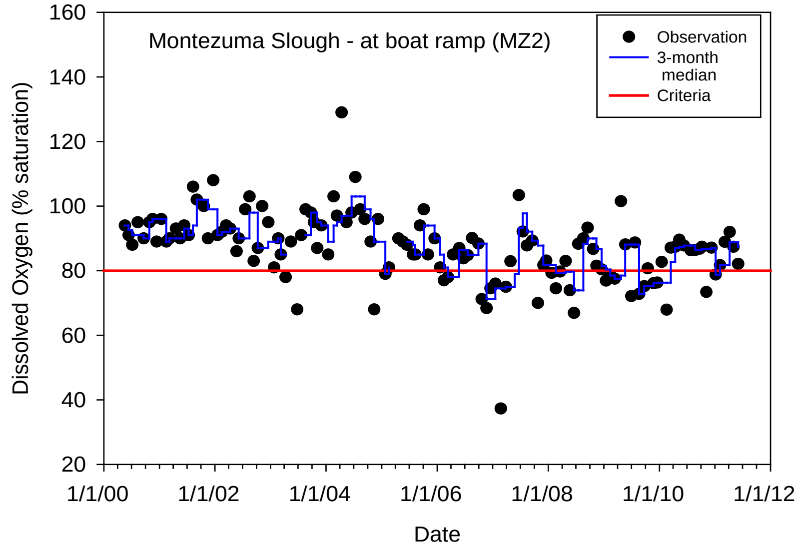


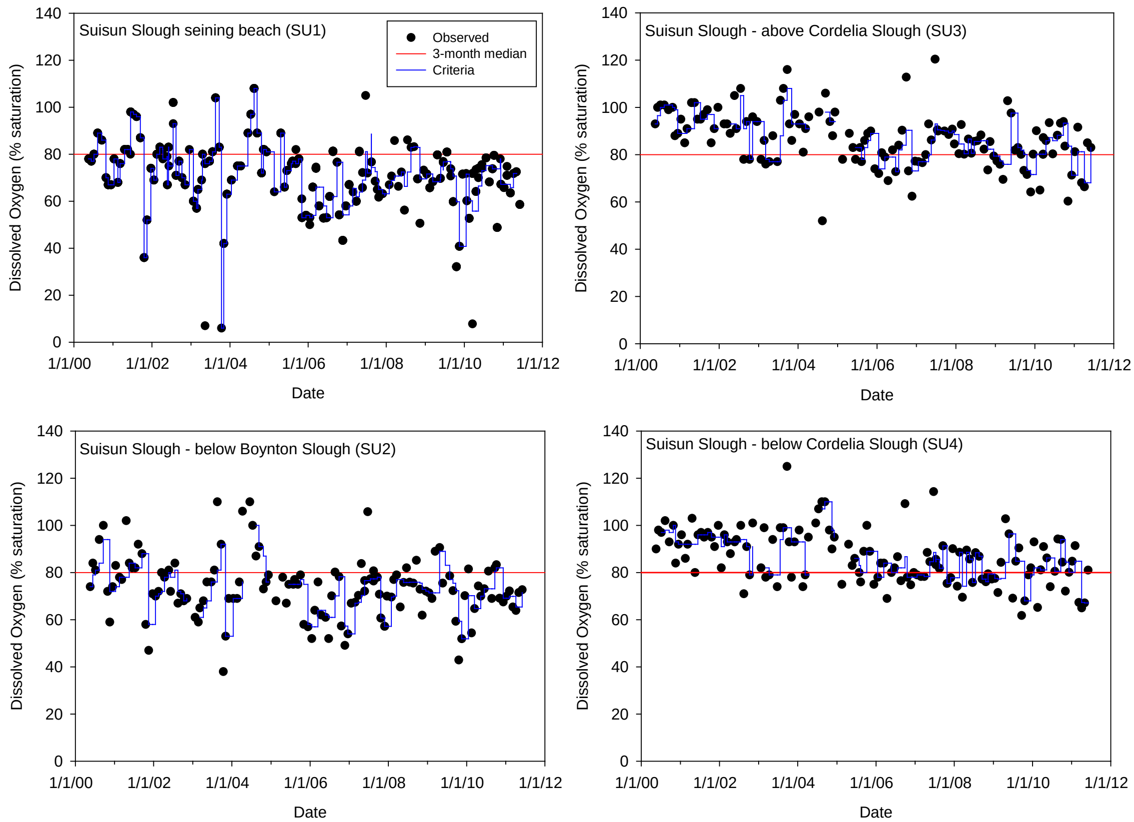
Figure B-2 Percent DO saturation measured at Montezuma Slough

(Sites MZ1 and MZ2 - Source: BDAT Project; Moyle, personal communication)

Table B-2
Stations with DO concentrations in Suisun Marsh

Site	Location	Record Period	% of Samples Below 7 mg/L	% of Samples with 3-month Median DO Saturation Below 80%
NZ032	Montezuma Slough, 2nd bend from mouth	1999–2007	3.7%	–
MZ1	Montezuma Slough at Roaring	2000–2011	7.75%	16.7%
MZ2	Montezuma Slough at boat ramp	2000–2011	8.8%	21.2%
SU1	Suisun Slough seining beach	2000–2011	48.2%	83.2%
SU2	Suisun Slough – below Boynton Slough	2000–2011	50.0%	80.7%
SU3	Suisun Slough – above Cordelia Slough	2000–2011	16.2%	22.3%
SU4	Suisun Slough – below Cordelia Slough	2000–2011	14.6%	26.1%
S42	Suisun Slough 300’ south of Volanti Slough	1978–1985	11.5%	–
GY1	Goodyear Slough – upper	2000–2011	76.9%	93.8%
GY2	Goodyear Slough – middle	2000–2011	72.1%	90.0%
GY3	Goodyear Slough – lower	2000–2011	31.6%	48.1%
BY1	Boynton Slough – upper	2000–2011	75.7%	95.4%
BY3	Boynton Slough – lower	2000–2011	67.4%	86.9%
PT1	Peytonia Slough – upper	2000–2011	68.1%	92.4%
PT2	Peytonia Slough – middle	2000–2011	66.7%	91.1%
CO1	Cutoff Slough –site 1	2000–2011	36.76%	64.62%
CO2	Cutoff Slough – site 2	2000–2011	33.33%	60.00%
DV2	Denverton Slough – middle	2000–2011	49.26%	67.94%
DV3	Denverton Slough – lower	2000–2011	43.70%	64.34%
NS2	Nurse Slough – middle	2000–2011	24.44%	41.86%
NS3	Nurse Slough – lower	2000–2011	18.94%	37.30%
SB1	Spring Branch – upper	2000–2011	52.94%	83.85%
SB2	Spring Branch – middle	2000–2011	51.85%	81.40%

Data from BDAT Project (P. Moyle personal communication)



(Site SU1, SU2, SU3, and SU4; Source: BDAT Project Moyle, personal communication)

Figure B-3 Percent DO saturation measured at Suisun Slough

A similar pattern of lower DO concentrations was observed in Boynton Slough (Figure B-5), with DO concentrations generally below 7 mg/L, and the median percent oxygen saturation below 80% saturation over a 3-month period for majority of the time (about 90%, Table B-2). DO concentrations and saturation measured at Peytonia Slough showed similar patterns, being frequently below DO objectives for majority of the time (about 70% and 90% of the time respectively, Figure B-6). The lowest DO concentrations generally occurred during the fall months.

DO concentrations at the monitored tributary sloughs are generally below 7 mg/L for over half of the time (Goodyear, Peytonia, and Boynton Sloughs; Table B-2), suggesting potential impairment. DO concentrations measured at Montezuma and Suisun Sloughs also showed concentrations lower than 7 mg/L but the frequency of low DO was significantly reduced and ranged from 7.8 to 8.8% of time and 11.5 to 50.0% of time, respectively.

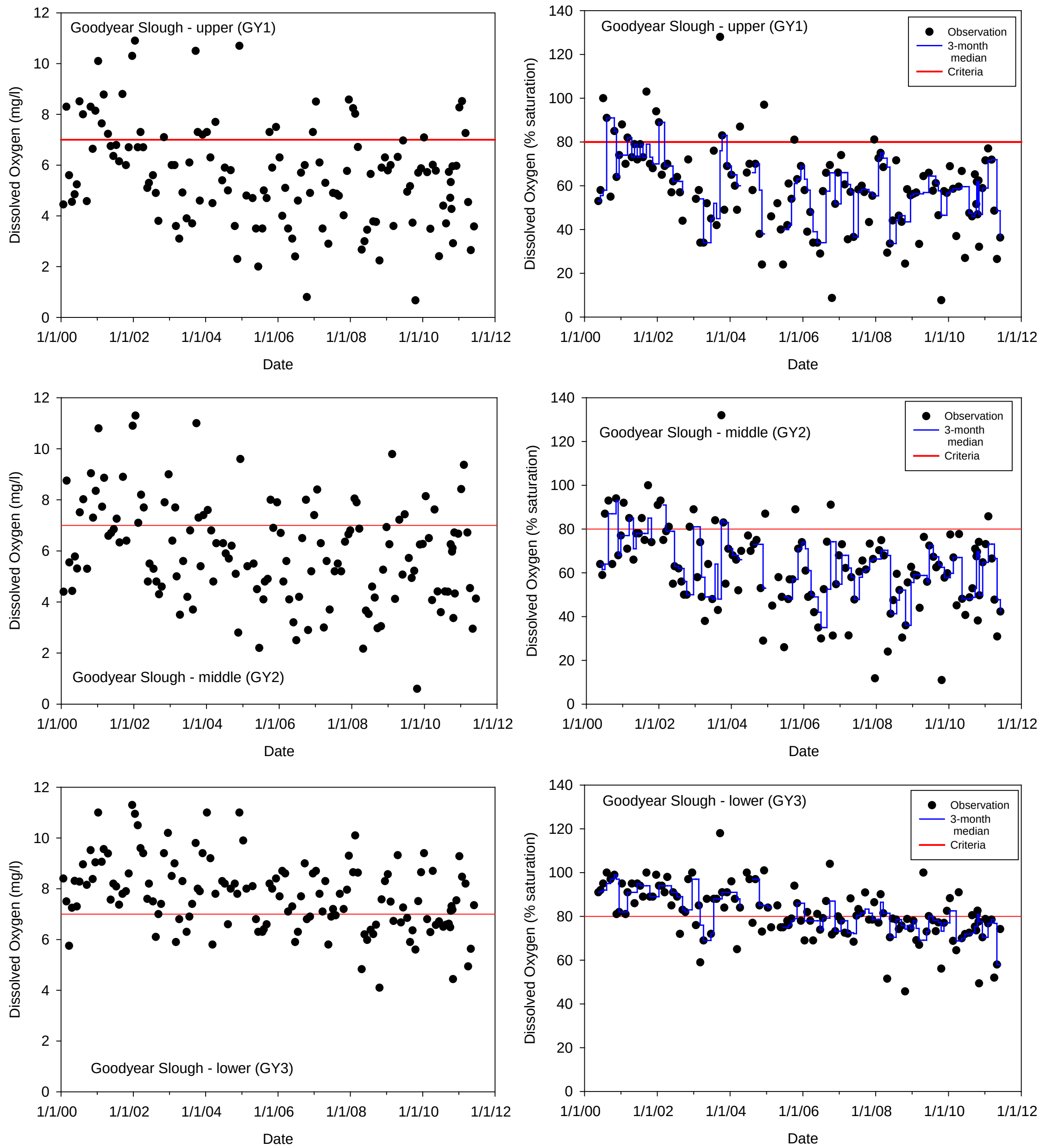
When compared to the 3-month median 80% DO saturation Montezuma Slough data showed that only 16–21% of the samples were below 80% saturation (Table B-2). Suisun Slough data showed that about 80% of the 3-month median DO values were below 80% saturation in the upper slough and 22% of time below water quality objectives in the lower slough. Goodyear, Peytonia, and Boynton Sloughs were routinely below the water quality objective of 80% saturation (86.9 – 93.8% of the time) except for one station at lower Goodyear Slough (GY3).

DO concentrations from Spring Branch, Cutoff, Nurse, and Denverton Sloughs were also compared to the existing DO objectives (Figure B-7 to Figure B-10). The conditions in Cutoff Slough are slightly better than in Spring Branch Slough, possibly due to better mixing with Suisun Slough. Conditions in these two sloughs are the best, possibly due to wider channels that allow better mixing with Montezuma Slough.

DO concentrations were also measured seasonally at several stations in the sloughs in the vicinity of the FSSD WWTP discharge. The locations of these stations are listed in Table B-3. DO concentrations in the receiving water sloughs are shown in Figure B-10. Higher DO concentrations were observed in Chadbourne and Sheldrake Slough than Boynton and Peytonia Slough. The lowest DO concentrations were found at Station CR1 in Peytonia Slough.

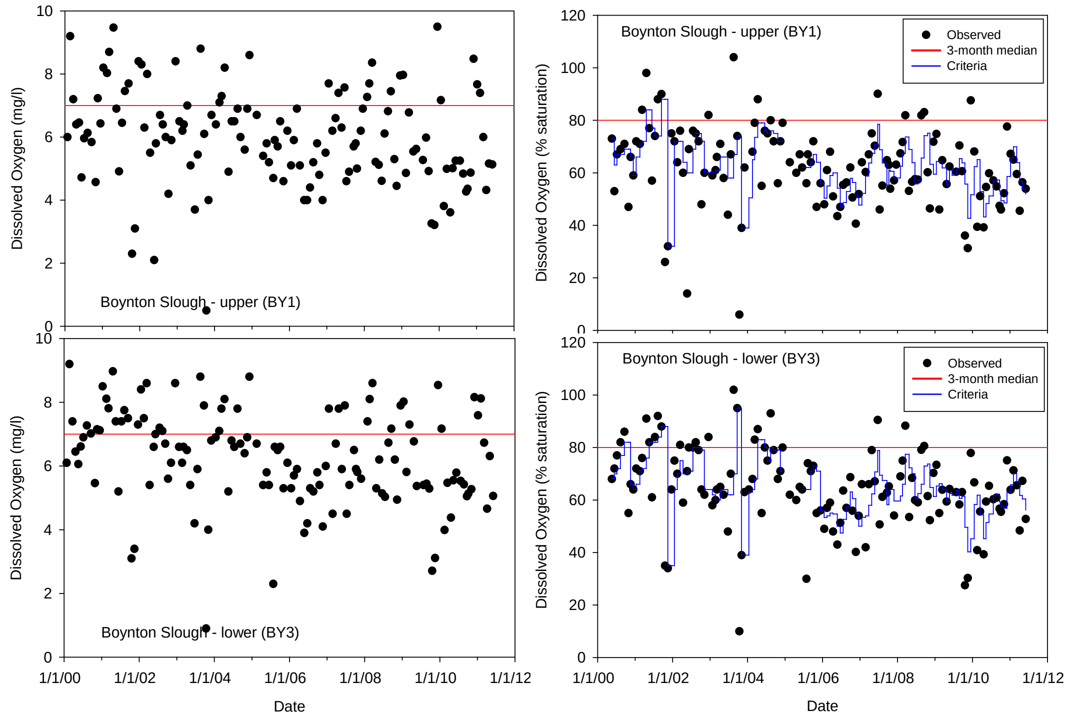
Table B-3
Monitoring stations in receiving water of FSSD discharge in Suisun Marsh

Station	Description
C-1(RW1)	Boynton Slough, about 100 feet downstream from the discharge outfall
C-2 (RW2)	Boynton Slough, about 100 feet downstream from Southern Pacific Railroad crossing
C-3 (RW3)	Boynton Slough, 1800 feet downstream from discharge outfall
C-4 (RW4)	Boynton Slough, in the mouth where it enters Suisun Slough
C-5 (RW5)	Mouth of Sheldrake Slough as it enters Suisun Slough
C-6 (RW6)	Peytonia Slough, in the mouth where it enters Suisun Slough
CR1 (RW7)	Peytonia Slough, about 100 feet downstream from railroad crossing
CR2 (RW8)	Chadbourne Slough, about 100 feet downstream from railroad crossing



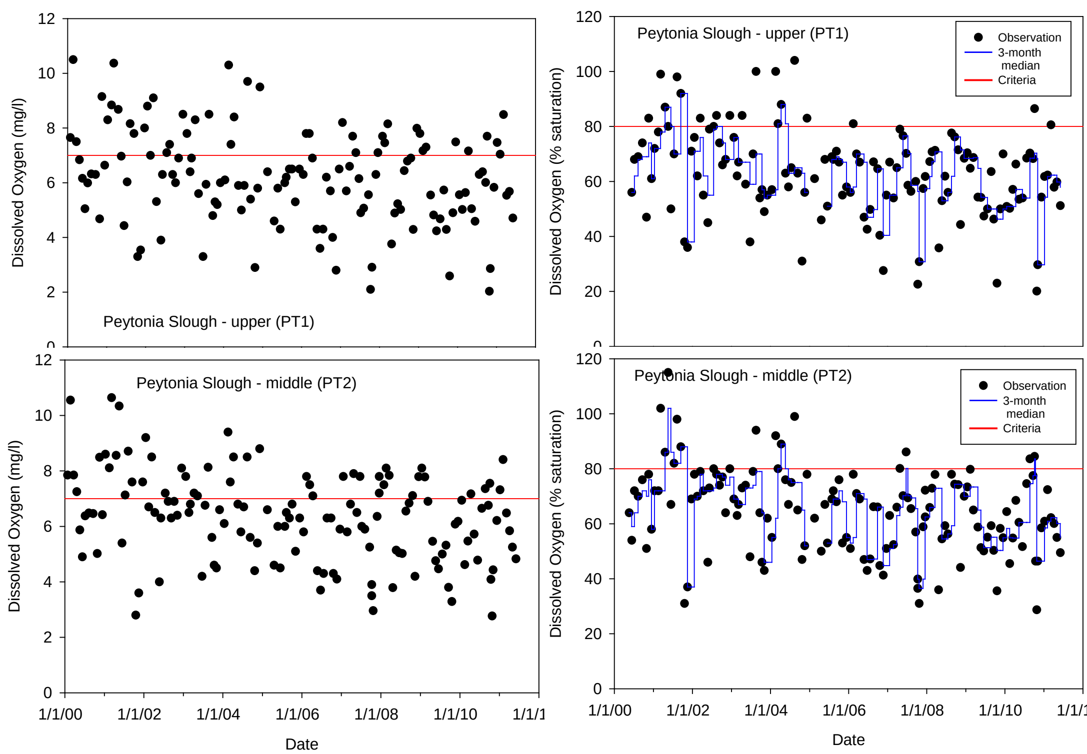
(Site GY1, GY2, and GY3; Source: BDAT Project; Moyle, personal communication)

Figure B-4 DO concentrations and percent oxygen saturation measured at Goodyear Slough



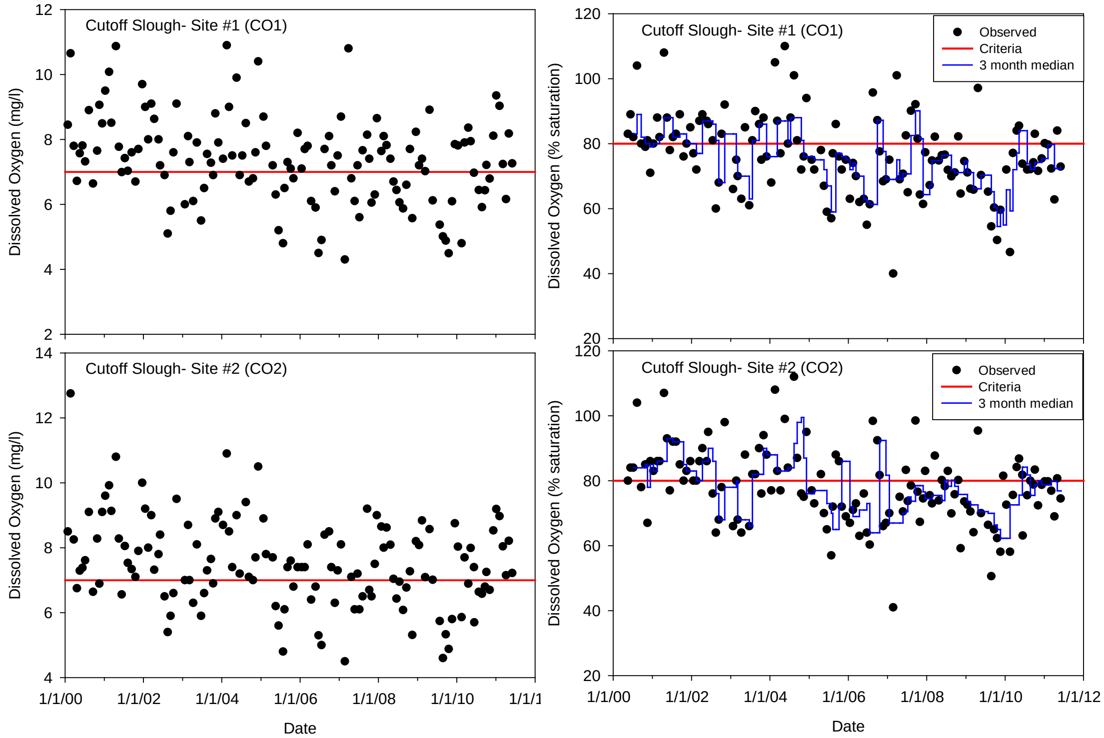
(Site BY1 and BY3; Source: BDAT Project; Moyle, personal communication)

Figure B-5 DO concentrations and percent oxygen saturation measured at Boynton Slough



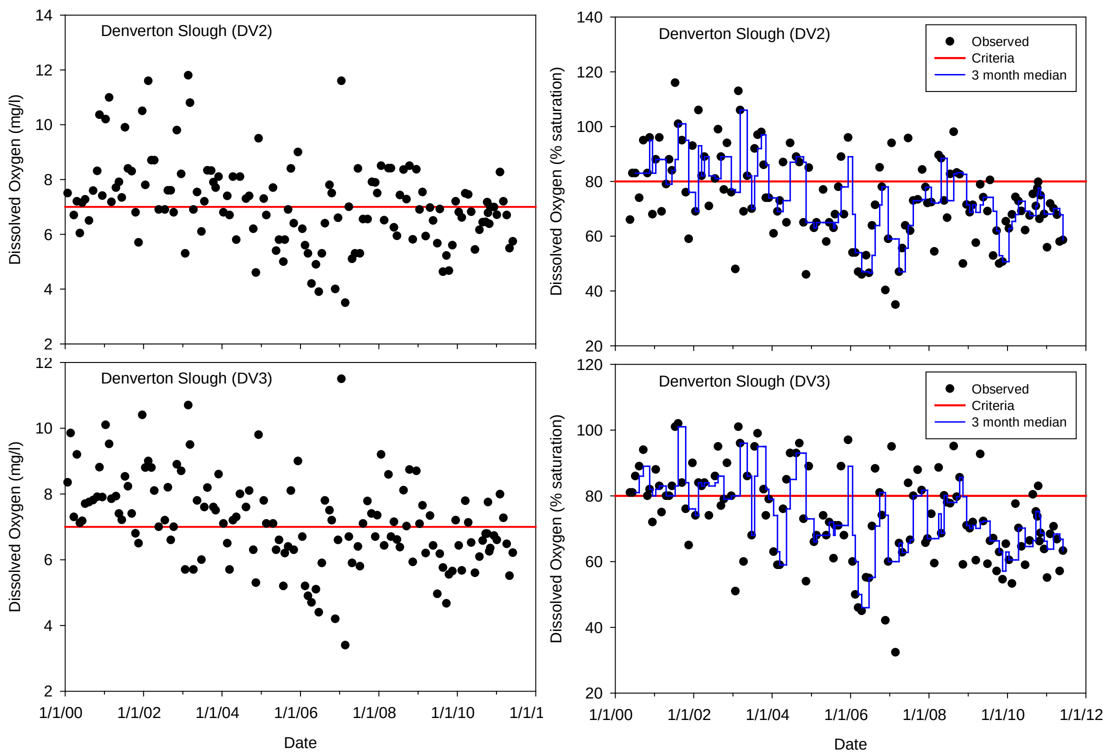
(Site PT1 and PT2; Source: BDAT Project; Moyle, personal communication)

Figure B-6 DO concentrations and percent oxygen saturation measured at Peytonia Slough



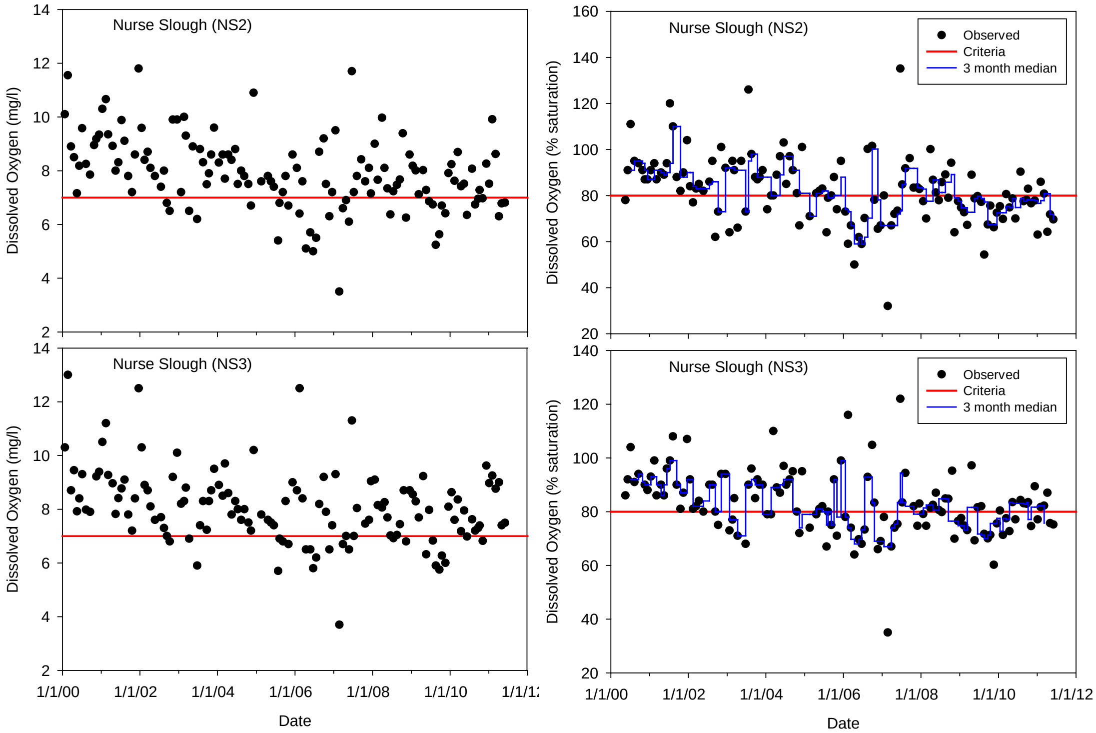
(Site CO1 and CO2; Source: Moyle, personal communication)

Figure B-7 DO concentrations and percent oxygen saturation measured at Cutoff Slough



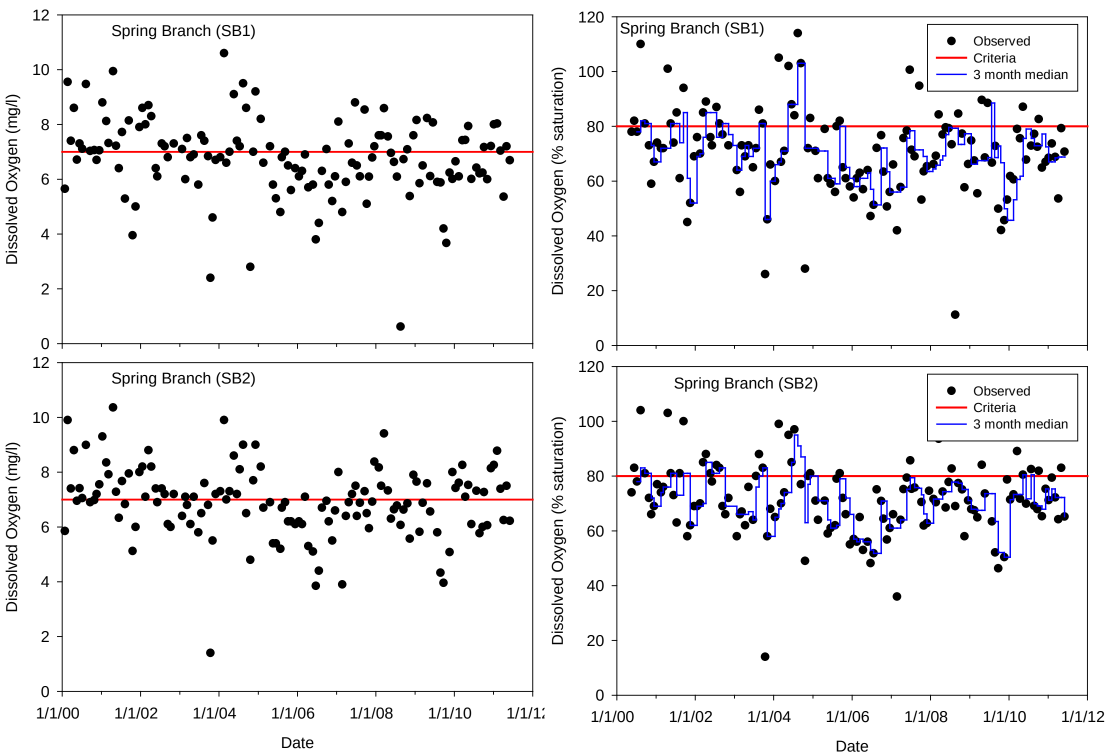
(Site DV2 and DV3; Source: Moyle, personal communication)

Figure B-8 DO concentrations and percent oxygen saturation measured at Denverton Slough



(Site NS2 and NS3; Source: Moyle, personal communication)

Figure B-9 DO concentrations and percent oxygen saturation measured at Nurse Slough



(Site SB1 and SB2; Source: Moyle, personal communication)

Figure B-10 DO concentrations and percent oxygen saturation measured at Spring Branch

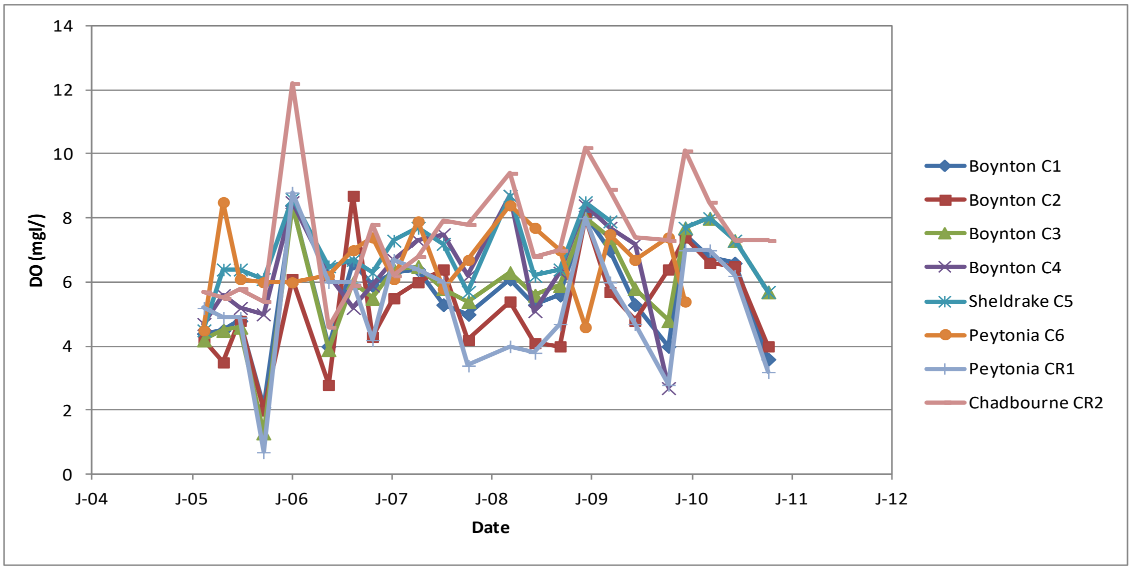


Figure B-11 Receiving water sampling of DO in Suisun Marsh

Comparison of DO Concentrations among the Sloughs

DO concentrations in several sloughs that receive FSSD discharge have been monitored seasonally. These concentrations were compared to concentrations at minimally impacted sites in First and Second Mallard Sloughs, and are similar for the overlapping period (Figure B-12). The concentrations at First and Second Mallard Sloughs were usually slightly lower than those observed at Chadbourne Slough and higher than the concentrations in Boynton and Peytonia Slough. Continuous monitoring data from Goodyear and Denverton Slough, collected by the Regional Water Board, was also used in this comparison. Concentrations in the receiving waters from Boynton and Peytonia Sloughs are similar to Goodyear Slough. Concentrations in Denverton Slough were slightly higher than in Goodyear Slough. Chadbourne Slough, First Mallard, and Second Mallard Sloughs had the highest DO concentrations among all monitored sloughs.

Long-term DO monitoring data for Boynton, Peytonia and Goodyear Sloughs, and continuous monitoring from Goodyear and Denverton Slough, were compared to continuous monitoring data at First and Second Mallard Sloughs (Figure B-13). The results show that long-term DO concentrations in Boynton Slough are generally similar to those in Goodyear Slough, but both were lower than the DO levels in First and Second Mallard Slough. Concentrations from Goodyear Slough are lower than Denverton Slough, particularly during the periods of low DO.

The comparison for Peytonia Slough indicates similar results (Figure B-14). The long-term data in Peytonia Slough showed the upper range of DO concentrations to be similar to First Mallard and Second Mallard Sloughs. The comparison at Goodyear Slough suggested lower concentrations than in First and Second Mallard Sloughs (Figure B-15).

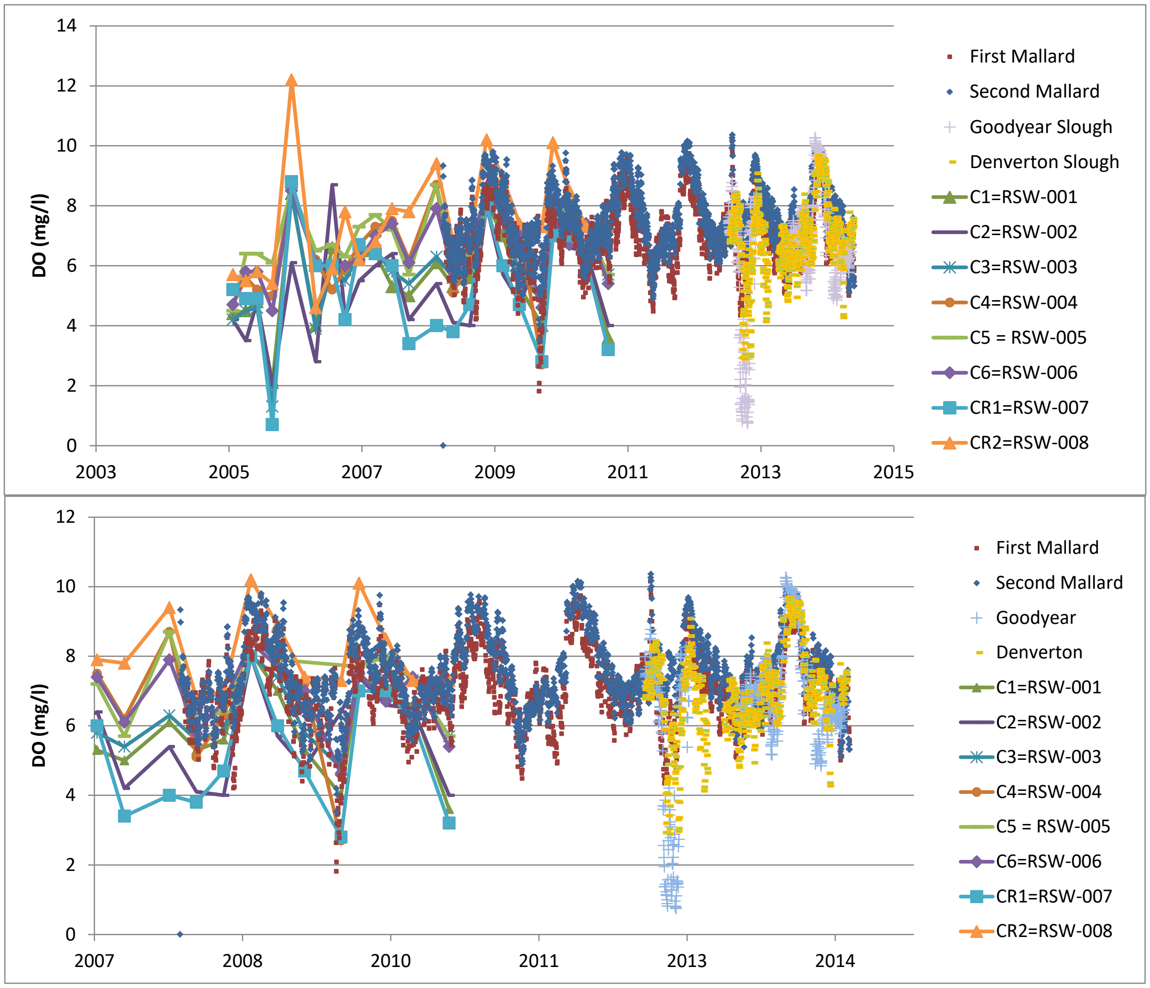


Figure B-12 DO concentrations in receiving water sloughs (seasonally), compared to First Mallard, Second Mallard, Goodyear, and Denverton Sloughs

Notes: Data from NOAA and the Regional Water Board;

15-min readings converted to daily;

C1: Boynton Slough 100 ft downstream from discharge; C2: Boynton Slough 100 ft downstream from Railroad; C3: Boynton Slough 1800 ft downstream from discharge; C4: Boynton Slough mouth; C5: Sheldrake Slough mouth; C6: Peytonia Slough mouth; CR1: Peytonia Slough 100 ft downstream from railroad; CR2: Chadbourne Slough 100 ft downstream from railroad.)

DO concentrations from Spring Branch, Cutoff, Nurse, and Denverton Sloughs were also compared to First Mallard and Second Mallard Sloughs (Figure B-12 to Figure B-18). The results show higher concentrations at First Mallard and Second Mallard Sloughs than the other sloughs. DO concentrations from Spring Branch, Cutoff, and Denverton Sloughs generally bound the lower end of the First Mallard and Second Mallard Slough concentrations. DO concentrations in Nurse Slough were most comparable to the minimally impacted sites.

A summary of the DO concentration data used in this comparison is listed in Appendix A.

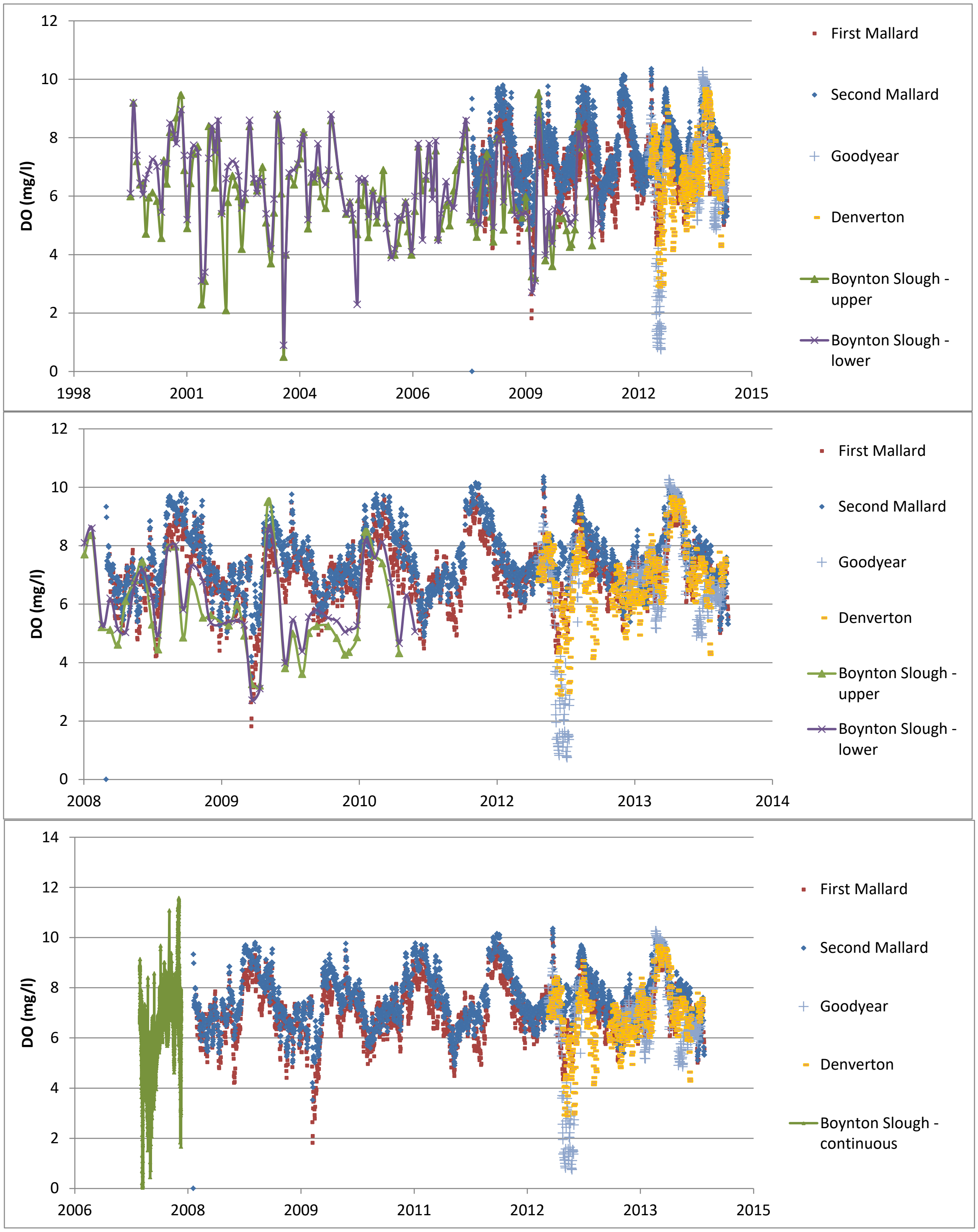


Figure B-13 DO concentrations in Boynton Slough (monthly, measured by UCD and continuous, measured by Sigel et al 2011) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

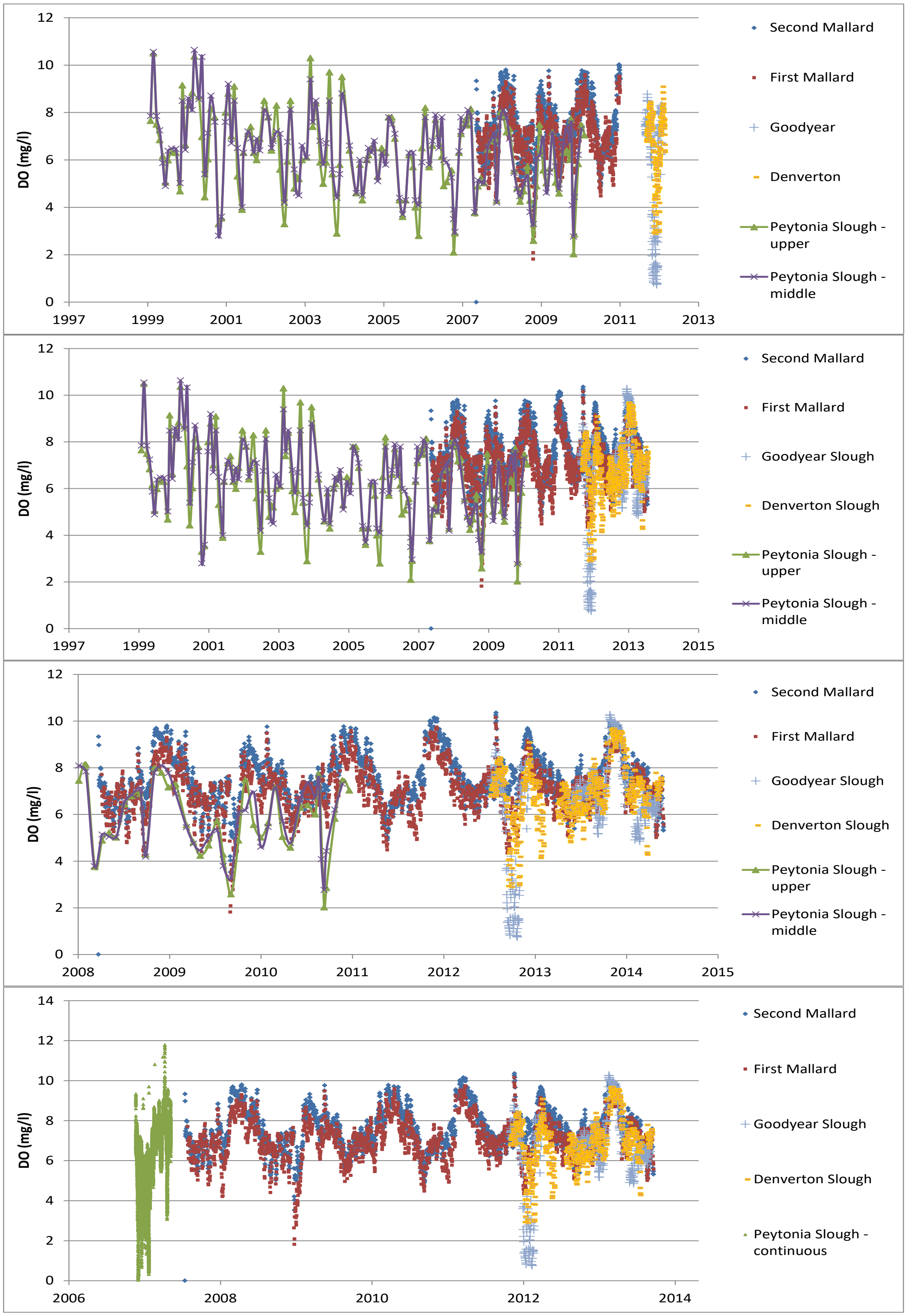


Figure B-14 DO concentrations in Peytonia Slough (monthly, measured by UCD and continuous, measured by Siegel et al 2011) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

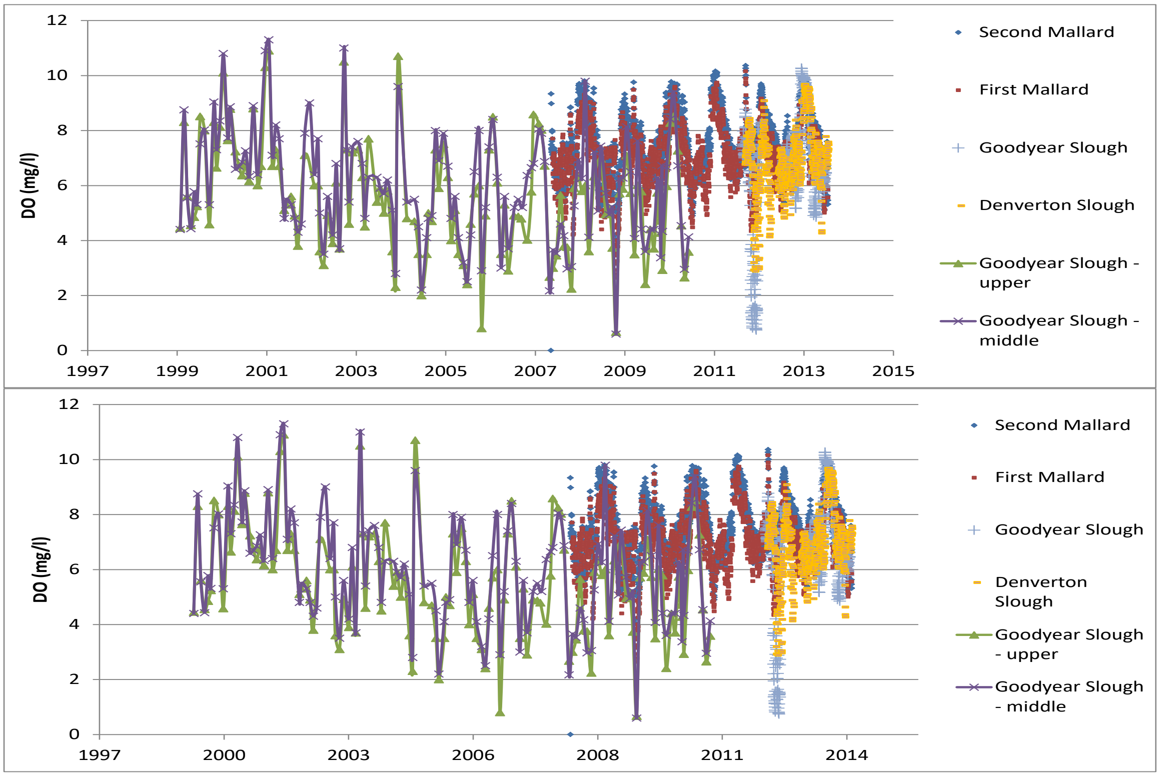


Figure B-15 DO concentrations in Goodyear Slough (monthly, measured by UCD) compared to First Mallard, Second Mallard, and Denverton Slough

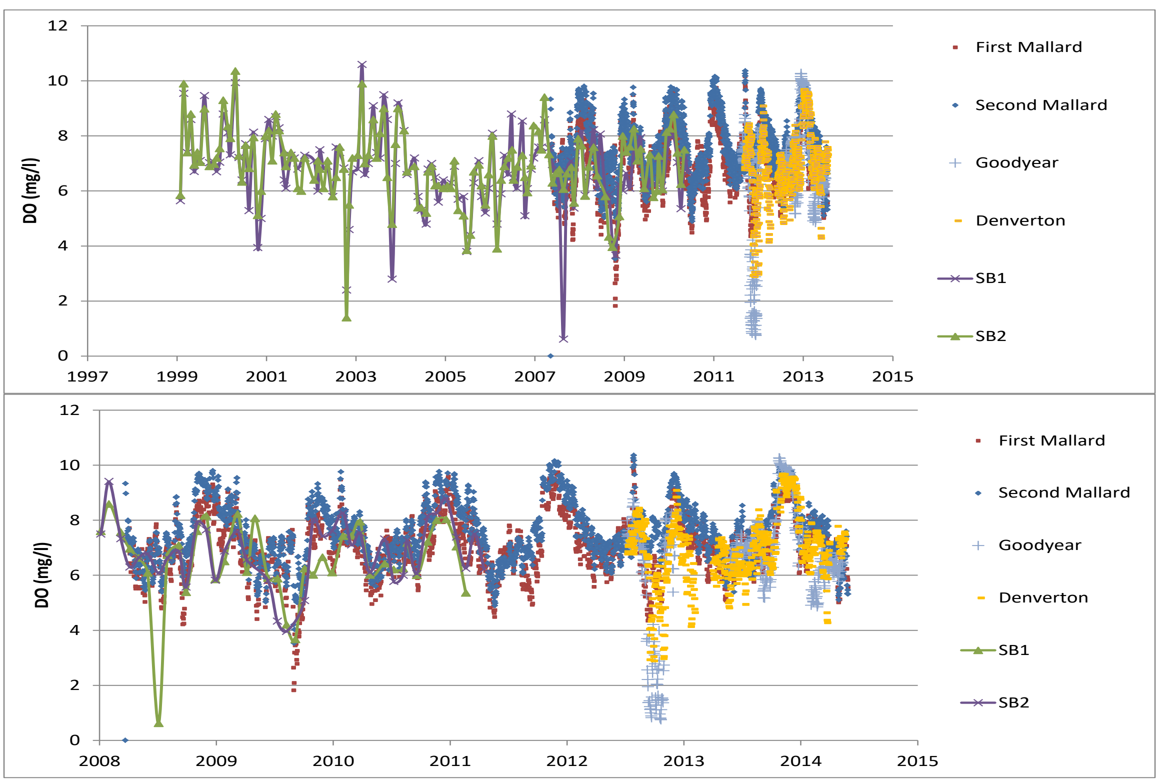


Figure B-16 DO concentrations in Spring Branch (monthly, measured by UCD) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

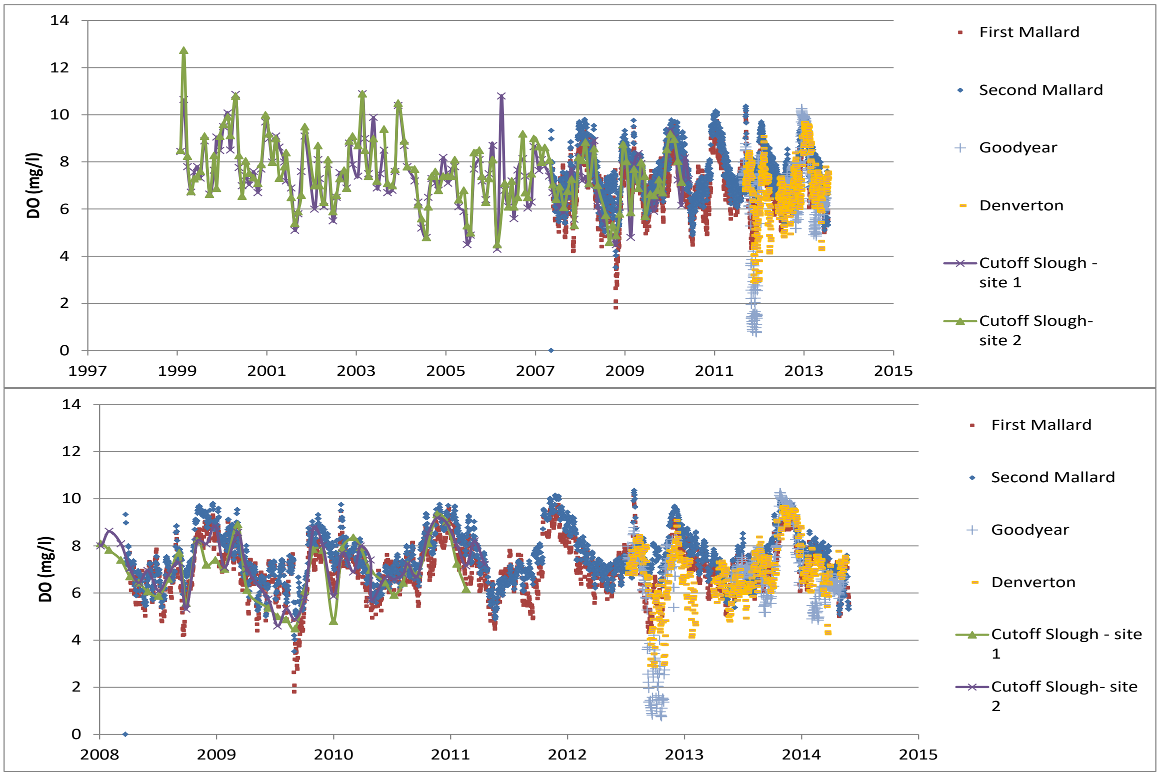


Figure B-17 DO concentrations in Cutoff Slough (monthly, measured by UCD) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

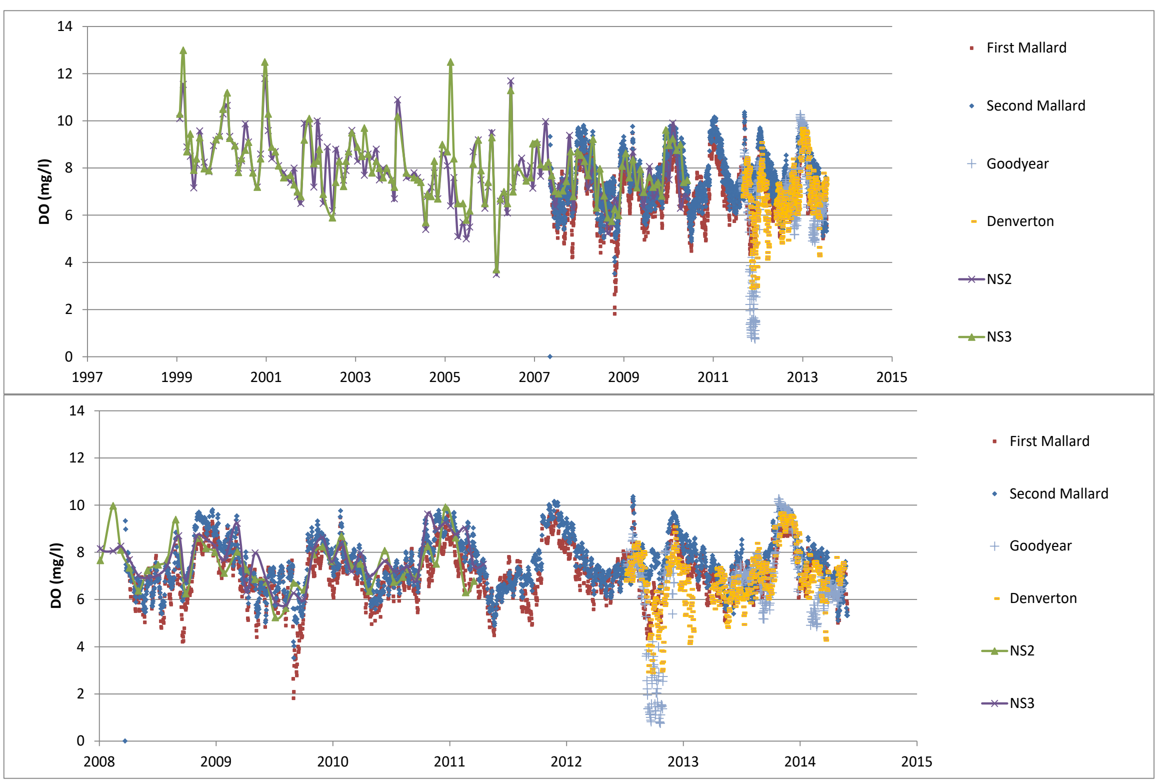


Figure B-18 DO concentrations in Nurse Slough (monthly, measured by UCD) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

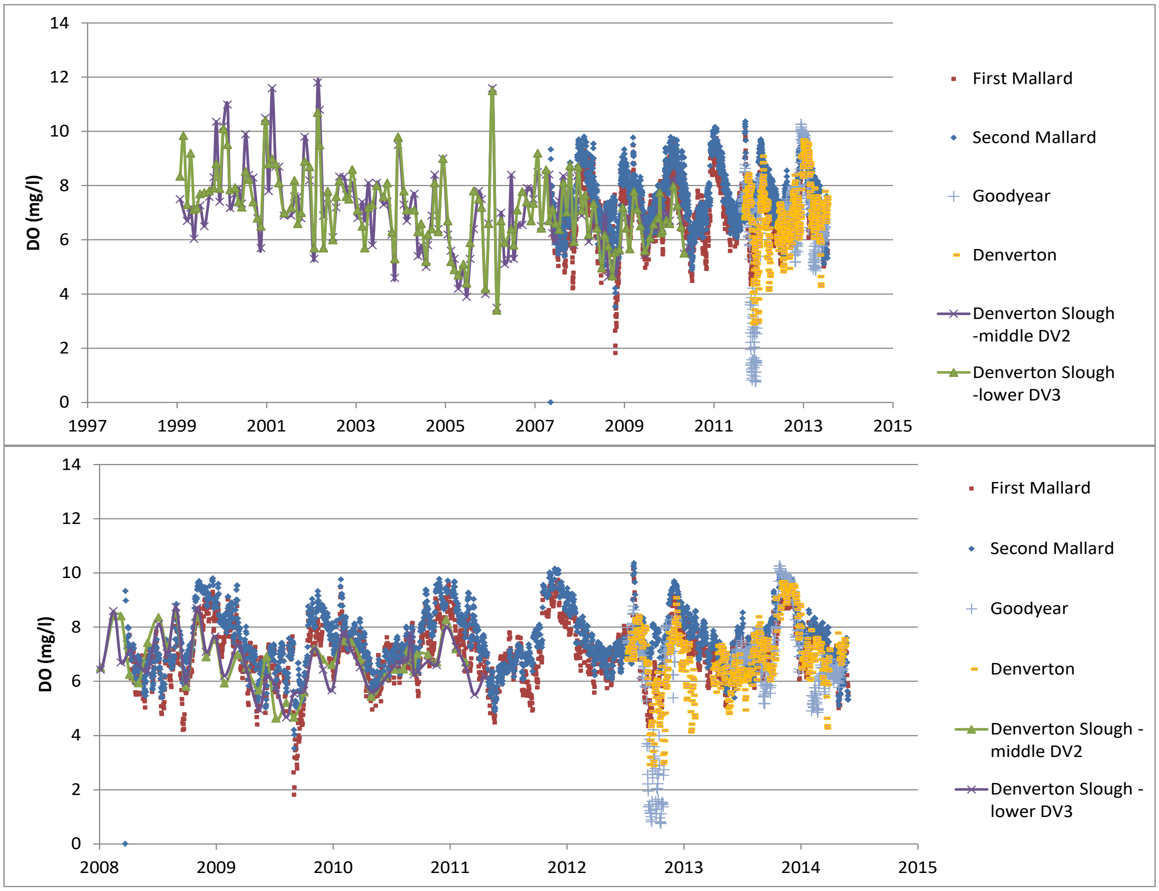


Figure B-19 DO concentrations in Denverton Slough (monthly, measured by UCD) compared to First Mallard, Second Mallard, Goodyear, and Denverton Slough

Nutrient Concentrations in Suisun Marsh

Nutrient data are available in Suisun Marsh from sampling conducted more than two decades ago by DWR and from a more recent program conducted over the last decade by FSSD. Because the sampling programs are different, the stations have changed over time.

Nutrient concentrations and total phosphorus (TP) concentrations were measured at Suisun Slough (300’ south of Volanti Slough) from 1978–1985 (station S42). Concentrations were as follows:

- Observed ammonia (NH_3) concentrations for this period ranged from 0 to 0.30 mg/L.
- Organic nitrogen concentrations ranged from 0.1 to 1.5 mg/L.
- Observed total Kjeldahl nitrogen (TKN) ranged from 0.5 to 1.8 mg/L.
- Observed nitrite + nitrate (NO_2 + NO_3) concentrations ranged from 0 to 0.9 mg/L.

The organic nitrogen and NO_2 + NO_3 concentrations are relatively high, and could result in high phytoplankton levels. For example, a total inorganic nitrogen concentration of 0.15 mg/L could result in maximum chlorophyll a of 150 µg/L in the region (Tetra Tech, 2006) and a TN concentration of 1.5 mg/L (approximated in this case as the sum of TKN and nitrite plus nitrate) was considered as a boundary of mesotrophic-eutrophic conditions (Dodds et al. 1998). Ortho-P (PO_4) concentrations in Suisun Slough ranged from 0.02 to 0.19 mg/L. TP concentrations range from 0.1 to 0.35 mg/L. Observed TN/TP ratios are usually below 16 (the Redfield ratio, representing stoichiometric ratios of nitrogen:phosphorus in biomass). This suggests that nitrogen is more likely to be limiting algal growth. Nitrogen has been found to be the predominant limiting nutrient in coastal marine systems. However, both N and P limitation is widespread and the importance of N and P limitation needs local assessment (Elser et al. 2007).

More recently, during 2000–2011, nutrient concentrations were measured in the receiving waters of the FSSD discharge in several tributary sloughs within Suisun Marsh. These include a total of 8 stations, located in Boynton Slough (4 stations), Peytonia Slough (2 stations), Sheldrake Slough (1 station) and Chadbourne Slough (1 station); DO concentrations from Spring Branch, Cutoff, Nurse, and Denverton Sloughs were also compared with the existing DO objectives (Figure B-7 to Figure B-10). The conditions in Cutoff Slough are slightly better than in Spring Branch Slough, possibly due to better mixing with Suisun Slough. Conditions in these two sloughs are the best, possibly due to wider channels that allow better mixing with Montezuma Slough.

DO concentrations were also measured seasonally at several stations in the sloughs adjacent to the FSSD wastewater discharge. The locations of these stations are listed in Table B-3. DO concentrations in the receiving water sloughs are shown in Figure B-11. Higher DO concentrations were observed in Chadbourne and Sheldrake Slough than Boynton and Peytonia Slough. The lowest DO concentrations were found at Station CR1 in Peytonia Slough.

The observed ammonia concentrations in Boynton Slough were generally in the range of 0–0.4 mg/L (Figure B-21). The concentrations were slightly higher than previously observed in Suisun Slough (0–0.3 mg/L). Ammonia concentrations in Peytonia, Sheldrake, and Chadbourne Sloughs were generally similar to concentrations in Boynton Slough, with a range of 0–0.4 mg/L, with values over 0.4 mg/L occurring in a few instances.

Organic nitrogen concentrations were generally in the range of 0.5–2.0 mg/L in Boynton and Peytonia Sloughs (Figure B-21). Concentrations in Sheldrake and Chadbourne Slough were slightly lower ranging from 0.3 to 1.5 mg/L. The organic nitrogen concentrations in these sloughs are higher than previously observed in Suisun Slough (0.2–1.0 mg/L).

TKN concentrations ranged from 1–2 mg/L in Boynton Slough and Peytonia Slough and showed an increasing trend in recent years (i.e., from 2000–2011; Figure B-22). TKN concentrations in Sheldrake and Chadbourne Sloughs were slightly lower, at 0.3–1.5 mg/L. The range of TKN concentrations in Sheldrake and Chadbourne Sloughs was similar to that previously observed in Suisun Slough (0.5–1.4 mg/L).

Relatively high NO_3 concentrations were observed in Boynton Slough (0–18 mg/L), particularly for stations above and below the FSSD and managed wetland discharges

(Figure B-23). Stations near the mouth of the slough showed the lowest concentrations. Nitrate concentrations in other sloughs are somewhat lower (generally below 2 mg/L). Overall, however, nitrate concentrations observed in these tributary sloughs are much higher than previously observed in Suisun Slough (0–0.8 mg/L).

Higher than in other sloughs concentrations of ortho-P (0.5–4 mg/L) were observed in Boynton Slough (Figure B- 24). Concentrations in Peytonia Slough were generally below 1 mg/L. Sheldrake and Chadbourne Sloughs showed lower concentrations, ranging from 0 to 0.6 mg/L. Concentrations observed in these sloughs are higher than previously observed in Suisun Slough (0.1 – 0.35 mg/L).

The concentrations for ammonia across the stations were generally similar (Figure B-25). Organic nitrogen and TKN concentrations were higher at headwaters of Boynton Slough and lower at Chadbourne Slough. Nitrate concentrations showed a very clear pattern of higher concentrations at stations in Boynton Slough, with lower concentrations in Peytonia and other sloughs. The observed ortho-P concentrations showed a similar pattern, with higher concentrations at stations in Boynton Slough than Peytonia and other sloughs (Figure B-26).

The observed NO_3 concentrations measured as part of the receiving water study by the FSSD were compared to concentrations at minimally impacted sites at First Mallard and Second Mallard Sloughs (Figure B-27). The results suggested elevated NO_3 concentrations in the receiving water sloughs, particularly in Boynton Slough and, to a lesser degree, in Peytonia Slough as compared to the minimally impacted sites. The NO_3 concentrations were highest in Boynton Slough, followed by Peytonia Slough, and were lowest in Chadbourne Slough. Higher concentrations in the receiving water sloughs could be due to discharges from FSSD and managed wetlands.

The observed NH_4 concentrations in the receiving water sloughs of Suisun Marsh were compared to concentrations at minimally impacted sites. The results suggested higher NH_4 concentrations in the receiving waters than in First Mallard and Second Mallard Sloughs (Figure B-28). The higher NH_4 concentrations in the receiving waters could be due to discharges from FSSD and managed wetlands.

The comparison of PO_4 concentrations in the receiving water sloughs to First and Second Mallard Sloughs similarly suggested higher concentrations in the receiving water sloughs than the minimally impacted sites (Figure B-29). The highest PO_4 concentrations were observed in Boynton Slough, followed by Peytonia Slough. The PO_4 concentrations in Sheldrake and Chadbourne Sloughs were similar to the minimally impacted sites.

Taken together, the results presented here suggest that higher nutrient concentrations in the receiving waters could be attributed to discharges from FSSD and the managed wetlands.

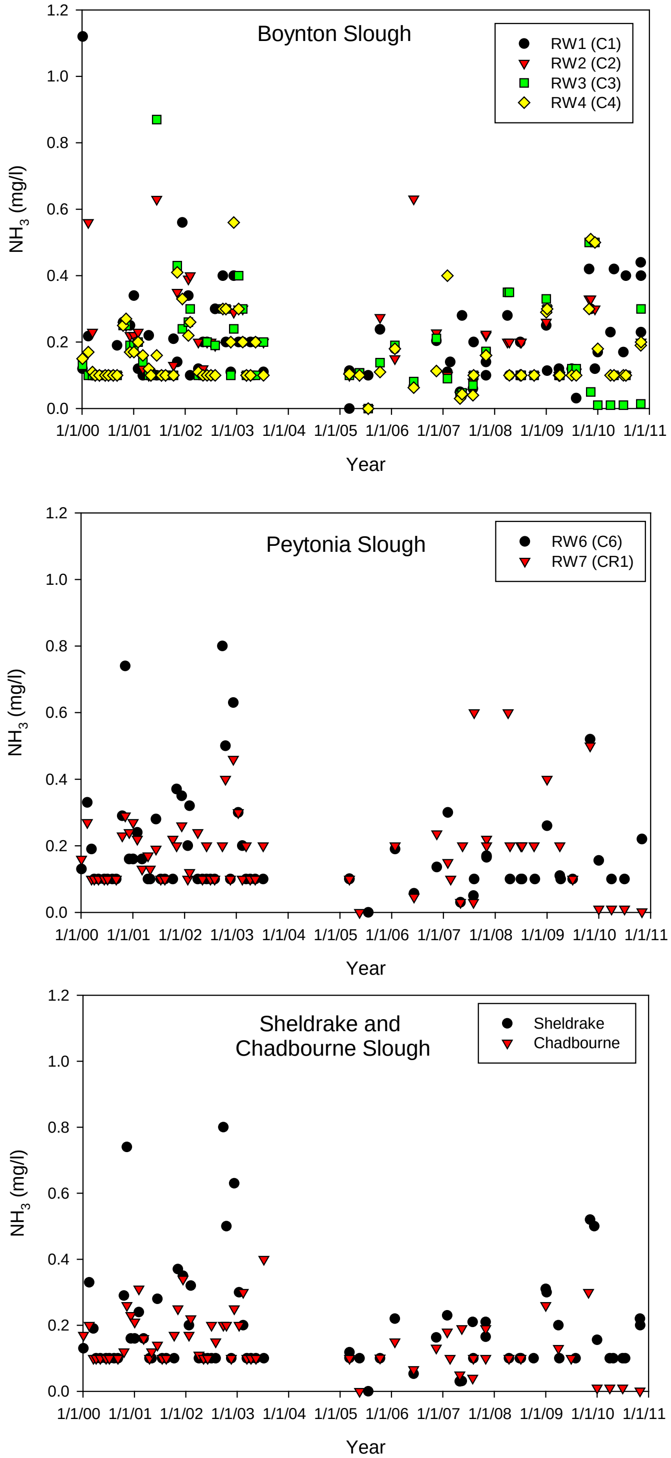


Figure B-20 Observed NH_3 concentrations in the waters of Suisun Marsh in the vicinity of FSSD

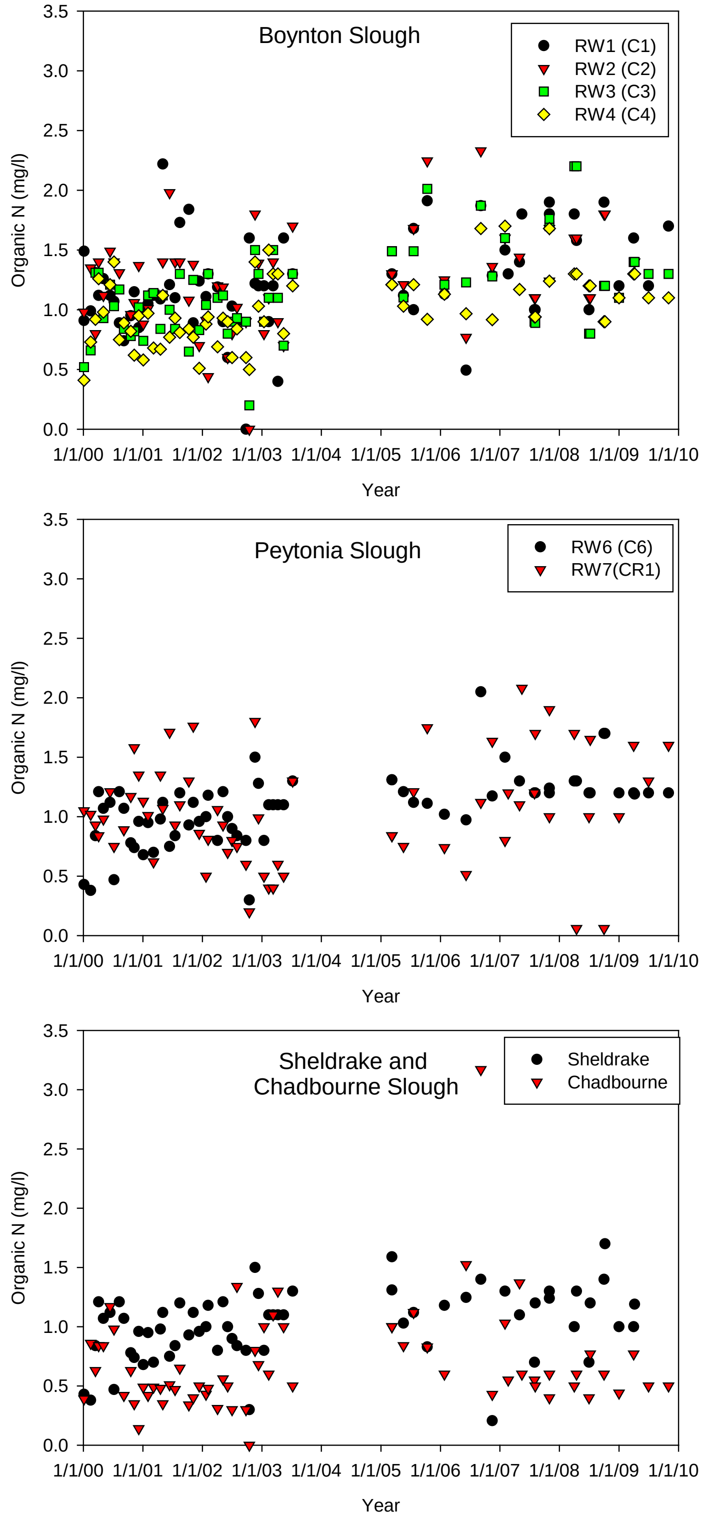


Figure B-21 Observed organic nitrogen concentrations in the waters of Suisun Marsh in the vicinity of FSSD

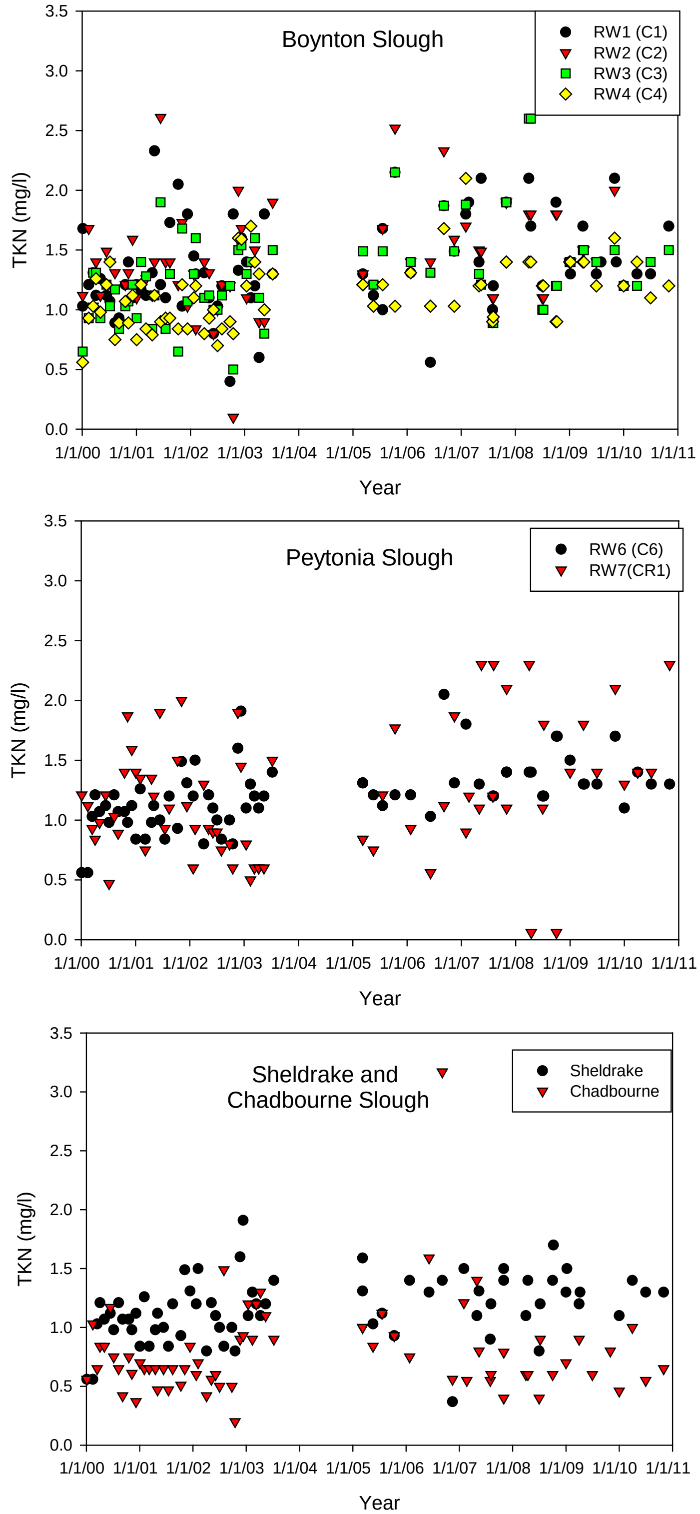


Figure B-22 Observed TKN concentrations in the waters of Suisun Marsh in the vicinity of FSSD

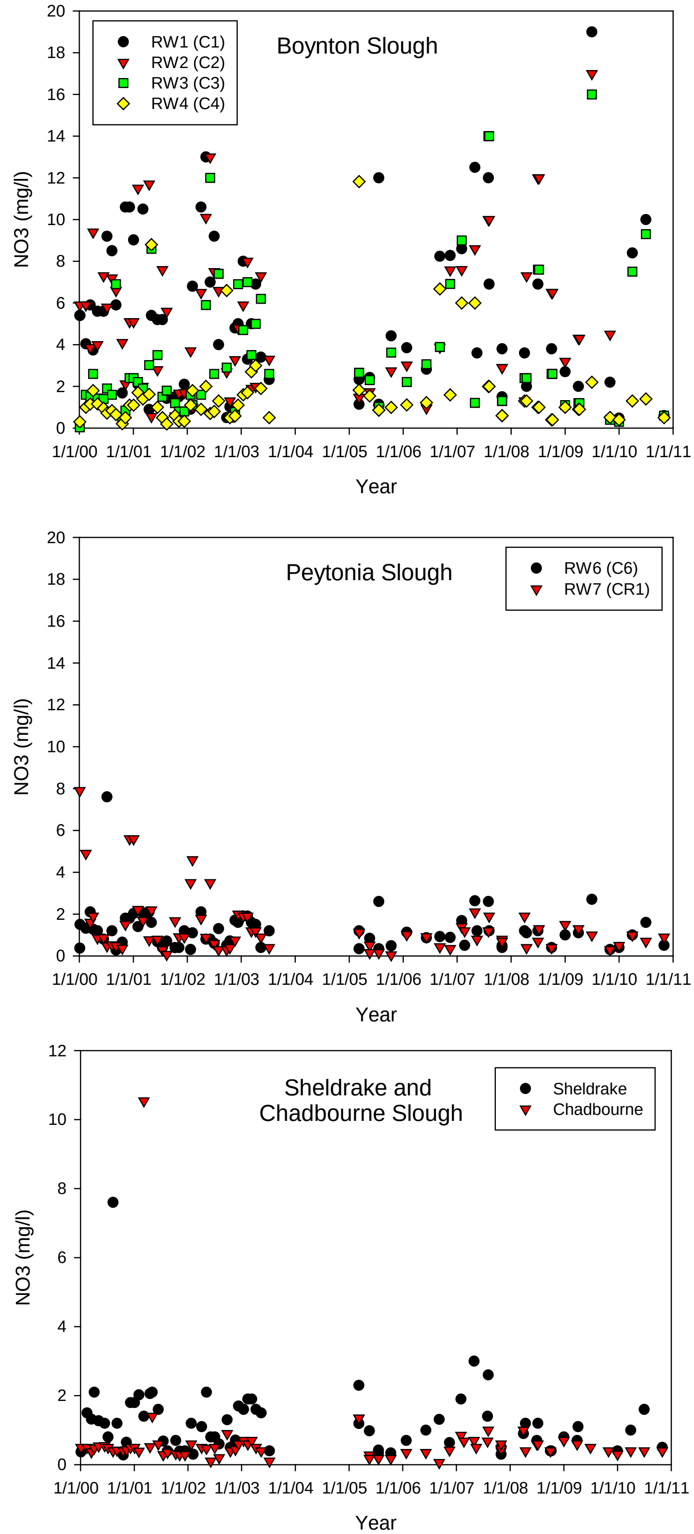


Figure B-23 Observed NO_3 concentrations in the waters of Suisun Marsh in the vicinity of FSSD

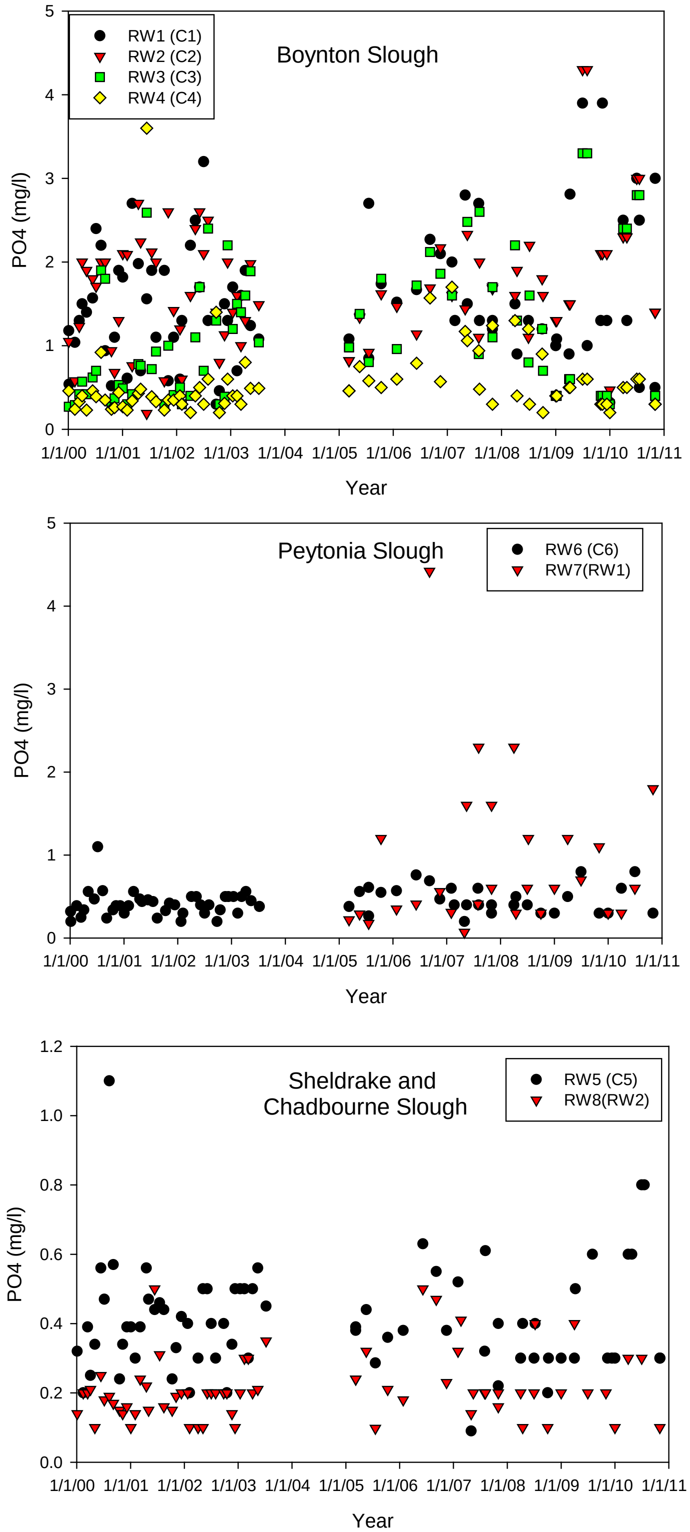


Figure B- 24 Observed ortho-P (PO_4) concentrations in the waters of Suisun Marsh in the vicinity of FSSD

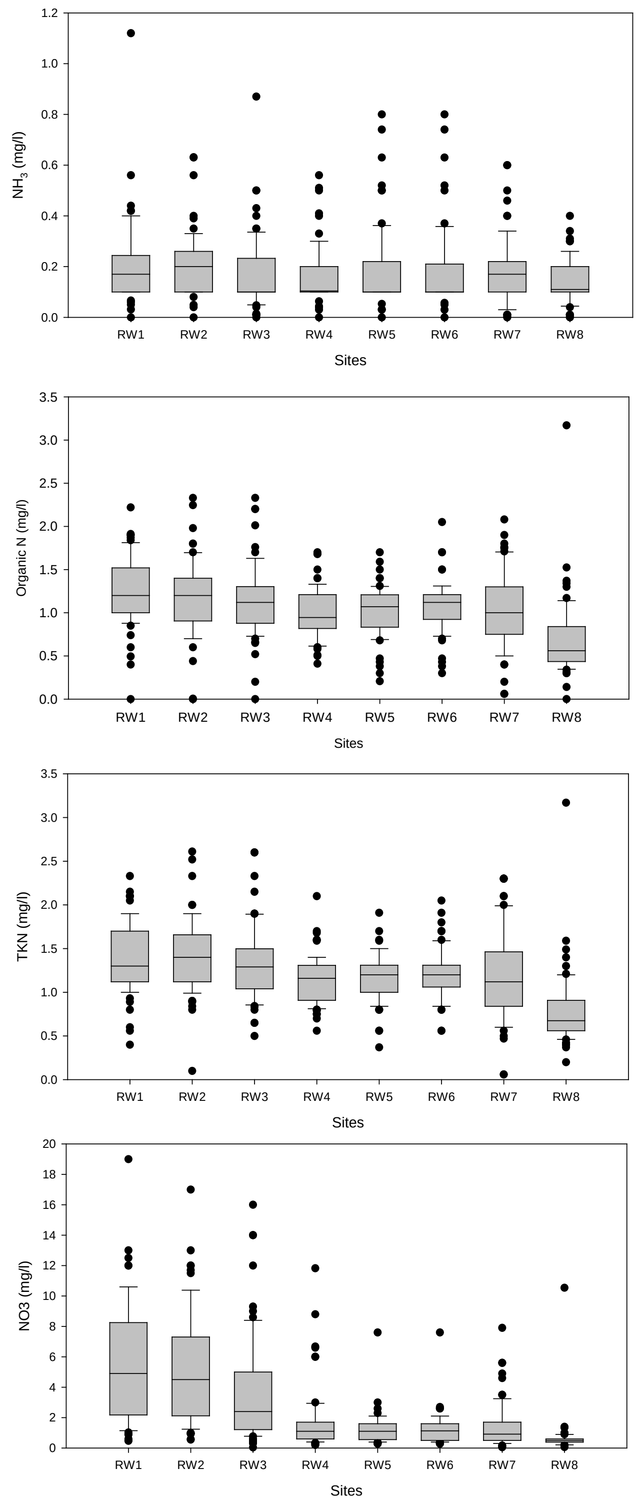


Figure B-25 Box plots of observed nitrogen concentrations in the waters of Suisun Marsh in the vicinity of FSSD

The upper and lower ends of the box represent the 75th and 25th percentiles of the data, the line represents the median, and the whiskers represent the 10th and 90th percentiles.

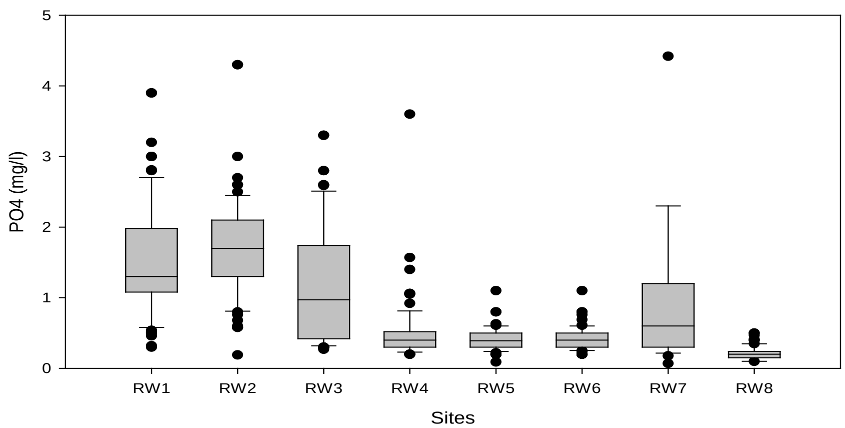


Figure B-26 Box plot of observed ortho-P (PO_4) concentrations in the receiving waters of Suisun Marsh

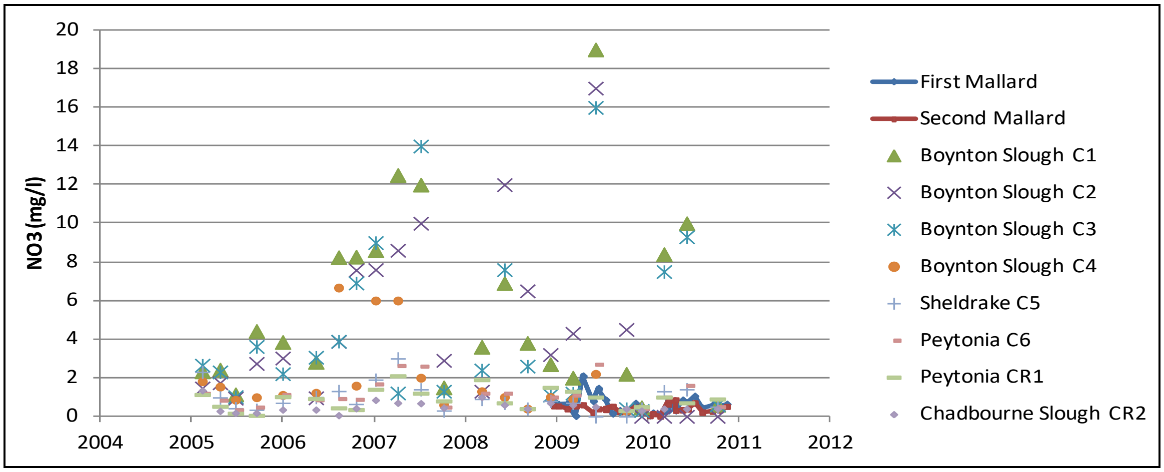


Figure B-27 Observed nitrate (NO_3) concentrations in the receiving waters compared to concentrations at First and Second Mallard Sloughs

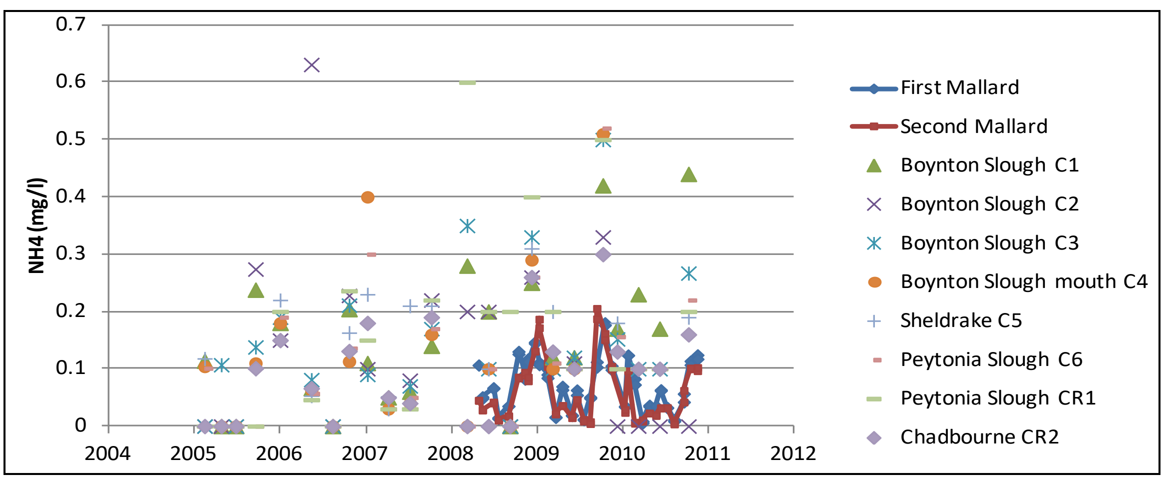


Figure B-28 Observed ammonia (NH_4) concentrations in the receiving waters compared to concentrations at First and Second Mallard Sloughs

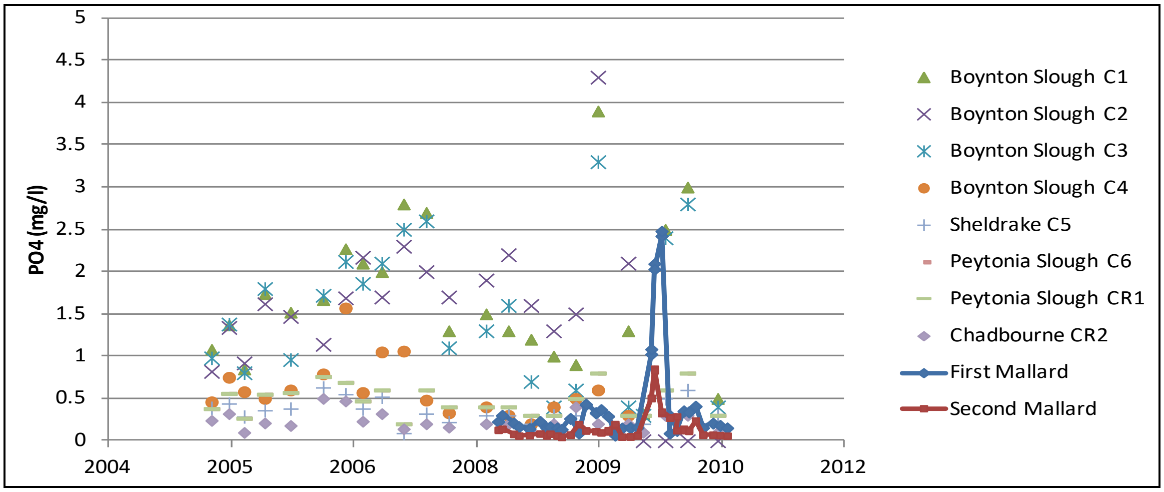


Figure B-29 Observed phosphate (PO_4) concentrations in the receiving waters compared to concentrations at First and Second Mallard Sloughs

Chlorophyll a Concentrations in Suisun Marsh

High nutrient concentrations potentially result in excess growth of phytoplankton, which, in turn, supports production of organic carbon and could result in low DO concentrations, increases in turbidity, or decreases in water clarity and Secchi depth.

Chlorophyll a concentrations were measured in Boynton and Peytonia Sloughs and two other sloughs (Sheldrake and Chadbourne Sloughs). Chlorophyll a concentrations in these sloughs are similar to concentrations measured at the minimally impacted sites: First and Second Mallard Sloughs near Cutoff Slough (Figure B-30). Chlorophyll a concentrations showed a seasonal pattern with higher concentrations in the summer and lower concentrations in the winter, and generally ranged between 2–40 µg/L. The concentrations in the sloughs are considered to be relatively high. Although nutrient concentrations were higher in the receiving water sloughs than the minimally impacted sites (First and Second Mallard Sloughs), the observed chlorophyll a concentrations in these sloughs are similar to the minimally impacted sites. This suggests that naturally occurring nutrient concentrations can contribute to relatively high chlorophyll a concentrations.

Limited chlorophyll a data are available in Montezuma Slough (station NZ032). Since 1998, observed chlorophyll a concentrations at NZ032 have been relatively constant, ranging between 2–5 µg/L, with some elevated concentrations above 5 µg/L (Figure B-31). The chlorophyll a concentrations were higher in the tributary sloughs than in Montezuma Slough.

Chlorophyll a concentrations have also been measured at the managed wetlands 112 and 123 (Figure B-32; Bachand et al. 2010). These concentrations could be extremely high (100–400 µg/L) during phytoplankton blooms. For Wetland 123, phytoplankton blooms occurred frequently during September to November and again in February to April. In Wetland 112, phytoplankton blooms occurred for longer periods. The observed chlorophyll a concentrations in managed wetlands strongly suggest conditions that favor algae growth, such as nutrient enrichment, long residence times, and lack of the filter-feeding *C. amurensis*.

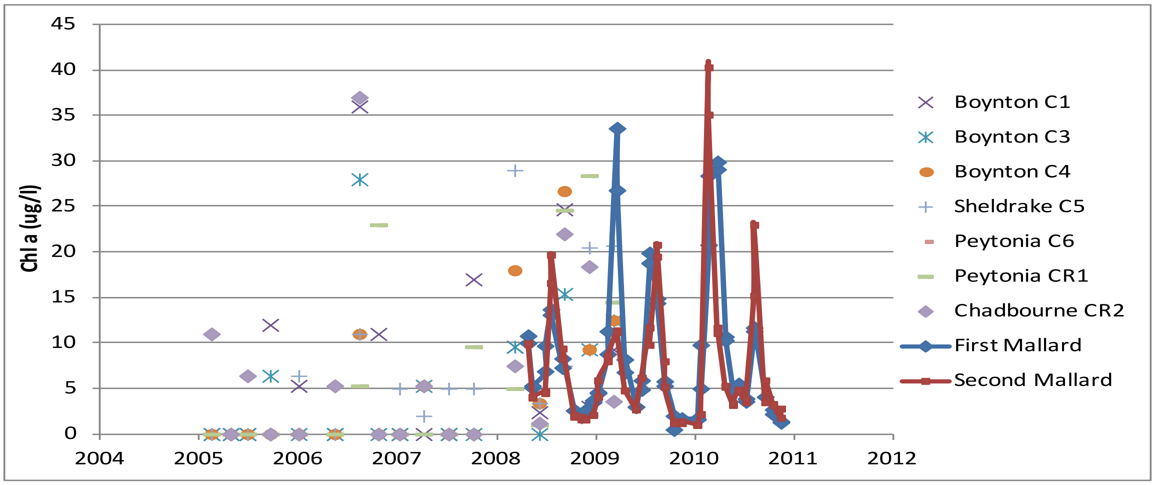


Figure B-30 Observed Chlorophyll a concentrations in receiving water sloughs compared to First and Second Mallard Sloughs

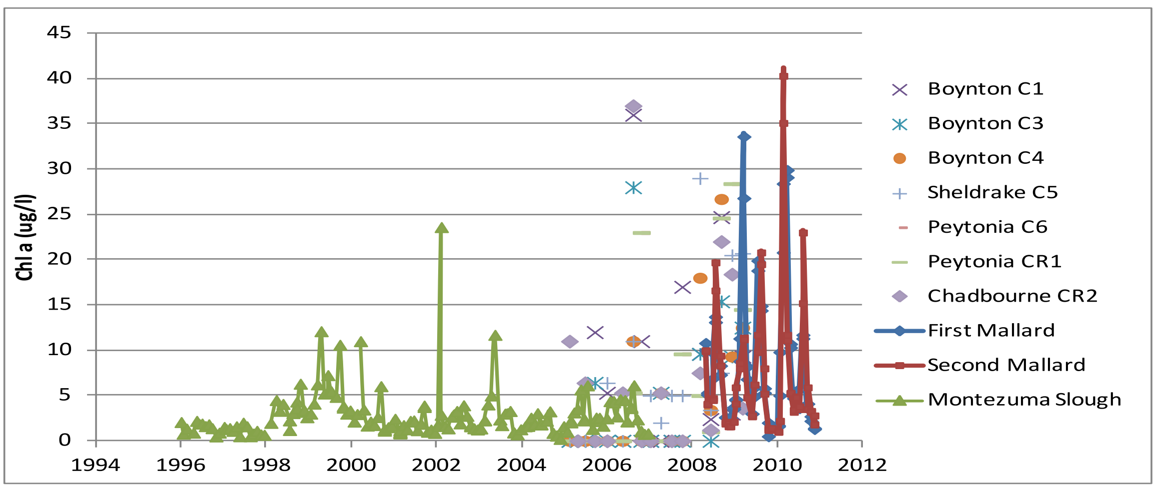


Figure B-31 Observed Chlorophyll a concentrations in receiving water sloughs compared to First and Second Mallard Sloughs and Montezuma Slough

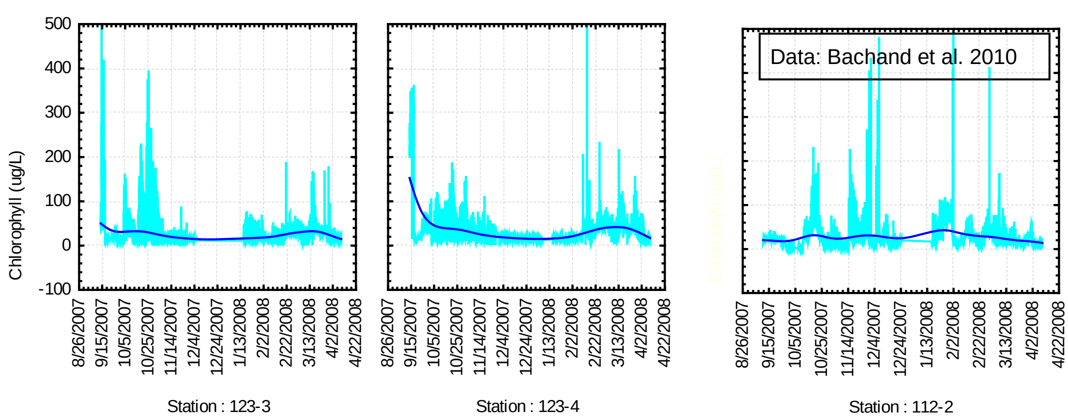


Figure B-32 Temporal chlorophyll a trends a perimeter stations for wetlands 112 and 123.

Conditions at Minimally Impacted Sloughs

Many sloughs within Suisun Marsh receive direct discharges from managed wetlands, and/or are substantially modified and affected by human activities. There are some sloughs, however, which are fully tidal, have good connectivity to larger sloughs (Suisun, Montezuma) or to the Bay, and do not receive discharges from managed wetlands. These sloughs were used here to represent background conditions in the marsh. Two such sloughs with water quality data were identified in Suisun Marsh: First Mallard and Second Mallard Slough. DO concentrations in First Mallard and Second Mallard Sloughs are monitored continuously by NOAA under the National Estuarine Research Reserve System's (NERRS) National Monitoring Program. These two stations are located at the intersection of Cutoff Slough with First Mallard and Second Mallard Sloughs, which drain different regions of the San Francisco Bay National Estuarine Research Reserve. First Mallard Slough drains the northwestern portion of Rush Ranch, while Second Mallard Slough drains the southeastern areas (Figure B-33). The area draining to these sloughs consists mostly of tidal marshes and non-tidal wetlands, covered by natural vegetation.

EPA recommends the use of natural background conditions in establishing the numeric site–specific criteria for temperature, DO, and pH for the protection of aquatic life designated uses (EPA 2015). The frameworks suggests that when appropriate data exist and when the non-attainment of the water quality criterion is due to natural processes, natural background conditions can be used to set site-specific criteria, regardless whether the existing water quality objectives are met or not. When deciding whether a given condition represents natural conditions, factors such as 1) undisturbed vegetation surrounding the site; 2) no historical anthropogenic impacts; 3) presence of evident hydrological alteration; 4) groundwater recharge is not impacted by anthropogenic activities; 5) no point or non-point source discharges. These conditions are met to a significant degree at the First Mallard and Second Mallard Sloughs and therefore these sloughs may be reasonably considered to represent natural background conditions or minimally impacted sites in Suisun Marsh.

Figure B-33 Locations of First and Second Mallard Slough monitoring stations

The daily average DO concentrations at First Mallard Slough range between 2 to 9.5 mg/L. The daily average DO concentrations at Second Mallard Slough range between 3.5 to 10 mg/L. Daily average DO concentrations at these two locations are compared to the existing DO objectives of 7 mg/L and 5 mg/L, and the 3-month medians of daily average DO saturation were compared to the objective of 80% saturation. In addition, hourly minimum DO concentrations were compared to the EPA recommended DO criteria for continuous exposure of saltwater, modified to aquatic life in Suisun Marsh: 1) 3.3 mg/L for criterion minimum concentration (CMC) for juvenile and adult organism survival for persistent exposure; 2) 5.0 mg/L for criterion continuous concentration (CCC) for growth effects on aquatic organisms for persistent exposure, and 3) criteria for episodic exposure based on hours of exposure to adjusted CMC and CCC (EPA, 2000; Table B-4). These thresholds are based on laboratory tests of biological effects of low DO to aquatic life, and therefore protect the survival and growth of estuarine species. The results of the evaluation are shown in Figure B-34 to Figure B- 39 and summarized in Table B-5 and Table B-6.

For the First Mallard Slough, when compared to the existing criterion of 7 mg/L, about half of the data points (51.7%) were below 7 mg/L, but only a few points (4.4% of the time) were below 5 mg/L. However, First Mallard Slough is below 80% DO saturation for most of the time. The comparison to persistent exposure criteria of CMC and CCC showed some incidences of not meeting the persistent exposure criteria. The hourly DO data are below continuous exposure criteria CMC occasionally (for 0.14% of the time), and below CCC 0.65% of the time. The comparison to sub-daily or episodic exposure criteria suggested some incidences of not meeting the adjusted CMC (0.25% of the time) or with cumulative growth reduction greater than 25% (1.36% of the time).

Table B-4
Summary of ambient aquatic life water quality criteria for DO recommended in EPA (2000) modified to aquatic life in Suisun Marsh

Endpoint	Persistent Exposure (24 hrs or greater continuous low DO condition)	Episodic and cyclic exposure (less than 24 hr duration of low DO conditions)
Juvenile and adult survival (minimum allowable conditions)	(1) A limit for continuous exposure **DO = 3.3 mg/L** (criterion minimum concentration, CMC)	(3) a limit based on the hourly duration of exposure **DO = 0.566* ln(t) + 1.4976** Where: DO = allowable concentration (mg/L) T = exposure duration (hours)
Growth effects (maximum conditions required)	(2) A limit for continuous exposure **DO = 5.0 mg/L** (criterion continuous concentration, CCC)	(4) a limit based on the intensity and hourly duration of exposure Cumulative cyclic adjusted percent daily reduction in growth must not exceed 25% $\Sigma \frac{ti * 1.56 * Gredi}{24} < 25\%$ And Gredi = -23.1*DOi + 138.1 Where: Gredi = growth reduction (%) DOi = allowable concentration (mg/L) Ti = exposure interval duration (hours) I = exposure interval

For the Second Mallard Slough, about 40% of the daily DO data are below 7 mg/L, however, with only a few data points below 5 mg/L during the time period monitored (0.38% of the time). Second Mallard Slough is below 80% DO saturation for over 78% of the time. The data showed no incidence of exceeding the persistent exposure criteria. The minimum hourly DO is below continuous exposure criteria CMC of 3.3 mg/L occasionally but for less than 24 hours, and the occasional incidences of DO below CCC of 5.0 mg/L do not last longer than 24 hours. For exposure less than 24 hours, the minimum hourly DO concentrations were occasionally less than the adjusted CMC (14 hours or 0.03% of the time). There are rare incidences of cumulative growth effects of greater than 25% (39 hours total, 0.07% of the time) for exposure less than 24 hours.

First and Second Mallard Sloughs can be considered to represent natural background conditions in Suisun Marsh. The fact that DO concentrations about 50% of the time in First Mallard Slough and 40% of the time in Second Mallard Slough were below the Basin Plan criterion of 7 mg/L suggests that this criterion cannot be met all the time even under no direct discharges from managed wetlands. Both First and Second Mallard Sloughs showed only a few occasions where concentrations were below 5 mg/L, suggesting that under the conditions of no direct discharges from the managed wetlands, the Cutoff Slough region in Suisun Marsh is able to meet a 5 mg/L target most of the time (>95% of the time, Table B-5 and Table B-6). The comparison to biological criteria of CMC and CCC at these two sloughs suggested that these criteria can be met more than 98% of the time.

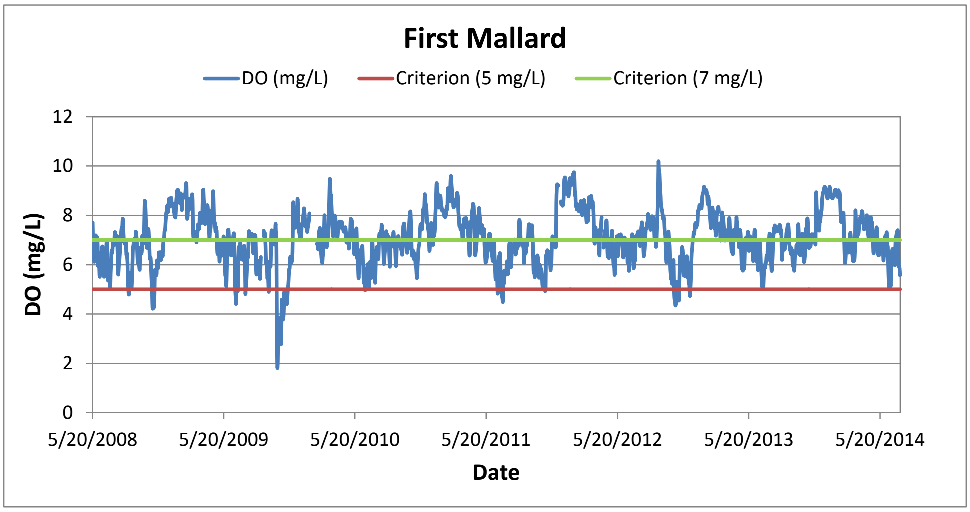


Figure B-34 Daily average DO at First Mallard Slough compared to the DO criteria of 5 and 7mg/L

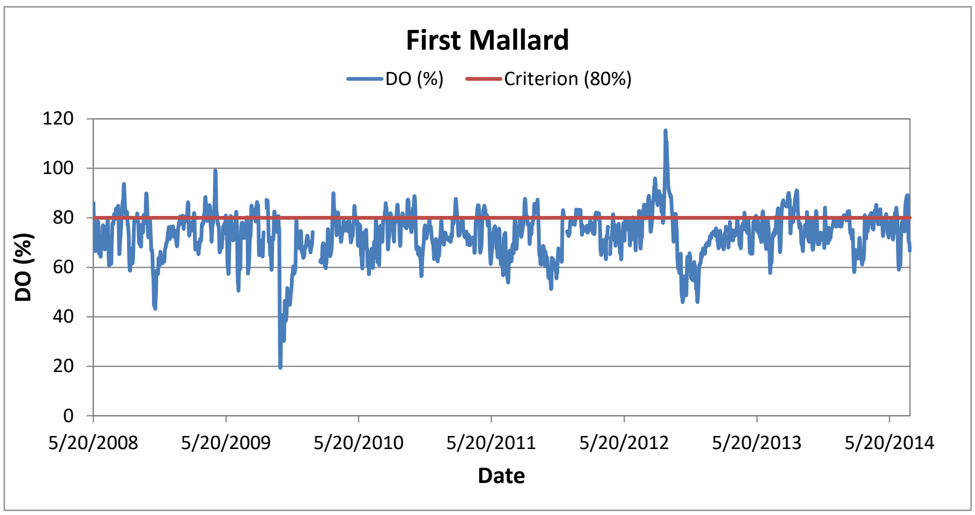


Figure B-35 Daily average DO at First Mallard Slough compared to 80% of DO saturation

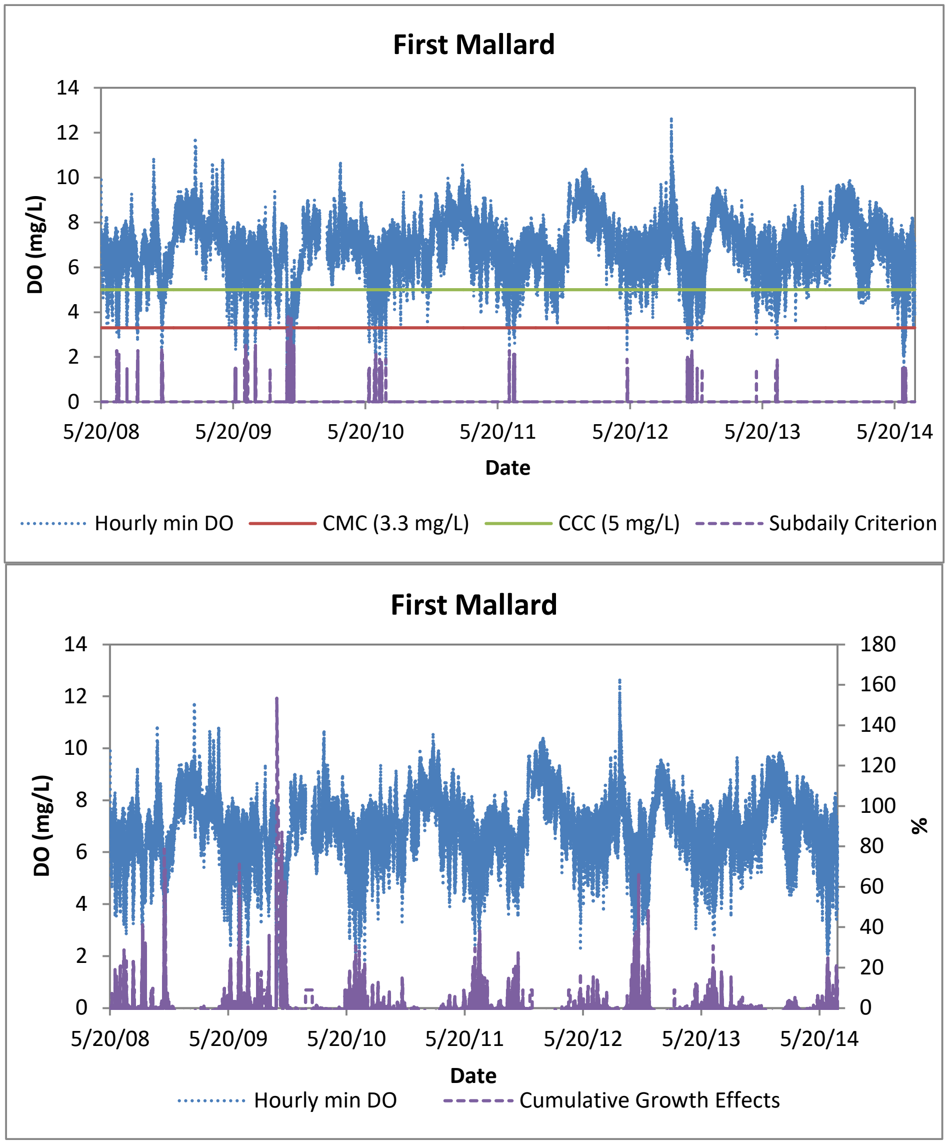


Figure B-36 Hourly DO concentrations compared to the criterion minimum concentration (CMC) and criterion continuous concentration (CCC) at First Mallard Slough

Table B-5
Summary of time below DO criterion for the First Mallard Slough

	Days below criterion of 5 mg/L	Days below criterion of 7 mg/L	Number of rolling 3-Month median of daily DO below 80% saturation	Hours below CMC of 3.3 mg/L	Hours below CCC of 5 mg/L	Hours below adjusted CMC* (based on hourly duration of exposure)	Hours with cumulative growth reduction >25%*
Number	71	1050	2074	76	346	131	716
Total Data Points	2209	2209	2155	52841	52841	52841	52841
Percent	3.21%	47.53%	96.24%	0.14%	0.65%	0.25%	1.36%

*EPA, 2000

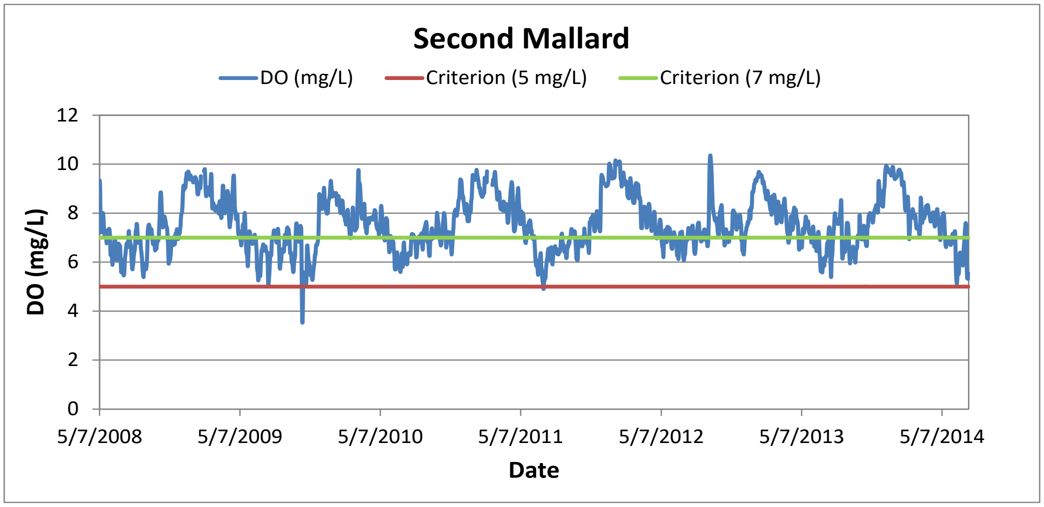


Figure B-37 Daily average DO concentrations at Second Mallard Slough compared to the DO criteria of 5 and 7mg/L

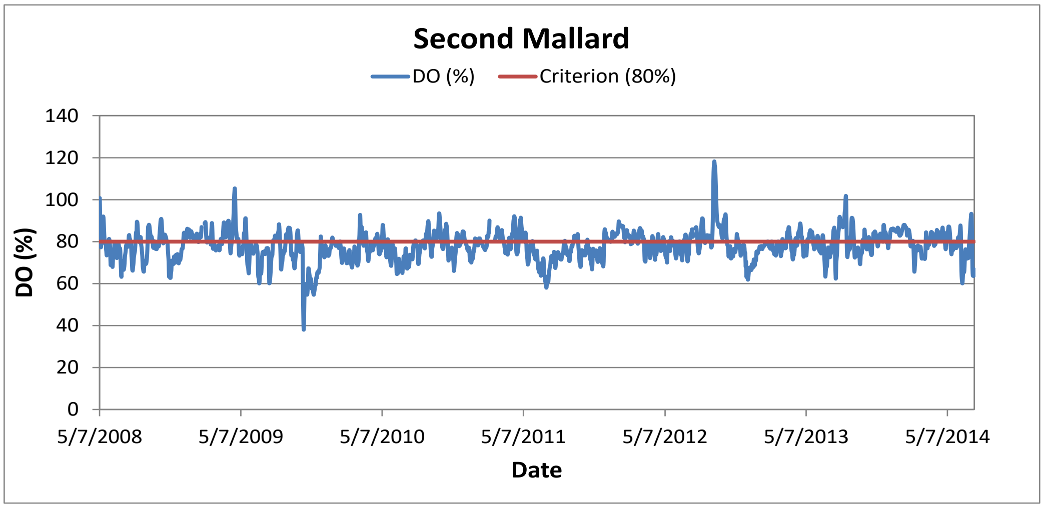


Figure B-38 Daily average DO concentrations at Second Mallard Slough compared to 80% of DO saturation

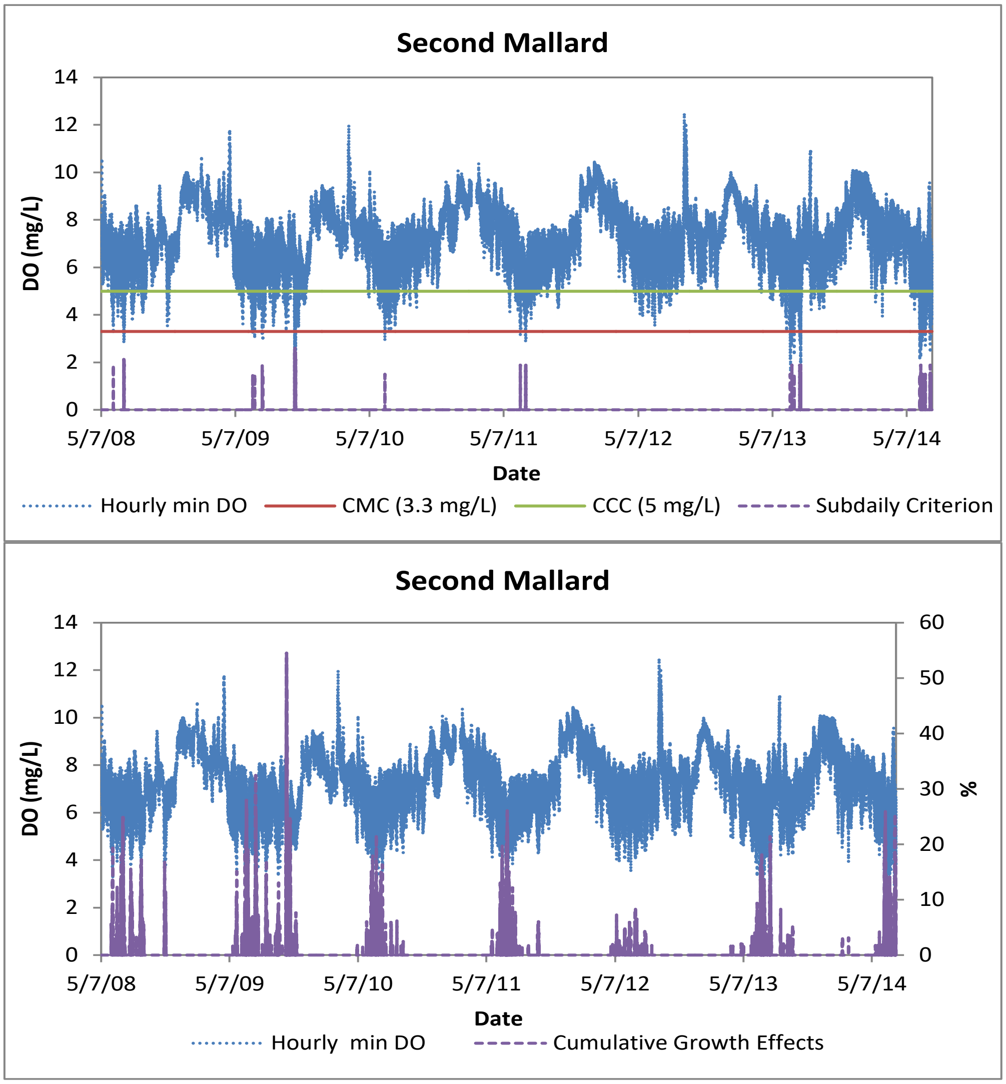


Figure B- 39 Hourly DO concentrations compared to the criterion minimum concentration (CMC) and criterion continuous concentration (CCC) at Second Mallard Slough

The cumulative distributions of 1-hour minimum, 4-hour minimum, 6-hour minimum and 24-hour minimum DO concentrations for First Mallard and Second Mallard Sloughs were estimated to show the frequency of exceedances (Figure B-40, Figure B-42). For 20% of the time, the 24-hour minimum DO is less than 5 mg/L. The 1-hour to 6-hour min DO is generally less than 6 mg/L for 15–25% of the time.

The DO concentrations at First Mallard Slough show seasonal variations, with lower concentrations during summer months when temperatures are higher (Figure B-41). However, the lowest DO occurs during the fall, usually in October and November, when the 24-hour and 30-day running averages can fall below 5 mg/L. Similar patterns were found for the Second Mallard Slough DO concentrations (Figure B-42 and Figure B-43).

The statistics relating to the 1-hour, 4-hour, 6-hour, and 24-hour minimum DO concentrations are shown in Table B-7. The mean values of the 1-hour to 24-hour minimum DO concentrations are generally less than 7 mg/L.

Table B-6
Summary of time below DO criterion for the Second Mallard Slough

	Days below 5 mg/L	Days below 7 mg/L	Number of rolling 3-month median of daily DO below 80% saturation	Persistent Exposure		Episodic Exposure	
				Hours below CMC of 3.3 mg/L*	Hours below CCC of 5 mg/L*	Hours below adjusted CMC (based on hourly duration of exposure)*	Hours with cumulative growth reduction >25%*
Number	5	749	1,368	0	0	24	39
Total Data Points	2,229	2,229	2,229	53,363	53,363	53,363	53,363
Percent	0.22%	33.6%	61.37%	0%	0%	0.04%	0.07%

*EPA, 2000

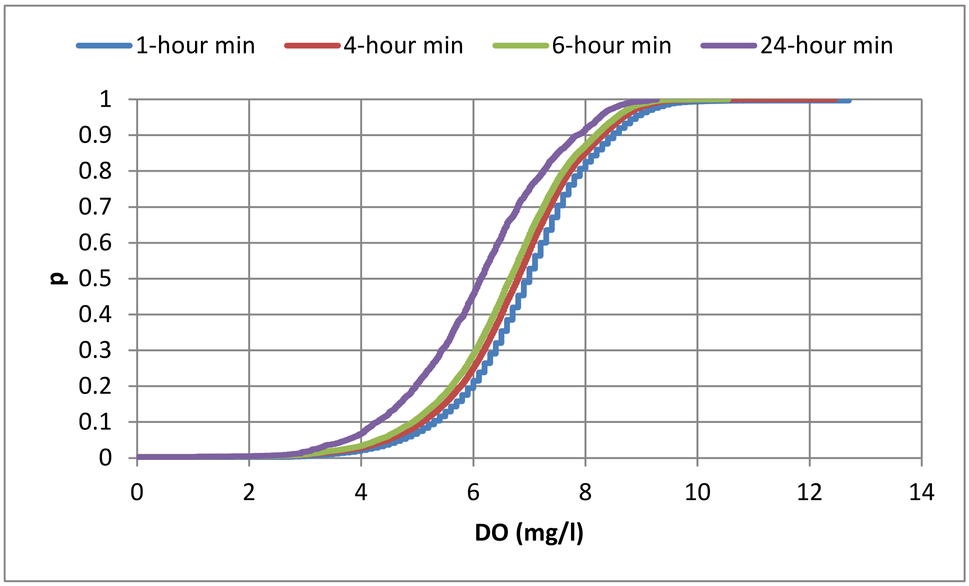


Figure B-40 Cumulative probability (p) distributions of 1-hour min, 4-hour min, 6-hour min, and 24-hour minimum DO concentrations at First Mallard Slough

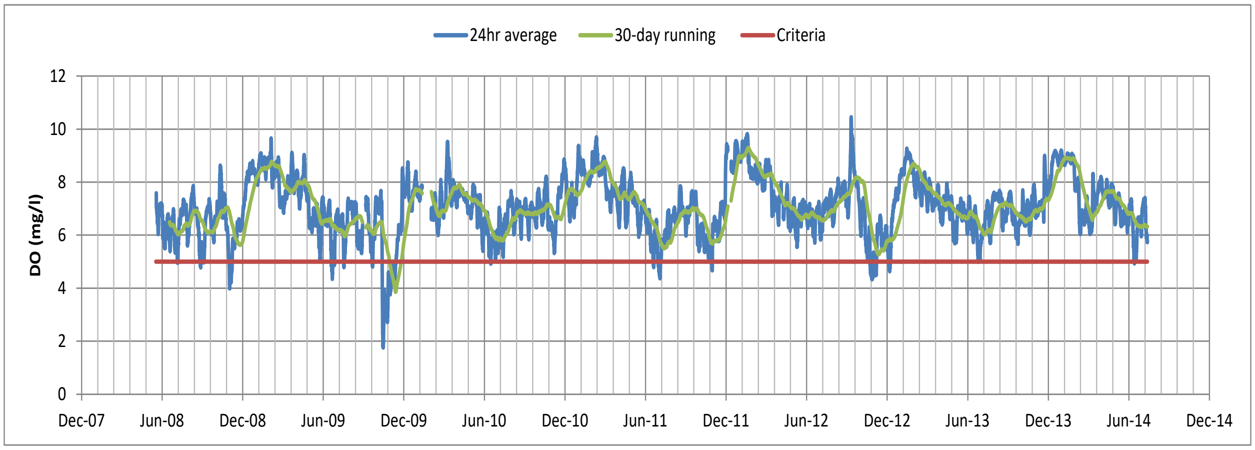


Figure B-41 24-hour running average and 30-day running average DO at First Mallard Slough compared to a target of 5 mg/L

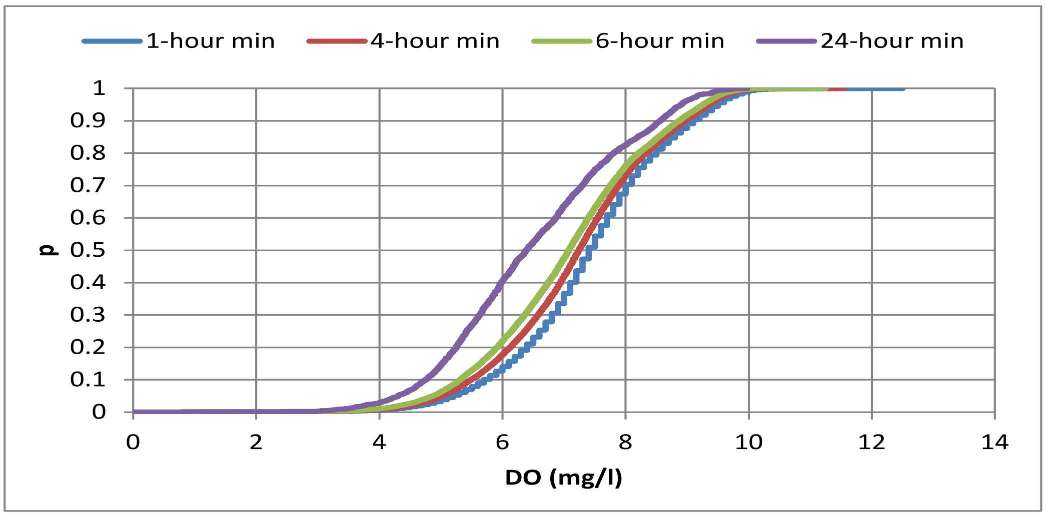


Figure B-42 Cumulative probability (p) distributions of 1-hour min, 4-hour min, 6-hour min, and 24-hour minimum DO concentrations at Second Mallard Slough

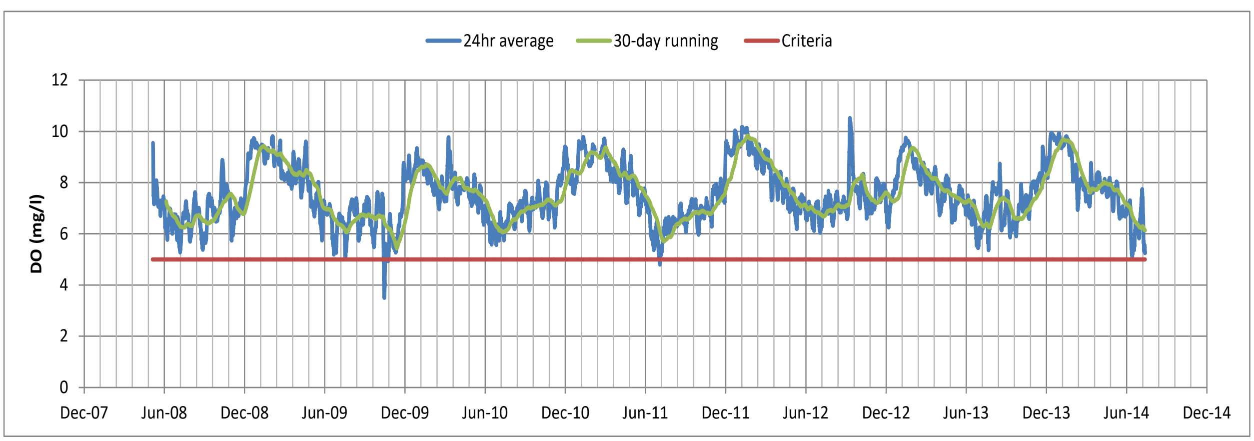


Figure B-43 24-hour running average and 30-day running average DO at Second Mallard Slough compared to a target of % mg/L

Table B-7 Evaluation of different time periods for continuous DO data collected at First and Second Mallard Sloughs

	1 hour	4 hour	6 hour	24 hour
Second Mallard				
Min	0.3	0.3	0.3	0.3
Max	12.5	11.4	10.8	9.9
Mean	7.4	7.0	6.8	6.2
Standard Deviation	1.3	1.4	1.4	1.5
95th percentile	9.5	9.2	9.1	8.7
5th percentile	5.2	4.8	4.6	3.9
First Mallard				
Min	0.0	0.0	0.0	1.5
Max	11.3	10.4	9.2	10.0
Mean	6.5	6.4	5.9	6.9
Standard Deviation	1.3	1.3	1.4	1.1
95th percentile	8.6	8.4	8.1	8.8
5th percentile	4.3	4.1	3.4	5.1

Explanation:
1 hour estimates represent min, max and mean values based on 4 DO readings in each hour
4 hour estimates - data were averaged first on hourly basis, and then min, max and mean values were estimated

Appendix B References

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APPENDIX C: DO MODELING WITH HEC-RAS

Prepared by Tetra Tech Inc., 2013

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DO Modeling with HEC-RAS

Prepared by Tetra Tech Inc., 2013

A numeric hydraulic model (HEC-RAS; USACE 2010) was used to simulate linkages between organic carbon loads from managed wetlands and dissolved oxygen in the Suisun Marsh sloughs. The model was run for two sloughs that experienced frequent low DO concentrations, Boynton and Peytonia Sloughs, which were continuously monitored by Siegel et al. (2011) during 2007–2008, and two other sloughs, Goodyear and Denverton Sloughs, which were recently monitored by the Regional Water Board from 2012–2013 (Figure C-1 through Figure C-3).

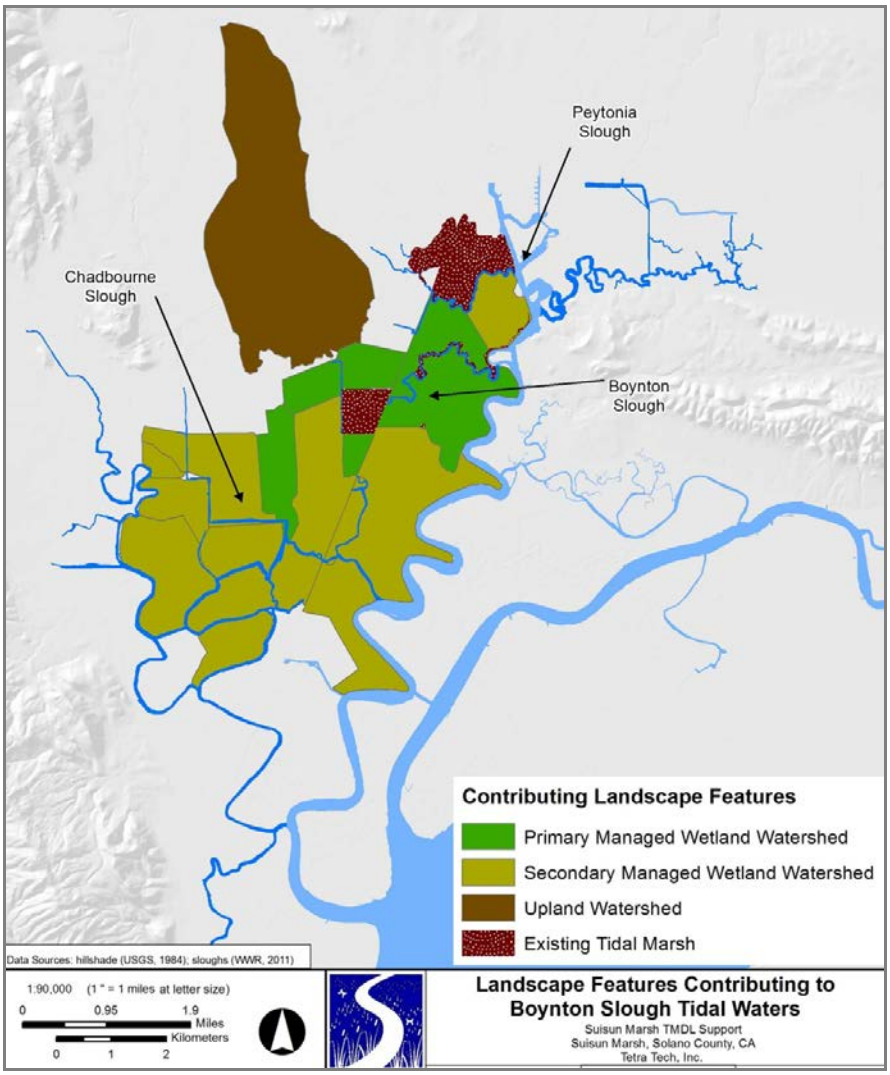

Figure C-1 Locations of Boynton and Peytonia Sloughs with surrounding wetlands and upland watershed

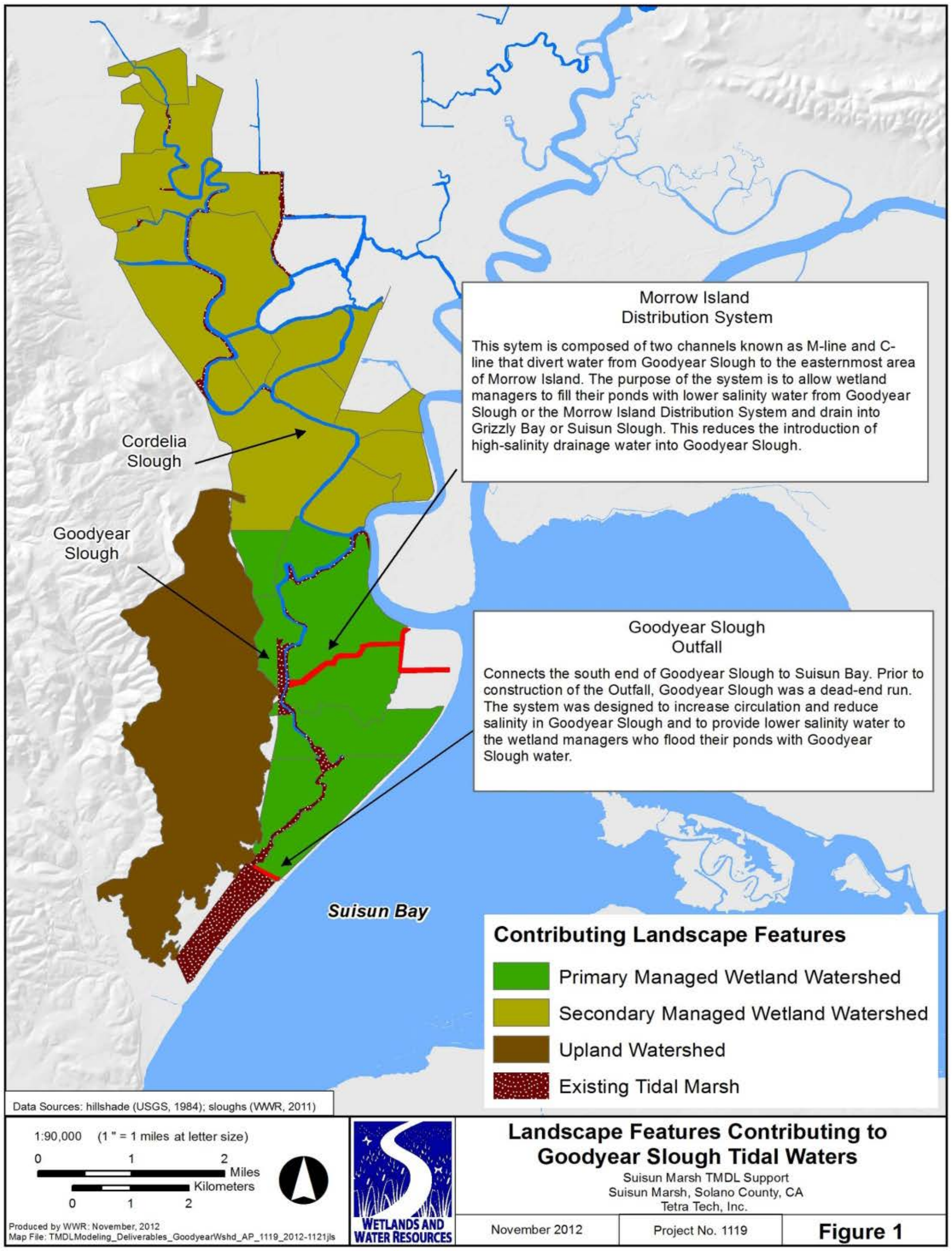

Figure C-2 Locations of Goodyear Slough with surrounding wetlands and upland watershed

Simulated Sloughs

Both, Boynton and Peytonia Sloughs had experienced periods of low DO in the past. These sloughs receive discharges from managed wetlands. Peytonia Slough is connected to Wetland 112, 113, 123 and 211 (Figure C-4 and Figure C-12). Boynton Slough is bounded by Wetland 211 at its confluence with Suisun Slough and Wetland 123 and 124, and connected to Wetland 133, 122, 130, and 131. In addition to the managed wetland discharges, Boynton Slough receives discharges from the FSSD wastewater treatment plant (Figure C-4). On average, Boynton Slough receives 90% of FSSD discharge and Peytonia Slough receives 10% of the FSSD discharge. Both sloughs are connected to

Wetland 123. It was documented that under normal conditions, Wetland 123 will draw water from Peytonia Slough and drain to Boynton Slough (Siegel et al. 2011). The comparison of Boynton and Peytonia Slough and their surrounding wetlands is shown in Table A-4 (Attachment).

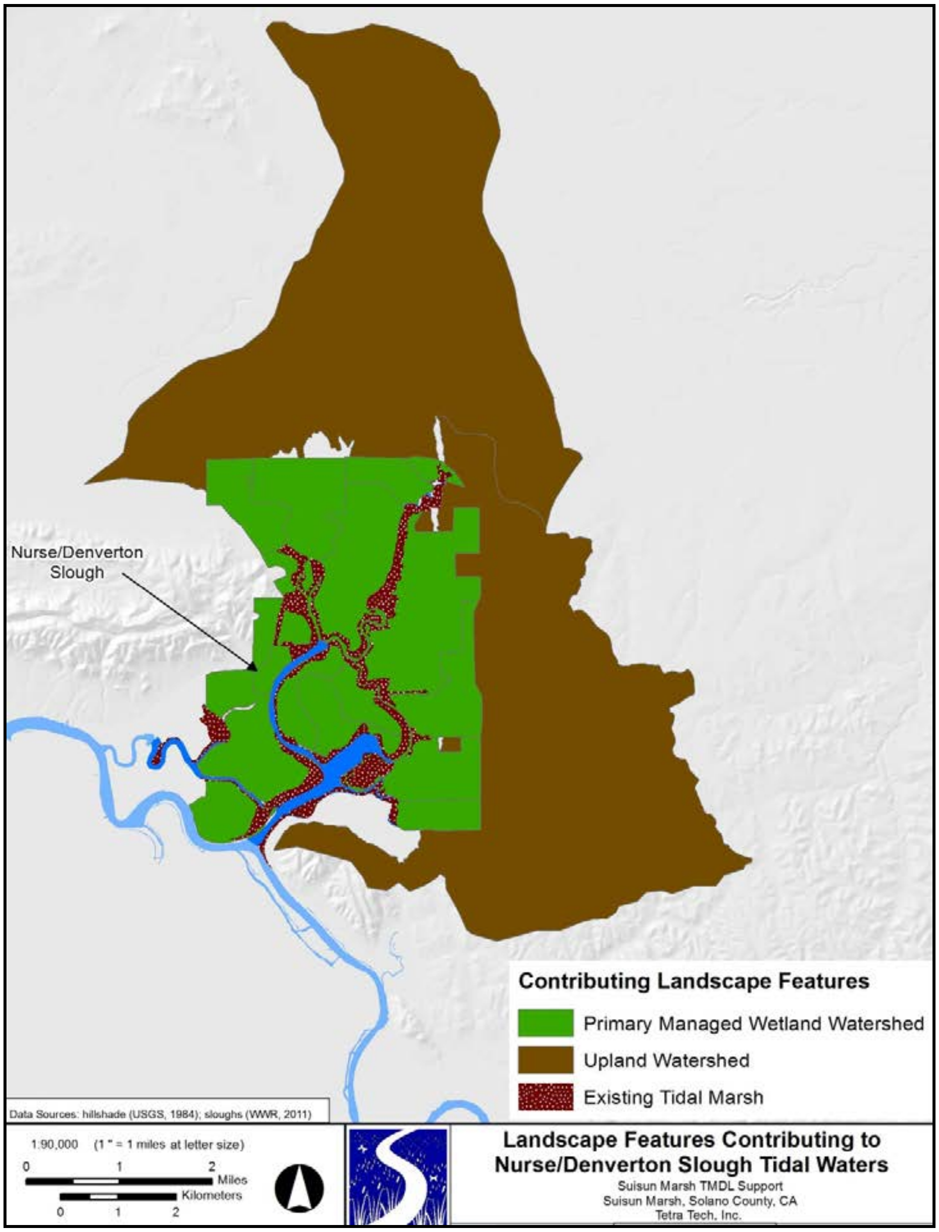

Figure C-3 Locations of Denverton Slough with surrounding wetlands and upland watershed

Goodyear and Denverton Sloughs are located in the southwest and northeast of Suisun Marsh. Similar to Boynton and Peytonia Sloughs, Goodyear Slough received discharges from managed wetland and has experienced frequent low DO events and fish kills in the past. Goodyear Slough watershed is also characterized by dead-end narrow slough channels. The mixing and reaeration in a narrow slough are considered to be limited. Denverton Slough, located in the northwest of Suisun Marsh, has wider channels and is considered to have higher DO concentrations. DO concentrations in Denverton Slough, although higher than Goodyear Slough, still showed frequent depressions under 5 mg/L possibly due to managed wetland discharges. In the following sections we describe the model application to Boynton, Peytonia, Goodyear, and Denverton Sloughs.

Model Simulations in Boynton Slough

HEC-RAS Model Set Up

The sloughs in Suisun Marsh are subject to tidal influence. The tidal energy that enters the sloughs can propagate upstream and dissipates when it reaches the upper slough. As a result, reaeration in the sloughs due to tidal mixing could be enhanced. In order to simulate mixing of tidal flow and slough water, the HEC-RAS model was run for a typical discharge period (09/27/2008–09/30/2008), using flow and stage data observed near the mouth (Siegel et al. 2011) as an input.

Boynton Slough receives discharges from FSSD and managed wetlands (Wetland 123). There are four flood and external water management structures on Boynton Slough, located roughly at 0.3, 1.3, 2.2, and 3.1 kilometers from the mouth (showed as purple arrow in Figure C-4). The discharge from FSSD (blue arrow) is located at roughly 2.8 km from the mouth of the slough.

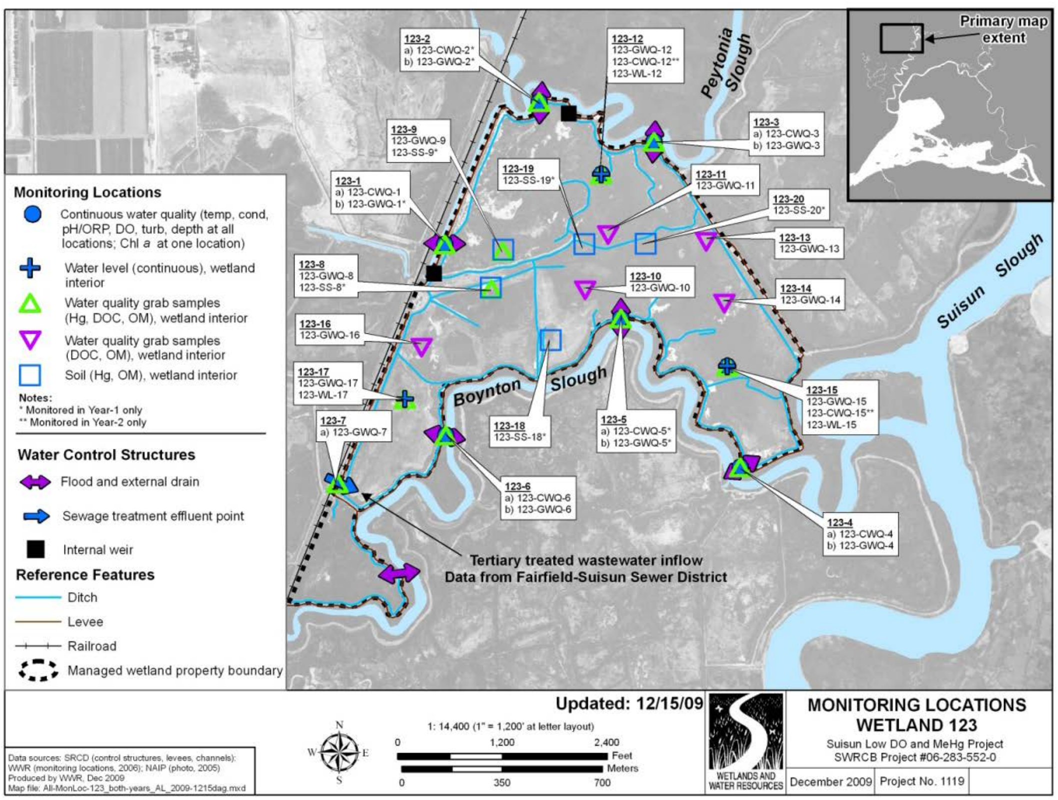

Figure C-4 Locations of FSSD and managed wetland discharges in Boynton Slough

For the HEC-RAS modeling, Boynton Slough is represented by a main reach (Reach 2) and two upstream tributaries (R1, and R1a) (Figure C-5). The slough was modeled by assuming a headwater flow of 5 cfs from the upland tributaries. The amount of discharge from FSSD (Table A-1 in the Attachment) and water management data for Wetland 123 were reported in an earlier study (Siegel et al. 2011). The major discharge events from wetlands 123 and 112 summarized in Table A-2 and Table A-3, and the observed concentrations of dissolved oxygen, organic carbon and chlorophyll a from perimeter sites of the managed wetlands were used in the modeling (Figure A-1and Figure A- 2 in the Attachment). Some smaller discharge events, which resulted in noticeable DO sags in the sloughs, were also included in the model setup. The resulting schedule of discharge events is shown in Figure A-3 (Attachment). The volume of discharge at each discharge location (a total of four) was assumed to be the same at 1/4th of the total discharge monitored during the period of 2007–2008 by Siegel et al. (2011). The discharge from FSSD was modeled as a point source, using the monthly monitoring data. The observed flow and stage data at the mouth of Boynton Slough were used as the downstream boundary conditions of the model (Figure C-6). Based on the available data, Boynton Slough was modeled for the period of 09/15/2007 – 03/14/2008.

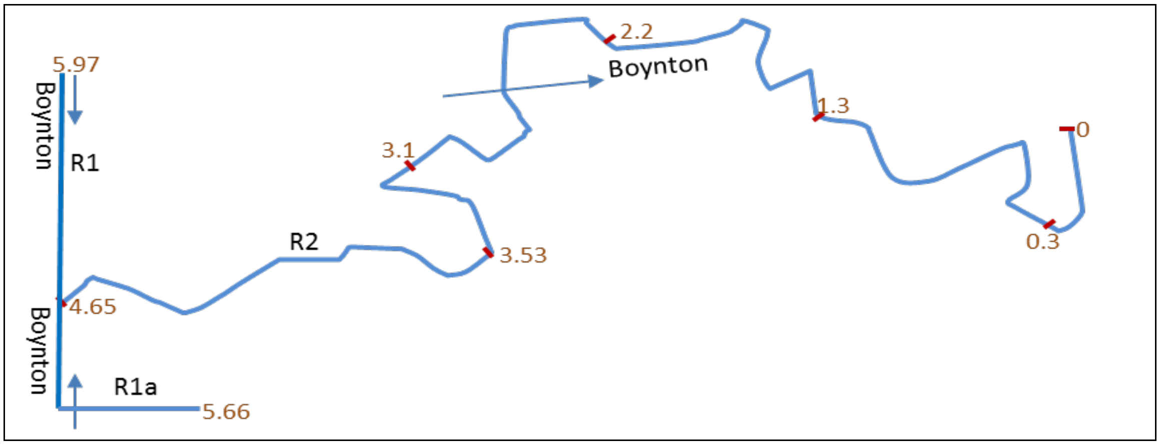

Figure C-5 Schematic representation of Boynton Slough in HEC-RAS model with distance (in km) from mouth and reaches (R1, R1a, and R2) shown

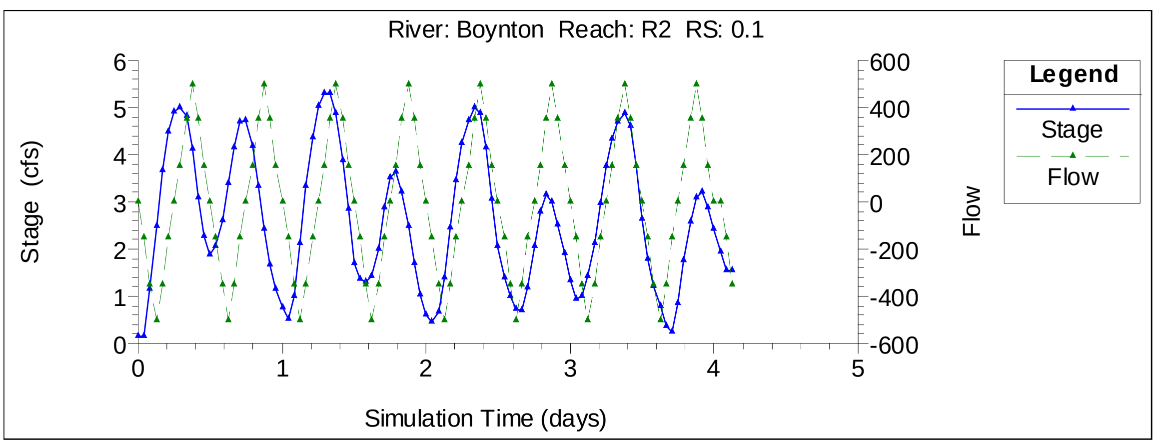

Figure C-6 Flow–stage relationship at boundary location of Boynton Slough

Model Results: Boynton Slough

The simulated flow, stage, and velocity at an hourly time step at different locations of Boynton Slough are shown in Figure C-7 and Figure C-8. The flow at the mouth of the slough changes between -400 to 400 cfs within a tidal cycle, and the magnitude of flow variation during a tidal cycle decreases upstream. The simulated tidal stage at the mouth of the slough varied from 0.3 to 5.3 ft within the tidal cycles. The tidal velocity at the mouth of the slough varied from -1.2 ft/s to 2.2 ft/s (Figure C-9). The model simulated tidal velocity agrees with a measured tidal velocity of 1 cfs. The simulated tidal stage and velocity decreases upstream, due to dissipation of tidal energy.

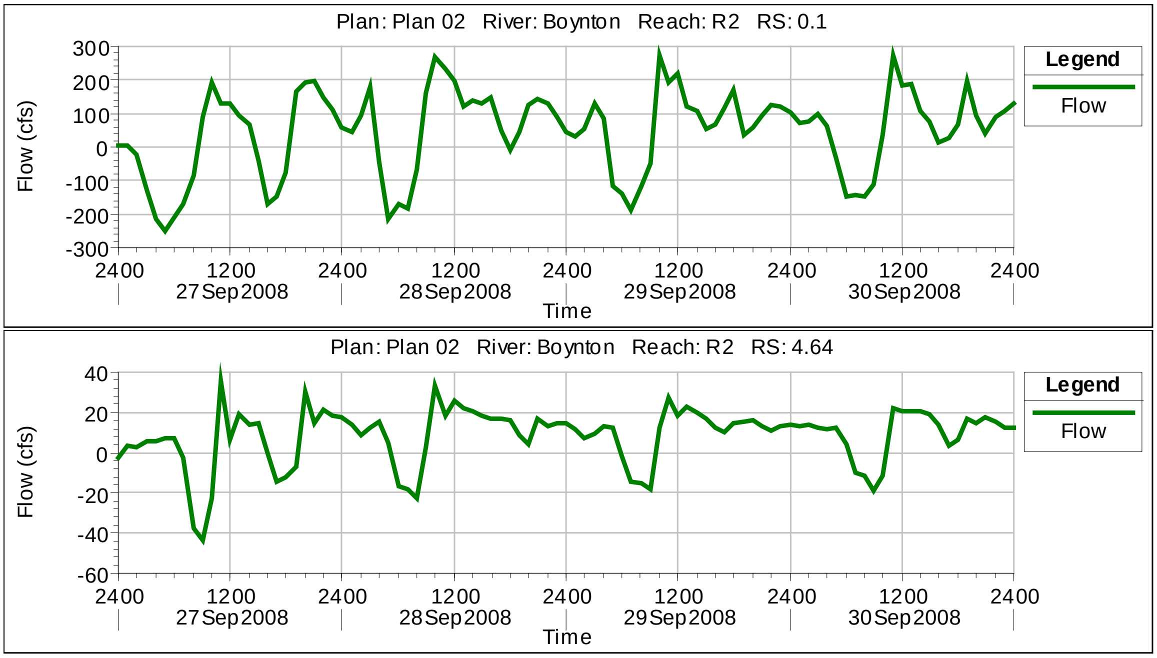

Figure C-7 Simulated variations in flow near the mouth of Boynton Slough (R2, 0.1 km from mouth) and upstream reach (R1a, 4.64 km from mouth) by HEC-RAS

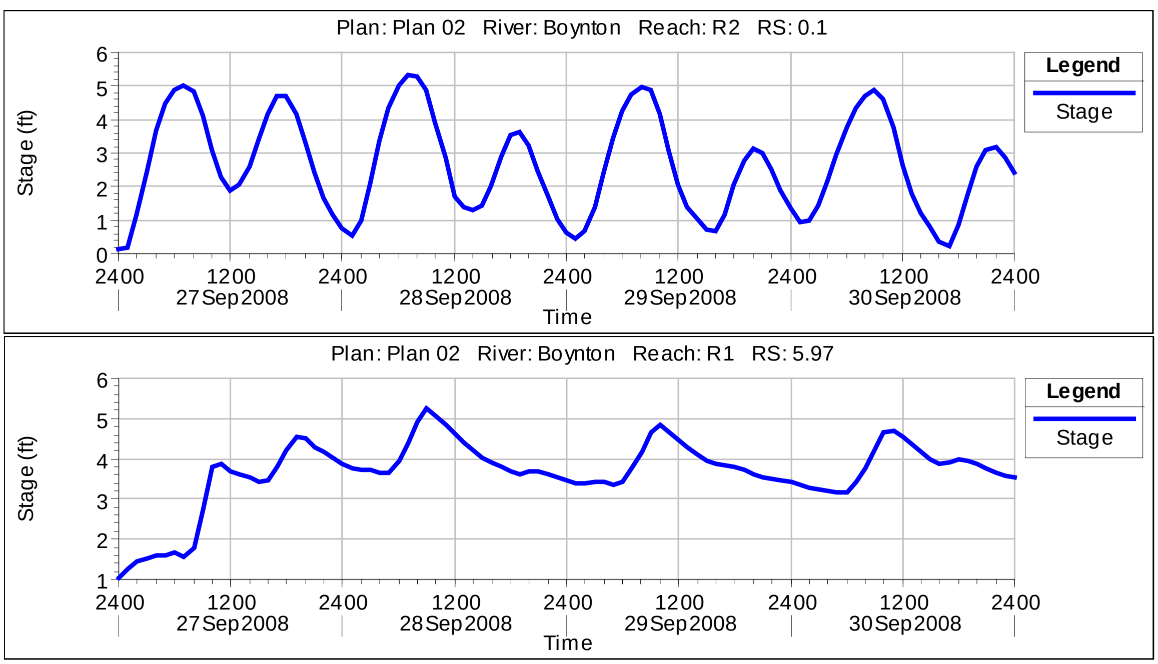

Figure C-8 Simulated variations in stage near the mouth of Boynton Slough (R2, 0.1 km from mouth) and upstream reach (R1a, 5.97km from mouth) by HEC-RAS

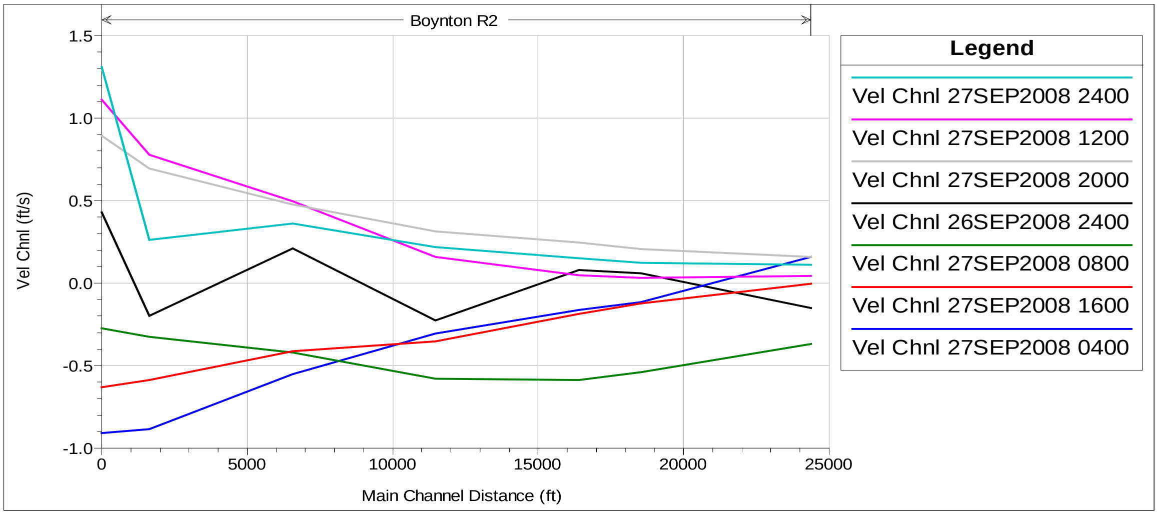

Figure C-9 Simulated velocity every four hours for a period of 24 hours in Boynton Slough from mouth to head by HEC-RAS

The model-simulated temperature and DO at 15-minute intervals were compared to the observed data for Boynton Slough (Figure C-10, Figure C-11). The measured temperature decreases from September to January and then increases from January to March. The model is able to capture this pattern in observed temperature. Boynton Slough receives significant discharges from managed wetlands during October and November, as indicated by frequent declines in observed DO. The model was able to capture these DO sags (October–November) and showed the increasing DO concentrations (December–February) that matched the observed data reasonably well.

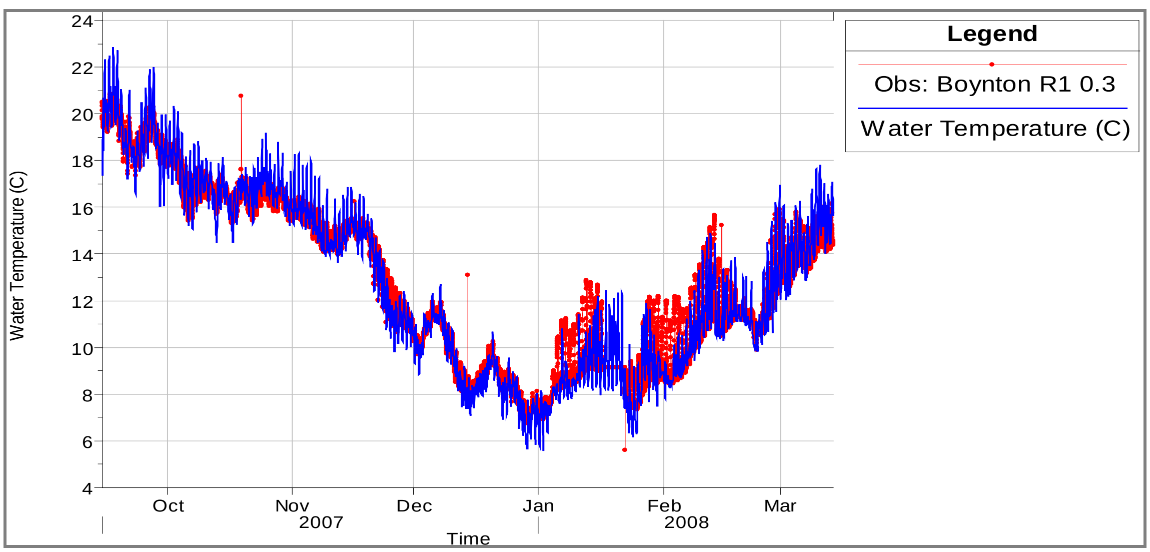

Figure C-10 Model simulated water temperature in Boynton Slough compared to 15-minute interval data

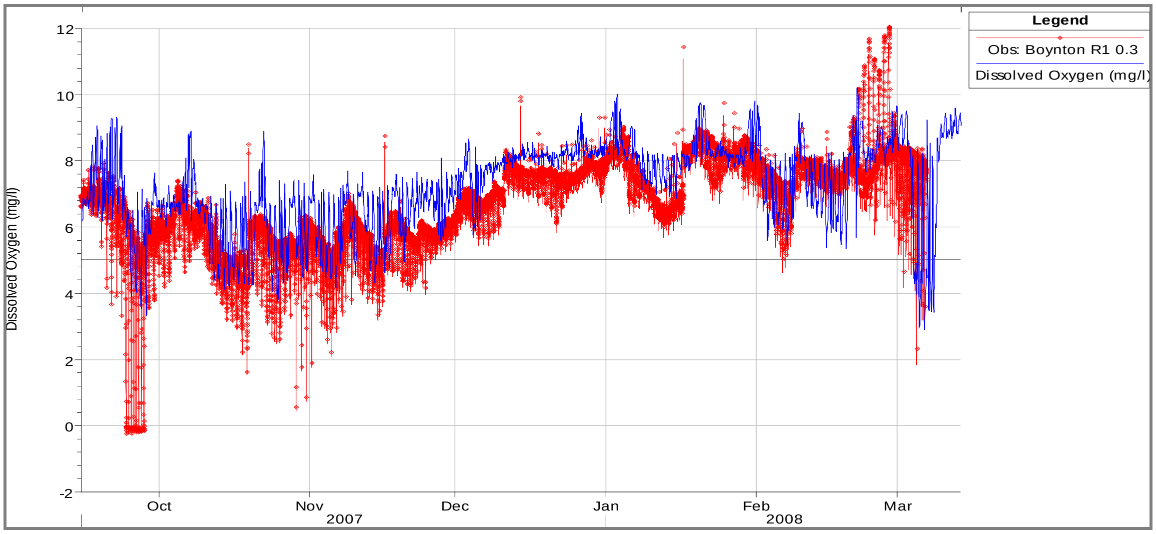

Figure C-11 Model simulated DO concentrations in Boynton Slough compared to observed data at 15-minute intervals

Model Simulations in Peytonia Slough

HEC-RAS Model Set Up

Peytonia Slough has a total length of 2.5 miles. Peytonia Slough receives 10% of the total FSSD discharge on average, and the discharge from only one managed wetland (Wetland 112). Therefore, it was assumed that all drainage from Wetland 112 drains to this slough measured at Station 112-1 located approximately 2.5 km from the mouth of the slough. Figure C-12 shows the points of discharge for FSSD (purple arrow) and Wetland 112 (blue arrow). Peytonia Slough also receives watershed inputs from Ledgewood Creek, which has 13,000 acres of drainage area. Inputs from the surrounding watersheds to the slough were specified based on a modeling study by Davis et al. (2000b), proportional to the drainage area. The location of continuous DO monitoring in Peytonia Slough is shown in Figure C-12.

For the HEC-RAS modeling, Peytonia Slough is represented by a single reach (R3, Figure C-13). The slough was modeled using a headwater flow of 8 cfs estimated from the surrounding upland watersheds. The discharge from managed wetlands was specified at the middle of the slough at approximately 2.5 km from the mouth. The discharge from FSSD was specified as point source at 1/10th of the FSSD discharge monitored by Siegel et al. (2011). The observed flow and stage data at the mouth of Peytonia Slough were assigned as the downstream boundary conditions (Figure C-14). Peytonia Slough was monitored for the period of 09/14/2007 – 03/14/2008.

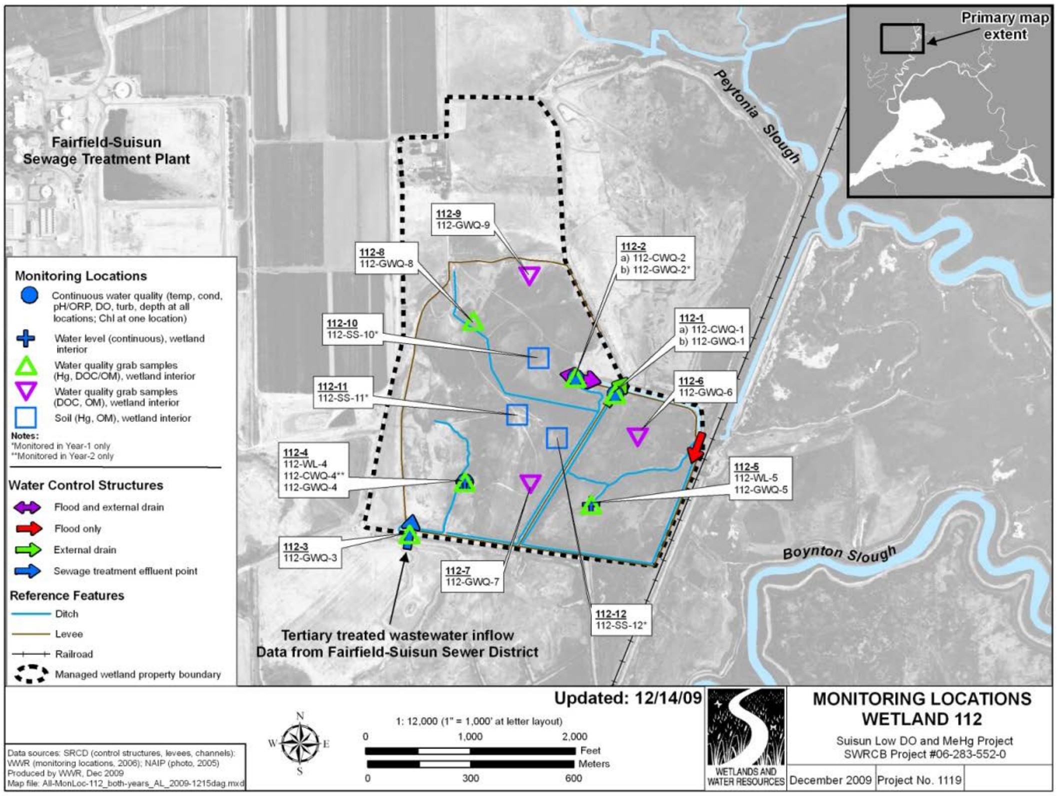

Figure C-12 Locations of sewage effluent inflow and managed wetland discharge for Peytonia Slough (Siegel et al. 2011)

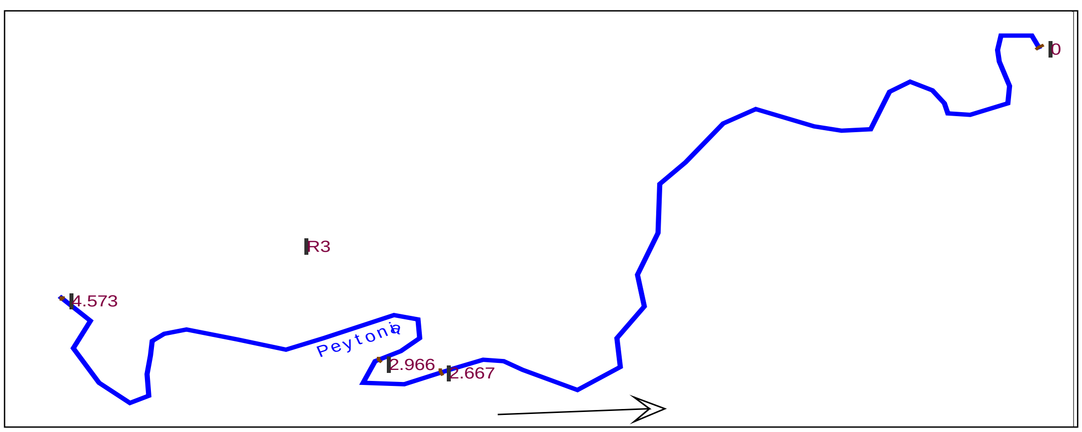

Figure C-13 Geometric data of Peytonia Slough in HEC-RAS model with river miles (in km from mouth) and reach (R3) shown

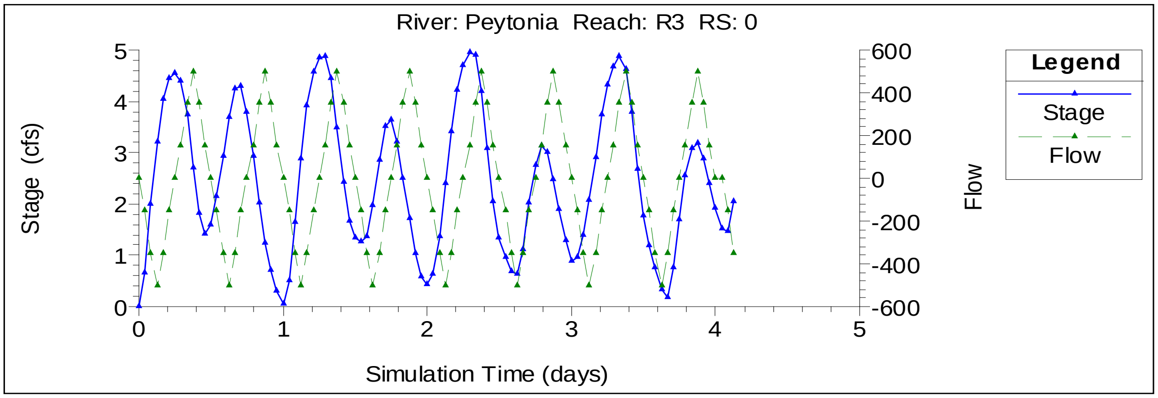

Figure C-14 Flow – stage relationship at the downstream boundary location of Peytonia Slough

Model Results: Peytonia Slough

The simulated flow, stage, and velocity at an hourly time step at different locations of Peytonia Slough are shown in Figure C-15 to Figure C-17. The flow at the mouth of the slough ranges between -300 to 300 cfs within a tidal cycle, and the magnitude of flow variation during a tidal cycle decreases upstream. The simulated tidal stage at the mouth of the slough varied from 0 to 5 ft within the tidal cycles while the tidal velocity at the mouth of the slough varied from -1 ft/s to 1 ft/s. The model-simulated tidal velocity agrees with the measured tidal velocity of 1 cfs. The simulated tidal stage and velocity decreases upstream, due to dissipation of tidal energy.

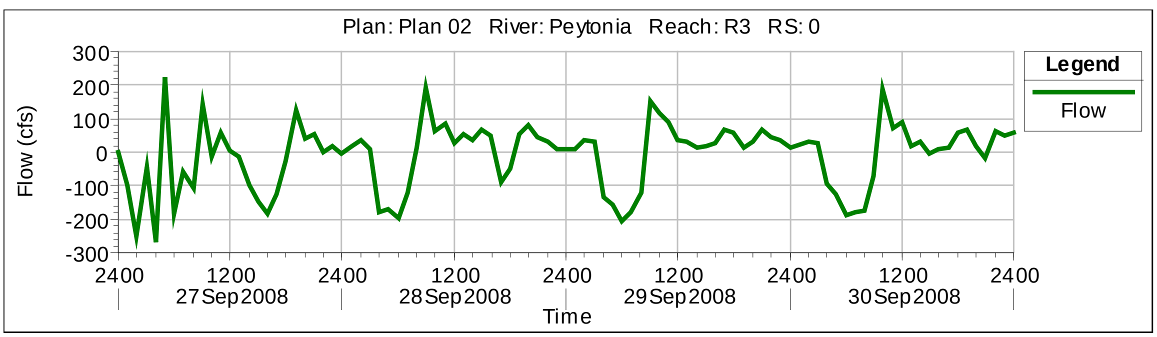

Figure C-15 Simulated variations in flow near the mouth of Peytonia Slough (R3, 0.0 km from mouth) by HEC-RAS

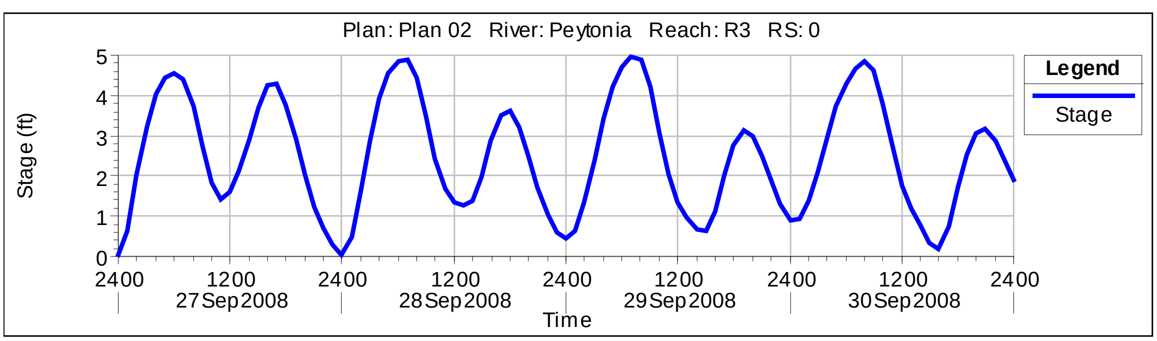

Figure C-16 Simulated variations in stage near the mouth of Peytonia Slough (R3, 0.0 km from mouth) by HEC-RAS

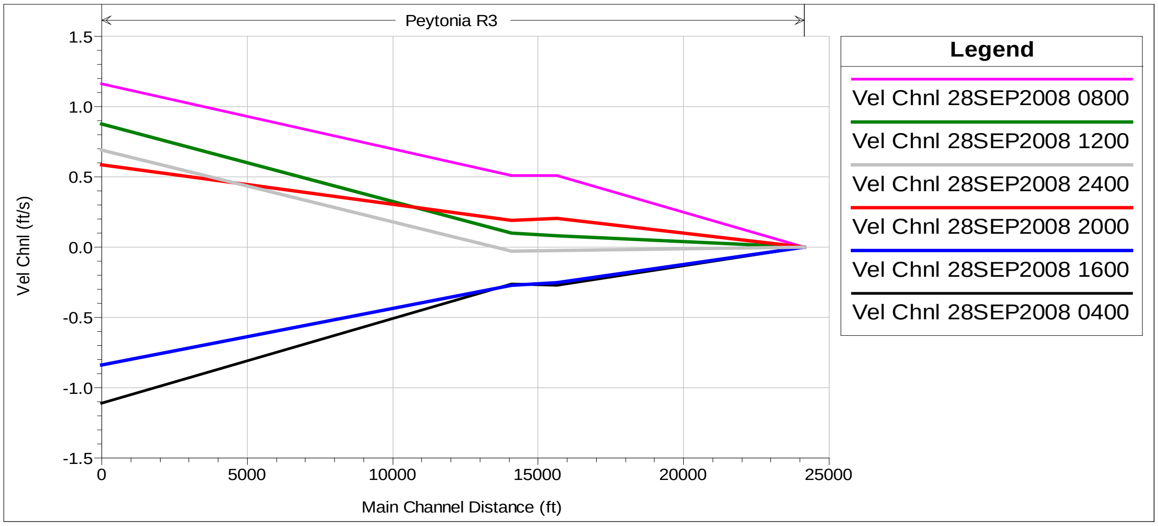

Figure C-17 Simulated velocity at every four hour for a period of 24 hours in Peytonia Slough from mouth to head by HEC-RAS

The model-simulated temperature and DO at 15 minute intervals were compared to the observed data for Peytonia Slough (Figure C-18 and Figure C-19). The observed temperature generally showed a decreasing trend from September to January, and then increasing trend from January to March. The model is able to capture this pattern in observed temperature. Peytonia Slough receives significant discharges during the months of October to December, as indicated by frequent declines in observed DO. Overall, the model is able to capture the low DO for most of the discharge events. However, the model does not represent well the significant diurnal changes in DO, which were frequently observed in Peytonia Slough during October-November 2007.

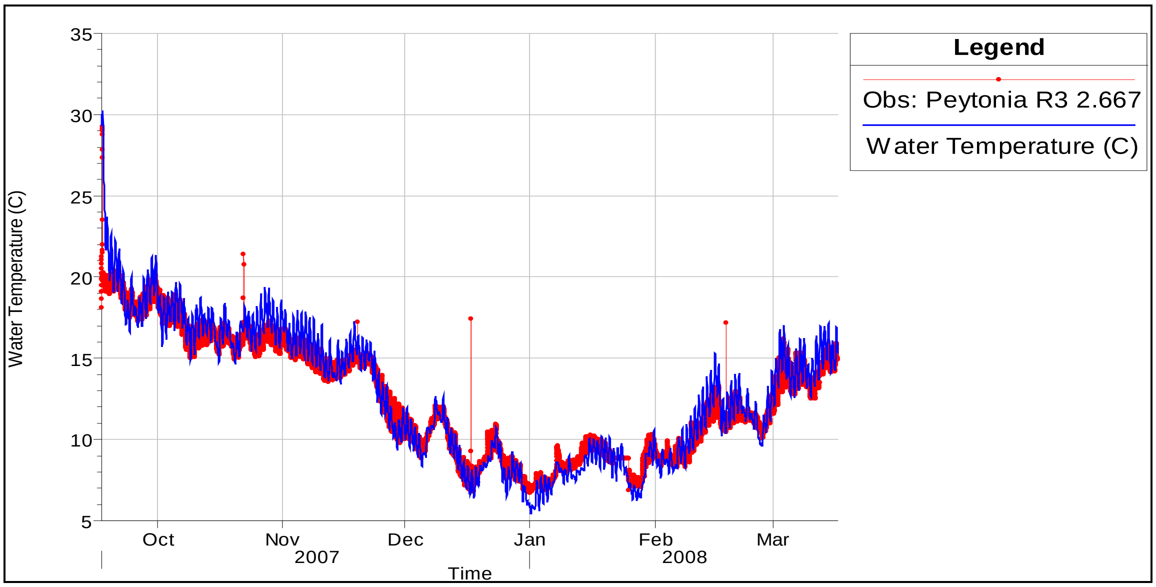

Figure C-18 Model simulated water temperature in Peytonia Slough compared to 15-minute interval data

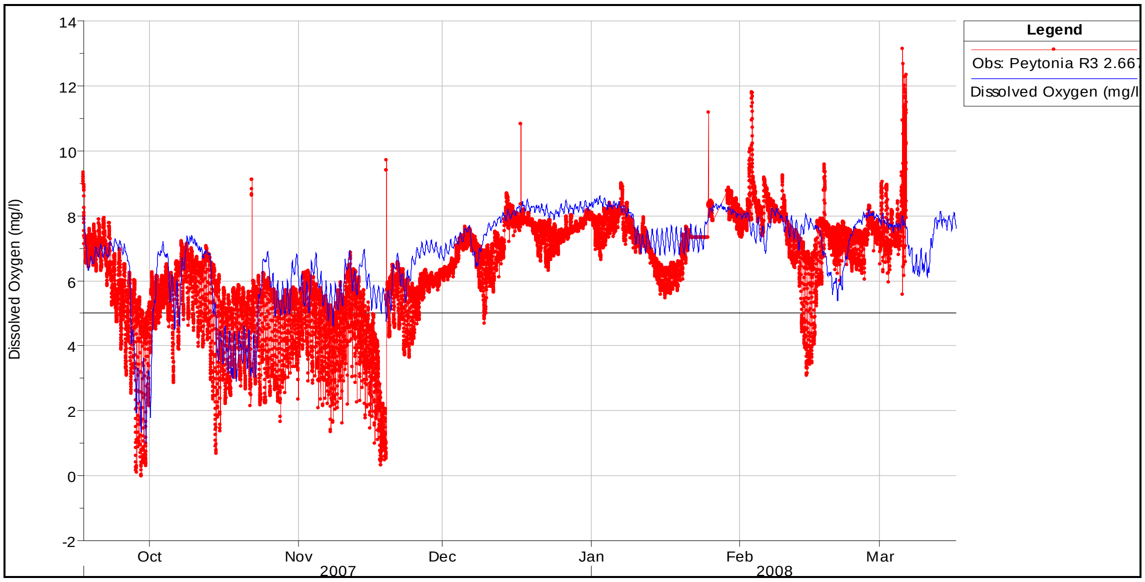

Figure C-19 Model simulated DO concentrations in Peytonia Slough compared to observed data at 15 minute intervals

Model Simulations in Goodyear and Denverton Slough

Goodyear and Denverton Sloughs also receive discharges from managed wetlands and experience low DO events. Goodyear Slough has been known to have reoccurring low DO conditions every fall and most severe and frequent fish kills. The magnitude of low DO events in Goodyear Slough is similar to those in Boynton and Peytonia Slough. Denverton Slough, on the other hand, shows better DO conditions. The Regional Water Board conducted continuous measurements of DO and temperature at 15-minute intervals from 2012–2013 in Goodyear and Denverton Sloughs.

HEC-RAS Model Set Up

The model set up for Goodyear and Denverton Sloughs followed the same approach as used for Boynton and Peytonia Sloughs. The geometry data (length and width) of the sloughs was obtained from Wetlands and Water Resources. The same meteorology data as used in Boynton and Peytonia Slough were also employed in Goodyear and Denverton Sloughs. The DSM2 simulated flow and stage at mouth of each slough was used as boundary inputs to the model. For these two sloughs, the wetland discharge information is lacking. Instead the discharges were estimated in the modeling by assuming several large discharge events to the sloughs, at a magnitude similar to those in Boynton and Peytonia Sloughs during the time when low DO concentrations were observed. The schedule and magnitude of the discharge events are shown in Figure A-5 and Figure A-6 (in the Attachment). The managed wetland discharges were conservatively assumed to have the same concentrations as those observed in managed wetlands discharging to Boynton and Peytonia Slough (Wetland 112 and 123) despite the fact that wetlands draining to Denverton Slough are known to be managed less intensively. Based on the available DO data for comparison, Goodyear Slough was modeled for the period of 08/24/2012 – 01/25/2013 and Denverton Slough was modeled for the period of 08/15/2012 – 02/01/2013.

Model Results: Goodyear and Denverton Slough

The model-simulated temperature and DO at 15 minute intervals were compared to the observed data for Goodyear Slough (Figure C-20 and Figure C-21). The temperature generally showed a decreasing trend from September 2012 to January 2013, and then increased from January 2013. The model is able to capture this pattern in observed temperature well. As a result, dissolved oxygen concentrations were higher from October to January. Goodyear Slough receives significant discharges from managed wetlands during October to December, as indicated by frequent declines in the observed DO. Goodyear Slough received four major discharges in October–December 2012 and one noticeable discharge in January 2013. Overall, the model is able to capture the low DO observed for most of the discharge events. Simulations for Denverton Slough again showed good agreement between water temperature and DO with the observed data (Figure C-22 and Figure C-23). However, the magnitude of diurnal variations in DO simulated by the model is much smaller than the variations observed in both sloughs.

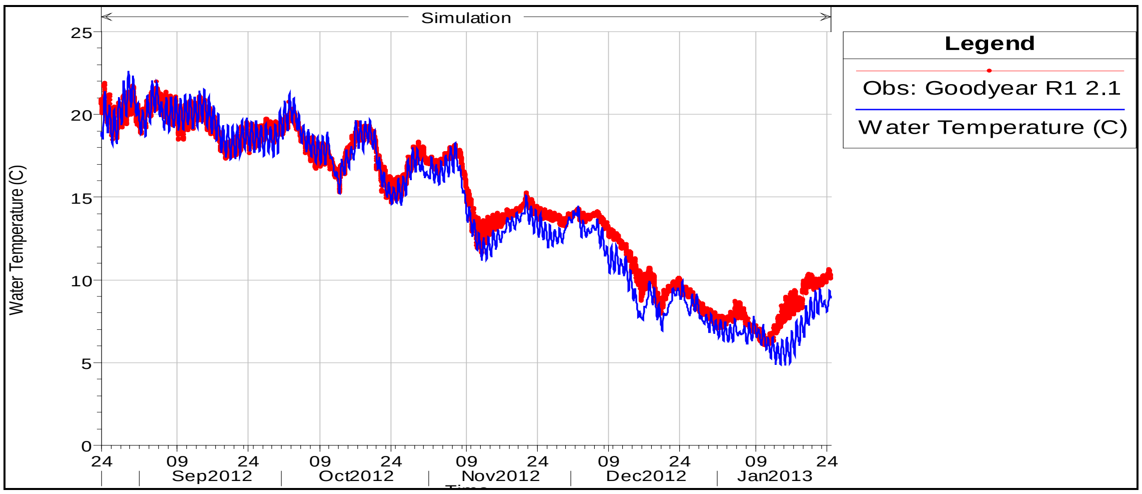

Figure C-20 Model-simulated water temperature in Goodyear Slough compared to observed data at 15-minute intervals

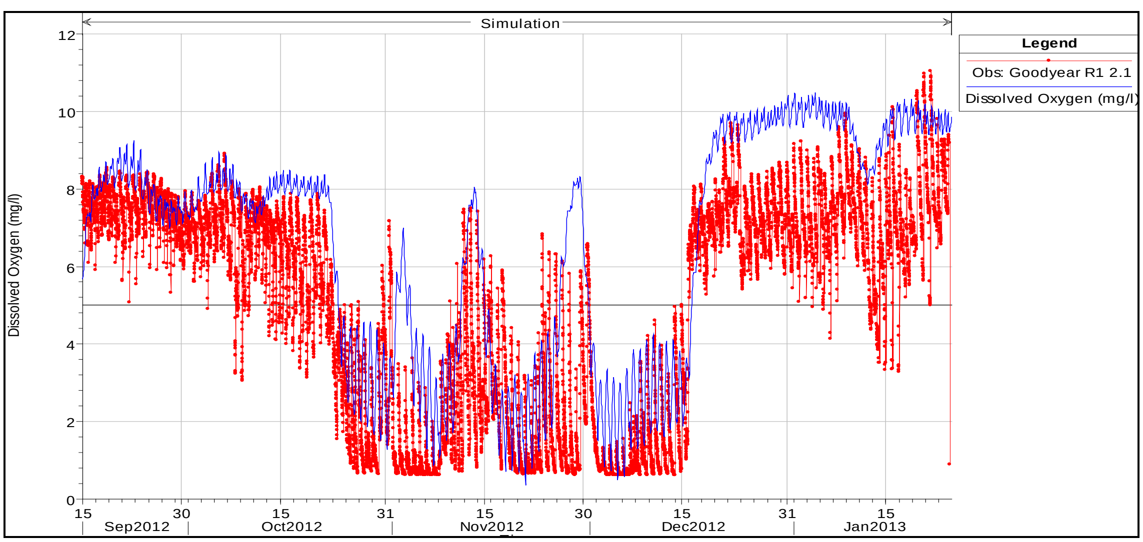

Figure C-21 Model-simulated DO concentrations in Goodyear Slough compared to observed data at 15-minute intervals

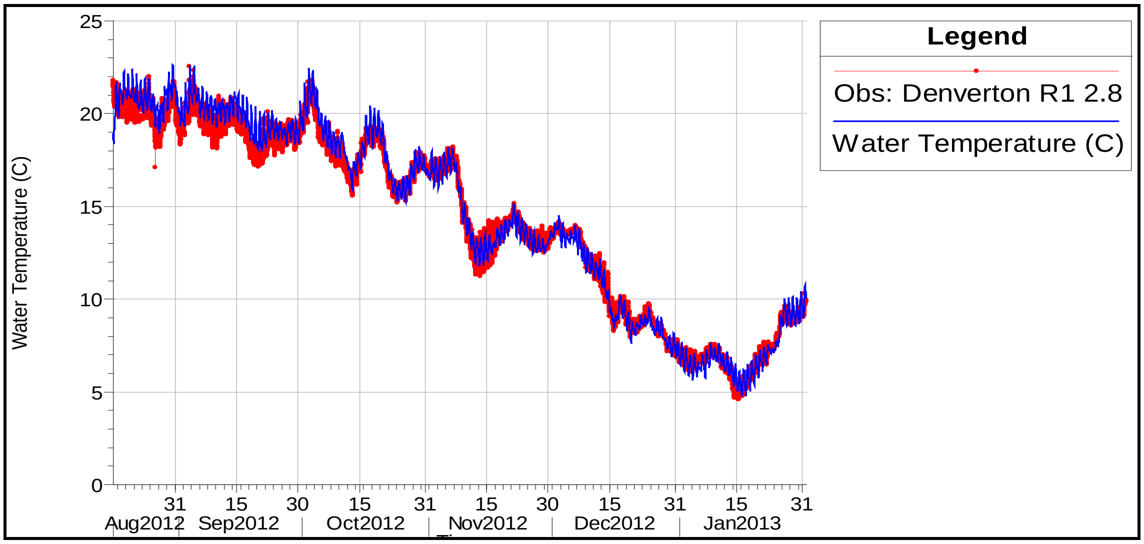

Figure C-22 Model-simulated water temperature in Denverton Slough compared to observed data at 15-minute intervals

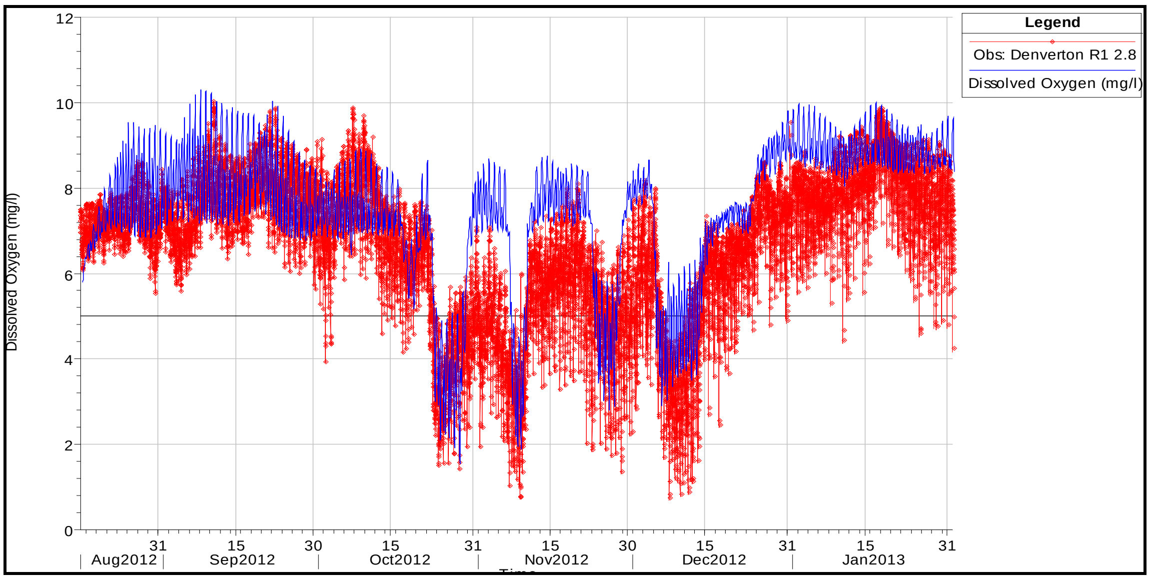

Figure C-23 Model-simulated DO concentrations in Denverton Slough compared to observed data at 15-minute intervals

Scenario Testing to Increase DO in Receiving Sloughs

The ability of Boynton, Peytonia, Goodyear, and Denverton Sloughs to maintain DO above 5 mg/L under continuous exposure was tested using the calibrated HEC-RES model. This DO level was assumed to protect fish from undesirable growth effects under the continuous exposure. A lower DO level of 3.3 mg/L, protective of juvenile and adult survival under the continuous exposure, was also tested. When the exposure is less than 24 hours, DO concentrations are allowed to go below 5 mg/L for short amount of time, as long as the cumulative growth effect is less than 25% (EPA, 2000). This suggests that DO at a specific site does not have to be above 5 mg/L for 100% of the time. Instead for episodic exposure of less than 24 hours, DO concentrations can go below 5 mg/L, as long as the cumulative growth effects from that event are less than 25%. The allowable exposure duration at DO lower than continuous exposure limit, such as 5 mg/L can be estimated using the functions established by EPA (2000). Details for deriving these site specific DO thresholds for Suisun Marsh are documented elsewhere (Tetra Tech, 2014). For this assessment, it was assumed that the simulated DO needs to be above 5 mg/L for exposures over 24 hours, with some occasional exposure allowed as long as the episodic exposure does not result in cumulative growth effects exceeding 25%.

Two model scenarios were tested to achieve the DO targets as defined above.

Model Scenario 1 estimated the managed wetland discharge volume reduction necessary to meet the continuous exposure DO target of 5 mg/L in the sloughs.

Model Scenario 2 tested the effect of discharging the total load without any reductions over a longer period, and the maximum allowable continuous daily discharge from managed wetlands that would result in attaining a continuous exposure DO target of 5 mg/L.

Boynton Slough

Under Model Scenario 1, discharges from managed wetlands to Boynton Slough need to be reduced by approximately 40% from the current rates of 19 to 41 cfs and existing schedule (Figure A-3, Table A-2, in the Attachment) during the period of 09/07 – 03/08 to achieve the DO concentration of 5 mg/L. At this level of load reduction, minimum DO concentrations are generally above 5 mg/L (Figure C-24). There was some occasional exposure to low DO of 5 mg/L, however, the exposure was generally less than 8 hours (allowable duration at 4 mg/L for growth effect impacts of < 25%). The level of reduction depends on discharge volume and observed concentrations from managed wetland 123 (i.e., organic carbon concentrations of 18 – 70 mg/L at different discharge locations, as shown in Figure C-4; DO near 0 mg/L).

Model Scenario 2 tested the feasibility of discharging the loads over a longer period without reductions in total load. The results suggested that with a continuous discharge (at 2.55 cfs, without changes in total load), DO concentrations were mostly above the target of 5 mg/L (Figure C-25). The allowable discharge is a 2.55 cfs on daily basis for the entire simulation period.

The model also tested a future scenario of 50% increase in the FSSD discharge with other discharges at baseline conditions. The results indicate a slight increase in DO in the channel due to increases in this discharge (Figure C-26). Discharges from FSSD are shown to benefit DO concentrations in sloughs in Suisun Marsh, due to higher DO and low organic carbon concentrations, in comparison to the managed wetland concentrations.

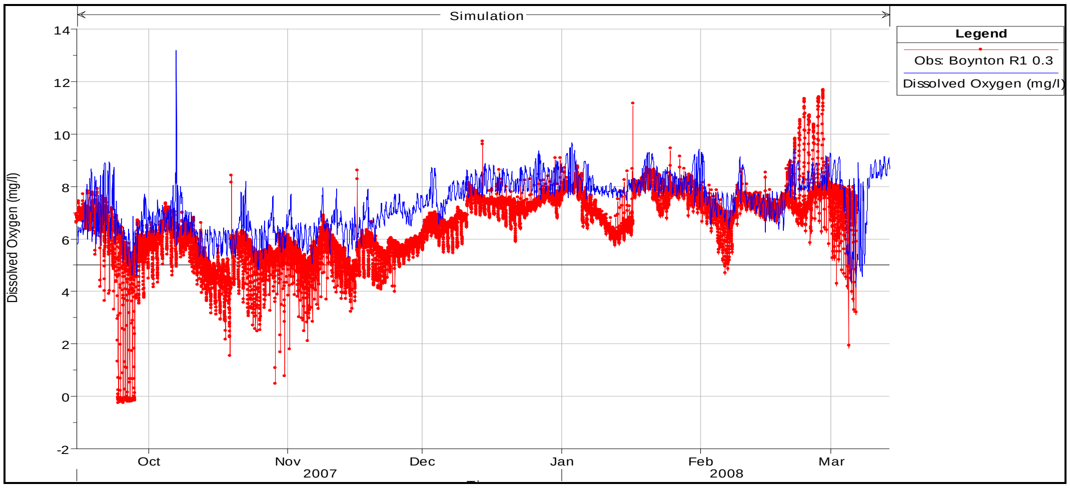

Figure C-24 Model-simulated DO concentrations in Boynton Slough with load reduction to achieve 5 mg/L DO (Model Scenario 1)

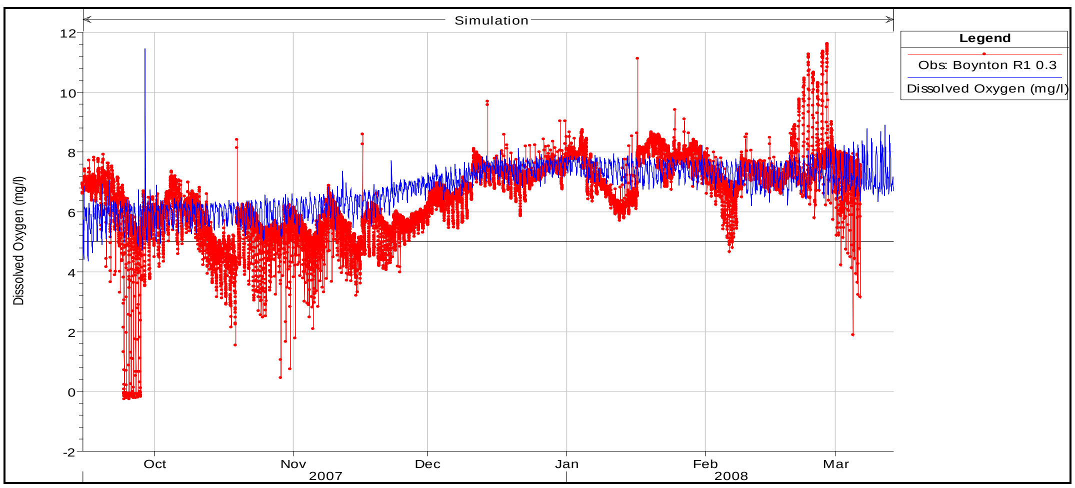

Figure C-25 Model-simulated DO concentrations in Boynton Slough with continuous low discharge to achieve 5 mg/L DO (Model Scenario 2)

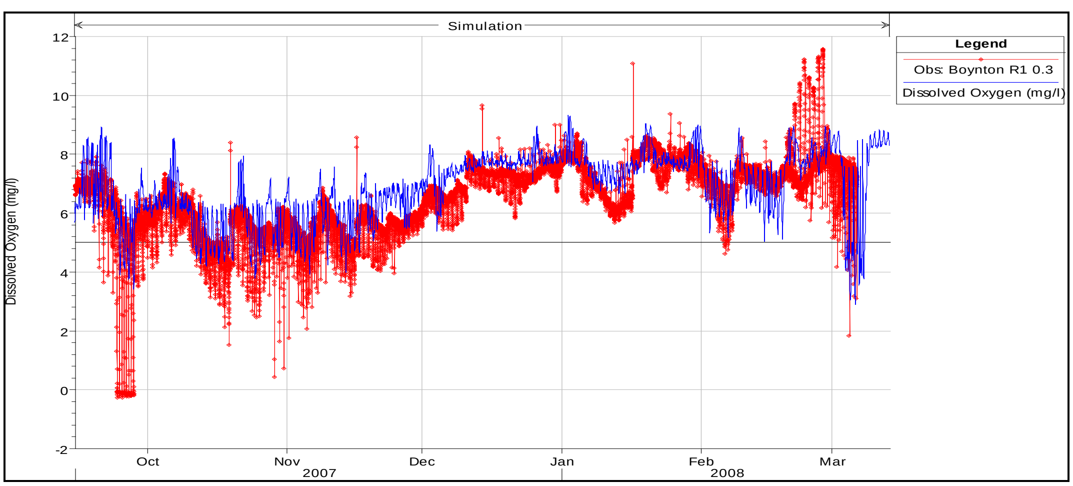

Figure C-26 Model-simulated DO concentrations in Boynton Slough as a result of 50% increase in FSSD discharge

Peytonia Slough

Discharges from managed wetlands to Peytonia Slough were simulated in a similar manner to Boynton Slough. Model Scenario 1 estimated the load reduction required in managed wetland discharges to achieve the DO target. The results indicate that a 65% reduction of wetland discharge from the current rate (maximum of 16 cfs observed, see Attachment: (Table A-3) and schedule (Figure A-4) will result in minimum DO greater than 5 mg/L (Figure C-27). The estimated allowable discharge under this scenario is 5.6 cfs at current concentrations of 70 mg/L DOC and 0.7 mg/L DO (Figure A-1and Figure A- 2 in the Attachment). The simulated DO is mostly above 5 mg/L, with one incidence of exposure to DO lower than 5 mg/L. The exposure to low DO is for short amount of time (< 8 hours with DO > 4 mg/L). The modeled scenario assumes discharge events ranging from 10 to 16 cfs (Figure A-4, Figure A-3 in the Attachment). All of these discharge events need to be reduced by more than 60%, for approximately 85 days out of the 207 modeled days.

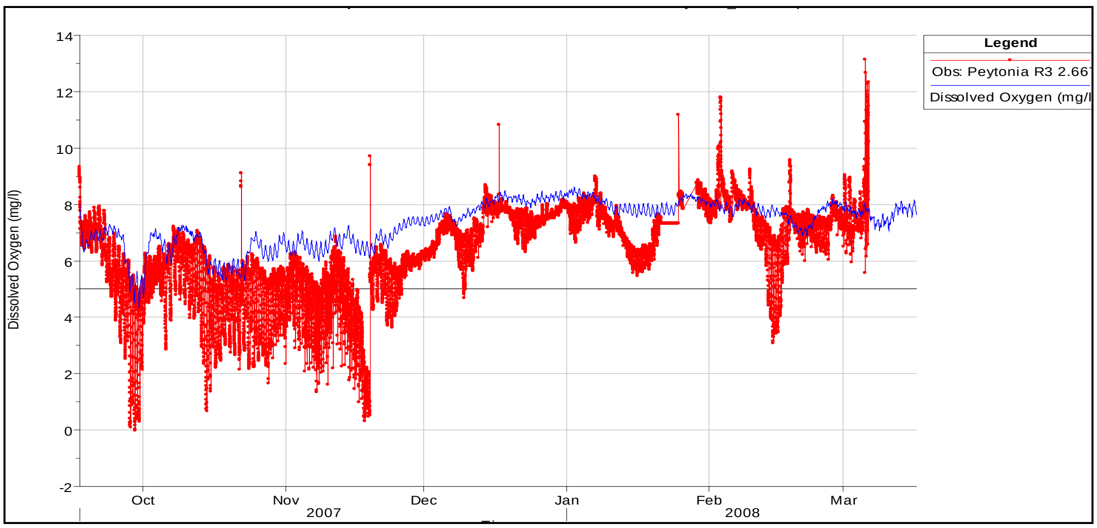

Figure C-27 Model-simulated DO concentrations in Peytonia Slough with load reduction to achieve 5 mg/L DO (Model Scenario 1)

Model Scenario 2 tested the possibility of discharging loads over a longer time period without reductions in total load. The results suggested that with a continuous low discharge, DO concentrations were above 5 mg/L for the simulation period (Figure C-28). To achieve the DO target, the allowed continuous daily discharge from managed wetlands is 4 cfs at current concentrations from managed wetlands (i.e., 70 mg/L DOC, 0.7 mg/L DO) for the entire simulation period. This situation is different from that of Boynton Slough, where the continuous flow alone could not achieve the 5 mg/L target, and had to be coupled with a flow reduction.

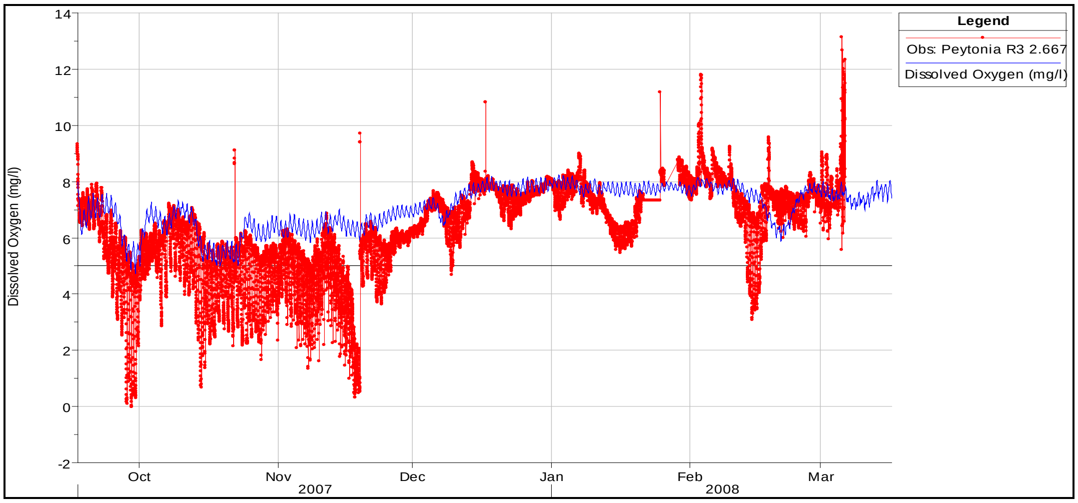

Figure C-28 Model-simulated DO concentrations in Peytonia Slough with continuous flow discharge without load reduction to achieve 5 mg/L DO (Model Scenario 2)

Goodyear Slough

For Goodyear Slough Model Scenario 1 estimated the load reduction required in managed wetland sources to achieve a DO target of 5 mg/L. The existing baseline was modeled assuming the current discharge schedule, four major discharge events at 40 cfs each at two locations, and a few minor events. The results suggest that the current wetland discharge rate has to be reduced by 62% to achieve DO concentrations greater than 5 mg/L (Figure C-29). The reductions will be required during 61 days out of the 200 days modeled.

Model Scenario 2 tested the possibility of discharging the loads through a longer time period without reductions in total load. To achieve the DO target of 5 mg/L, the estimated allowed continuous daily discharge from managed wetlands is 26 cfs at current concentrations (i.e., 70 mg/L DOC, 0.1 mg/L DO). Figure C-30 shows that at this discharge rate the DO concentrations will remain well above 5 mg/L throughout the entire year.

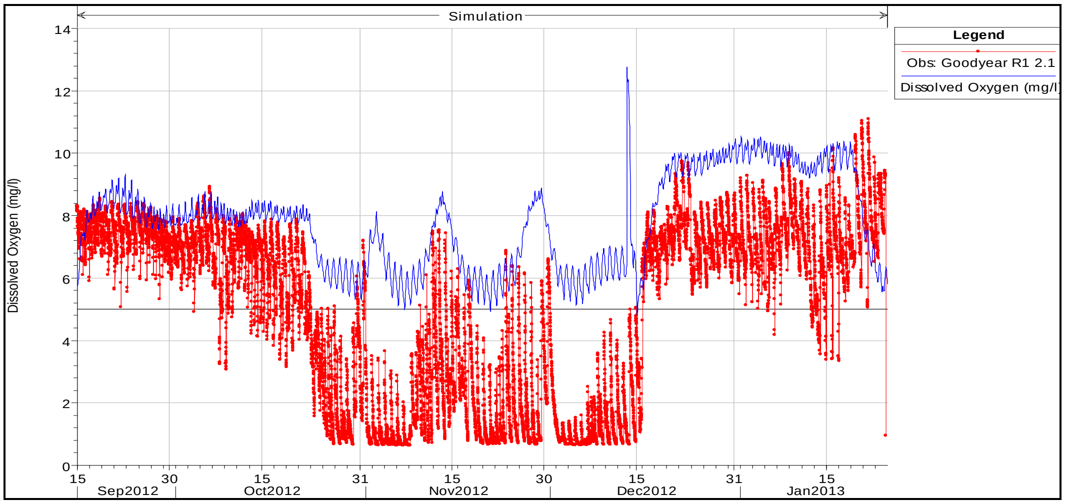

Figure C-29 Model-simulated DO concentrations in Goodyear Slough with load reduction to achieve 5 mg/L DO (Model Scenario 1)

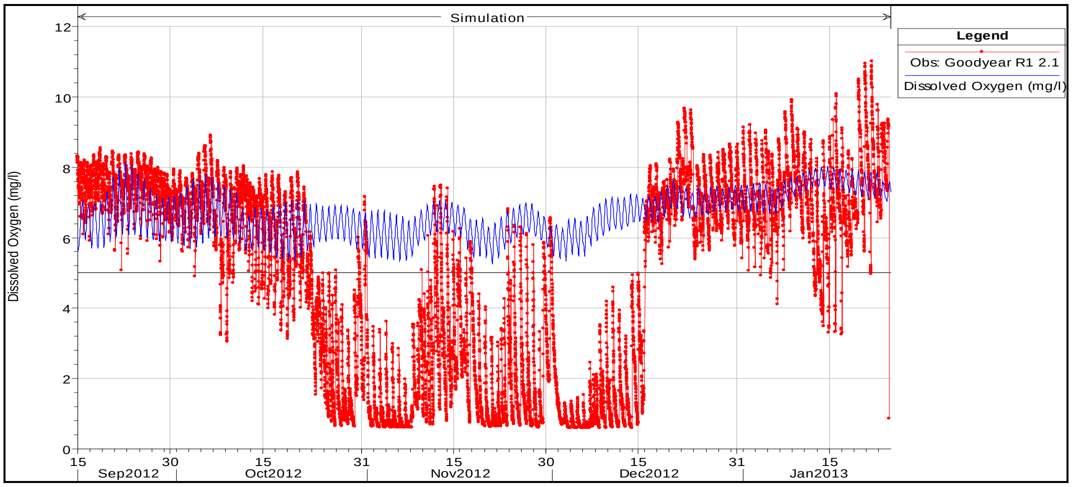

Figure C-30 Model-simulated DO concentrations in Goodyear Slough with continuous low discharge (Model Scenario 2)

Denverton Slough

For Denverton Slough Model scenario 1 estimated the load reduction to achieve the DO target of 5 mg/L. The results show that a 57.5% reduction of managed wetland discharge compared to current discharge rate and schedule will result in DO greater than 5 mg/L (Figure C-31). Under this scenario the discharge of 20 cfs from managed wetlands at current concentrations (i.e., 70 mg/L DOC, 0.1 mg/L DO) will result in DO remaining generally above 5 mg/L. There are a few incidences of low DO below 5 mg/L, however for a short amount of time (< 8 hours with DO > 4 mg/L).

Model scenario 2 tested the possibility of discharging the loads through a longer time period without reductions in total load. The results suggest that with a continuous low discharge rate of 9.84 cfs (at current concentrations, i.e., 70 mg/L DOC, 0.1 mg/L DO), DO concentrations were above 5 mg/L for the simulation period (Figure C-32).

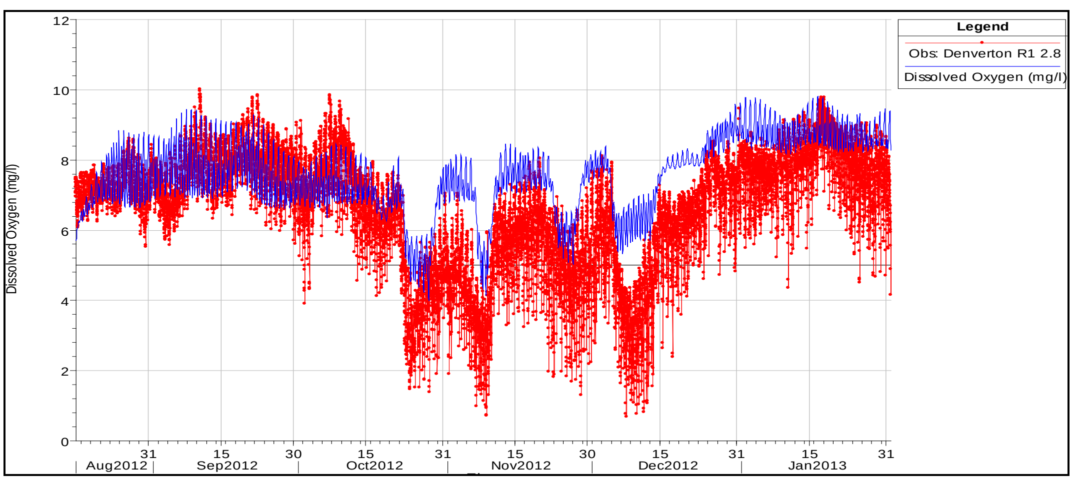

Figure C-31 Model-simulated DO concentrations in Denverton Slough with load reduction to achieve 5 mg/L DO (Model Scenario 1)

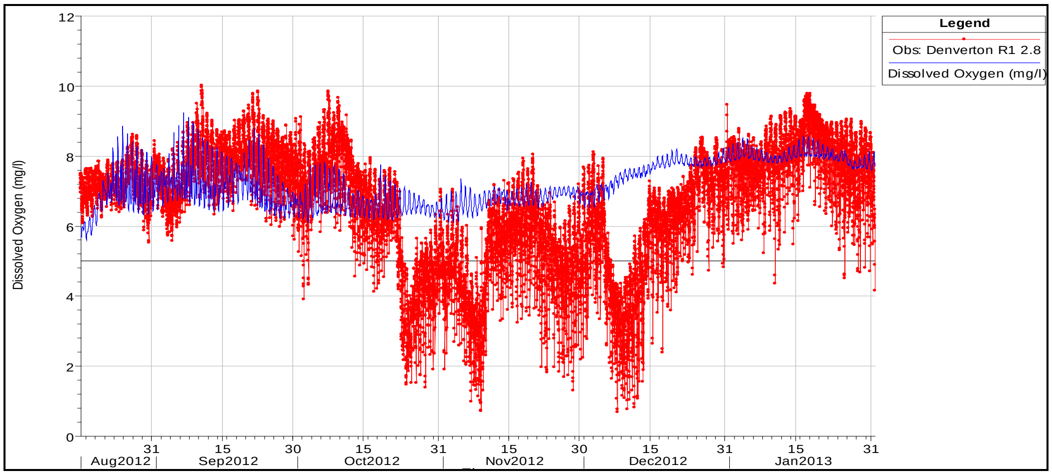

Figure C-32 Model-simulated DO concentrations in Denverton Slough with continuous low discharge to achieve 5 mg/L DO (Model Scenario 2)

Appendix C References

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ATTACHMENT

Data and Information Used in HEC-RAS Modeling

Table A-1 Discharges from Fairfield – Suisun Sewer District (Siegel et al. 2011)

Month	**FSSD**		**To Club 112**		
2007	AC-FT	AC-FT/d	AC-FT	AC-FT/d	% from FSSD
Sep	961	32			
Oct	1296	42	165	5	13%
Nov	1327	44	169	6	13%
Dec	1530	49	195	6	13%
Average	1279	42			
2008					
Jan	2089	67	111	4	5%
Feb	1818	65	128	5	7%
Mar	1701	55	90	3	5%
Apr	1157	39	0	0	0%
May	1160	37	20	1	2%
June	941	31	0	0	0%
July			45	1	NA
Aug	1092	35	5	0	0%
Sep	966	32	0	0	0%
Oct	1051	34	120	4	11%
Nov	1427	48	235	8	16%
Dec	1426	46	147	5	10%
Average	1348	44	75.1	2.5	5%

Table A-2 Wetland 123 discharge events

Date	DO Boynton (mg/L)	Wetland discharge Qave (cfs)	FSSD discharge (ac-ft/d)	Boynton Slough flow (cfs)	Temperature (ºC)
9/23/2007 (9/23/2007 – 9/27/2007)	3.5	19	32		20
2/15/2008 (2/9/2008-2/13/2008)	6.2	27	65	40-80 cfs	12.5
3/4/2008 (3/4/2008-3/07/2008)	7	41	55	40-50 cfs	13.5
9/29/2008 (9/28/2008 – 10/3/2008)	No data	34	34	0	19

Table A-3 Wetland 112 discharge events

Date	DO Peytonia	Wetland discharge Qave (cfs)	FSSD discharge (ac-ft/d)	Peytonia Slough flow (cfs)	Temperature (ºC)
10/1/07 (10/1/2007-10/3/2007)	5.7 mg/L	15	42	-20 - 40 cfs	17.5
2/1/08 (1/30/2008 – 2/2/2008)	7.7 mg/L	16	65	360 cfs	8.5
2/7/08 (2/6/2008 – 2/9/2008)	8 mg/L	10	65	60 cfs	9
2/15/08 (2/14/2008 – 2/19/2008)	7-7.2 mg/L	5	65	50 cfs	12.5
10/20/2008 (10/19/2008 – 10/22-2008)	6.8 mg/L	22	34	40 cfs	16
11/5/2008	2.9 mg/L		48	50 cfs	15

Table A-4 Comparison of Boynton and Peytonia Slough

	Boynton Slough	**Peytonia Slough**
Latitude	38' 12.614N	38' 13.567 N
Longitude	122'02.329 W	122' 02.395 W
Rating curve	Area = 2.7304*stg2 + 76.278 * stg + 442.8	Area =1.9166 *stg2 + 69.45*stg + 401.5
Mean channel velocity	V = 0.8420*Index Velocity + 0.0328	V = 0.8427*Index Velocity + 0.0041
Tidal velocity (fps)	1 foot/sec (fps)	1 foot/sec (fps)
Tidal flows (cfs)	-800 cfs (upstream flow) +1200 cfs (downstream flow)	-700 cfs (upstream) + 800 cfs (downstream)
Peak ebb flows (cfs)	1500 cfs	1400 cfs
Net flow	Filling 10 – 40 cfs full/new moon, draining during lunar quarters	Filling 10 – 40 cfs full/new moon, draining during lunar quarters
Net flow	Fairly minor rainfall-runoff combined with larger spring tides	Winter positive outflows are due to watershed outflows
Wetlands	Six wetlands: Wetland 122, 123, 131, 124, 130 and 133 with a total area of 3,000 acres are connected to Boynton Slough.	Four wetlands Wetland 112, 113, 123, and 211 with a total area of 980 acres are connected to Peytonia Slough
Managed wetland discharges	Under normal operations, wetland 123 will draw water from Peytonia Slough and FSSD and discharge to Boynton Slough	
FSSD discharges	90%	10%
Sewage treatment effluent	FSSD discharges a majority of its tertiary treated effluent to Boynton Slough	A smaller discharge point exists on Ledgewood Creek in the case of high effluent flows
Tributary	Diked lands and adjacent uplands in agricultural use and containing stormwater and irrigation ditches	Ledgewood Creek
Watershed inputs	No significant watershed inputs. A portion of lowlands sod farm and the industrial areas in the northwest corner of Suisun Marsh	Ledgewood Creek (drains 11,300 acres) and unnamed open storm drain. The watershed contains agricultural, urban and open space lands

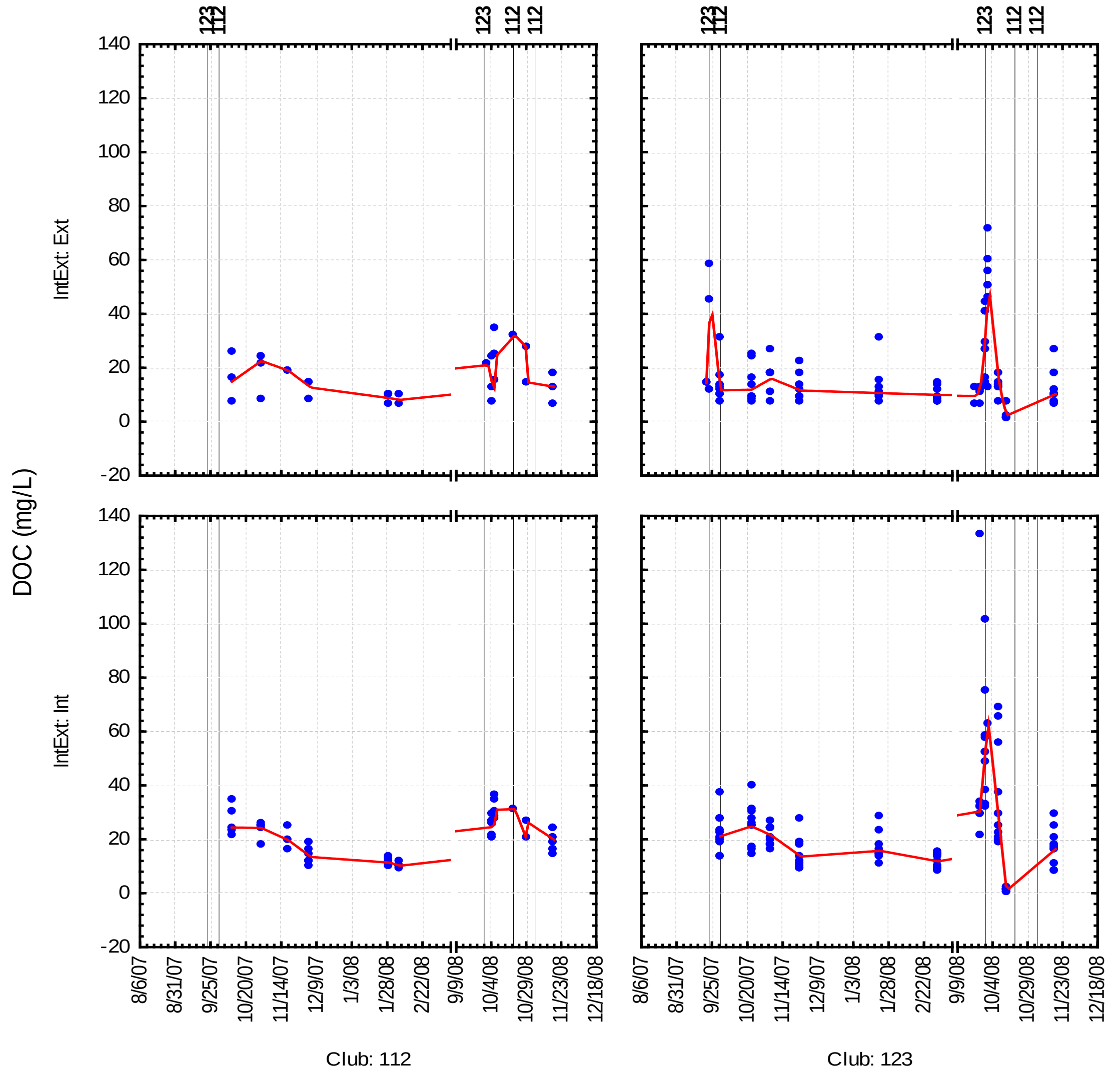

Figure A-1 Changes in DOC at Wetlands 112 and 123 perimeter and interior stations

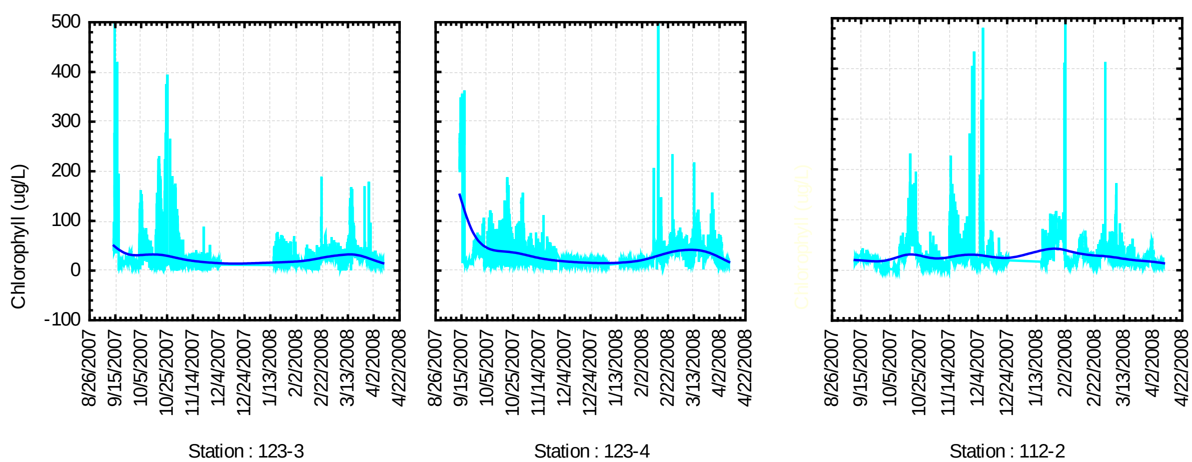

Figure A- 2 Temporal chlorophyll trends at perimeter stations for wetlands 112 and 123

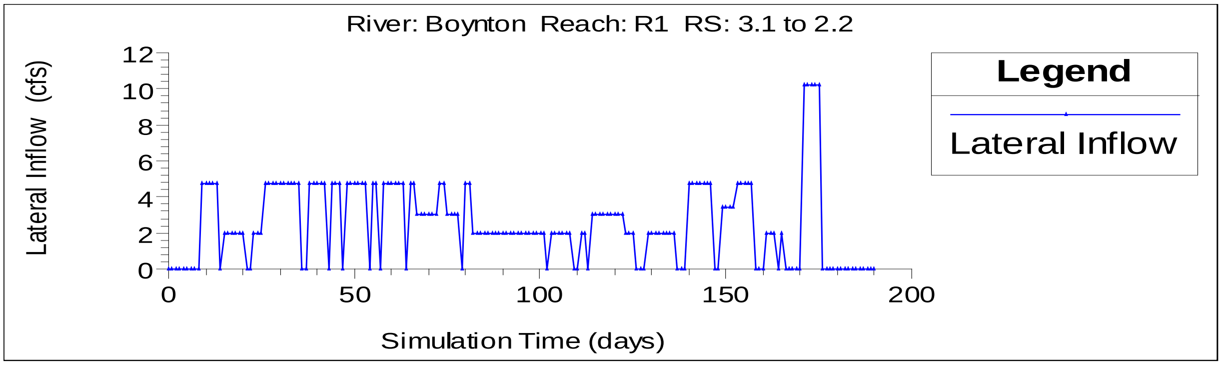

Figure A-3 Assumed wetland discharge schedule for Boynton Slough (1 out of 4)

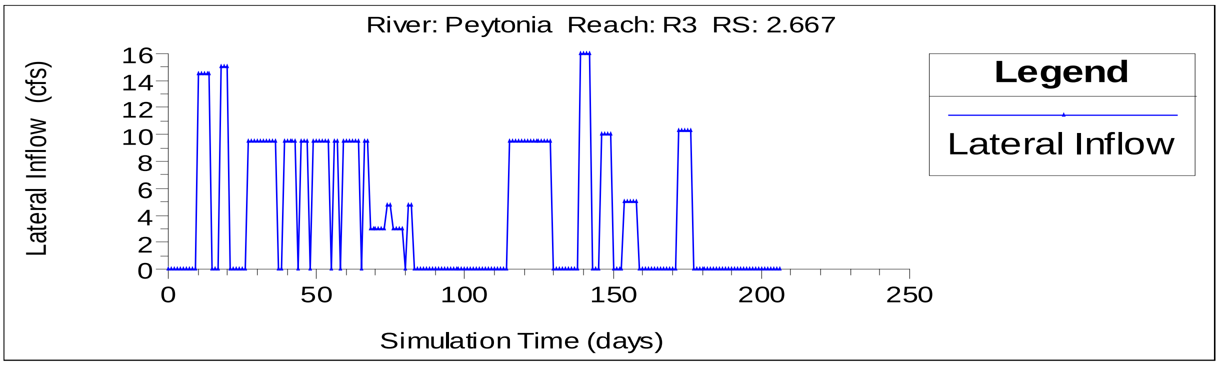

Figure A-4 Assumed wetland discharge schedule for Peytonia Slough at one location

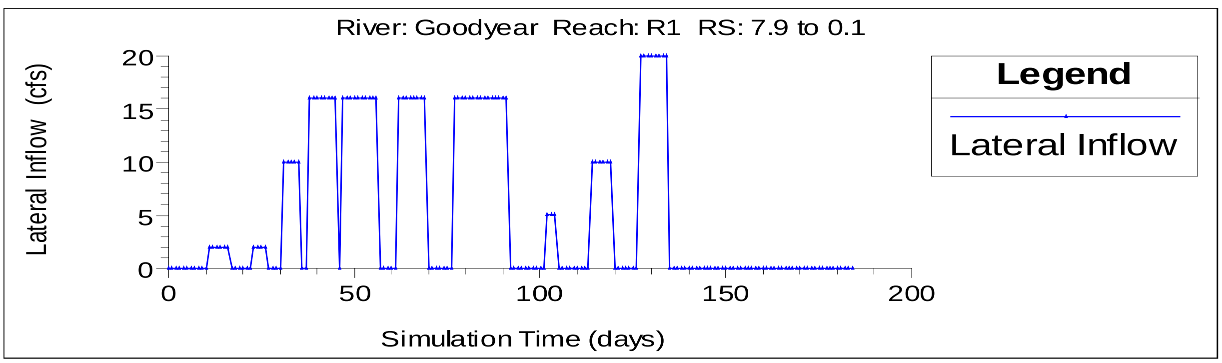

Figure A-5 Assumed wetland discharge schedule for Goodyear Slough (1 out of 4 and with a multiplier of 2.5

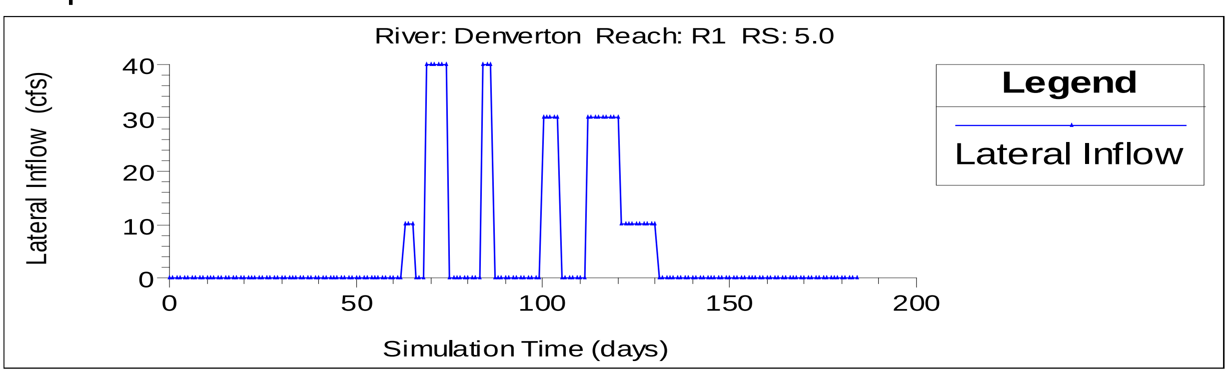

Figure A-6 Assumed wetland discharge schedule for Denverton Slough (1 out of 2)

Appendix D: Scientific Advisory Panel Recommendations for Refining DO Objectives in Suisun Marsh Sloughs

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Expert Panel Review

3 May 2017

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Executive Summary

Suisun Marsh (Solano County, USA), provides habitat for many species of plants, fish, and wildlife, including rearing and spawning grounds for migratory fish and waterfowl. The marsh has been subject to many impacts over the past century (Moyle et al. 2014), including land use change, channelization of sloughs, and changes in the timing and magnitude of freshwater delivery because of water diversions upstream in the watershed, which have led to, among other issues, periodic occurrences of low dissolved oxygen (DO). An analysis supporting the development of a DO site-specific objective (SSO) was completed for Suisun Marsh, as part of the San Francisco Bay Regional Water Quality Control Board's goal of developing a Total Maximum Daily Load (TMDL) analysis for this water body. A scientific advisory panel (SAP) was engaged to review the work plan, preliminary findings and completed technical report (Tetra Tech 2017) supporting the development of the DO SSO. The Tetra Tech (2017) study consisted of four major components: 1) calculation of DO criteria (thresholds), utilizing the Virginia Province (VP) approach, 2) specification of temporal aggregation periods for acute and chronic thresholds, 3) use of reference system approach to determine allowable frequencies of non-compliance with the criteria, and 4) independent confirmation of the acute and chronic thresholds using existing fish abundance and DO data collected synoptically in Suisun Marsh (P. Moyle, UC Davis).

The purpose of this report is to summarize the findings of the SAP in reviewing the Tetra Tech (2017) study, addressing specific charge questions that were provided to the Panel by San Francisco Water Quality Control Board (SWQCB). Questions are embedded within the report below. Key findings of the SAP are highlighted and presented on these focus question issues. Additional insights are provided by the SAP in extended discussion in the report, providing greater insights into the issues. The SAP provided supporting appendices with (a) examples of statistical approaches to assessments using concepts covered during the SAP review process and information addressed in Tetra Tech (2017), (b) a survey of State applications of criteria with examples of criteria exceedance and impairment definitions using continuous monitoring data, and (c) references to literature on ecosystem recovery periods for consideration by the SWQCB. The latter is needed for determining an appropriate application period (in years) for assessing impairment of the yet-to-be determined DO standard.

Key Findings of the Expert Panel

- The SAP finds that the use of the VP approach is considered as a viable and protective technical framework for setting DO criteria.
- Application of the VP approach to Suisun Marsh supports establishment of DO criteria based on a reasonably comprehensive assessment of the available information, which considers tolerance, exposure, and growth/recruitment factors applied to representative species.
- Adequate consideration was given to the DO needs of sensitive species (e.g., salmonids) and rare and endangered species (e.g., sturgeon).
- Given that DO tolerance data for native species were largely not available, and because Suisun Marsh is a “novel ecosystem” inhabited by an established community of native and nonnative species, a focus on the DO-sensitive striped bass is appropriate.
- The frequency of allowable exceedances should be based on the ability of aquatic ecosystems to recover from the exceedances, which will depend in part on an understanding of the magnitudes and durations of the exceedances in reference conditions. This study suitably employed available monitoring data on reference sloughs to assess the frequency of allowable excursions from derived criteria; however, similar analyses should be conducted to determine the magnitude and duration of the exceedances to ensure aquatic life is adequately protected from exceedances.
- Use of DO concentration rather than percent saturation is practical for supporting the management of the resource and communication among stakeholders.
- The need to consider spatial heterogeneity in Suisun Marsh is reasonable, given the well documented variability of DO in different marsh habitats (e.g., small sloughs, large sloughs).
- The averaging period cannot be divorced from other critical aspects of the water quality standard: 1) minimum monitoring station density, 2) minimum sampling frequency and type (discrete, continuous), 3) allowable frequency of non-compliance, 4) the magnitude and duration of exceedances, and 5) the temporal averaging statistic, which should define low DO exposure risk that accounts for frequency, magnitude and duration of exceedances. Per the proposed criteria, “multiple samples” could use more explicit definition.
- The averaging period for the CMC was shown to be effective for implementation of the criterion, both as a moving average and daily mean.
- The reference-based approach provides valuable insight into the allowable exceedance frequency within years. However, following the lead of other states such as Delaware, some thought should be provided about the definition of “a violation event” that translates to an exceedance and frequency, magnitude and duration of exceedances. Further, there are multiple measures of exceedance that need to be considered: 1) the criteria exceedance rate that equates to a violation, i.e., how many violations are allowable sider a season or year as impaired, 2) exposure risk that considers magnitude and duration dimensions of exceedances, and 3) how many years can the system

experience impairment and in what period of years (3, 5, 10?) is reasonable to declare a waterway failing to meet its standard.

- Minimum requirements for monitoring were not fully defined in this process. Without a declaration of any final habitat segmentation decisions, final criteria selection, and assumptions about how representative a monitoring site is of a certain habitat area, the panel could not provide a minimum requirement. However, the panel used its understanding of the information considered during the process and provided some directions and two examples of monitoring approaches that could support monitoring and assessment needs to support the impairment decision-making process. It is essential that monitoring data treatment be adequate to quantify not only frequency of exceedance, but the risk from magnitude and durations of exceedances as well.
- We recommend collecting temperature, conductivity, and depth, along with DO. Data loggers that provide these parameters are readily available and very reliable.
- The panel is generally supportive of a 15-minute sampling frequency.
- Setting the criteria is very dependent on the needs of the living resources or the intended use. To that end, the use of diverse tools here to derive criteria (VP approach, larval recruitment model, reference system approach, biological monitoring as supporting data) provide an excellent example of application of DO criteria development concepts.

Final Questions and Responses from the Expert Panel

Q1 Please comment and provide perspectives on the methods, quality of technical analyses, and discussion and interpretation for the ability to use those findings to establish site-specific objectives in Suisun Marsh (see summary Table below), including:

a. Protectiveness of Aquatic Life Support beneficial uses, including listed and sensitive species (salmonids, sturgeon, delta smelt, splittail), important native and introduced estuarine fishes, and marsh invertebrates;

b. Comprehensiveness of the Virginian Province approach, the species list, and their life history stages to derive the objectives;

c. Confirm the rationale for protecting salmonids when they are present (January-April)

d. Assumption that striped bass is sufficiently sensitive, so it's larval recruitment curve is likely to characterize conditions protective of other larval/juvenile species in Suisun Marsh

e. Analysis and interpretation of data on natural background DO concentrations in Suisun Marsh sloughs, and magnitude, deviation, and timing of ranges of low DO under minimally impacted conditions

f. Support for the concentration-based objectives rather than DO saturation;

g. *Spatial specificity (large sloughs versus back-end sloughs).*

Protectiveness and Comprehensiveness of Approach to Supporting Aquatic Life:

Criteria should attempt to provide a reasonable and adequate amount of protection with only a small possibility of considerable overprotection or underprotection (U.S. EPA 2016). Criteria must be used in a manner that is consistent with the way in which they were derived if the intended level of protection is to be provided in the real world. Although derivation of water quality criteria for aquatic life is constrained by the ways the tests are usually conducted, the means used to derive and state criteria should relate, in the best possible way, to the kinds of data that are available concerning chronic and acute affects and the ways criteria can be used to protect aquatic organisms and their uses (U.S. EPA 2016).

The Tetra Tech study features the Virginian Province (VP) approach, selected as most appropriate to address protection of Suisun Marsh living resource and as a viable and protective technical framework for setting DO criteria. A thorough literature search of appropriate species with supporting DO data was based on the selection of diverse species that provided the best available representation of the fish community. In the absence of acute and chronic laboratory exposure data for the range of Suisun Marsh species, the VP approach provides a scientifically defensible approximation of DO tolerances suitable for protecting the Aquatic Life Use. Its application in Suisun Marsh represents a comprehensive assessment of the available information, considering tolerance, exposure, and growth/recruitment factors that were appropriately applied to the representative species.

Consideration of Salmonids:

Consideration was given to sensitive species (e.g., salmonids) and rare and endangered species (e.g., sturgeon). Juvenile Chinook salmon are not as common in Suisun Marsh as they should be; they occur when temperatures are low and duck clubs are not as active in management, so the probability of juvenile salmon encountering harmful DO habitat conditions is limited at this time. As such, the rationale supports a suitable application of salmonid life history, monitoring and sensitivity data and science to ensure special protection during the period salmonids are likely to be present. However, restoration projects to improve salmonid habitat are ongoing and because the presence of juveniles can change in response to the impact of habitat restoration projects or, presumably, with climate change, this should be evaluated on an ongoing basis.

Assumption that Striped Bass is Sufficiently Sensitive to Represent Protection of the Fish and Benthic Macroinvertebrate Communities:

While striped bass is an introduced species, we note that they are an established species within the marsh fish community for over 100 years and are among the most sensitive species to dissolved oxygen levels in the marsh. Given that DO tolerance data for native species or other species that are possibly more sensitive were not available, the striped bass provided a suitable species for the analysis. In addition, Suisun Marsh is a “novel ecosystem,” an ecosystem that is inhabited by an established community of native and nonnative species, and as such it is appropriate to include striped bass in the analysis, both in the calculation of proposed criteria as well as in the larval recruitment model. Most of the life stages for striped bass found in the marsh are juveniles and adults, life stages which have the ability to avoid poor DO conditions compared with egg and larval phases. The native species that has a prolonged larvae stage in the marsh is prickly sculpin (January-May), but data are not available to run a larval recruitment model with this species.

Use of Reference Study Data:

This study suitably employed available monitoring data on reference and impacted sloughs to assess the frequency of allowable excursions from derived criteria. The frequency of allowable exceedances should be based on the ability of aquatic ecosystems to recover from the exceedances, which will depend in part on the magnitudes and durations of the exceedances (U.S. EPA 2016). Exceedances are extreme values in the distribution of ambient concentrations and this distribution is the result of the usual variations exhibited by dissolved oxygen in the system. Because exceedances are the result of usual variation, most of the exceedances will be small and exceedances as large as a factor of two will be rare (U.S. EPA 2016).

This review and statistical assessment of the low and high temporal density time series of dissolved oxygen dynamics in reference and impacted sloughs has helped to ensure the criteria and their application are appropriate to the setting and informing the application of the criteria (e.g., monitoring, averaging period, exceedances). A comparison with reference conditions added insight into its application and the appropriateness of the VP approach. A CCC approach was used to capture the alternative exposure model used in the VP approach, and proved to be applicable and protective.

We note, however, that spatial data are limited and factors driving reference profiles can change rapidly. We cannot discount the possibility that characterization of reference

conditions could be refined with the addition of data from other station locations. The suitability of these data for application to other habitats may not be appropriate.
Often times, the DO issues for water quality management are closely aligned with the warmest times of the year and the longest daylight hours. A conceptual model of the stressor-impact relationships affecting DO conditions facilitates targeting the critical periods and metrics for monitoring and management. At Suisun Marsh, there are multiple periods of concern that include the warm season, a season associated with growth and survival of rare, threatened and endangered species, and finally a period where the marsh conditions are affected by the impacts of culturally relevant activities (e.g. wetland management supporting suitable duck hunting conditions) that can introduce potentially harmful water quality conditions to the sloughs late in the year. The suite of considerations given to varied stressors in time throughout the year underlies the need for adaptive monitoring and management. Therefore, this criteria derivation process is not for a one-size-fits-all DO issue but considers targeting key seasons related to marsh management and the timing of sensitive species habitat use. The DO saturation levels and diel swings in the data might be indicative of nutrient enrichment, or effects of regulated marsh drainage and mixing of low DO waters, and diminish the utility and appropriateness of the data for setting system-wide, allowable criterion excursions. Nevertheless, until future work is done, the recommended excursions appear to be protective of the resource, only minimally deviating below the proposed criteria.

Existing Suisun Marsh non-probability spot survey data of fish abundance and water quality conditions (P. Moyle) represented an outstanding resource to support the approach by presenting an independent check on the derived criteria, as it presents a good idea of DO tolerance ranges. Additional monitoring, research or modeling would help confirm the representativeness of Mallard Slough as a “minimally impacted” system, as a natural condition, and relative to other habitats. It will also help to provide an independent check when future exceedances might be natural or related to climate change.

Use of DO Concentration versus Percent Saturation as Basis of Criteria:

Criteria should be as simple as is practical for supporting the management of the resource and communication among stakeholders. Oxygen concentration is perhaps our simplest common index of the DO conditions and is used effectively across the country to manage our aquatic resources. We acknowledge that saturation has had support in assessing water quality in San Francisco Bay (e.g. 3 months at or above 80% saturation) and Florida recently considered a DO saturation-based standard for their water quality assessments (P. Tango, Pers. Comm). Saturation can further provide useful diagnostic information on eutrophication and diel and seasonal DO patterns as to cause and whether the conditions are caused by natural or human drivers. It is worth moving the science and management world forward on how we might further use percent saturation in the criteria setting and assessment processes, because this measure is directly relevant to oxygen supply for fish and invertebrate respiration. In addition, climate change can bring direct influences on temperature and salinity, upon which concentration measures are dependent. Therefore, while not part of the criteria, saturation should be reviewed to assess natural excursions and for setting allowable exceedances from the criteria, specifically with regard to temperature and salinity.

Spatial Heterogeneity:

The need to consider spatial heterogeneity in Suisun Marsh is reasonable, given the well documented spatial heterogeneity of DO dynamics in marsh habitats (Boynton et al. 2014). In Suisun Marsh, small dead-end sloughs can naturally have low DO due to DOC loads from productive marsh and subtidal habitats. However low DO is rarely a problem in larger sloughs, due to mixing effects of wind, tides, and inputs of river water, especially during the critical summer season.

The study and its component analyses considered large and small sloughs, which was a reasonable level of classification. While segmentation of habitats supports site-specific DO criteria and standards assessments, consideration may be given to further spatial specificity in the study area given the addition of new data streams and sources. In addition to spatial variation, the vertical dimension warrants further evaluation to ensure that near-bottom conditions, which may affect benthos and demersal fish or life stages, are similar to monitoring data that have been taken at various depths.

Q2 Comment on the recommended averaging periods to assess attainment and DO evaluation, including:

*a. Averaging periods for CMC (**1-day** mean) and CCC (**30-day** mean), including step-wise approach to calculate daily and 30-day averages to compare against objectives;*

b. Should there be an allowable period of non-compliance of the CMC and CCC protective of aquatic life and estuarine communities, but not to be overprotective?;

c. Comment on whether, in back-end sloughs the CMC exceedances may occur multiple times in a month without adversely affecting the beneficial uses, as long as the CCC criteria are maintained;

d. Preferred monitoring window to detect the worst DO conditions (e.g. from mid-September through mid-November);

e. Comment on whether temperature and conductivity should be recorded together with DO to aid data interpretation and troubleshooting.

f. Preferred Monitoring Interval? 15-min?

Overview of Components Comprising the Water Quality Standard:

The averaging period cannot be divorced from several other critical aspects of the water quality standard: 1) minimum monitoring program station density, 2) minimum sampling frequency and type (discrete, continuous), 3) allowable frequency of non-compliance, and 4) the temporal averaging statistic. Per the proposed outline of criteria, “multiple samples” could use more explicit definition - How many stations will be monitored and need to pass the criterion/criteria to support a decision of attainment, OR, what is the assumption about how much water a single monitoring station represents, (i.e., what is the implicit interpolation of the results for how much water is represented by station results?).

Agreement will be needed on the criterion/criteria application periods. Presently those periods proposed appropriately address the critical periods of the warm season, the time period associated with actions linked to socially relevant activities, and rare and threatened species. Additional details of the sampling plan to support the water quality assessment should address the relevant depth or depths of sampling, location of samples or include the method for choosing sample sites (will samples be collected mid-channel, nearshore or both?). Boundaries to the criteria application should be detailed - do the criteria apply to some portion of the water with a minimum depth boundary of perhaps 1m or 0.5m? With respect to these considerations, here we review the recommendations and note areas where the recommendations could be strengthened to provide greater specificity for their linkage to the recommended monitoring program.

Averaging Period:

The averaging period for the CMC was shown to be effective for implementation of the criterion, both as a moving average and daily mean. Neither approach of block versus rolling is necessarily incorrect, what is important is that the method used to evaluate natural conditions and determine acceptable exceedances should be reflected in the assessment protocol. Such decisions will maintain the continuity for the basis for understanding the target status for the system based on a consistent understanding between characterizing the conditions and carrying out their assessment. Variances within a data stream are reflective of the sample intensity; the greater the sample density, the higher the probability of detecting outliers. If the assessment of reference conditions and likely exceedance rate of a criterion is, for example, 5% of daily means over a year based on 15 minute interval data, then monitoring protocols should attempt to be consistent with the behavior of the system as understood by also applying a 15 minute interval data collection for the assessment.

While the case was made that there were only small statistical differences between 7-day and 30-day static or block averages (i.e. stepwise) and rolling averages, data are somewhat limited and may not reflect the range of conditions that might be experienced in Suisan Marsh habitats. Use of the 30-day block averaging appears to provide a protective CCC under general conditions reflective of the data, but may not fully capture the combined impact of concentration and duration reflected in the larval recruitment model (Table 13 of the Tetra Tech report). Just as averaging period (i.e., 7 vs 30 day) in the block approach shows differences between the two in Table 17, depending on the starting and ending date for each “block”, a 30-day block approach may miss the duration factor (i.e., allowable days) as the clock is “reset” after 30 days. However, the cumulative stress effect on aquatic life would, of course, continue into the next block but may be missed depending on when the consecutive blocks intersect the hypoxic period. Use of 7-day and 30-day moving averages were viewed as providing a more powerful statistical assessment of the conditions and, thus, better protection for aquatic life by assuring the durations assessed are indeed “continuous”. As more locations are monitored and evaluated and more data become available, better understanding of condition variability by location, change over time (new sources, climate effects, management improvements), or other variations may be revealed that will guide and confirm appropriate monitoring and attainment protocols.

Minimum Requirements for Monitoring:

It will be helpful to state clearly the proposed assessment protocol which is integral to the monitoring program.

When developing a sampling plan, the basic question is whether or not the criterion is met. This is a binomial question where the foundations of the criteria derivation can be linked to the assessment method. Assume the reference data for a complete year show that the fish community is not stressed by low oxygen when no more than 5% of the daily means fall below the criterion. This would reasonably support a reference condition-based foundation for setting a binomial hypothesis to protect the related beneficial use. Without these supporting data, a 10% exceedance might be an allowable value acceptable to EPA if there were nothing else to go on. But in this case an assessment based on data is more supportable.

The criterion test should also be computed in the manner in which the criteria were derived. For example, if the daily mean criterion is computed from 15 minute data, sampling data should likewise be derived from 15 minute intervals. Every change in the sampling interval changes the variation that is captured. In this case, 5% of the conditions were known to be allowable based on the reference analysis, hence the 5% came about from variance in the data set collected at 15 minute intervals, which needs to be preserved in the sampling program.

There are at least two paths to consider given the stated criteria:

1. Use of a continuous monitoring sensor. Sampling continues for the entire year (or a specific target season). As described above, the assumption applied in this analysis is that this monitoring site is representative of the average conditions for the year in this habitat area, and a percent violation rate is computed. This assumption is reasonably supported since there is complete knowledge of system behavior based on a full year (or target season) of data. If the computed percent violation is below or equal to 5% then the waterway is presumed to meet the criterion. If the violation rate is more than 5% then that year fails its criterion. The continuous data represents comprehensive knowledge of the site conditions in time, and if the assumption of spatial representativeness for the area is supported, then also in space. (If another assumption is appropriate, e.g., a site is representative of "X" km^2 – for a local example, see Jassby et al. 1997 for an approach considering monitoring site representativeness in San Francisco Bay - then additional sampling sites could be required. For this example, it is assumed that one representative, continuous monitoring site to represent slough conditions is used.) This is not testing a hypothesis; a full accounting of the conditions is available so the output comparison is made directly against the criterion to support a statement about meeting or exceeding the criterion.

2. Limited resource and data assessments. Assume a daily mean criterion test is based on a continuous monitoring sensor deployed for 24 hours at a time, 12 days a year. In this case, some attention to randomization is needed. For example, a site or station is sampled beginning on a random starting date in January (e.g., Jan 17^{th}) and then sampled the 17^{th} of every month. Alternatively, a random date could be selected for sampling each month. Either way, the random element supports the statistical integrity underlying the tests. Further randomization could be used to select sites to address spatial variation concerns. So, data are collected on 12 random days, measuring every 15 minutes, 24 hours each sampling day. It is known from setting the criteria that the allowable exceedance rate is 5%. To test the sampling results against the allowable rate consider: With 12 sample dates, what is the probability that one daily mean in 12 will fail the criterion? What is the probability that your system experiences less than or equal to 5% violation rate of the criterion and that two daily means of your 12 fall below the criterion? Attachment 1 provides further details of applying this approach and understanding the likelihood of an event given an expected violation rate

and translating the results to support statements of meeting or violating the criterion. A survey of State programs across the U.S. further shows the use a variety of monitoring approaches and decision criteria to support decisions on noncompliance with the criteria and nonattainment of a standard (Attachment 2).

Assessment Period to Determine Impairment:

Finally, regarding appropriate assessment periods that provide adequate grounds for a decision on impairment, understanding ecosystem recovery pace provides an important perspective (Attachment 2).

For example, a standards decision rule based on a 1 in 5 year allowable exceedance technically translates to an allowable exceedance of 20%, which does not constitute an impairment unless the violation rate is 40% (i.e., 2 or more years in a 5 year period). A "1 in 3" rule by comparison would mean the violation rate is 67% before an impairment is declared; however, the opportunity to take management action is nearer term than with a 5-year or longer period.

In related standards assessment work that considers decision rules for declaring impairments, under Chesapeake Bay criteria assessment protocols, a 1 in 6 years has recently been given consideration for future chlorophyll *a* assessments and provides for an allowable exceedance rate of 16.7%; 2 or more years out of attainment, or a minimum of 33.4% failure, equates to nonattainment (P. Tango, Pers. Comm.). By comparison, the State of Georgia uses a decision rule with a 5-year lake assessment period for chlorophyll *a* where 1 in 5 years moves the lake to Category 3 (i.e., Clean Water Act 303d listing classification that characterizes assessments as having insufficient available data and/or information to make a use support determination) and additional information is then used to evaluate attainment or impairment. For chlorophyll *a* assessment in Beaver Lake, Arkansas, Scott and Haggard (2015) suggested one alternative to assessing changes in average condition in 5-year windows may be to use a window as large as 10 years. The 10-year window was suggested to take into consideration decadal patterns associated with common climate cycles. Further, 1 year in 10 would be a 10% allowable exceedance. The adoption of a decision framework should further reflect an expectation that common recovery from impairments can occur and consider how attainment is tracked which can be in two forms – one for regulatory reporting requirements and one for a management tracking indicator.

Exceedance Frequencies:

There are two measures of exceedance that need to be considered. First is the criteria exceedance rate that equates to a violation. The second is associated with the decision on impairment – how many years can your system fail to meet criteria and over what time frame and still be considered in attainment?

This body of work conducted on Suisun Marsh data is probably supportive of "reasonable potential" protection for understanding an appropriate measure of allowable exceedances, but the exceedances are a measure of DO condition with respect to the criteria and may not always be indicative of supporting aquatic life beneficial uses. Using moving averages at two time scales for CCC will reduce potential for Type I and II error. It is necessary, if not pragmatic, to allow excursions in highly variable estuarine environments, but it does not necessarily indicate that the criteria are "overprotective" – just not always attainable. Not being overprotective is important because DO sags can be natural. The VP larval exposure model approach might be a way to translate exceedances into cumulative duration and have a stronger biological basis for "protectiveness" if there is uncertainty that even a moving average does not provide quantitative certainty of exposure stress and beneficial aquatic life use protection. This option notwithstanding, the combined use of moving averages on a 1-day, 7-day and 30-day basis and the targeted exceedance percentages is reasonable.

The second form of exceedance mentioned above is better addressed in this next section.

Whether Allowable Periods of Non-Compliance Are Scientifically Reasonable:

One focus of this work is on within-year allowable exceedance periods of noncompliance. Because natural background excursions from CCC and CMC are known to occur in productive marsh habitat, some exceedances are reasonable. Ten percent has traditionally been an EPA suggested rule of thumb when: 1) there is no other information upon which to base an allowable exceedance rate, 2) AND it was provided in consideration of grab samples. However, the 10% rule is not particularly recommended for use with dissolved oxygen assessments or used with high frequency assessment of dissolved oxygen conditions.

The reference based approach provides valuable insight as to the allowable exceedance frequency within years. The proposed reference-derived values (4% and 16% values for CMC and 7-day average CCC are more encouraging for use since they are based on best available site data. However, as pointed out in other states like in Delaware, some thought should be provided about the distribution of the criteria violations and what is your definition of "a violation event" (i.e., can you allow all the violations to occur on single long event? - see Tidal Murderkill River guidance text in Attachment 2). To count violations, must they be separated by a period of time to be considered as separate events? Then are you allowing that many events in a year or season or assessment period (i.e., like 3 yrs or 5 yrs or some other assessment). Another consideration is the degree or intensity of the exceedance, e.g., severe hypoxia or anoxia can be immediately lethal, but if the condition is of short duration, it would not constitute an exceedance under the percent criteria.

Here again, the stringency of criteria is dependent on monitoring program specifics and treatment of the data; blocking versus moving average will make a difference in how exceedance frequency is applied. This is where the understanding of the behavior of dissolved oxygen in the reference system versus impacted system is important. In the reference system, the diel cycle might occasionally dip below a threshold value in a random fashion. Diel hypoxic events differ from your impacted sloughs where there is an extended period of low dissolved oxygen. We return to the derivation of exceedance rate such that if you are using 30 day blocks – a single long event that might last for 2-3 weeks could register as one violation of the mean. By comparison, a daily time step of the rolling 30 day mean will register many violations. Therefore, your expectation on how the system behaves and your expected measure of protection should again be consistent in terms of how you view allowable exceedances (e.g. based on means computed from 15 minute interval data) and the subsequent monitoring and assessment approach (i.e., also from 15 minute interval data).

Finally, biological monitoring (fish and benthic macroinvertebrates) can be used as an additional line of evidence to assess status of impairment and the allowable noncompliance rate over a period of years. Community integrity has been used in freshwater and estuarine ecosystems as integrated measures reflecting habitat health (Karr 1981, Weisberg et al. 1997, Alden et al. 2002). The biology should inform the decision on how stable the desired communities are relative to the frequency of years of noncompliance. As referred to in the earlier section on recovery rates, the abilities of ecosystems to recover differ greatly, and depend on the pollutant, the magnitude and duration of the exceedance, and the physical and biological features of the ecosystem. Documented studies of recoveries are relatively few, but some systems recover from small stresses in six weeks whereas other systems take more than ten years to recover from severe stress (U.S. EPA 2016). EPA highlights many system level measures of health returned to pre-impairment conditions in about 2 years and therefore a 1 in 3 year allowable exceedances; alternatively, the Borja et al. 2010 review pointed towards 5-6 year recovery rates such that a 1 in 5 or 1 in 6 year allowable exceedance rate could be considered scientifically supported. Recovery rates were outside the scope of our discussion, however, additional information on the consideration of recovery rates to guide your standard setting and decision rules is provided in Attachment 3.

Exceedances in Back-End Sloughs:

The Panel supports the concept that in back-end sloughs the CMC exceedances may occur multiple times in a month without adversely affecting aquatic life. The CMC does not consider cumulative or repetitive exposure that might result in a lower tolerance, or the degree of the exceedance (e.g., severe hypoxia or anoxia) that might result in acutely lethal conditions. However, if the CCC is maintained as a moving average, conditions protective and supportive of the CMC with respect to cumulative stress may be reasonably assured.

Critical Period for Monitoring Compliance:

A strategic monitoring plan should be developed that considers several factors to characterize DO conditions that might exist in time and space in Suisun Marsh, and assesses changes that may occur over time. Yes, if there are known characteristic periods of the year that experience hypoxic events, it makes sense to monitor at those times more intensively and at the locations where they are known to occur. One should be aware that the foundation processes that drive these patterns can change with restoration or some other human intervention, or climate change. Monitoring can be flexible, and adaptive, with scoping or reconnaissance monitoring used to survey the potential for DO criteria exceedances over a range of habitats, locations and time periods. Monitoring needs to be most intensive in areas and at times when the DO conditions are close to the criteria. If surveys show that there are never problems, infrequent checks may be enough; if it's always hypoxic, extensive monitoring similarly may be unnecessary. The worst DO resources conditions under natural conditions are likely to occur when temperatures are warm and inflow low, mid-July through mid-October.

Because weather can have an important effect on hypoxia (or human causes such as the pond draining), it is important to "bracket" those periods to ensure if an early start or late end of the hypoxic period is captured, and so enough data are available to make moving averages work. Ideally, year-round monitoring should be used initially until the regularity of hypoxic events is known, and the sampling regime can be set with an appropriate temporal buffer preceding and following the hypoxic event period can be included in the sampling strategy. As noted above, missing part of the hypoxia cycle in a static or block averaging period could give a misleading result. Likewise, applying an exceedance frequency based on an annual monitoring cycle may be erroneous if applied to a much shorter monitoring period.

Monitoring Interval:

In general, the Panel is supportive of a 15-minute sampling frequency. Sampling density in time will affect your estimate of the mean and uncertainty about the mean. As sample size increases, error is reduced on the estimate of the variance and monitoring results move towards near perfect knowledge of the mean of that high temporal density data stream. Data storage is cheap. We could collect measurements at 1 sec intervals. A key question here is what is the phenomenon we are most concerned about and is 15 minutes or some other interval suitable to detect the phenomenon? Further, what was the basis for the data in the studies when they were evaluated for 24-48 hours? Did they develop the results with hourly measurements or continuous second by second measurements? And lastly, how representative is the station of the surrounding waters and for how long? In the case of a water release from an impoundment, the impact may be extensive in area while a dip in DO under natural summer conditions may reflect local scale processes at work (hence a desire to have 2-3 sites in operation if possible).

This question really speaks to the definition applied in the water quality standard. What is the regulatory definition of an event that is associated with the definition of "impairment" of the designated use? (For reference again, the Tidal Murderkill River guidance in Attachment 2 provides some consideration for defining an event and how many events in a year represent an impairment of the use when using continuous DO monitoring data for assessment.) A daily mean can be estimated from one measurement albeit with large uncertainty or from sub-daily scale measurements with increased accuracy with increasing sampling intensity. Hourly measurements can track the diel cycle of DO, sub-hourly measurements can provide strong support for understanding hypoxic event duration. A 15-minute interval is likely reasonable to estimate a mean and provide diagnostic data about event durations and causes of fish kills, for example. Given the physics of estuarine system, the detection of short duration events are probably a reflection of very local processes and consistent records of low DO events would be indicative of the system at the brink of a threshold of concern. By contrast, detecting longer duration hypoxic events at a station given with the tidal dynamics of these sloughs likely reflects a larger mass of water is experiencing the low DO phenomenon and therefore more of a concern.

Collateral Parameters for Data Interpretation:

We recommend collecting temperature, conductivity, and depth as key parameters to collect, along with DO. Data loggers that provide temperature, salinity and DO are readily available, not too expensive and very reliable.

Q3 Please comment on whether additional lines of evidence are necessary to assess DO attainment (e.g. biological confirmation) and overall beneficial use support.

The analysis presents a viable path forward that is protective of aquatic life beneficial uses. However, as noted above, historical data are somewhat limiting and may not cover the full range of conditions in time and space that occur in the study area. The best prospects are to continue to sample for compliance, and use those data to evaluate and refine the criteria, if warranted. And, research into sensitivity of resident organisms along with continued fish surveys, may reveal more sensitive species, additional areas of concern, and changes due to climate or other anthropogenic factors associated with pollutant loading, hydrologic modifications or habitat change as well as combined effects of other stressors. In Chesapeake Bay, benthic macroinvertebrate community assessments support State's decisions on listing a management segment as impaired or not. If the science develops such that benthic community data for Suisun Marsh could provide reliable diagnostic results to separate healthy from degraded habitat conditions, it has been used in other systems to supplement attainment decisions.

Q4 Given available data in Suisun Marsh and lessons learned, identify if there are other analyses/data and refinements that could strengthen the site-specific objectives for Suisun Marsh, and aid derivation of the criteria in similar habitats in SF Bay.

Setting the criteria is very dependent on the needs of the living resources or the intended use. To that end, the elements used here to derive criteria (Virginian Province approach, larval recruitment model, reference system approach, biological monitoring as supporting data) are an excellent example of the application of DO criteria development concepts. Application of these criteria to other places cannot proceed without redoing the steps, because different systems with have a different list of species and different aspects to this interpretation.

Future research may serve to refine this approach in other systems. Better documentation of life stage will help clarify the seasonal requirements for DO. Modeling has been used to target site specific understanding in setting criteria (e.g. Chesapeake Bay has a variance for blackwater systems DO targets that are lower than systems not so affected by natural DOC load, e.g., review the Delaware tidal Murderkill River document for their modeling assessments of the system.). Supporting the research to develop the larval recruitment curve(s) and encouraging laboratory mesocosm experiments on data lacking for native species, particularly for chronic exposures, will address important west coast-wide data gaps (Sutula et al. 2012).

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Attachments

Attachment 1: An example of binomial assessment of water quality meeting or exceeding the criterion.

Assume you have limited resources. You are only able to send a crew out to sample 12 days a year. There is some form or randomization that would be needed here – for example, randomly pick a start date in January, suppose it is Jan 15^{th}. You sample Jan 15^{th} then sample the 15^{th} of every month. Alternatively you could randomly select a day each month. Either way, including the random element supports the statistical integrity underlying the tests. However, now you have in this case 12 samples. You know from setting your criteria that the allowable exceedance rate is 5%. You want to test your sampling results against this allowable rate. If I sample 12 times, what is the probability that 1 daily mean will fail the criterion? What if I get 2 daily means below the criterion? We can build a table of binomial probabilities to meet any sampling effort:

Binomial probability b(y; 12, 0.05) looks like this:

Y = 'successes' or in this case, actual measured exceedances/failures of the criterion in your monitoring program.
12 is the number of samples being collected for this example.
0.05 equals the 5% expected allowable violation rate based on an imagined allowable exceedance rate from a study of reference systems and a proposed criterion.

This example uses a reasonable set of conditions and measurement effort that might be appropriate for an assessment program with limited resources.

If you wanted to set your allowable violations as satisfying the criterion with a p-value of 0.1, or something close to it, we can use the table of probabilities below to see where the probability of a result becomes unlikely.

Reading the table, if I take 12 samples, and I am expect that the DO conditions will provide no more than 5% of measures below the criterion because that is what my reference told me we could have, then we look at where we get a probability less than 0.1. What I see is that we can allow 0, 1 or 2 daily means that were collected at random. 2 violations could happen 10% of the time a random sample was collected from a population of values where we select 12 samples and have an expected violation rate of 5%. If we get 3 samples that violate the daily mean, the likelihood of that is 1 in 100. The likelihood of 4 sample violating the criterion and still collecting it from water that only violates its criterion 5% of the time is at least 1 in 1000 (Note, with rounding here you only see 0.00 probability of the event. But if you carried out more decimal places you would compute and see the very small probability of the event beyond 1 in 100) – a very rare and unlikely result with 12 samples. The decision would be that the system is no meeting its criterion. Similarly, if 4 or more samples violated the criterion it would be even more rare to get that result if you are truly sampling from a population that looks like reference conditions. The decision for 3 or more samples not meeting the criterion would that your system is not meeting its goal of no more than 5% exceedances for the year and would be a failure that year.

Y	The computed binomial probability of getting Y ‘successes’ from 12 samples (Bernoulli formula used for computing the binomial probability)
0	0.54
1	0.34
2	0.10
3	0.01
4	0.00
5	0.00
6	0.00
7	0.00
8	0.00
9	0.00
10	0.00
11	0.00
12	0.00

In this example we picked a small but no unusual sample size for natural resource assessment. It probably has low power, we can calculate that as another step if we wanted to. For our purposes here I just provide the example to show this is one viable test and not unlike some states that collect around 10 samples in a year or season to compare against a criterion.

Attachment 2: A subsample of assessment approaches and decision frames from across the United States with regard to evaluating compliance to DO criteria.

Many states are exploring a variety of assessment approaches for DO criteria across a variety of habitats. States highlight the importance of taking into account the time of day for their sampling to address the minimum DO criteria. One example is Minnesota that applies a daily minimum of 5 mg O_2/L to its cool and warm water fisheries and splits the year into two seasons; May through September and October through April. Their assessment for dissolved oxygen requires no more than ten percent of the measurements taken in either period can violate the standard. Furthermore, measurements must be taken before 9:00 am to be representative of minimal conditions. Similarly, Oklahoma has a criterion of 5 mg O_2/L for warm water aquatic communities, but decreases that to 4 mg O_2/L during June 16 to October 15. Impairment is cited if more than 10% of the samples are below the criterion or if more than 2 samples are below 2 mg O_2/L. Under this form of wording for impairment assessment caution is recommended basing such assessments on percent of samples such that sufficient numbers of samples are collected for representative assessments.

Kansas (2011) was considering a variety of options to updating their 5 mg O_2/L minimum DO criterion. Options included: 1) lowering the DO criterion to a 4 mg/L instantaneous minimum. 2) assessing DO as a chronic impairment with binomial statistics (10% allowance of exceedance), explicitly stating allowances accounting for natural conditions, 4) explicitly excluding applying the criterion to the deepest portions of lakes (i.e. hypolimnetic waters).

For Massachusetts, in estuaries, their analysts compare DO data to the appropriate criterion (depending on a waterbody's classification) for surface water and depth measurements. (The national criteria daily minima (1.0 mg O_2/L less than the 7-day mean) were set to protect against acute (mortality) of sensitive species and they were also designed to prevent significant episodes of continuous or regularly recurring exposures to dissolved oxygen at or near the lethal threshold. DWM analysts use this daily minimum deviation (1.0 mg O_2/L) from the criterion for impairment decisions.) If all DO data meet (i.e., are above) the criterion, DO is considered sufficient to support the *Aquatic Life Use*. The analyst must evaluate the frequency and duration of excursions (whether or not they exceed 10% of the measurements) as well as the magnitude of any excursions (i.e., >1.0 mg O_2/L below the criterion). DO is identified as a cause of impairment if data indicate frequent, prolonged and/or severe excursion(s) from the appropriate criterion.

The temporal resolution and spatial density of measurements are variously considered across the country. In Oklahoma for example, for lakes, volume and space are taken into account and impairment is claimed if more than 50% of the lake water column has a dissolved oxygen concentration less than 2 mg O_2/L or if 10% of the surface samples are below the 5/4 mg O_2/L criteria.

Avoiding some of the challenges of grab sampling approaches to address temporal issues of diel cycling in DO behavior, states are advancing the uses of continuous monitoring data assessments. Washington State notes "Continuous sampling throughout the day can provide the lowest daily DO values; however, single "grab" samples are also used to determine compliance" (Department of Ecology, State of Washington 2009). Missouri evaluates stream reaches and recommends continuous monitoring data assessments at representative points in the stream (Missouri DNR 2010). Note, Missouri lists a sample period of days, a number of locations and a number of years involved in supporting a decision on impairment. The recommended sample size needed to estimate average daily mean and minimum DO concentrations in each of Missouri's ecological drainage units (EDU) are as follows:

- Continuous DO data collection efforts should target a deployment period of 68 days during the summer sampling period (July 1 – September 30);
- Data should be collected at 2 locations on each reference reach;
- All reference reaches should be monitored; and,
- Three years (summers) of data should be collected at each site.

Statistically, if they are randomly choosing the start date within the season from the period that would allow 68 days of monitoring, this would add a level of integrity to their assessment.

Rhode Island saltwater DO criteria are evaluated on cumulative exposures of low DO with established minimum standards. Therefore, Rhode Island is also moving to a reliance on continuously collected saltwater DO data or data that can be correlated to continuous data. Data are not interpolated but considered based on site specific assessment representing a region of the estuary (RI State Office of Water Staff, Pers. Comm.). Grab samples or similar DO data may still be considered if it can be correlated to continuous data or is representative of a longer time period.

Delaware has recently adopted site-specific DO criteria for the tidal Murderkill River (see http://www.dnrec.delaware.gov/swc/wa/Documents/WAS/Murderkill%20River%20Reports/Updated%20Drafts/Proposed%20Site-specific%20Dissolved%20Oxygen%20Criteria%20for%20Tidal%20Murderkill%20River.pdf.

The criteria and the assessment of the standard are:

The tidal portion of the Murderkill River has criteria for a daily averages and a one hour-average minimum criteria. Where continuous data are available, it will be assessed as rolling averages for the one hour minimum criteria and simple arithmetic averages for the daily average.

- For the one hour calculations, events less than 24 hours apart will be considered a single event. Two or more events more than 24 hours apart in one season will be considered not supporting of the use.
- Daily average criteria will be simple daily averages of the continuous data for each day in the period. Because of the hydrodynamics of the system, violations can occur over multiple day periods caused solely by tide and weather events.
- Violations less than 3 days apart will be considered a single event. Two or more violations in a single year, of the daily average will be considered as not supporting the use.

Attachment 3: Additional thoughts on considerations for selecting an assessment period for the impairment decision.

New literature on ecosystem recovery rates is available and highlights longer recoveries from stress than those used in U.S. EPA (2003). Using ecosystem recovery rates as a basis for defining an appropriate assessment period (e.g., U.S. EPA 2003), the new literature would suggest a longer assessment period than 3 years may be warranted and supported. U.S. EPA (2003) states "EPA guidance recommends use of a 1 in 3 year maximum allowable excursion recurrence frequency – number of times conditions in water are worse than those specified by the concentration and duration components of a freshwater life criterion for a toxic chemical". A key basis for this recommendation that defined a decision rule within a 3-year assessment period context was a 1989 literature survey of over 150 studies looking at recovery rates of freshwater ecosystems from various kinds of natural disturbances and anthropogenic stressors. The vast majority of macroinvertebrate and fish metric endpoints recovered in 2 years or less. However, a more recent review on recovery rates specific to estuarine and coastal ecosystems was published by Borja et al. (2010) in Estuaries and Coasts. Borja et al. summarized results from 51 studies used to evaluate recovery patterns as a function of various stressors. To be fair, many of the studies cited by Borja et al. (2010) pertained to systems that had experienced long-term degradation from a variety of stressors, as opposed to episodic impacts associated with a single parameter. However, similar to the 1989 EPA review, some studies showed near-term (months to a few years) recoveries of certain taxonomic groups. However, the lower boundaries for the majority of studies (see Table 2 in Borja et al.) is frequently 2-3 years while central tendencies are longer, and many recoveries take 6 years or more. Following the basis for EPA's support for decision rules based on a 3 year assessment, and now using the same logic with the support of this estuarine synthesis of new research on recovery rates of living resources by Borja et al. (2010), support here would suggest that longer assessment periods of 5-6 years instead of 3 years are supported and may be warranted.

What this leads you to consider is the difference between meeting your regulatory obligations versus having a tracking indicator. Your EPA-regulatory obligation may be to report impairment status in, for example, 5 year blocks. However, for your agency and as a means of tracking changes in the system, 5 year blocks are a long timeline for management to wait for a trend to show itself. Assuming you need at least 3 points to show a trend, that would be 15 years to get your first three data points. In the interim, you can use a rolling 5 year assessment with an annual time step as your annual tracking indicator of change. In this way you maximize the benefits of both approaches to follow change in your system. You get the sensitivity of the annual update to inform your managers of change over time in short time steps coupled with the regulatory performance of your 5-year block assessments to fulfill your EPA Clean Water Act 303d list reporting requirements. Over time, you should be able to leverage the two forms of tracking to evaluate status and highlight change and progress.