

Suisun Marsh TMDL

for Methylmercury, Dissolved Oxygen and Nutrient Biostimulation

Part 1: Project Definition (<-click here)

Part 2: Project Plan (<-click here)

San Francisco Bay
Regional Water Quality Control Board

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Photo: Peter Baye

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PART 1: Project Definition

GENERAL SETTING AND OVERVIEW OF 303(D) LISTING

Environmental Significance and Beneficial Uses

The Suisun Marsh, located within Southern Solano County, is the largest contiguous brackish water marsh remaining on the west coast of North America (Figure 1). It is part of the San Francisco Bay-Sacramento/San Joaquin River Delta estuary ecosystem and encompasses 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 shows the major features of the Suisun Marsh.

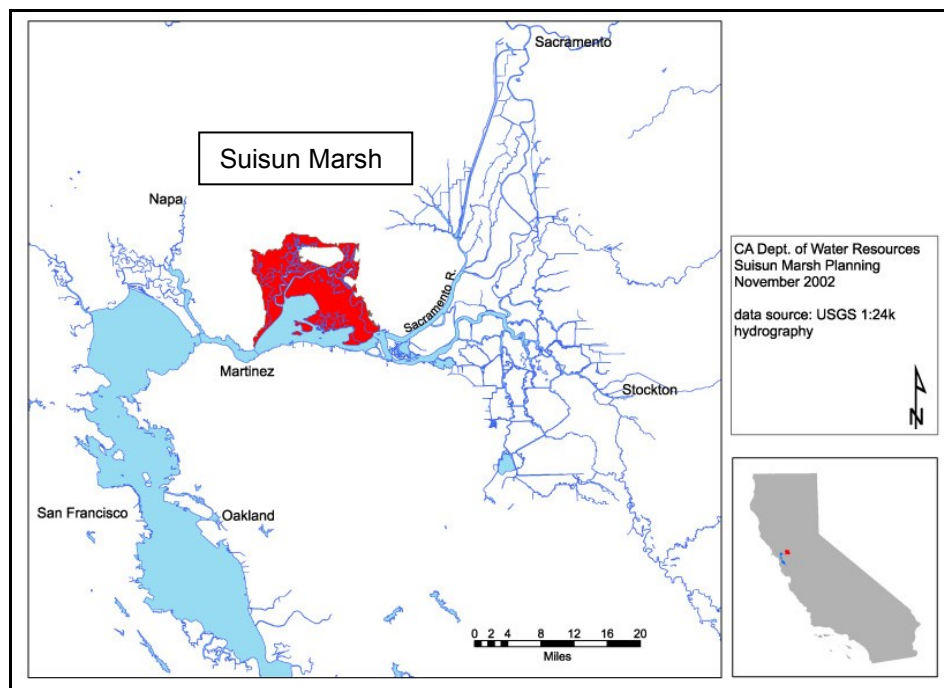


Figure 1: Project Location

Since the 1860s the historic tidal marshes have been converted to diked marshes in order to reclaim the land for agricultural uses. When agriculture 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. In both the historic tidal marshes and today's seasonal 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. It 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 the central California wintering waterfowl population.

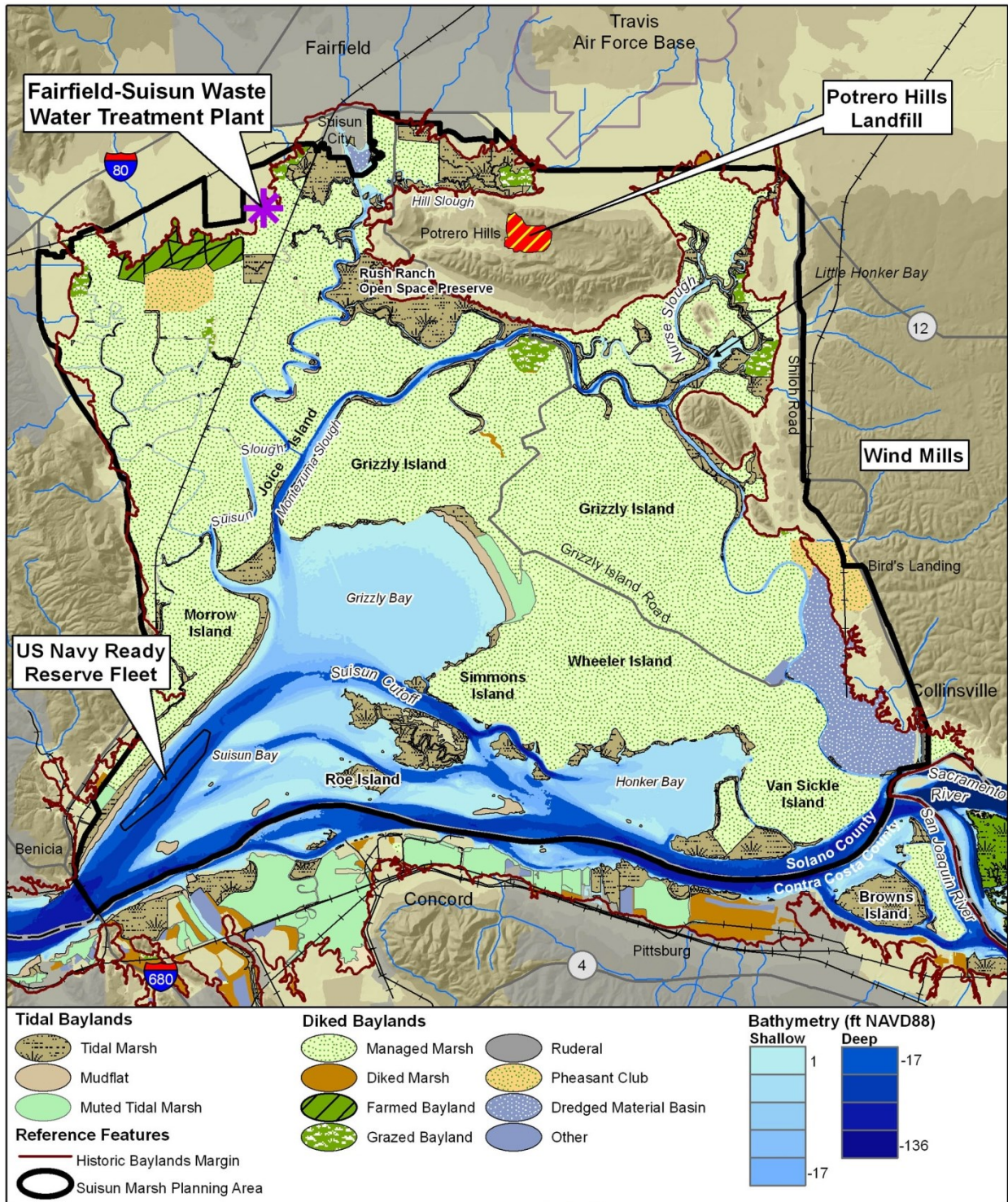


Figure 2: Suisun Marsh wetland and aquatic habitats (from Siegel et al., 2011)

Portions of the marsh, such as the Grizzly Island Wildlife Area, are managed as wetlands supporting public waterfowl hunting areas. The majority of the marsh is used by over 150 private duck clubs, which maintain diked seasonal wetlands for wintering waterfowl and hunting.

The beneficial use classifications for Suisun Marsh comprise human consumptive uses and aquatic life and wildlife uses. Existing human consumptive uses include freshwater replenishment (FRESH) and sport fishing (COMM) in the tributaries (Suisun Creek and Ledge wood Creek) and sport fishing in the sloughs. Existing aquatic life uses include estuarine habitat (EST), fish migration (MIGR), preservation of rare and endangered species (RARE), fish spawning (SPWN), and warm freshwater habitat (WARM) in the Suisun Slough and Montezuma Slough, and estuarine habitat (EST), fish migration (MIGR), and preservation of rare and endangered species (RARE) in smaller sloughs such as Goodyear, Cordelia, Boynton, Peytonia, and Denver ton Sloughs. In particular, Suisun Slough has been designated as an area of critical salmon habitat and migration.

All the tributaries and sloughs are required to support wildlife habitat (WILD), water contact recreation (REC-1), and non-contact water recreation (REC-2).

Beneficial uses for the Marsh's wetland areas include estuarine habitat (EST), fish migration (MIGR), preservation of rare and endangered species (RARE), water contact recreation (REC-1), non-contact water recreation (REC-2), fish spawning (SPWN), and wildlife habitat (WILD).

Aquatic habitat evaluations conducted during development of the Suisun Marsh Habitat Management, Preservation and Restoration Plan (2011) and the draft Delta Plan (DSC 2012) indicate that water quality in the marsh is generally adequate, in terms of salinity, turbidity, temperature and pollution levels, and there is no clear evidence to quantify the effect of contaminants on aquatic populations and communities (e.g. Siegel et. al., 2010, Engle et al., 2010). Contaminant concerns affecting aquatic species and ecosystem processes seem to be focused on elevated levels and production of methylmercury because of the risks to ecological and human health, and low levels of dissolved oxygen.

Extent of 303(d) Listings and Pollutants to be Addressed

The Suisun Marsh wetlands are listed in the 2010 Clean Water Act Section 303(d) impaired water bodies list as impaired by mercury, low dissolved oxygen/organic enrichment, nutrients, and salinity.

The Water Board is required to initiate a total maximum daily load (TMDL) project that would review the basis for the listings of the Suisun Marsh wetlands and determine the measures necessary to attain water quality standards and to ensure that beneficial uses in the marsh are supported. Despite a wide range of concerns signified by the 303(d) listing our current understanding is that the principal sources of impairment in the marsh are mercury/methylmercury (Hg/MeHg) and dissolved oxygen (DO) (Tetra Tech 2011).

Mercury poses significant health risks for humans and wildlife, causing reproductive impairment in humans and many bird species. Consequently, the beneficial uses most directly affected by Hg/MeHg include commercial/sport fish harvesting activities (COMM), which pose human health concerns, and wildlife (WILD) and rare/endangered species (RARE) resources that can be adversely affected by bioaccumulation of mercury.

In the Suisun Marsh and San Francisco Bay, mercury originates from a number of historical and existing sources. Its bioavailability and toxicity are greatly enhanced through the bacterial transformations to MeHg that often take place naturally in wetlands. Higher MeHg concentrations were found in managed wetlands than in other areas of Suisun Marsh. Although MeHg production is not well understood, the drying and wetting regime, high organic carbon concentrations, and low DO concentrations in managed wetlands are known factors that promote formation of reactive Hg and increase methylation potential.

Dissolved oxygen (DO) is essential for a healthy aquatic ecosystem. Low DO levels are known to adversely affect all main aquatic life beneficial uses including WARM, COLD, MIGR, SPWN, EST, and RARE. They can result in fish kills, fish egg mortality, and growth rate reductions, and may serve as a barrier to migration of anadromous fish such as Chinook salmon (CVRWQCB 2004, Raabe et al., 2010). High organic carbon content from natural and anthropogenic sources and subsequent decomposition of organic material contributes to low DO concentrations due to the consumption of oxygen by organic carbon decay, which, in turn, amplifies the anoxic stress. Similarly, nutrient loading from point and nonpoint sources can fuel primary production and increase macrophyte and algal growth rates, thereby lowering DO levels. By focusing the TMDL on attainment of the DO water quality objectives, we will protect aquatic life beneficial uses from the consequences of biostimulatory substances.

The Suisun Marsh is also listed on the 303(d) list as impaired by salinity, yet during the past decade or so, our understanding of the salinity levels necessary to protect beneficial uses of the marsh and, in particular, waterfowl has changed significantly. The first salinity objectives established for the protection of fish and wildlife, adopted by the State Board in Decision 1485, date back to 1978. These objectives, with some modifications, are still in place today. They were based primarily on ecological studies that examined the relative value of marsh plants as “duck food” and recommended by the Department of Fish and Game (DWR 2001). The Suisun Marsh Salinity Control Gates installed in Montezuma Slough in 1988 provide the means to control salinity intrusions from Suisun Bay during the periods of low Delta outflow and ensure that the salinity objectives are met at all but two compliance monitoring locations. The number of exceedances detected is limited and the operation of the gates appears to be effective in regulating salinity in Suisun Marsh as per current standards.

Nevertheless, a question exists whether the current salinity objectives are protective of a wider range of beneficial uses and diverse marsh habitats. After a comprehensive re-evaluation of the technical basis of the water quality objectives in Suisun Marsh and the relevant new scientific information, the Suisun Ecological Workgroup, in their recommendation to the State Water Resources Control Board (State Water Board), called for the salinity objectives to be revised and the operation of the salinity control gates greatly altered (DWR 2001). Most experts agree that more variable tidal salinity conditions may allow equal or better waterfowl abundance and diversity, and that relaxation of salinity regimes could benefit native fish populations.

Salinity conditions in the Suisun Marsh are to a great degree dependent on the large-scale water diversions in the Delta and statewide water management decisions. These fall beyond the Region 2 Water Board’s geographic limits. Therefore, salinity concerns in Suisun Marsh will not be addressed by this TMDL project. The State Water Board oversees the development and implementation of salinity objectives in the marsh and decisions regarding the need to modify and/or change the salinity objectives in Suisun Marsh will be ultimately made through the State Water Board’s regulatory process as part of revisions to the San Francisco Bay/Sacramento-San Joaquin Delta Estuary Water Quality Control Plan.

Existing Water Quality Standards

Federal Clean Water Act regulations and the San Francisco Bay Basin Water Quality Control Plan (Basin Plan) contain water quality standards that identify the beneficial uses of San Francisco Bay Basin water bodies, numeric and narrative water quality objectives to protect those uses, and provisions to enhance and protect existing water quality. Suisun Marsh exhibits brackish conditions at its border with the marine waters of Suisun Bay and almost freshwater conditions in the interior

of the marsh, making it difficult to determine the most-pertinent objectives. In general, the Basin Plan recommends that for waters in which the salinity is between 1 and 10 parts per thousand (ppt), the applicable objectives are the more stringent of the freshwater or marine objectives. Thus, the following existing water quality objectives are currently applicable for Suisun Marsh.

NUMERIC OBJECTIVES

Mercury

For protection of aquatic life from acute toxicity adverse effects, the Basin Plan limits total mercury in marine waters, with salinity greater than 10 ppt, to a 1-hour average concentration of 2.1 µg/L. On average, salinity in the Suisun Marsh sloughs is below 10 ppt, but the marine objective applies in the marsh because it is more stringent than the freshwater objective of 2.4 µg/L.

Mercury measured in a small number of samples collected in Suisun Marsh sloughs does not exceed the acute marine water quality objective.

The Basin Plan also lists a marine and freshwater chronic objective for mercury of 0.025 µg/L (4-day average concentration). This chronic objective still applies in Suisun Marsh, but is no longer applicable in San Francisco Bay. In 2006, the San Francisco Bay mercury TMDL vacated the marine chronic objective in all Bay segments, including Suisun Bay and the portion of the west Delta that are directly connected to the marsh. Instead, the TMDL established the site-specific mercury objectives, thought to be more relevant to protection of wildlife (California least tern) and human health. These site-specific objectives are expressed as fish tissue concentrations (Table 1). We intend to extend the applicability of these site-specific objectives to Suisun Marsh.

Table 1: Site-specific water quality objectives for mercury in San Francisco Bay

Marine ^a Water Quality Objectives for Mercury in San Francisco Bay		
Protection of Human Health	0.2 mg mercury per kg fish tissue	Average wet weight concentration measured in the edible portion of trophic level 3 and trophic level 4 fish
Protection of Aquatic Organisms and Wildlife	0.03 mg mercury per kg fish	Average wet weight concentration measured in whole fish 3–5 cm in length

Notes: ^a Marine waters are those in which the salinity is equal to or greater than 10 parts per thousand 95% of the time, as set forth in Chapter 4 of the Basin Plan. For waters in which the salinity is between 1 and 10 parts per thousand, the applicable objectives are the more stringent of the freshwater or marine objectives.

The most recent inland silverside samples (2005-2006) from the major sloughs in Suisun Marsh exceeded the 0.03 mg/kg site-specific aquatic organisms and wildlife objective, with samples from 2006 showing concentrations greater than 0.1 mg/kg. In 2006, mercury concentrations in silversides from sloughs were also much higher than those measured in silversides from the Yolo Bypass.

Dissolved Oxygen

The Basin Plan includes numeric objectives for dissolved oxygen for tidal and nontidal waters. The DO concentrations for tidal waters in the vicinity of Suisun Marsh should be no less than 7.0 mg/L.

For nontidal waters designated as cold water habitat, the Basin Plan requires a minimum of 7.0 mg/L, and for warm water habitat, a minimum of 5.0 mg/L.

The median dissolved oxygen concentration for any three consecutive months shall not be less than 80 percent of the dissolved oxygen content at saturation.

The DO concentrations in Suisun Marsh sloughs vary seasonally. The lowest monthly concentrations usually occur in the fall, when DO may drop to as low as 2 mg/L, which is sufficiently low to result in the mortality of most fish, invertebrates, and organisms that use the sloughs and water channels of Suisun Marsh (O'Rear and Moyle 2010, Tetra Tech 2011). These severe depletions in DO concentrations are often observed in Peytonia, Boynton and Goodyear Sloughs. DO concentrations as low as 0 mg/L that lasted for prolonged periods of time were also observed during the 2007-2008 study conducted at two managed wetlands (Siegel et al., 2011).

NARRATIVE OBJECTIVES

In addition to its numeric objectives, the Basin Plan also lists the narrative objectives that are relevant to the mercury and dissolved oxygen impairments in Suisun Marsh.

Bioaccumulation

Many pollutants can accumulate on particles or in sediment, or bioaccumulate in fish and other aquatic organisms. The Basin Plan requires that controllable water quality factors shall not cause a detrimental increase in concentrations of toxic substances found in bottom sediments or aquatic life. Effects of mercury bioaccumulation on aquatic organisms, wildlife, and human health will be considered in this TMDL.

Biostimulatory substances

The Basin Plan requires that waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses. Changes in chlorophyll a and associated phytoplankton communities follow complex dynamics that are sometimes associated with a discharge of biostimulatory substances. Irregular and extreme levels of chlorophyll a or phytoplankton blooms may indicate exceedance of this objective and require investigation.

MAIN CAUSES OF IMPAIRMENT

Water quality in the Suisun Marsh is mainly influenced by the flows from the Sacramento-San Joaquin Delta, Bay tidal action, and runoff from local watersheds that may contribute pollutants from urban, agricultural, and industrial activities. In addition, the advanced secondary level Fairfield-Suisun Wastewater Treatment Plant, which serves more than 130,000 residential, commercial and industrial customers, is located in the northwest portion of the marsh. The Plant discharges more than 90% of its treated effluent into Boynton Slough (Figure 2). Managed and tidal wetlands within the marsh have the potential to contribute large amounts of organic material and other pollutants, as well as to accelerate mercury transformations and methylmercury production.

All these sources may contribute to the degradation of water quality in Suisun Marsh, but only the operations at the managed wetlands could be linked directly to the adverse water quality impacts.

Managed wetlands are diked and separated from the tidal sloughs by levees, with water exchange controlled by gated culverts. The following are the primary tools used in managed wetlands to create a habitat mosaic desired by waterfowl (Figure 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

The general wetland management cycle includes the summer period, when wetlands are left to be relatively dry and annual maintenance is completed, although some level of ponding may be retained.

This is followed by the fall floodup. When managed wetlands are flooded, vegetation in them starts to decompose, which may result in the depletion of oxygen and the production of sulfites. During the fall floodup, water is also discharged from the managed wetlands. This water includes water that has remained ponded in the wetland over the summer. Because of the decomposition of organic matter in the ponded wetland, the ponded water, and the water that has initially entered during the fall floodup, may have very low DO concentrations or be anoxic. When this potentially anoxic water is discharged to adjoining sloughs, it can 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-leaved vegetation and other organic material (DFG undated). This situation is not atypical in the fall.

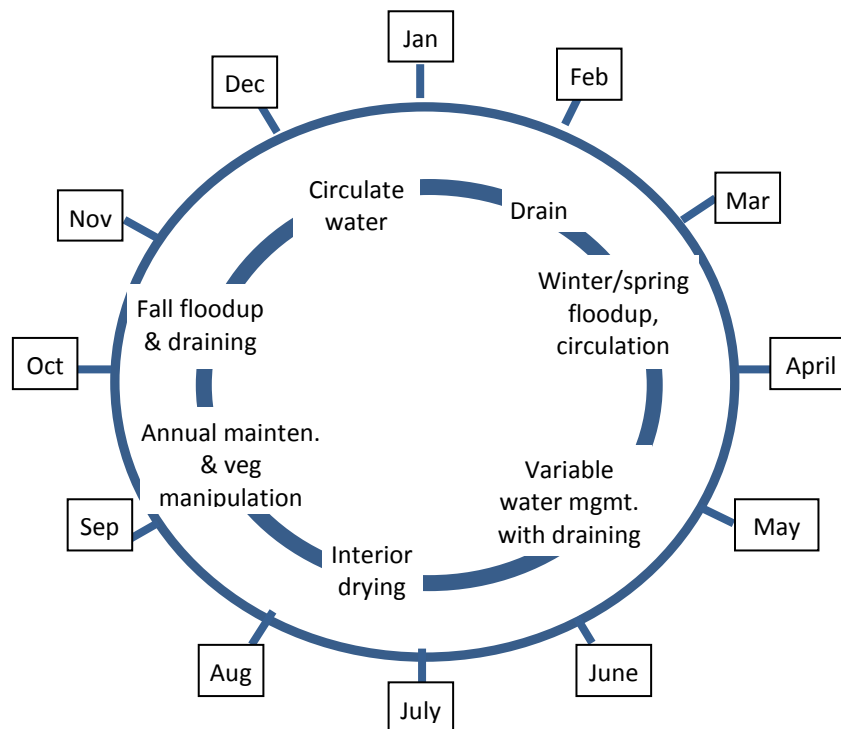


Figure 3: Conceptual representation of the typical water management cycle at a managed wetland (after DFG undated)

A similar flooding and drying cycle may also occur in spring to further leach surface salts and decrease mosquito production. Marsh oxygen concentrations are usually highest in winter, lower in spring and summer, and lowest in fall (October-November), and these DO fluctuations coincide directly with the managed wetland activities.

The prolonged periods of flooding and drying, together with a buildup of organic carbon in the soils, have been also found to increase MeHg production and, in general, enhance methylation potential. Kelly et al. (1997) identified three changes in environmental conditions that stimulate mercury methylation and are present in the 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.

Moreover, hydrological conditions in the managed wetlands are quite different than in the tidal portions of the marsh. The diked wetlands have simplified channels that reduce natural dendritic geometry and heterogeneity of the estuarine habitat, which promotes growth of invasive species from macrophytes to fish.

Making changes to the water management operations in the managed wetlands and restoring portions of these wetlands to tidal action would likely alleviate many of the key environmental problems. Above all, it would reduce incidents of dissolved oxygen depletion and diminish MeHg impacts.

DEVELOPING A WATER QUALITY ATTAINMENT STRATEGY

The goal of this project is to develop a TMDL that will address at least two impairment listings: low DO/organic enrichment and mercury, and, when possible, formulate a plan and evaluate options for nutrients. The State Water Board is in the process of considering potential changes to the Suisun Marsh and Suisun Bay salinity objectives, to be implemented at the beginning of 2015. Therefore, salinity issues will not be resolved by this project.

Over the next two years, Water Board staff will work with stakeholders to develop and adopt TMDLs, allocations, and implementation plans to attain water quality standards for DO and mercury in Suisun Marsh. In 2011, Tetra Tech, a technical consultant on the project funded by U.S. EPA, prepared a draft report (The Suisun Marsh Conceptual Model/Impairment Assessment) that reviews the basis for the assessment and documents current knowledge regarding sources, fates, and effects of low DO, nutrients and mercury. This report also helps identify the main uncertainties and information gaps and provides a starting point for development of a Water Quality Attainment Strategy (Attainment Strategy) for DO/organic enrichment, mercury and, to the degree possible, nutrients. The purpose of the Attainment Strategy is to identify a reasonable course of actions that will be taken by regulators and other stakeholders to ultimately achieve the goal of meeting water quality standards. As part of preparing the Attainment Strategy, we will identify early implementation actions and additional technical studies required as part of an adaptive implementation strategy. A detailed discussion of the approach and rationale proposed for the Suisun Marsh TMDL is provided in Part 2 of this document: "Project Plan".

REFERENCES: PROJECT DEFINITION

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PART 2: Project Plan

For details on the Suisun Marsh project location, beneficial uses, and existing water quality objectives see “Project Definition” in **Part 1** of this document.

TMDL Background

The Suisun Marsh wetlands are listed in the 2010 Clean Water Act Section 303(d) impaired water bodies list as impaired by mercury, low dissolved oxygen/organic enrichment, nutrients, and salinity. The listings are more than 20 years old and the basis for the listings has never been clearly explained.

However, for over 20 years, anecdotal information has existed about periodic discharges of “black” water from the managed wetlands that caused anoxia and fish kills in certain back-end sloughs (Figure 4). These conditions persist. For example, 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 fish was observed in Goodyear Slough (O’Rear et al. 2010). The dissolved oxygen concentrations in these sloughs can fall below 2 mg/L in the fall, which may result in mortality of most species of fish.

The current 303(d) listings are for the Suisun Marsh wetlands. A review of archive information for dissolved oxygen from August 2001 (Table 2) indicates that the placement of the wetlands on the 303(d) list was driven by observations of the adverse conditions not in the wetlands, but in the adjacent sloughs. Therefore, in devising a strategy for the TMDL, we are focusing on the actions and measures necessary to attain water quality standards in the sloughs and to ensure that beneficial uses in these sloughs are supported. This is likely to be our approach for the other listed pollutants, mercury and nutrients.

Table 2: Water quality assessments for Suisun Marsh sloughs for the 2002 303(d) list

Boynton Slough part of Suisun Marsh Wetlands	DO List	38% of samples violate Basin Plan objectives (<7mg/l)	144 samples	7/2/97- 5/3/2001	Fairfield-Suisun Water Treatment Plant Slough Data June 1997-June 2000, NPDES Permit CA0038024
Peytonia Slough part of Suisun Marsh Wetlands	DO List	40.4% of samples violate Basin Plan objectives (<7mg/l)	47 samples	7/2/97- 5/3/2001	Fairfield-Suisun Water Treatment Plant Slough Data June 1997-June 2000, NPDES Permit CA0038024
Suisun Slough part of Suisun Marsh Wetlands	DO List	56% of samples violate Basin Plan objectives (<7mg/l)	144 samples	7/2/97- 5/3/2001	Fairfield-Suisun Water Treatment Plant Slough Data June 1997-June 2000, NPDES Permit CA0038024

TMDL APPROACH

The purpose of this TMDL project is to devise a strategy to attain water quality objectives for DO and mercury, and restore and protect the beneficial uses of the Suisun Marsh sloughs. The TMDL will also attempt to resolve the 303(d) listing of the marsh for nutrients. This integrated approach will help address multiple water quality issues that are likely interconnected, and provide a more effective way of assessment, planning and implementation of the TMDL.

Major challenges with respect to addressing nutrient levels in the marsh are a lack of algal blooms—typically thought of as a significant indicator of eutrophication—a lack of guidelines on how to interpret nutrient concentrations in the brackish environment, the absence of numeric objectives for nutrients, and the proximity of the marsh to Suisun Bay and the Delta, which are currently the focus of multiple efforts aiming to determine the sources, processes, and conditions leading to nutrient impairment.

In contrast to many other estuaries, the San Francisco Estuary has always been considered relatively resilient to nutrient pollution and has not shown many of the common symptoms of eutrophication, such as enhanced algal growth (Kimmerer 2004). Still, nutrients have been identified as potential pollutant of concern by many estuary-wide planning documents (e.g. DSC 2012). In general, the role of nutrients in the Delta and Suisun Marsh is widely debated and additional research is needed to reduce the uncertainty about their impact on harmful algal blooms, changes in phytoplankton species composition, and their consequences for the entire food web.

Suisun Marsh's location at the fringe of the Sacramento-San Joaquin Delta and the San Francisco Bay, its long recognized environmental significance, and its proximity to the largest water supply systems in California make the marsh one of the most-regulated wildlife habitat areas in the State. This TMDL project will take into account complex long-term regulatory and scientific efforts that are being undertaken to formulate the California Bay Delta Plan and the Suisun Marsh Habitat Management, Preservation and Restoration Plan, as well as the initiatives of the Suisun Marsh Charter, just to mention a few.

TMDL pollutants of concern

The results of the most recent data analysis and review of potential causes of water quality impairment are compiled in the draft Conceptual Model Impairment Assessment report (Tetra Tech 2011). The findings of this report point to low dissolved oxygen (DO) and high mercury/methylmercury (Hg/MeHg) concentrations as the major water quality issues in Suisun Marsh. The impact of these two constituents on water quality is driven by physical processes and hydrological constraints. The marsh environment is also naturally enriched with nutrients and is characterized by high levels of organic material. Both, nutrients and organic carbon, play a role in controlling dissolved oxygen concentrations and influence the potential for MeHg production, although they are likely to affect DO and mercury in different ways.

The TMDL for Suisun Marsh will focus on addressing the low DO problems that have been linked to the persistent fish kills, and on potential Hg contamination. We will consider nutrients in the source analysis and linkage analysis, as a necessary step to evaluate the degree to which nutrients contribute to DO deficits, and will devise actions that would likely alleviate nutrient problems if they exist. However, we may need to reevaluate the role of nutrients in the marsh when the results of the comprehensive studies in Suisun Bay and the Delta become available, and a decision on the need for site specific objectives has been made. Recent interpretations of chlorophyll *a* and phytoplankton species composition data in the San Francisco Estuary indicate that patterns of chlorophyll *a* in

Suisun Marsh major sloughs follow closely those in Suisun Bay (Mueller-Solger 2012). In the meantime, the observed shifts in phytoplankton community composition and declines in phytoplankton biomass continue to be the subject of scientific studies.

The Suisun Marsh TMDL will establish a link between managed wetland operations in particular, flooding and releasing of the high organic content low DO waters from duck ponds, and the observed acute drops in DO levels in the back-end sloughs (Figure 4).



Figure 4: Black anoxic water discharging into lower Goodyear Slough on 19 October 2010
photo by Carson Jeffres (from O'Rear and Moyle, 2011)

Figure 5 shows a typical pattern of the DO concentrations throughout the marsh in October, when managed wetland managers are typically conduct their flooding and draining cycle.

Despite the fact that most managed wetlands in the marsh employ cycles of flooding and draining to promote the growth of preferred waterfowl food plants and for vector control, the areas that experience the most severe adverse water quality impacts are limited to the smallest back-end sloughs. In these smaller sloughs around the margins of Suisun Marsh, fall floodup can also trap the low quality waters at the headward end of the sloughs, which reduces already-limited tidal exchange and leads to reduced DO levels and elevated concentrations of constituents such as MeHg in these waters (Siegel et al., 2011).

These duck pond releases are also rich in nutrients and organic matter that further stimulate microbial activity, which continues to reduce the receiving water DO after the discharges have ended. The low DO and high organic carbon concentrations also establish conditions that favor production of MeHg. In the field study in the marsh, Siegel and others (2011) confirmed that below DO concentrations of 3 mg/L, filtered and unfiltered MeHg levels increased dramatically. In the TMDL, we will show that a relationship exists between DO sags, site vegetation, and MeHg production, and propose changes to water and vegetation management that would be beneficial to water quality in the sloughs.

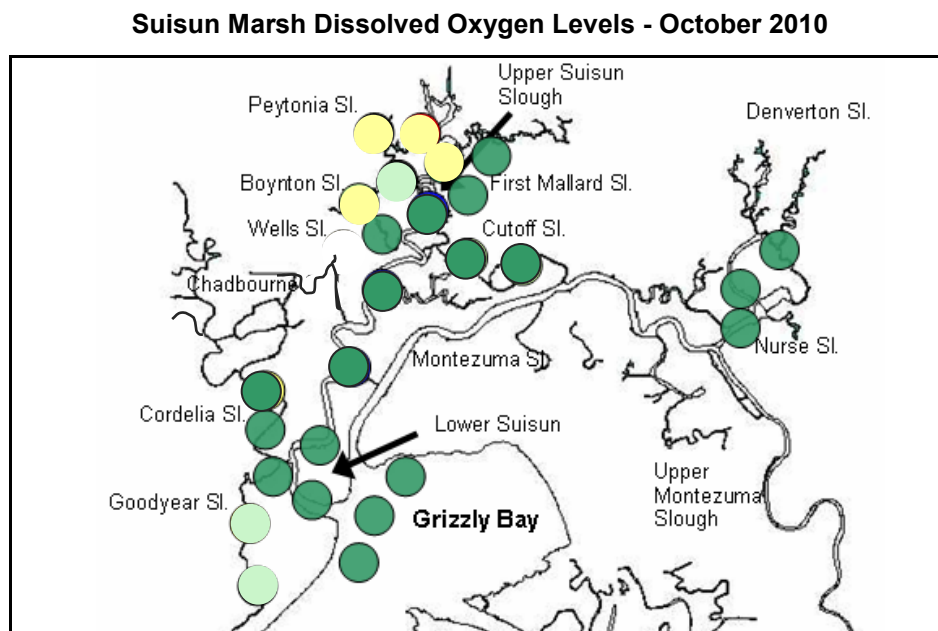
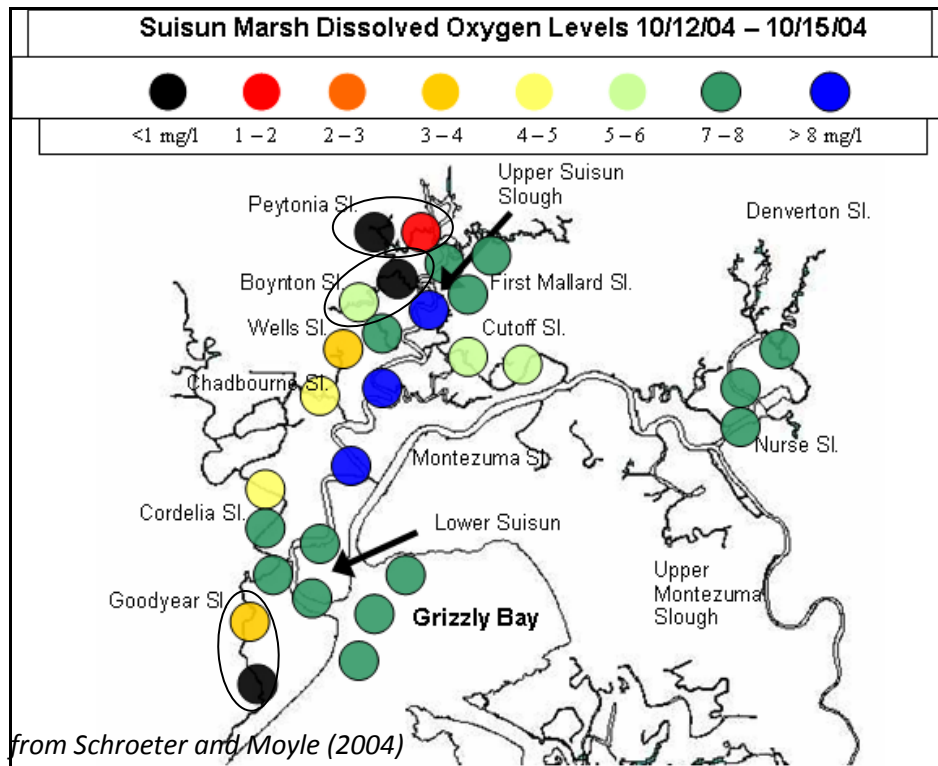


Figure 5: Dissolved oxygen concentrations following pond release into sloughs of Suisun Marsh

TMDL Spatial Context

Patterns of DO levels are not well-understood in Suisun Marsh sloughs. Multiple factors influence oxygen solubility and spatial distribution throughout the day and seasonally. As available DO data are mostly intermittent monthly measurements, Figure 5 provides only a snapshot of the DO distributions in the marsh. However, it clearly indicates that water quality problems and recurring

fish kills are most evident in the northwestern part of the marsh, where adverse water quality conditions are amplified by long distances from the tidal source and reduced hydraulic connectivity to larger sloughs and channels. These conditions are well explained by the hydrodynamic mixing and connectivity conceptual model (Figure 6). The Suisun Marsh system is highly fragmented into discrete managed water bodies that are often disconnected from each other. The limited connectivity has significant consequences for the cycling of nutrients and organic carbon which, in turn, has an impact on water quality, regular exchange of primary/secondary productivity between wetland and slough habitats, and organism movements within the marsh (Wetlands and Water Resources 2011).

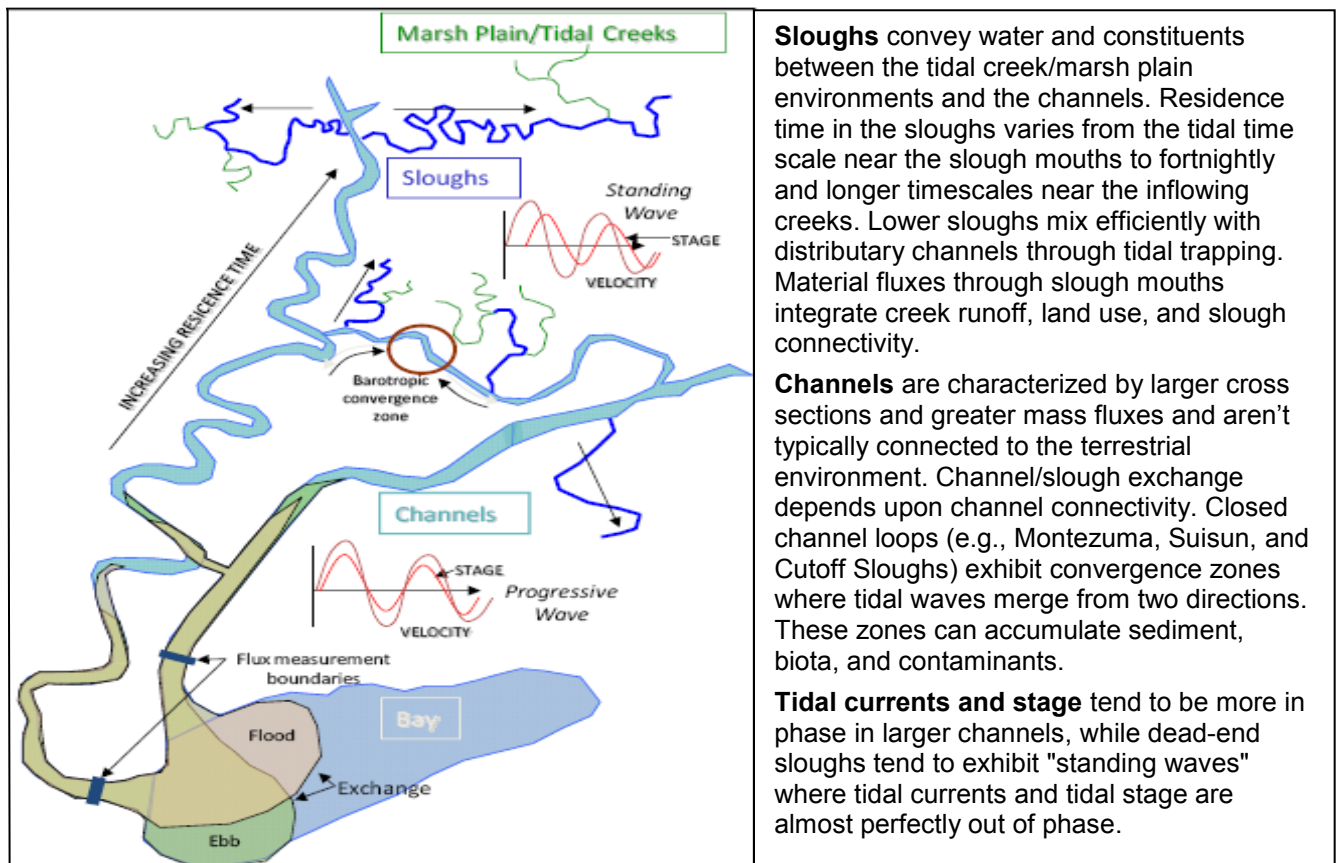


Figure 6: Conceptual model of hydrodynamics and mixing across a regional scale
(from Siegel et al., 2010)

Hence, we propose, for technical analysis and modeling, to focus on the sloughs in the northwestern part of the marsh that represent the worst case conditions. The TMDL report will provide further lines of evidence to support this approach. Nevertheless, from a hydrodynamics perspective, there is only one other area in the marsh, encompassing Denverton and Nurse Sloughs, that may experience conditions similar to those in the northwestern part of the marsh. However, despite the large variability in measured DO (Figure 7) a fish kill has never been recorded in Denverton Slough. Moreover, the slough is often considered to represent conditions of good habitat and water quality (P. Moyle, pers. comm.).

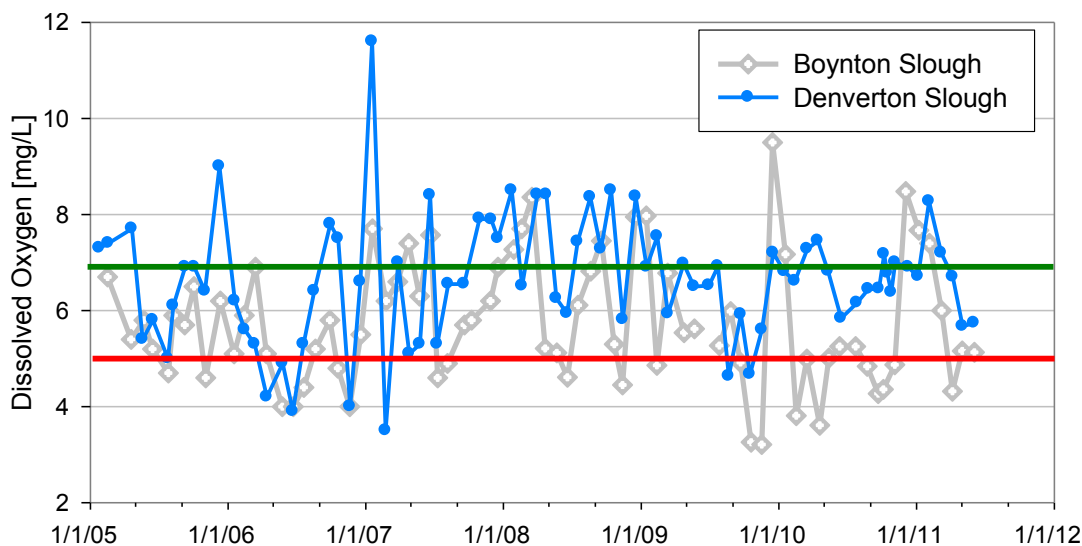


Figure 7: Monthly dissolved oxygen concentrations in Boynton Slough and Denverton Slough
(data collected by UC Davis for Suisun Marsh Fish Study)

TMDL Targets and Objectives

The Suisun Marsh's diverse beneficial uses and complex ecosystem, its proximity to Suisun Bay and its tidal influence, and the timing, variability and magnitude of freshwater flows from the Delta all contribute to a significant challenge while selecting the water quality targets for dissolved oxygen and mercury. The sloughs within the marsh experience an array of conditions from almost saline to fresh, which makes the choice of target values even more difficult.

Dissolved Oxygen/Organic Enrichment

The Basin Plan broadly divides tidal waters in the San Francisco Bay system into two sections, requiring that the DO concentrations be no less than 5 mg/L for the section below the Carquinez Strait Bridge and at least 7 mg/L for all tidal waters upstream from the bridge. This requirement also applies to Suisun Marsh sloughs, which are upstream of the bridge. Through the increasing number of restoration projects around the Bay margins, it has been recognized that DO concentrations in shallow water habitats, such as tidal wetlands and slough networks, vary much more than in the main segments of San Francisco Bay (the Bay). These peripheral areas frequently exhibit DO concentrations of less than 5.0 mg/L under otherwise unimpaired conditions. DO concentrations measured in Suisun Marsh exhibit similar patterns (Figure 7 and Figure 8). The last Basin Plan Triennial Review identified a need to establish water quality objectives for DO that might be more applicable to wetlands, slough channels, and other shoreline habitats. Work on the new objectives has not yet been initiated, but there is ongoing support for the project by Bay Area stakeholders.

The plan for this TMDL is to evaluate two potential sets of targets:

- for the small back-end sloughs (e.g. Peytonia, Boynton) – DO concentrations of **5 mg/L**
- for the larger sloughs (e.g. Suisun Slough) – DO concentrations of **7 mg/L**

These potential target DO levels are still within the optimum range of DO for fish and aquatic life (i.e., from 5 to 9 mg/L) (CDFG 2010). When DO levels drop below this range, behaviors such as feeding, migration, predator avoidance, and reproduction could be negatively affected in some fish species.

Using the QUAL2K model, we will simulate DO dynamics, organic carbon decay, and algal growth, and the contribution of nutrients from point and non-point sources to DO deficits. The testing of critical conditions leading to fish kills will help establish the link between operations of managed wetlands and occurrences of DO sags as well as the DO levels attainable in the back-end sloughs.

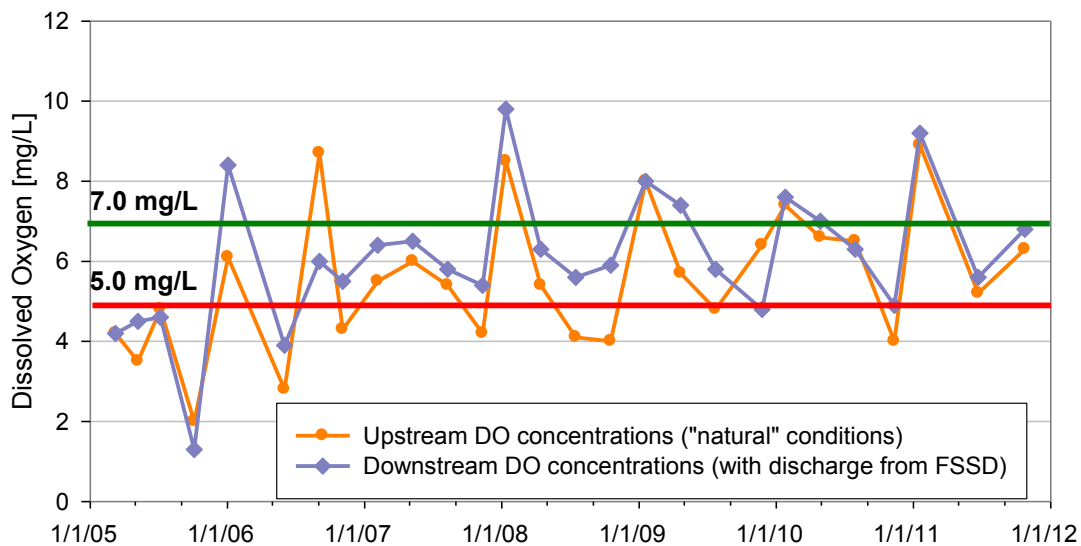


Figure 8: Quarterly DO concentrations in Boynton Slough upstream and downstream of the Fairfield Suisun Wastewater Treatment Plant's discharge point

Mercury

The water quality concerns about mercury in Suisun Marsh are somewhat similar to those considered in the San Francisco Bay Mercury TMDL adopted in 2006. They include human health concerns related to the consumption of mercury-contaminated fish, as well as protection of wildlife that feeds on fish and other aquatic organisms that bioaccumulate mercury. The historical and present sources of mercury to Suisun Marsh are also similar to those in the Bay. The targets established in the Mercury TMDL for San Francisco Bay are intended to reduce the risks to humans and wildlife, and therefore are applicable to this project. For the mercury part of the Suisun Marsh TMDL, we intend to implement the same targets and to follow the process that was used in establishing the Mercury TMDL in San Francisco Bay.

As discussed in the Project Definition (see Part 1 in this document), for protection of aquatic life from acute toxicity adverse effects, the Basin Plan limits total mercury in marine waters (those with salinity greater than 10 ppt) to a 1-hour average concentration of 2.1 µg/L. On average, salinity in the Suisun Marsh sloughs is below 10 ppt, but the marine objective applies in the marsh because it is more stringent than the freshwater objective of 2.4 µg/L.

The Basin Plan also lists a chronic objective for mercury of 0.025 µg/L (4-day average) that is somewhat outdated. For most of the San Francisco Bay segments, including Suisun Bay and the portion of the west Delta, the chronic objective was vacated and instead, site-specific objectives expressed as fish tissue concentrations thought to be more relevant to protection of wildlife (California least tern) and human health were established (Table 3). The Suisun Marsh area was not reflected in the decision to establish site-specific objectives, which appears to be an oversight. In this project, we will consider the most efficient way of replacing the chronic objective with the scientifically-based site-specific objectives that apply in adjacent Suisun Bay. There is a consensus

that fish tissue concentrations provide a better way to assess protectiveness for humans and wildlife and the State Board is currently in the process of developing a set of objectives for safe amounts of MeHg in fish. When developed, these objectives will apply to a range of water bodies, including Suisun Marsh, and will provide a useful tool to guide wetland restoration projects, water quality permits, and other actions aiming at mercury pollution prevention.

Table 3: Site-specific objectives for mercury expressed as fish tissue concentrations

Marine ^a Water Quality Objectives for Mercury in San Francisco Bay		
Protection of Human Health	0.2 mg mercury per kg fish tissue	Average wet weight concentration measured in the edible portion of trophic level 3 and trophic level 4 fish
Protection of Aquatic Organisms and Wildlife	0.03 mg mercury per kg fish	Average wet weight concentration measured in whole fish 3–5 cm in length

Notes: ^a Marine waters are those in which the salinity is equal to or greater than 10 parts per thousand 95% of the time, as set forth in Chapter 4 of the Basin Plan. For waters in which the salinity is between 1 and 10 parts per thousand, the applicable objectives are the more stringent of the freshwater or marine objectives.

In the Suisun Marsh TMDL we will focus particularly on environmental and anthropogenic conditions and factors leading to bacterial transformations of mercury to MeHg. Although these transformations often take place naturally in marshes and wetlands, higher MeHg concentrations were found in managed wetlands than in other areas of Suisun Marsh. While MeHg production is not well understood, the drying and wetting regime, high organic carbon concentrations, and low DO concentrations in managed wetlands are known factors that promote formation of reactive Hg and increase methylation potential.

Nutrients

There are no numeric water quality objectives for nutrients in the Basin Plan. New research indicates that the traditional use of surface water nutrient concentrations as objectives is generally not effective for assessing eutrophication because biological response in a water body, such as algal productivity, depends on several factors, and not just an excess of nitrogen and phosphorus (SCCWRP 2007).

For the past few years, the Water Board has participated in the statewide initiative to develop numeric nutrient endpoints (NNE) for estuaries. The California NNE framework intends to use a range of selected biological response indicators, in addition to nutrient concentrations, to address impacts from nutrient over-enrichment or eutrophication. Although this work could provide an important insight into the role of nutrients in the San Francisco Bay estuary, it will not be completed within the timeframe of this TMDL and will not specifically address the brackish environment of Suisun Marsh.

The development of site-specific water quality objectives for nutrients is not within the scope of the Suisun Marsh TMDL. Instead, we plan to simulate nutrient-related impacts with the QUAL2K model by linking nutrient loads to chlorophyll *a* concentrations and organic carbon to nutrient-induced primary productivity in the marsh sloughs.

OPTIONS FOR EARLY IMPLEMENTATION

During the development of the Suisun Marsh TMDL we will actively look for early implementation opportunities that may arise from other programs that are currently in place. In particular, the tidal restoration efforts planned as part of the Suisun Marsh Restoration Plan offer opportunities to target areas experiencing dissolved oxygen and mercury problems. To the degree possible, we will cooperate with the lead agencies on selection of areas within the marsh scheduled for tidal restoration. The effectiveness assessment and follow-up monitoring required by the programmatic EIR/EIS for the Suisun Marsh Plan will provide further opportunities to advance the understanding of the processes in the Marsh and help track progress towards meeting the water quality objectives.

Siegel et al. (2011) conducted a 2-year field study to identify best management practices that can be used to reduce occurrences of dissolved oxygen sags and high MeHg concentrations in the managed wetlands in Suisun Marsh. We will review the proposed water management, vegetation, and soil management BMPs and evaluate options for early deployment of the BMPs in strategic locations in the marsh, with help from the Suisun Resource Conservation District (SRCD).

SRCD provides the private landowners in Suisun Marsh with technical assistance in permitting, water control, and habitat management to ensure the wetland and wildlife values of the Suisun Marsh are sustained and enhanced. We will work together with the SRCD to communicate the results of this project to the stakeholders, and engage in BMPs selection and placement in the key areas of the marsh to reduce stress on the environment.

Moreover, in our implementation plan we will consider allocations, management techniques and control strategies already required by the Delta and San Francisco Bay mercury TMDLs, which over time will contribute to the overall improvement of water quality conditions in Suisun Marsh. The Delta Mercury TMDL requires State and Federal agencies to take actions including the following:

- meet the MeHg allocations for open water habitats within channels and floodplains in the Delta and Yolo Bypass
- conduct MeHg control studies for projects that affect the transport of mercury and production and transport of MeHg through the Delta and Yolo Bypass
- include requirements for projects under their authority to implement MeHg reductions as necessary to comply with the TMDL allocations

Likewise, the San Francisco Bay Mercury TMDL requires wetland restoration projects to include pre- and post-restoration monitoring to demonstrate that they have been designed and are operated to minimize MeHg production and biological uptake, and result in no net increase in mercury or MeHg loads to the Bay.

In addition, the San Francisco Fish Project, managed by the San Francisco Estuary Institute, provides a vehicle to reduce the exposure of recreational/subsistence fishermen to harmful effects from eating mercury-contaminated fish. The Project goal is to improve communication to the public about how to reduce their exposure to mercury and PCBs from consuming San Francisco Bay fish, while numerous measures are employed throughout the Bay and the Delta to reduce the levels of these harmful contaminants in aquatic organisms. These are just a few examples of actions that could be undertaken before the Suisun Marsh TMDL is completed.

The final implementation plan for the Suisun Marsh TMDL will identify prevention measures, control strategies, and restoration actions necessary to attain the allocations and the targets. It will also set timeframes and designate parties responsible for carrying out the proposed plan. In addition, the

plan will identify short and long-term milestones and a monitoring strategy necessary for adaptive implementation and to measure effectiveness of the TMDL.

FUTURE RESEARCH AND REGULATORY ACTIONS

Research conducted in the Delta and elsewhere has found that wetlands are efficient sites for MeHg production, and the existing methods to reduce mercury methylation and bioaccumulation in wetlands are still at the testing stage. At the same time, efforts to restore wetland ecosystems and seasonally flooded habitat in the Bay-Delta almost doubled in the last decade. For example, the Bay Delta Conservation Plan calls for tidal restoration of almost 20,000 acres for near-term implementation of the Plan, with total of 65,000 acres being proposed for restoration over the next 40 years. Therefore, new research is needed to determine appropriate floodplain restoration and management techniques that would reduce the degree to which restoration efforts may promote MeHg production.

U.S. EPA is supporting these efforts by funding projects that will identify methods for minimizing the formation and transport of MeHg, such as development of MeHg and carbon sequestration methods by USGS and restoration efforts to reduce potential for mercury methylation at Dutch Slough tidal restoration project.

As new information continues to be collected and synthesized, the risk and uncertainty associated with restoring wetland habitat are expected to decrease, leading to better protection of aquatic resources in the Bay Delta Estuary. The outcomes of the new research will be built into the TMDL through the proposed adaptive implementation component.

STAKEHOLDER PARTICIPATION

In order to address the water quality problems in Suisun Marsh, we intend to engage multiple stakeholders to build understanding and support for the TMDL and its proposed implementation actions. The marsh has a diverse range of ownership and land uses. It is also the focus of attention from multiple local, state, and federal agencies managing drinking water supplies and protecting the water quality of this unique ecosystem. As a result, TMDL development necessitates an interagency and community-wide effort.

The public participation component of the project will include close work with the following major groups of stakeholders:

- The private landowners of the duck clubs in Suisun Marsh
- The Suisun Resource Conservation District (SRCD)
- The Fairfield Suisun Sanitary District
- The agencies responsible for managing and implementing the Suisun Marsh Restoration Plan (U.S. Fish and Wildlife Service, U.S. Department of the Interior, Bureau of Reclamation, California Department of Fish and Game, California Department of Water Resources, National Marine Fisheries Service and SRCD)
- Other interested parties (e.g. California Waterfowl Association, Ducks Unlimited, Solano County, Solano Land Trust, Solano Hills Landfill, City of Fairfield)

Throughout the life of the project we will actively seek to engage all interested stakeholders and expand a list of interested parties by maintaining up-to-date stakeholder lists, and encouraging public participation by signing up to the Water Board's subscription lists.

In particular, we will work closely with SRCD, which helps marsh landowners with water control and habitat management, to ensure adequate protection of the marsh. The private landowners of duck clubs in the marsh are likely to be the most significantly affected stakeholders in terms of implementation. Through the SRCD, we will seek the landowners' feedback when new information is gathered and analyzed, and discuss the water management changes that may result from the TMDL. With help from the SRCD, we have already secured a landowner's agreement to install automatic monitoring equipment in Denverton Slough to fill an important data gap.

The Department of Water Resources (DWR) oversees a monitoring program in the marsh to collect water quality data to verify compliance with the salinity standards set to mitigate the adverse effects on Suisun Marsh channel water salinity from the operations of the State and Central Valley Water Projects and other upstream diversions. We will work collaboratively with DWR to include DO among the parameters measured at its salinity compliance stations, and to coordinate monitoring efforts to improve understanding of the water quality issues in the Marsh.

We will continue to participate in the development of the Suisun Marsh Restoration Plan to provide recommendations and to complete Clean Water Act Section 401 water quality certifications for tidal wetland restoration projects. The Restoration Plan provides for a collaborative effort of all major agencies responsible for management of water resources in the marsh and the San Francisco Bay Estuary. We intend to use this forum and, in particular, the SRCD, one of the principal agencies working on the Restoration Plan, as a platform for information exchange, providing updates on the development of the TMDL, and for input and coordination of regulatory processes.

A series of technical information workshops about the TMDL will be conducted beginning in December 2012. On December 11, 2012, we will present an outline of the TMDL Project to the agencies that are involved in the Suisun Marsh Restoration Plan, at a regular quarterly meeting of the Plan's Environmental Coordination Advisory Team (ECAT). In April 2013, we will present to interested marsh landowners at one of the regular meetings hosted by SRCD. These meetings will be followed by subsequent meetings and/or work sessions, as appropriate. SRCD has also offered use of its quarterly newsletter as an opportunity to provide outreach to interested and affected landowners, and we will use that, as appropriate. The goal of these meetings will be to provide information to interested parties about the existence and likely direction of the TMDL project and to get feedback, including generating a discussion of opportunities and constraints with respect to implementation.

The technical information workshops will be followed by the project's CEQA scoping meeting, and then informational and adoption Board hearings in 2014.

TMDL ANALYSIS AND REPORTS

Water Board staff, with support from Tetra Tech, the technical consultant on the project, funded with TMDL contract funds provided by U.S. EPA Region IX, will conduct data analysis, develop an understanding of patterns and fate of mercury and DO within the marsh, and evaluate the contribution of nutrients to the low DO levels in the marsh sloughs.

In particular, Water Board staff will consider and recommend potential numeric targets and allocation schemes, assess the degree to which management actions taken in response to DO and mercury will also alleviate impairment by nutrients, develop monitoring and implementation plans, and gauge the effectiveness of regulatory actions.

The development of this TMDL includes the following main steps:

- Evaluate existing water quality criteria, determine the most sensitive endpoints and recommend TMDL targets for dissolved oxygen and Hg/MeHg.
- Identify a range of possible water quality objectives that correspond to safe fish MeHg levels protective of humans and wildlife that consume Suisun Marsh fish. The fish tissue objectives for MeHg and total mercury adopted in the San Francisco Bay Mercury TMDL, the Sacramento-San Joaquin River Delta Estuary TMDL, and the recommendations of the mercury control programs that implement both TMDLs will be considered in this process.
- Prepare a detailed analysis of the data in the impairment assessment, and recommend prioritization of the data needs. In particular, consider the following issues:
 - the information necessary to describe linkages between the key pollutants, environmental conditions, and beneficial uses
 - the role of biostimulatory substances (organic material and nutrients) in the occurrence of low DO events in the marsh, and methylation potential
 - ways to minimize the exposure of biota to MeHg
- Explore opportunities to collect significant DO water quality information as part of the existing salinity compliance monitoring network and fish mercury data as part of DFG's bi-annual fish screening surveys. Additional strategic data collection efforts would improve our understanding of the relationship between managed wetlands and DO, mercury, and biostimulation in the marsh.
- Calculate total maximum daily loads for dissolved oxygen and mercury and determine the associated wasteload and load allocations
- Identify DO, mercury, and biostimulatory substance source reduction strategies; evaluate control mechanisms for minimizing MeHg production and bioaccumulation; and identify other appropriate implementation actions. Work is currently underway to evaluate the significance of managed wetland contributions to the impairment in the marsh and test on-the-ground best management practices for source control (Siegel et al., 2011).

Tetra Tech is assisting Water Board staff with the TMDL problem statement, source assessment, modeling of DO and mercury, and the linkage analysis. They will develop reports that summarize the technical information for the Suisun Marsh TMDL and support the basis for regulatory action.

TMDL TIME SCHEDULE

Table 4 shows the preliminary schedule for developing the technical reports, regulatory actions and a brief outline of steps to prepare and adopt the Basin Plan Amendment.

Table 4: Suisun Marsh TMDL Preliminary Schedule	
Task	Timeline
Conceptual Model/Impairment Assessment Report <i>DRAFT</i>	July 2011
Technical TMDL report for dissolved oxygen and nutrients <i>DRAFT</i>	February 2012
Additional modeling and linkage analysis for DO and nutrients	April 2012
Technical TMDL report for mercury <i>DRAFT</i>	November 2012
Stakeholder informational workshop: agency stakeholders	December 2012
Additional modeling and assessments for DO and/or mercury	February 2013
Stakeholder informational workshop: public stakeholders	April 2013
Technical Project Report for DO, Hg and Nutrients <i>FINAL DRAFT</i>	June 2013
Implementation and Monitoring Plan	November 2013
CEQA and Regulatory analysis	December 2013
CEQA scoping meeting	January 2014
TMDL Staff Report <i>DRAFT</i>	February 2014
Draft Basin Plan Amendment	March 2014
Peer Review Process: send document for peer review, review comments and prepare responses	March 2014-June 2014
Revised Staff Report <i>FINAL DRAFT</i>	August 2014
Regional Board process (public notice, testimony hearing, RTC, adoption hearings)	September-December 2014
State Board approval process	February-April 2015

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