Best Management Practice Recommendations
Suisun Marsh TMDL Development

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1. INTRODUCTION

Suisun Marsh is on the State of California's 303(d) of impaired waters for the following constituents: organic enrichment, low dissolved oxygen (DO), and metals (principally mercury). Although organic enrichment and low DO are the most visible impairments and directly related to one another, there is also a connection between these and mercury, in that the toxic methylmercury (MeHg) form is observed at high concentrations when DO levels are low. A Total Maximum Daily Load (TMDL) is being developed for Suisun Marsh for these constituents by the San Francisco Bay Regional Water Board. The present memorandum has been developed in support of future implementation activities that may be addressed through the TMDL.

Suisun Marsh is periodically subject to low dissolved oxygen (DO) events, primarily occurring in the smaller tidal sloughs found around the margins of the marsh. These events can adversely impact beneficial uses of tidal waters in Suisun, most notably ocean, commercial and sport fishing (COMM), preservation of rare and endangered species (RARE), fish migration (MIGR), fish spawning (SPWN), estuarine habitat (EST), and wildlife habitat (WILD). Past low DO events, some of which resulted in fish kills of salmonids and other species, have been documented in Peytonia, Boynton, and Goodyear sloughs, mainly by the University of California (UC) Davis long-term aquatic monitoring program. No water quality or fish data are known to exist for tidal waters west of the Union Pacific Railroad (UPRR) tracks in the western Marsh, due to the railroad line precluding access by the UC Davis boats.

Approaches to addressing low dissolved oxygen events in Suisun Marsh tidal waters center, in large part, upon operations of the diked, managed wetlands, the predominant land use within the marsh. Other factors, including stormwater runoff and land use in the upper watershed, may also be at play but have not been investigated in this analysis. However, such analysis may be conducted as part of the TMDL for Suisun Marsh. Applying Best Management Practices, or BMPs, in managed wetlands may be one approach to address conditions that lead to adverse tidal slough water quality. However, in recognition of the other non-managed wetland sources, the emphasis of this analysis on BMPs does not imply that these are the sole implementation mechanism for the TMDL.

The 2011 Final Report from the State Water Resources Control Board-funded study on low DO and methylmercury in Suisun Marsh[1] ("Low DO Report") identified a range of BMPs that cover three main approaches for the managed wetlands. These approaches are: managing the labile organic carbon supply, managing individual wetland/slough hydrology, and coordinating operations across multiple wetlands. The research group developed these BMPs from a series of conceptual models it prepared, based on literature reviews and findings from supporting field data collected for the study.

[1]Siegel *et al*. 2011. Final Evaluation Memorandum, Strategies for Resolving Low Dissolved Oxygen and Methylmercury Events in Northern Suisun Marsh. Prepared for the State Water Resources Control Board, Sacramento, California.SWRCB Project Number 06- 283- 552- 0.May.

The focus of this assessment is on the identification of geographic sub-areas within the marsh where the specific application of individual BMPs is likely to benefit the overall organic enrichment-low DO problem. The method used in this analysis is the development of an index to represent relative impacts through the marsh, and the use of this index in a semi-quantitative manner to recommend the placement of BMPs.

2. IDENTIFYING AND PRIORITIZING SLOUGH SYSTEMS FOR WATER QUALITY IMPROVEMENT MEASURES

This assessment utilized a Geographic Information Systems (GIS)-based analytical approach to yield three quantitative indices and one quantitative index of potential adverse water quality conditions. These indices derive from the Low DO Report conceptual models and their relevance are:

1. **Slough length-to-width ratio** – surrogate for tidal mixing capacity to remove low DO waters from a slough system. Sloughs with a low value of this ratio (i.e., those that are wider and shorter) have greater mixing with higher DO tidal waters, and thus a lower propensity for low DO problems.

2. **Percent of primary contributing wetlands as tidal marsh** – because hydrologic exchanges from managed wetlands are thought to be related to low DO problems, slough systems with extensive tidal marsh (instead of managed wetlands) may exhibit low DO conditions less frequently or intensively.

3. **Percent of watershed land uses that could be adverse water quality contributors** – though an uninvestigated factor, runoff from upstream urban and irrigated agriculture may contribute nutrients or organic carbon that could exacerbate tidal slough water quality in Suisun Marsh.

4. **Knowledge of past problems** – accounts from the UC Davis aquatic monitoring program and other entities such as the Suisun Resource Conservation District.

A key cautionary note is that the GIS data necessary to conduct the analyses for the three quantitative indices at a slough system or property scale is very limited and consequently the index values and the recommendations from these indices possess a reasonable degree of uncertainty. This assessment has not attempted to quantify that uncertainty. For example, water quality data are non-existent for several of the slough systems and datasets characterizing water flow through the marsh, such as slough geography and the location and attributes of managed wetlands water control structures, are incomplete or known to be flawed.

2.1. SLOUGH SYSTEM STUDY AREAS

An initial review of the hydrology and geography of Suisun Marsh led us to segregate the sloughs around the margins of Suisun Marsh into several "slough systems" for the purposes of evaluating water quality conditions and developing BMP recommendations (Figure 1). Some of these slough systems are interconnected while others are not. All nine slough systems drain into Suisun Slough or Montezuma Slough, the two major tidal sloughs within Suisun Marsh.

Defining these slough systems involved editing existing GIS data from multiple sources to reflect slough geography and tidal connectivity more accurately. As some slough systems are interconnected, boundaries of each had to be drawn and were based on a qualitative understanding of marsh hydrology. These boundaries can be drawn differently and function mainly to support informed BMP recommendations.

2.2. Significant Infrastructure Features that Could Influence Water Quality

The marsh has several substantive infrastructure features along its western edge that affect hydrology and geomorphology (Figure 2). These features and their possible roles in water quality conditions and improvement are:

- **Union Pacific Railroad** – cuts through the western marsh, is at a fairly low elevation, and has six defined-size tidal slough crossings that limit hydrologic exchange
- **Fairfield-Suisun City Wastewater Treatment Plant** – located in the northwest Marsh, it has tertiary treated discharges that can be directed to three managed wetlands and to Boynton and Peytonia Slough
- **Morrow Island Distribution System** – constructed by the Department of Water Resources (DWR) to facilitate managed wetlands water supply and drainage for properties between Goodyear Slough and Grizzly Bay
- **Goodyear Slough Outfall** – constructed by DWR to facilitate improved water circulation in Goodyear Slough
- **Creeks, Watershed Land Uses, and Stormwater Drainage Outfalls** – several creeks and numerous outfalls drain stormwater from Travis Air Force Base, the cities of Fairfield and Suisun City, agriculture north of Highway 80, and developed and agricultural lands west of Highway 680. Stormwater enters the Marsh unfiltered and untreated. Most creeks are either seasonal or have low dry-season flows. No data on creek flows have been compiled for this assessment.
- **Suisun City Marina** – has the potential to contribute organic matter into Suisun Slough. No discharge data has been sought.
- **Potrero Hills Landfill** – drains into Hill Slough and has potential to contribute nutrients or organic matter. No discharge data has been sought.

2.3. Index 1: Slough Hydrology

The Low DO Report drew attention to the importance of tidal hydraulics in the slough systems as a key driver of contributing to or helping to avoid adverse water quality conditions. Tidal sloughs have the potential to dilute the low DO water and high BOD loads discharged from managed wetlands, thereby minimizing or avoiding DO sags in the slough water column. The primary mechanism is that of tidal mixing with downstream waters that are well oxygenated. Each flood and ebb tide cycle introduces downstream waters (flood tide) and sends upstream waters downstream (ebb tide). Thus, wide, short sloughs have a much greater potential for tidal mixing processes to allow for dilution. In contrast, long, narrow sloughs have a far smaller potential for tidal mixing dilution. The basic flood-ebb mixing processes are also altered by managed wetlands withdrawals that can result in net upstream flow, further reducing tidal mixing processes.

2.3.1 Approach

A mechanistic approach for assessing tidal mixing processes is through application of hydrodynamic models that require input data on bathymetry, tidal flows, freshwater inputs from upstream watersheds, and managed wetlands hydrologic exchanges. Because of existing data limitations and costs, this approach was not pursued.

For this analysis, we used a simpler approach of the ratio of slough length (miles) to slough width (feet). This index was based on the logic that low DO inputs from managed wetlands will have longer residence times, and less tidal dilution, as the length-to-width ratio increases.

2.3.2 Results

Slough length-to-width ratios varied from a low of 0.02 mi/ft (Cross Slough) which reflects relatively short, wide slough systems to 0.21 mi/ft (Cordelia Slough) which reflects relatively long, narrow sloughs (Table 1). Qualitatively assigning these results to groups of low, medium, and high potential for impaired tidal dilution processes, and thus, greater likelihood of low DO, yields the following: low potential for the Nurse/Denverton/Cross Slough complex, medium potential for Boynton and Goodyear sloughs, and high potential for Hill, Peytonia, Chadbourne, and Cordelia sloughs.

2.4. Indices 2 and 3: Contributing Area Characteristics

Two indices capture contributing area characteristics: percent of contributing area that is tidal marshlands and acres of upland watershed in land uses the runoff from which could contribute to adverse water quality conditions in Suisun Marsh tidal sloughs.

2.4.1 Approach

In order to assess the potential low DO issues, and to make comparisons between slough systems, we developed a GIS dataset that linked all available slough, in-marsh, and upland data. Contributing areas were grouped into four classifications:

1. **Primary contributing managed wetlands** – managed wetlands connected directly to a slough system, via water control structures. The key number in this section is the total diked area, given in acres. This number serves as an indicator of the volume of water that is drawn out of the slough by managed wetlands during flood-up activities, as well as the amount of potentially low DO water dumped into the slough when the managed wetlands are drained. Many clubs are bordered by more than one slough, and utilize both for flood and/or drain activities. Several of the major sloughs are also connected directly to each other via shared channels.

2. **Secondary contributing managed wetlands** – managed wetlands connected indirectly to a slough system, via either a hydrologic connection to a primary contributing managed wetland or a direct connection to a slough system that is interconnected to the slough system of interest. These “secondary” managed wetlands give an indication of potential managed wetland-related low DO inputs that may be entering the slough system from outside the primary watershed.

3. **Primary contributing tidal marshlands** – tidal marshlands along the margins of the slough (fringing marsh between managed wetlands levees and the slough open waters) or discrete patches of tidal marsh, be they natural or restored

4. **Watershed lands** – uplands that drain into a slough system via local creeks and storm drains. Total acreages for each cover type are given for each major slough system, with the exception of Upper Nurse, Upper Denverton, and Cross sloughs. These three sloughs are part of the larger Nurse/Denverton/Cross slough complex, and it wasn't appropriate to subdivide the upland watershed of this complex as hydrologic inputs from these areas impact the water quality of the entire slough complex.

Currently, there is no comprehensive dataset defining the location, attributes, or management functions of water control structures within Suisun Marsh. Each club or parcel owner maintains and manages their own infrastructure, often with assistance from the Suisun Resource Conservation District (SRCD), and data on the water control structures are generally compiled on a club-by-club basis, as needed. To determine which managed wetlands were connected to the major sloughs of interest, we used the best available information, including existing water control structure GIS datasets from SRCD and developed for the Low DO Report, inspection of aerial photographs, and personal knowledge.

Tidal marshlands geography comes from the EcoAtlas first prepared by the San Francisco Estuary Institute in 1998 and edited over the years by Wetlands and Water Resources as part of many past Suisun Marsh projects, with cross referencing to the Department of Fish and Game (DFG) triennial Suisun Marsh vegetation monitoring efforts.

The final step required was to characterize slough inputs to define the upland watershed areas and land uses that contributed surface flow and groundwater to each major slough. We used topographic data sets from the U.S. Geological Survey to subdivide the large Solano County upland watersheds, following the subtle topography in the lowlands adjacent to Suisun Marsh as best as possible. Once delineated, upland watersheds were then assigned to their receiving water slough system, recognizing uncertainty due to no available stormwater system spatial data. We then summarized land use classification data, obtained from the Department of Water Resources 2003 Solano County Land Use Survey, for each watershed.

2.4.2 Results

Maps of each slough system showing the contributing wetland areas and upland watersheds are displayed in Figure 3 through Figure 12. Figure 13 shows landcover classifications for the upland watersheds of all nine slough systems. For each of the nine slough systems, Table 1 summarizes statistical comparisons that were applied across the nine sub-watersheds to inform the BMP recommendations:

- **Index 2: Percent of Contributing Area as Tidal Marsh** – values range from a low of 1.4% (Chadbourne) to a high of 56% (Hill Slough). Tidal marsh within a slough system helps avoid or minimize adverse water quality under most conditions through a combination of two main factors. First, it is an alternate land use that does not exhibit episodic events of low DO and discharges like those of diked, managed wetlands. Tidal marshes do export nutrients and organic matter that can contribute to DO sags, but those exports tend to be very frequent (each tide cycle) and of low magnitude each event. In other words, tidal marshes tend to release their exports “slow and steady”. Second, the tidal prism of the tidal marshes can support greater tidal exchange in the slough, helping to promote mixing processes and dilution. A higher percentage of tidal marsh would increase the tidal prism of the slough, and could generate a "pumping" effect where enough high DO water would be drawn into the slough during each tide cycle to dilute low DO inputs from managed wetlands.

- **Index 3: Upland Watershed in Land Uses that May Contribute to Poor Water Quality in Suisun Marsh Tidal Sloughs** – four mapped land uses have some potential to contribute to adverse water quality conditions in Suisun Marsh tidal sloughs if those land uses supply nutrients and/or organic carbon to the streams and those discharges reach Suisun Marsh: urban, irrigated perennial crops, irrigated annual crops, and dairy pasture. No data exist on inflows to Suisun Marsh from these land uses, so this index is speculative.Three views of these data yield insight into their possible contributions: (A) percent of watershed that is in these land uses, (B) extent of these land uses in the watershed, and (C) their extent relative to the diked and tidal marshes in each slough system. In other words, how big on absolute and relative scales are these watershed land uses and is the watershed more or less likely to have the ability to process nutrients and organic carbon before either reaches Suisun Marsh.
    - **Index 3A: Percent of Watershed (%)** – these ‘potentially detrimental’ land uses range from 4% of the upland watershed (Nurse/Denverton/Cross) to 84% (Boynton). The greater the percentage in these land uses, the greater are the anticipated potential for contributing to adverse water quality.
    - **Index 3B: Area of Watershed (acre)**– Absolute area in ‘potentially detrimental’ land uses is also very important as it gauges magnitude potential to discharge nutrients and organic carbon. Acreages range from 643 (Nurse/Denverton/Cross) to 6,495 (Hill).
    - **Index 3C: Ratio of Watershed Land Use to Primary Wetlands (Diked and Tidal) (%)** – the final view is that of how large these ‘potentially detrimental’ land uses are relative to the extent of diked and tidal marsh in each slough system. The higher the ratio, the greater potential for contributing to adverse water quality. A 1:1 ratio (100%) means equal area of watershed land uses to wetlands. Less than 1:1 (<100%) means less watershed land use area than wetlands and thus lesser potential to affect water quality. More than 1:1 (>100%) means more watershed land use area than wetlands and thus greater potential to affect water quality. Values ranged from 15% (Nurse/Denverton/Cross) to 384% (Hill).

2.5. INDEX 4: PAST RECORDS OF POOR WATER QUALITY

This qualitative index reflects prior documented adverse water quality conditions in Suisun Marsh, identified through direct observations, monitoring instruments, or third-party reporting. It is important to note that lands west of the railroad have no monitoring and thus any records would have to originate from third-party reporting. To date, documented problems have occurred in Goodyear, Boynton, and Peytonia sloughs. No significant problems have been documented in Hill Slough nor in the Nurse/Denverton/Cross Slough complex. Cordelia and Chadbourne sloughs west of the railroad have no available data.

2.6. Integrating Indices: Prioritizing Slough Systems for BMP Implementation

As shown in Table 1, our analysis yields the following prioritization recommendations: low priority, high priority, and need more data to establish need.

2.6.1 Low Priority for BMPs

Hill Slough and the **Nurse/Denverton/Cross Slough** complex appear to have a low priority for BMP implementation. Prior monitoring data has not identified significant adverse water quality conditions. The Nurse/Denverton/Cross complex is more likely to be well mixed given its geomorphology and it has a reasonable amount of its lands as tidal marsh (21%). Hill Slough may have less mixing but it has a very large percentage of its lands as tidal marsh (56%).

2.6.2 High Priority for BMPs

Goodyear, Boynton and Peytonia sloughs all are candidates for BMP implementation. All three have documented fish kills and other significant adverse water quality conditions. Each slough system yields distinct findings from each of the other three water quality indices, indicating the important of tailored strategies for BMP implementation.

2.6.3 Need More Data to Determine if BMPs Needed

Chadbourne and Cordelia sloughs appear to be strong candidates for poor water quality conditions, based on the three quantitative indices and on examination of the science in the Low DO Report. Neither slough has been monitored because the railroad line precludes boat access, and there are no third-party reports we are aware of. Thus, while BMP implementation may prove appropriate in the future, at this stage baseline data collection is warranted to begin identifying whether problems do in fact exist.

3. BMP RECOMMENDATIONS

The BMPs developed in the Low DO report are presented in Table 2. The impact of individual BMPs is tied to specific water quality constituents, with the assumption, based on data from Suisun Marsh, that incidences of high organic enrichment, low DO, and high MeHg are related. Thus, a BMP that may improve low DO conditions is expected to improve MeHg conditions (lower MeHg production).

These BMPs generally fall into two categories:

- **Hydrology Management BMPs (H-1 to H-14)**: These BMPs involve modifying the management of club or slough hydrology to (1) reduce or prevent conditions in the wetlands that may produce low DO events, (2) restrict the amount of low DO water discharged from the clubs at any one time, (3) discharge water to sloughs more capable of assimilating and dispersing low DO water, and (4) change the hydrology of the receiving sloughs to improve their capacity to assimilate and disperse low DO water.
- **Carbon (Vegetation and Soil) Management BMPs (VS-1 to VS-5):** These BMPs involve reducing the amount of labile organic carbon present on the managed wetlands, which is the "fuel" for the production of low DO conditions. These BMPs rely on (1) managing vegetation type, (2) eliminating or changing the schedule of mowing activities, (3) removing mowed vegetation, and (4) reducing soil disturbances (disking).

The overall BMP implementation approach is that of carbon management for all diked, managed wetlands and selective application of hydrology management measures for properties along each slough system (Figure 14).

It is important to note that many of the BMPs recommended in Table 2 have not yet been implemented and evaluated within Suisun Marsh, but were developed based on the analysis of data collected during the Low DO Study and conceptual models created to explain how the system works. It is recommended that these BMPs be tested in pilot studies and through modeling of slough channels before being implemented throughout Suisun Marsh. As indicated in the table, several of the BMPs have been eliminated from further consideration due to demonstrated inability to improve low DO conditions, or incompatibility with wetland management or public health (mosquito control) goals.

Any BMP implementation strategy for resolving low DO issues within Suisun Marsh must be coordinated at the individual slough level and involve the participation of all (or at least most) managed wetlands on the slough. The un-coordinated implementation of BMPs on individual properties throughout the Marsh may do little to combat the low DO issue. Also, different sloughs will require different BMP strategies due to variations in slough hydrology, watershed characteristics, managed wetland characteristics and property infrastructure, amount and location of tidal marsh along the slough system, and other infrastructure considerations. The general, proposed approach to BMP implementation on a given slough is depicted in Figure 14. Carbon management BMPs are recommended on all managed wetlands on a given slough, since the presence of labile organic carbon within these wetlands acts as the "fuel" for low DO conditions and the reduction/removal of this carbon is essential to addressing the low DO issue. The specific carbon management BMPs implemented on a given wetland will depend on individual wetland characteristics and management concerns. Water management BMPs should be applied to managed wetlands and sloughs on a case-by-case basis. Depending on the hydrologic characteristics of a given wetland/slough, certain BMPs may be more appropriate and effective than others. A more in-depth discussion of this general strategy is provided below.

3.1. Carbon Management BMP Strategies – Apply to All Diked Managed Wetlands

As described above, carbon management across all managed wetlands is recommended in all slough systems to reduce the fuel that drives low DO conditions. If resources are limited, these BMPs should be prioritized first to the high-priority slough systems. Almost all managed wetlands implement some amount of mowing or disking to create open water areas to attract waterfowl and other wildlife. These activities create a large pool of labile organic carbon in the form of dead/senescing vegetation and newly exposed soil organic matter. Once flooded, bacteria and other microorganisms break down this material, consuming oxygen in the process and driving down water column DO levels. Reduction in the size of this carbon pool will help to reduce the level of DO reduction in managed wetlands.

The carbon management BMPs implemented on a specific managed wetland should be tailored to that wetland's characteristics and management goals. There are two, universally recommended carbon management BMPs for those wetlands that currently engage in some level of vegetation or soil management: **BMP VS-1** (manage for less leafy green vegetation) and **BMP VS-5** (reduce soil disturbance activities).

BMP VS-1 involves actively managing the vegetation on site through selective seeding/planting, weeding, or mowing to reduce the presence of leafy green vegetation that produces large amounts of biomass per unit area, and through altered hydrology related to hydroperiod requirements of different wetland plant species. This reduced standing vegetation biomass, when mowed or otherwise introduced to the labile organic carbon pool, will have a weaker DO reduction effect on the water column. Managing for less leafy green vegetation is a well-established wetland management goal in Suisun Marsh. Implementation feasibility depends in part by hydrology management capabilities which vary between individual managed wetlands.

BMP VS-5 involves reducing the amount of disking that takes place on a managed wetland, which is a key strategy to reducing the soil labile organic carbon pool with the wetland. Where appropriate, mowing (along with implementation of other vegetation management BMPs) should replace disking as a tool for creating open water areas within wetlands.

Generally, managed wetlands that mow large areas of land each year would be encouraged to implement **BMP VS-3** (remove mowed vegetation from wetlands), which would involve baling the mowed vegetation and hauling it off the site. The current assumption is that this material would be composted, but it may be possible to find another beneficial reuse for it (e.g., cattle fodder, bedding, etc.), depending on the type, quality, and quantity of vegetation.

Some wetlands that currently mow each year may not be able to implement **BMP VS-3** due to having soft, peat soils that cannot support heavy baling equipment. Under these conditions, wetland managers may implement **BMP VS-2** (mow vegetation earlier in the season), which allows the mowed vegetation more time for decomposition prior to wetland flood-up. While not as effective for reducing the standing labile carbon pool, this BMP will offer some reduction over current practices.

Another option for reducing vegetation-derived labile organic carbon pools in wetlands with soft soils is **BMP VS-4** (graze wetlands to remove unwanted vegetation), which has a similar goal to BMP VS-3. This practice has shown benefits in reducing water quality problems on the Yolo Bypass, however, its implementation would require working out logistical and cost issues associated with introducing and managing grazing animals on the managed wetlands.

3.2. Hydrology Management BMPs – Apply to High Priority Sloughs, Tailor to Each Managed Wetland

The hydrology management BMPs fall into three main categories: (1) practices implemented on an individual club, (2) coordination of activities across multiple clubs, and (3) use of treated wastewater (limited to a select number of clubs/sloughs). The recommended BMPs within these categories are described below.

3.2.1 Practices Implemented on an Individual Club

All managed wetlands should implement **BMP H-12** (high exchange rates) to the extent feasible. This BMP aims to reduce residence time within the managed wetlands which would reduce opportunity for organic matter decomposition. As Suisun diked managed wetlands use the tides to flood and drain, this BMP essentially seeks to modify the hydrology of a managed wetland to increase its tidal time scale fluctuation as much as possible. This BMP would generate higher rates of exchange between wetland and slough. The ability to implement this BMP at a given managed wetland will vary based on several factors including, number, type, and spatial distribution of water control structures, site elevations, ability to circulate water effectively within the wetland (see BMP H-13 below), synchronizing with spring/neap tidal cycles, and time of year diversion restrictions. Some clubs may require substantial infrastructure upgrades, including upgrading or adding water control structures and pumps, in some cases, to achieve a rate of exchange necessary to reduce water quality problems. Regulatory issues would have to be addressed for infrastructure modifications and funds would need to be secured.

All clubs that exhibit isolated, backwater areas that tend to accumulate stagnant water should implement **BMP H-13** (maximize internal wetland circulation). This BMP involves improvements to ditches, swales, water control structures, and vegetation management to reduce stagnant areas and improve circulation. Improving internal circulation will improve hydrologic mixing within the wetland and reduce the occurrence of poor water quality hotspots, thereby improving overall internal water quality and thus quality of discharged waters. Implementation of the actions called for in this BMP may be expensive. Also, as with BMP VS-3, the ability to construct certain circulation improvements may depend on the ability for the site soils to support construction equipment. Wetlands with soft, peaty soils may not be able to implement all necessary modifications.

Certain clubs that have water control structures on Montezuma or Suisun sloughs or any of the four large bays should implement **BMP H-6** (reroute wetland flood <u>and</u> drain events to large sloughs). This BMP is modified from the original suggestion in the Low DO report to consider only those clubs near the mouths of problematic sloughs that also adjoin the major sloughs or bays, so that the re-routing flood and drain events will not lead to increases in netupstream flows in the slough systems. Implementation of this BMP will be limited to very few clubs, and may require substantial infrastructure upgrades, including upgrading or adding water control structures and possibly pumps to achieve the necessary rate and locations of exchange.

3.2.2 Coordination of Activities across Multiple Clubs in Each Slough System

All managed wetlands on a given slough should implement **BMP H-7** (stagger flood/drain events across multiple wetlands). This BMP involves coordinating the flood/drain activities among all managed wetlands on a slough to (1) reduce the magnitude of net-upstream flows when wetlands are flooding, and (2) reduce the magnitude of low DO impacts when wetlands are draining. The implementation of this BMP will require coordination by the SRCD and cooperation among all wetlands on the slough.

BMP H-8 is an extension of BMP H-7 and involves using real-time DO data collected within problem sloughs to schedule the wetland drain events across multiple wetlands on a given slough. By timing wetland discharges during periods of good water quality, the adverse impacts upon slough water quality of a given wetland discharge will be reduced. This BMP would require the purchase, installation, maintenance, and management of automated water quality sensors and real-time data storage and transmission equipment for each slough of interest. Barring funding and/or managerial constraints, this modification of BMP H-7 should be considered.

3.2.3 Use of Treated Wastewater – Limited to Peytonia and Boynton Sloughs

The use of treated wastewater from the Fairfield-Suisun Sanitary District (FSSD) Wastewater Treatment Plant for wetland/slough hydrology management is limited by geography and infrastructure to three wetlands (Clubs 112, 123, 122) on Peytonia and Boynton sloughs and to the sloughs themselves. Under its NPDES permit, FSSD is allowed up to 16 million gallons of water per day (MGD) discharge during the wet season. **BMP H-9** (maximize use of treated wastewater for initial flood-up) should be implemented at all three managed wetlands. This BMP involves preferentially using treated wastewater during the fall flood-up period to reduce the amount of water drawn from the sloughs, thereby reducing net upstream flows. Implementing this BMP will require close coordination with FSSD and staggering the flooding of these three wetlands.

As a corollary to BMP H-9, **BMP H-10** (maximize FSSD discharges into Boynton and/or Peytonia sloughs during drain events) should also be implemented. This BMP, which applies only to Peytonia and Boynton sloughs, involves routing FSSD discharges into the sloughs for the purposes of providing flushing flows and higher DO waters during periods when drain events occur.The added FSSD outflows will increase ebb tide flow rates and speed transport of wetland discharge water from the smaller sloughs, while at the same time raising DO levels due to the relatively high DO levels of the FSSD discharge water. This BMP should also be implemented along with BMP H-7 (stagger flood/drain events across multiple wetlands) so that SRCD can coordinate the drainage events of the managed wetlands with the operations of the sewage outfalls by FSSD. Validating compliance with the FSSD NPDES permit will be necessary and modifications to that permit may be needed if this BMP is not consistent.

3.3. ADDITIONAL BMP RECOMMENDATIONS

In addition to the BMPs developed during the Low DO Study, three additional BMPs warrant implementation: tidal restoration, hunting season timing, and fund mosquito control.

3.3.1 Restore Managed Wetlands to Tidal Marsh

The general state of knowledge indicates that the quality of water discharged from tidal wetlands is higher than the water discharged from managed wetlands. Extended hydroperiod (long duration, low frequency inundation) is a key driver of poor water quality, a condition inherent with diked managed wetlands and generally absent from tidal marshes (short duration, high frequency inundation). Restoration, therefore, would be a strategy to minimize or avoid generation of low DO waters. Tidal restoration also alters the hydrology of the tidal sloughs to which sites are connected. The added tidal prism can function to increase tidal mixing processes, thereby helping to address a second factor that leads to low DO conditions within a tidal slough.

This second effect – altered slough hydrology – can have negative consequences upstream along the tidal slough to which a restoration site is connected. The added tidal prism of a restoration site can result in reduced tide ranges upstream, an effect that has been documented in Suisun Marsh through prior hydrodynamic modeling[2] and observations following a levee breach. The narrower and longer the slough, the greater potential restoration has to exhibit this effect. Reduced tide range can have two deleterious effects upstream: it can increase slough residence times, thereby exacerbating low DO conditions, and it can reduce the managed wetlands operational flexibility for flooding and draining via gravity and for implementing other BMPs. Site location along a slough system, thus, is a critical factor to consider when planning restoration efforts.

Restoration of tidal marsh, as a water quality improvement strategy, should be prioritized for shorter slough systems with few managed wetlands (Peytonia, Boynton and Goodyear sloughs) to achieve maximum benefit with the least restoration effort. Hydrodynamic modeling would be important to predict details of the hydrologic effects. Longer, more complex slough systems with large numbers of managed wetlands along them (Cordelia and Chadbourne sloughs) would benefit less from restoration and run the risk of adverse hydrologic effects overwhelming restoration benefits. These two slough systems are also constrained greatly by the fixed sizes of the railroad crossings over them limiting the magnitude of tidal prism increases without running a risk of scour at the crossings. Thus, restoration would require more involved hydrodynamic modeling to determine where restoration could be beneficial. Hill Slough and the Nurse/Denverton/Cross Slough complex already have restoration projects planned and the sloughs are comparatively “short and wide” limiting the potential adverse effects of restoration.

3.3.2 Coordinate with CDFW to Time Opening of Duck Hunting Season in Suisun Marsh with Spring Tides

The California Department of Fish and Wildlife (CDFW) (formerly Department of Fish and Game) regulates the timing of the duck hunting season and sets opening day schedule on considerations wholly unrelated to Suisun water quality. Opening day varies year to year and is typically in late September to mid-October, with the second week of October being common. Wetland managers generally begin fall flood-up activities approximately two weeks prior to opening day. This schedule will correspond with spring tides in some years and with neap tides in others. Flood-up and discharge events that occur during spring tides will have less of an impact on net upstream flows and slough water quality due to the higher degree of tidal mixing that occurs. By coordinating opening day to correspond with a spring tide series approximately two weeks earlier, the impacts of fall water management activities upon slough water quality

[2] Performed as part of hydrodynamic modeling in support of the Suisun Marsh EIS/EIR, on the Internet at: http://www.usbr.gov/mp/nepa/nepa_projdetails.cfm?Project_ID=781

may be lessened. Implementation of this BMP will require close coordination with and cooperation by CDFW to schedule dates of opening day based on the tidal cycle. Other impacts to the hunting season not currently foreseen, if any, will need to be evaluated. Spring and neap tidal cycles oscillate on approximately a two-week schedule, so the start date of duck hunting season under such a management scenario should not vary by more than a week from what CDFW may set based on its other considerations.

3.3.3 Fund Mosquito Control Efforts to Increase Flexibility on Timing of Fall Flood-Up

If a managed wetland is flooded during warm weather (~March-September), it will typically have a high mosquito production rate and the Solano County Mosquito and Vector Control District (District) will require the landowner to drain the wetland or pay for treatment. As treatment is expensive (several thousand dollars), the landowner usually chooses to drain the wetland. Drainage can lead to negative water quality impacts, particularly during the fall. Providing funds to help landowners cover the costs of mosquito treatment will allow wetland managers to flood wetlands earlier in the fall and therefore provide more flexibility in timing wetland flood-up events on a given slough. This BMP may be essential to the implementation of BMPs H-7 and H-8; however, it will require the identification of a stable funding source to help pay for mosquito treatments.

3.4. Slough-Complex Specific BMP Recommendations

Based on the understanding of documented and projected poor water quality conditions, and the GIS analysis presented within this document, we have developed the following general recommendations for developing BMP implementation strategies for the nine slough systems considered here. As stated earlier in this document, we recommend pilot-scale testing of these BMPs before widespread implementation throughout Suisun Marsh.

3.4.1 Peytonia and Boynton Sloughs

These two slough systems have very similar characteristics and both have documented low DO issues during fall flood up and winter salt leaching. Since monitoring infrastructure already exists within both sloughs and Clubs 112 and 123, left over from the Low DO Study, these slough systems are excellent sites for pilot-scale BMP studies. For these slough systems, the following BMPs are recommended:

- **Vegetation Management:** Implement vegetation management **BMPs VS-1** (manage for less leafy green vegetation) and **VS-5** (reduce soil disturbance activities), as these are universally recommended for all managed wetlands that engage in vegetation and soil management. Also implement **BMP VS-3** (remove mowed vegetation from wetlands) on Clubs 112 and 123 since soils on both these clubs should be suitable for baling equipment access.
- **Hydrology Management**: Implement **BMP H-7** (stagger flood/drain events across multiple wetlands). There are relatively few managed wetlands on these two sloughs, so coordination should not be too arduous. If funding exists, implement **BMP VS-8** to test the use of real-time DO data in coordinating managed wetland operations. Implement **BMP H-12** (high exchange rates) on Club 123 as suitable water management exists on this wetland. If stagnant areas are present on Clubs 112 and 123, and funding exists, implement **BMP H-13** (maximize internal circulation). Peytonia and Boynton are the only two sloughs

within Suisun Marsh with FSSD discharge outfalls on them. Therefore, **BMPs H-9** and **H-10** should be implemented and evaluated.

3.4.2 Goodyear Slough

Goodyear Slough has documented low DO problems at certain times of the year, but does not have the extensive monitoring data record that exists for Peytonia and Boynton sloughs. Further monitoring is suggested to understand frequency, intensity, and duration of problems. Therefore, for this slough only very general BMP implementation guidelines are provided:

- **Vegetation Management:** Implement BMPs **VS-1** and **VS-5** across all wetlands that engage in vegetation and soil management. Investigate and implement remaining vegetation management BMPs where appropriate.
- **Hydrology Management:** Implement **BMP H-7**, and if funding exists, **BMP H-8**. Implement other hydrology management BMPs in individual wetlands based on site-specific conditions and available funding.

3.4.3 Cordelia and Chadbourne Sloughs

No data have been collected Cordelia or Chadbourne sloughs to determine if water quality problems exist. However, based on the Low DO Report and results of analyses here, these sloughs have hydrologic, geomorphic, and watershed characteristics that indicate high potential for low DO water quality problems. Before developing any BMP strategies for these sloughs, we recommend data collection to document the aerial extent, frequency, intensity, and duration of water quality problems.

3.4.4 Hill, Nurse, Denverton, and Cross Sloughs

The limited water quality data for these sloughsindicate that low DO events are not currently a problem. No BMPs are recommended for implementation at this time. However, based on the results of pending pilot-scale BMP studies, successful BMPs especially those around carbon management should be implemented on these sloughs to the extent feasible.

4. Funding Options for BMPs

Pilot scale testing and full scale implementation of BMPs incur costs for physical landscape modifications, ongoing operations, and monitoring. Three possible funding sources have been identified to date that may be suited to meet these needs.

4.1. Federal Environmental Quality Incentives Program

The federal Environmental Quality Incentives Program (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[3]. EQIP provides funds to eligible program participants based on a portion of the average cost of practice implementation. The maximum amount of EQIP funds provided to any program participant, under all EQIP contracts, may not exceed $300,000 during any six-year period. Program participants, whose projects have been deemed to have special environmental significance by the NRCS, may petition the NRCS chief for the maximum payment amount to be increased to $450,000.

While EQIP is geared primarily toward improvements on agricultural and forest lands, SRCD has used funds from this program before to produce a publication describing vegetation management practices for use in Suisun Marsh managed wetlands (Bruce Wickland, SRCD, *pers. comm.*, 1/23/2013). An applicant for EQIP funds must demonstrate income from agricultural sources in order to qualify for the program. However, the location (property) where improvements funded by the EQIP program will be implemented does not need to be in the same location where agricultural activities take place (Alan Forkey, NRCS, *pers. comm.*, 1/23/2013).

4.2. The Suisun Marsh Preservation Agreement Implementation Fund

The SMPA PAI Fund, established as part of the Suisun Marsh Plan, provides cost share to defined activities in managed wetlands that mitigate for the impacts of the Central Valley Project and State Water Project. Many of the twelve activities eligible for PAI funding (see Table 2-8 in the Suisun Marsh Plan[4]) align well with several of the BMPs recommended here. The fund has a total of $3.7 million and provides either 50% or 75% cost share depending on the specific activity. Contact: Steve Chappell, Suisun Resource Conservation District, (707) 425-9302, *schappell@suisunrcd.org.*

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[3] Natural Resource Conservation Service, Environmental Quality Incentives Program webpage. *http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/*. Accessed 1/23/2013

[4] U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, California Department of Fish and Game. 2011. Final Environmental Impact Statement/Environmental Impact Report, Suisun Marsh Habitat Management, Preservation and Restoration Plan. Sacramento, CA. November. Available online at: *http://www.usbr.gov/mp/nepa/nepa_projdetails.cfm?Project_ID=781*

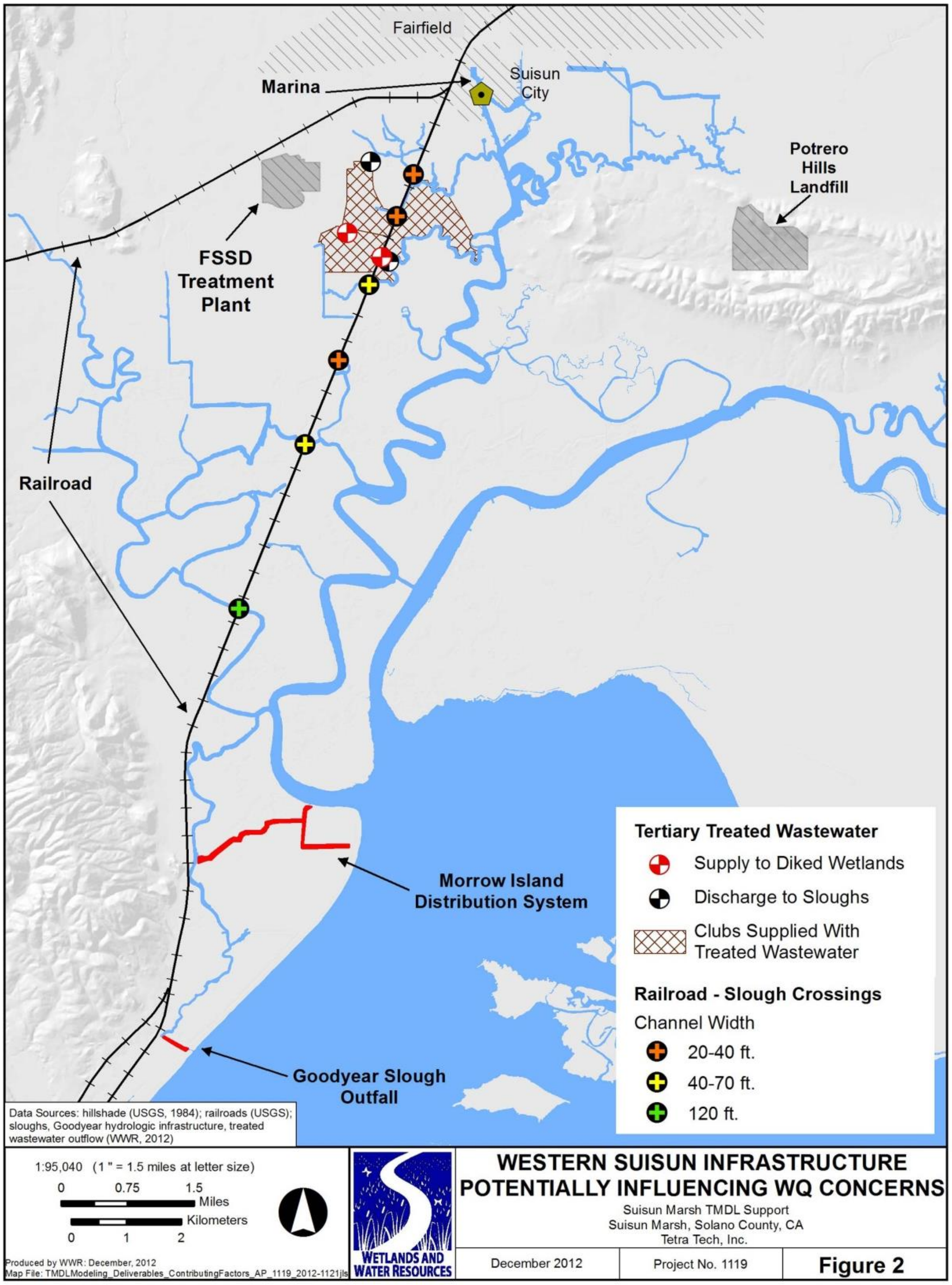
4.3. U.S. EPA GRANTS

The U.S. EPA has at least two grant programs that may be well suited to pilot scale BMP implementation as each offers funds that can be used over a finite number of years. The San Francisco Bay Area Water Quality Improvement Fund makes large grants (± $1 million range) that can be used over a period of up to four years for activities that "protect and restore the water quality of the San Francisco Bay and its watersheds." Contact: Luisa Valiela, U.S. EPA Region 9, (415) 972-3400, *valiela.luisa@epa.gov*.

The federal Clean Water Act Section 319(h) grant program is administered in California by the State Water Resources Control Board. This program is an annual federally funded nonpoint source pollution control program that is focused on controlling activities that impair beneficial uses and on limiting pollutant effects caused by those activities. States must establish priority rankings for waters on lists of impaired waters and develop action plans, known as Total Maximum Daily Loads (TMDLs), to improve water quality. Project proposals that address TMDL implementation and those that address problems in impaired waters are favored in the selection process. There is also a focus on implementing management activities that lead to reduction and/or prevention of pollutants that threaten or impair surface and ground waters. See *http://www.waterboards.ca.gov/water_issues/programs/grants_loans/319h/index.shtml*.

5. FIGURES

Figure 1


Fairfield
Suisun City
Marina
Potrero Hills Landfill
FSSD Treatment Plant
Railroad
Morrow Island Distribution System
Goodyear Slough Outfall
Tertiary Treated Wastewater
Supply to Diked Wetlands
Discharge to Sloughs
Clubs Supplied With Treated Wastewater
Railroad - Slough Crossings
Channel Width
20-40 ft.
40-70 ft.
120 ft.
Data Sources: hillshade (USGS, 1984); railroads (USGS); sloughs, Goodyear hydrologic infrastructure, treated wastewater outflow (WWR, 2012)
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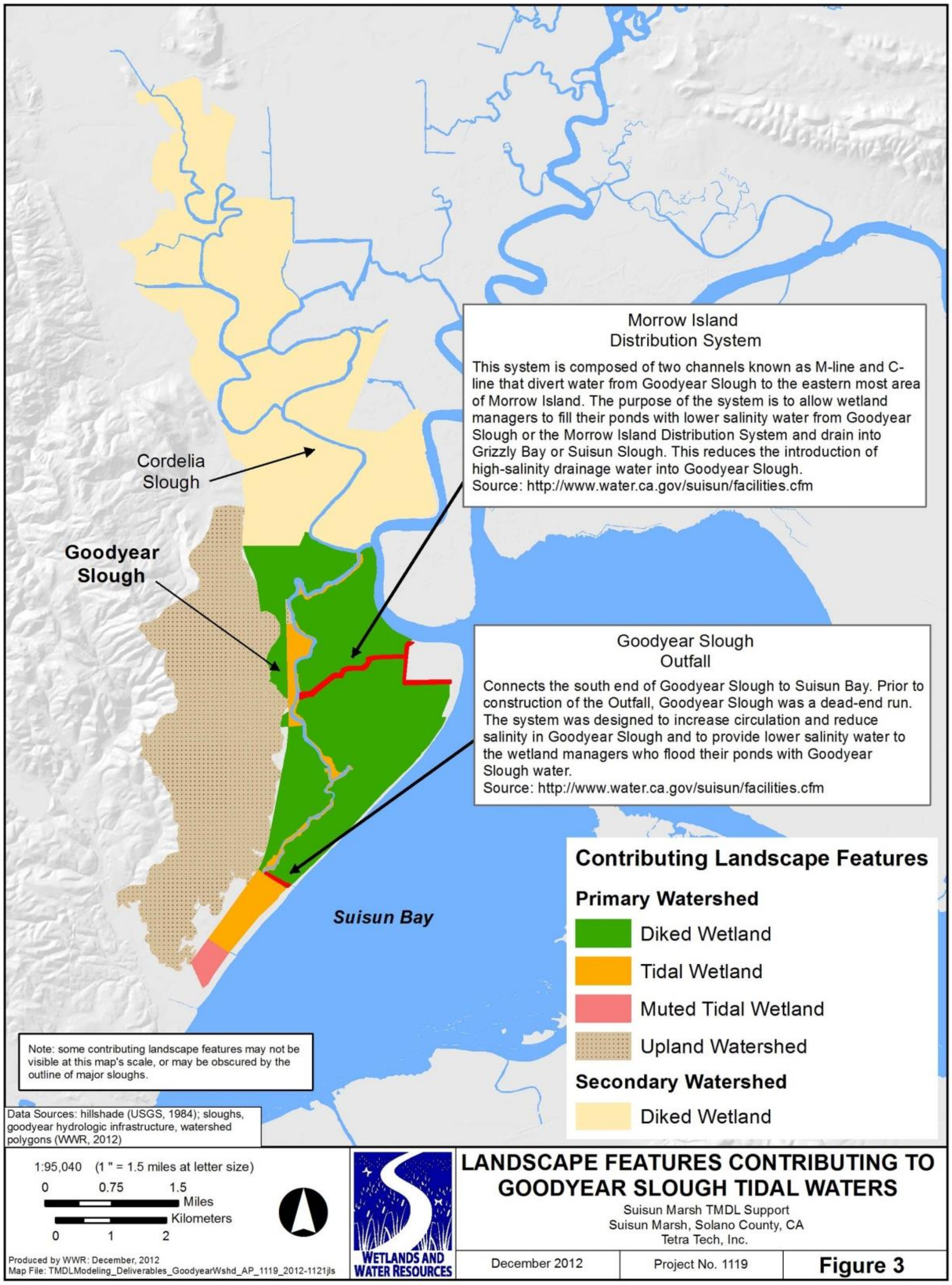
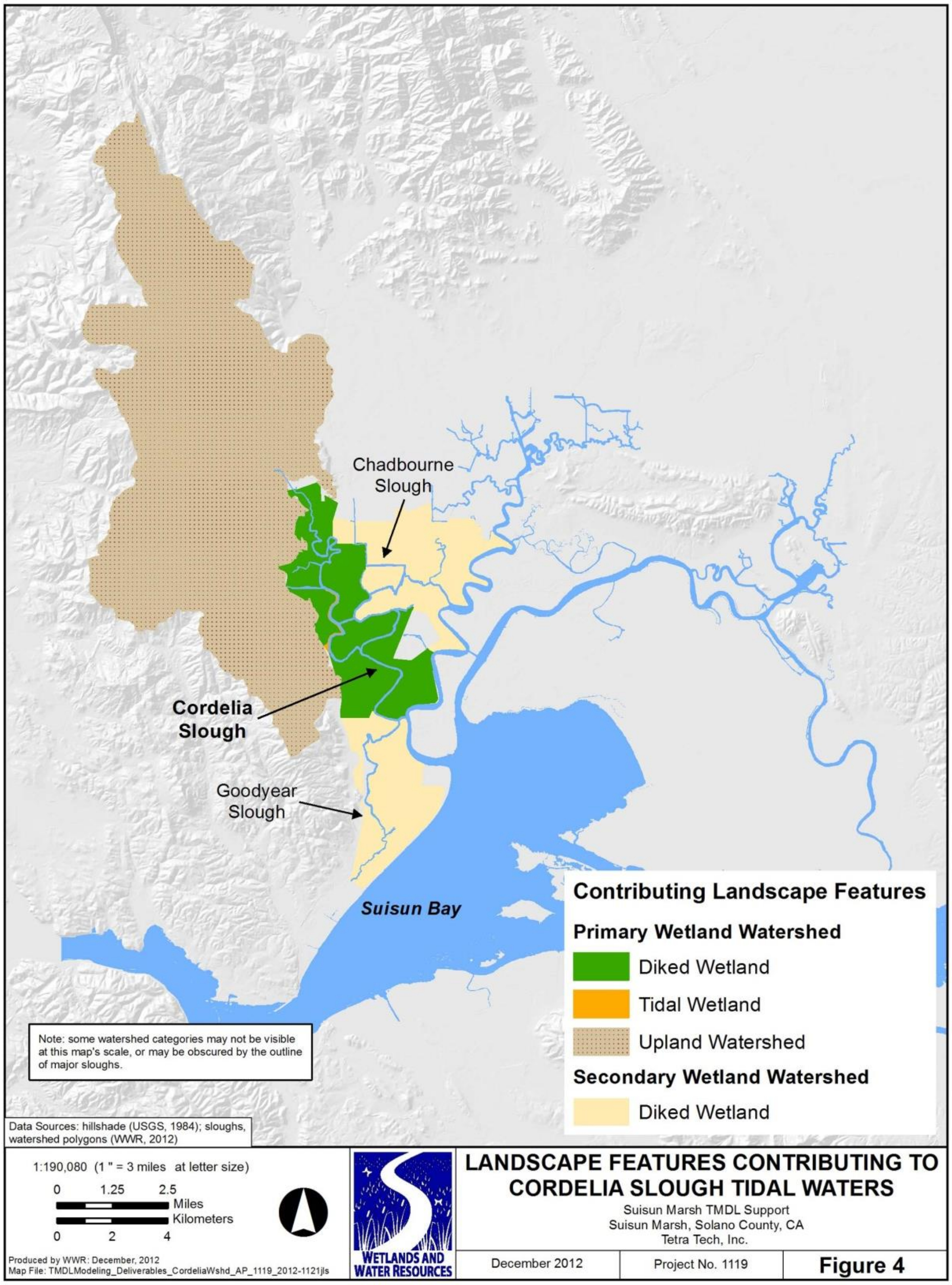
0 0.75 1.5 Miles
0 1 2 Kilometers
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_ContributingFactors_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
WESTERN SUISUN INFRASTRUCTURE POTENTIALLY INFLUENCING WQ CONCERNS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 2


Morrow Island
Distribution System
This system is composed of two channels known as M-line and C-line that divert water from Goodyear Slough to the eastern most area of Morrow Island. The purpose of the system is to allow wetland managers to fill their ponds with lower salinity water from Goodyear Slough or the Morrow Island Distribution System and drain into Grizzly Bay or Suisun Slough. This reduces the introduction of high-salinity drainage water into Goodyear Slough.
Source: http://www.water.ca.gov/suisun/facilities.cfm
Cordelia Slough
Goodyear Slough
Goodyear Slough Outfall
Connects the south end of Goodyear Slough to Suisun Bay. Prior to construction of the Outfall, Goodyear Slough was a dead-end run. The system was designed to increase circulation and reduce salinity in Goodyear Slough and to provide lower salinity water to the wetland managers who flood their ponds with Goodyear Slough water.
Source: http://www.water.ca.gov/suisun/facilities.cfm
Suisun Bay
Contributing Landscape Features
Primary Watershed
Diked Wetland
Tidal Wetland
Muted Tidal Wetland
Upland Watershed
Secondary Watershed
Diked Wetland
Note: some contributing landscape features may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Data Sources: hillshade (USGS, 1984); sloughs, goodyear hydrologic infrastructure, watershed polygons (WWR, 2012)
1:95,040 (1 " = 1.5 miles at letter size)
0 0.75 1.5 Miles
Kilometers 0 1 2
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_GoodyearWshd_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO GOODYEAR SLOUGH TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 3


Chadbourne Slough
Cordelia Slough
Goodyear Slough
Suisun Bay
Contributing Landscape Features
Primary Wetland Watershed
Diked Wetland
Tidal Wetland
Upland Watershed
Secondary Wetland Watershed
Diked Wetland
Note: some watershed categories may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Data Sources: hillshade (USGS, 1984); sloughs, watershed polygons (WWR, 2012)
1:190,080 (1 " = 3 miles at letter size)
0 1.25 2.5 Miles
0 2 4 Kilometers
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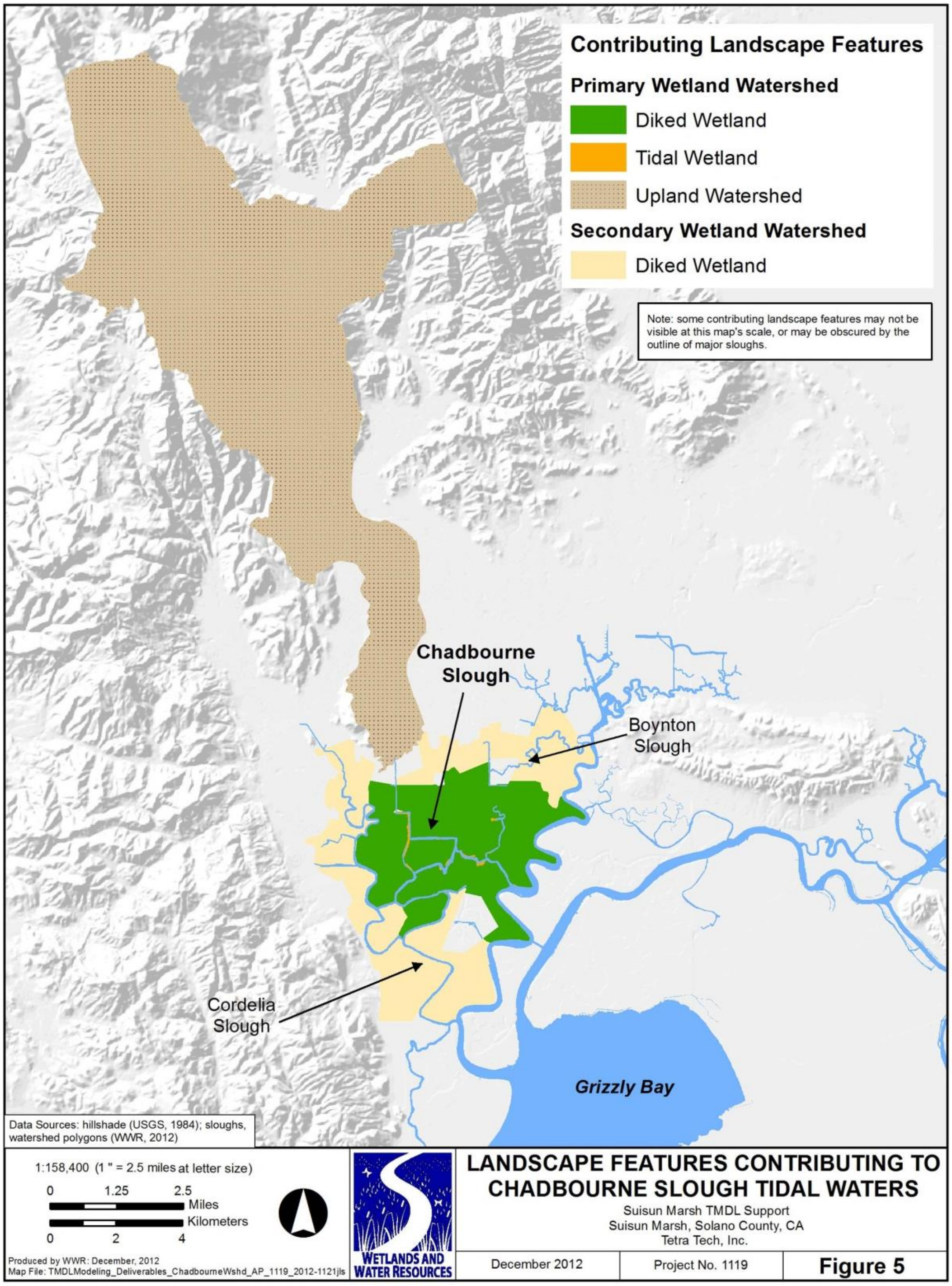
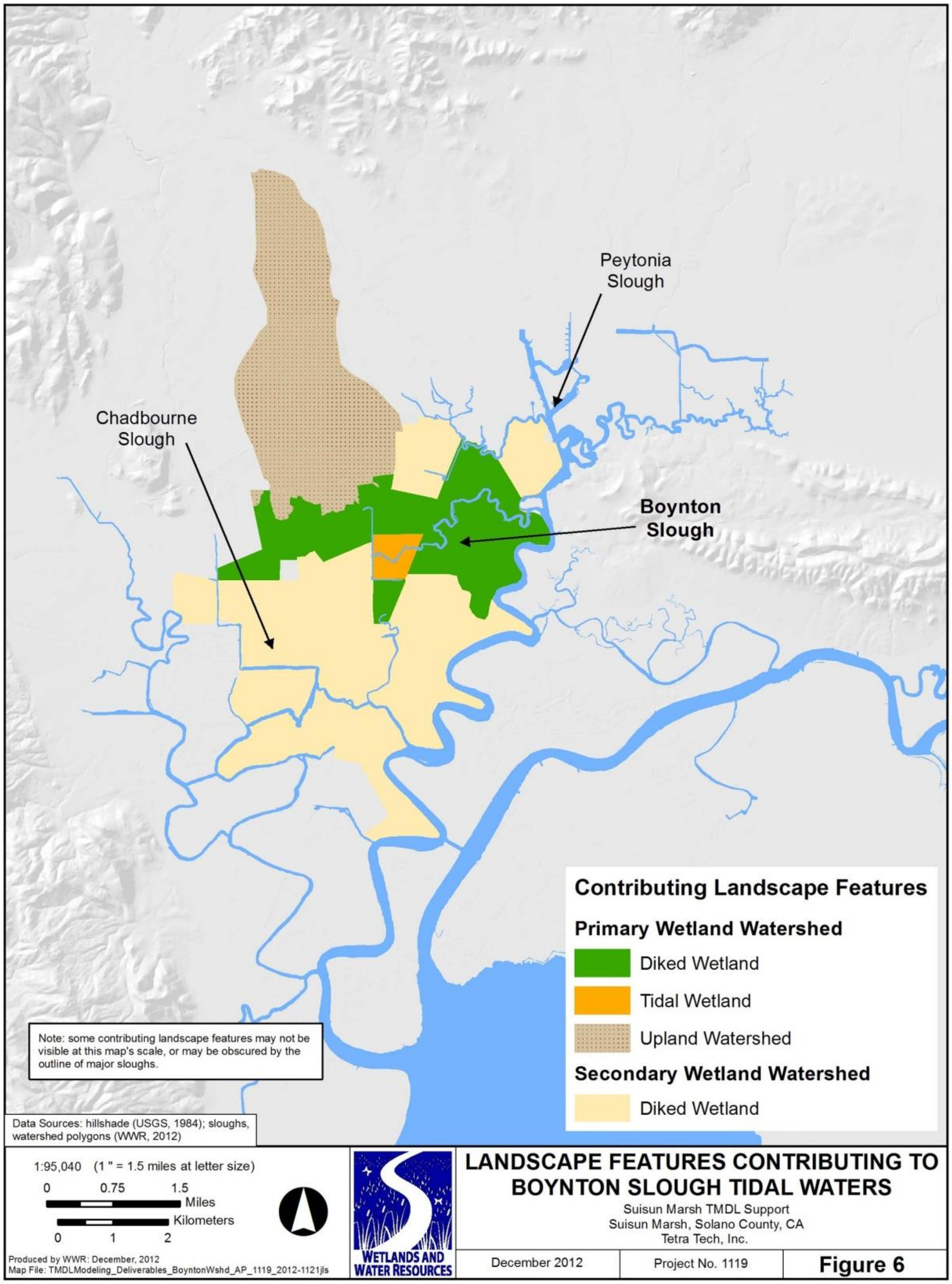
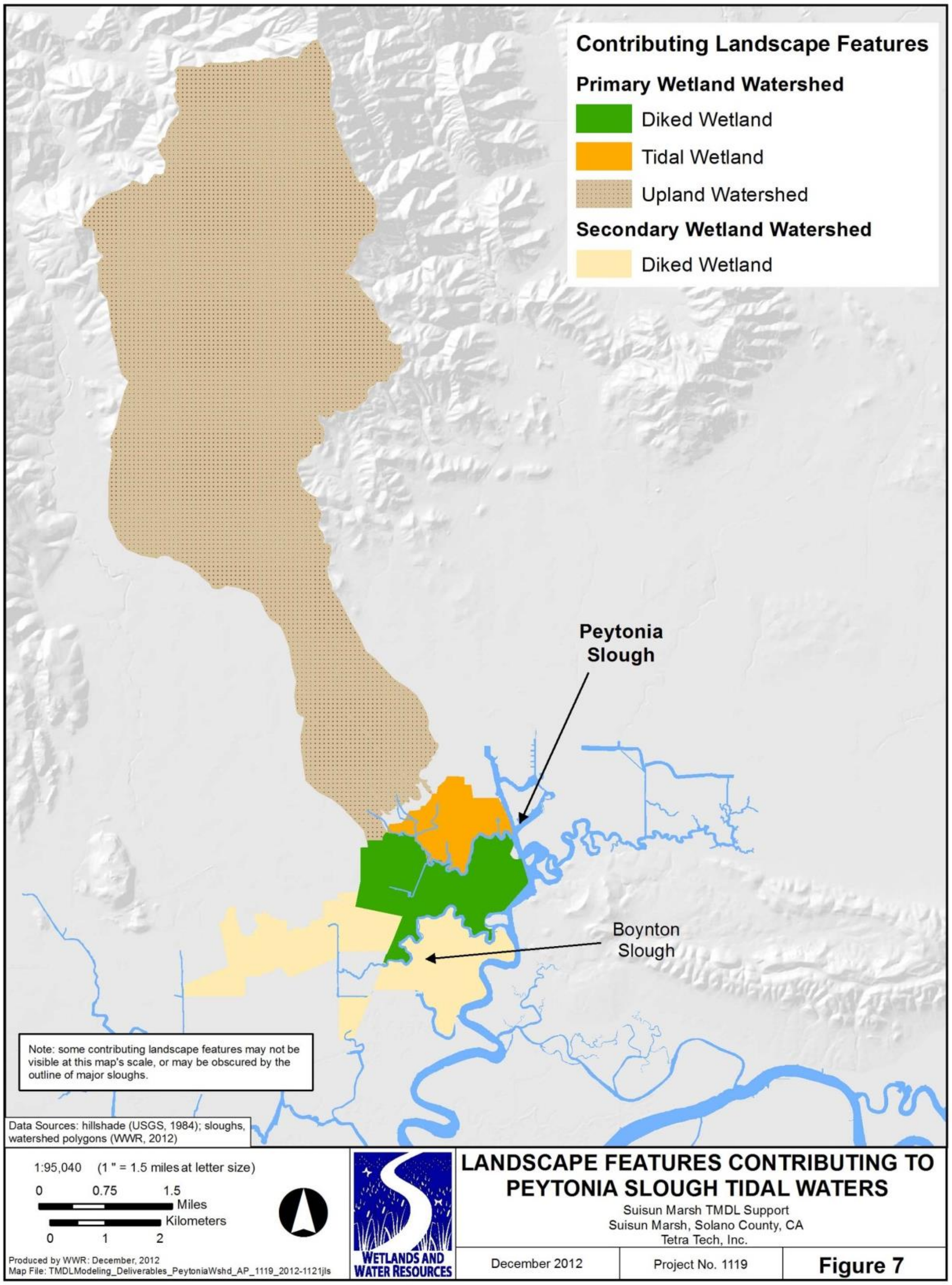
Map File: TMDLModeling_Deliverables_CordeliaWshd_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO CORDELIA SLOUGH TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 4


Contributing Landscape Features
Primary Wetland Watershed
Diked Wetland
Tidal Wetland
Upland Watershed
Secondary Wetland Watershed
Diked Wetland
Note: some contributing landscape features may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Chadbourne Slough
Boynton Slough
Cordelia Slough
Grizzly Bay
Data Sources: hillshade (USGS, 1984); sloughs, watershed polygons (WWR, 2012)
1:158,400 (1 " = 2.5 miles at letter size)
0 1.25 2.5
Miles
Kilometers
0 2 4
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_ChadbourneWshd_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO CHADBOURNE SLOUGH TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 5


Peytonia
Slough
Chadbourne
Slough
Boynton
Slough
Contributing Landscape Features
Primary Wetland Watershed
Diked Wetland
Tidal Wetland
Upland Watershed
Secondary Wetland Watershed
Diked Wetland
Note: some contributing landscape features may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Data Sources: hillshade (USGS, 1984); sloughs, watershed polygons (WWR, 2012)
1:95,040 (1 " = 1.5 miles at letter size)
0 0.75 1.5
Miles
Kilometers
0 1 2
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_BoyntonWshd_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO BOYNTON SLOUGH TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 6


Contributing Landscape Features
Primary Wetland Watershed
Diked Wetland
Tidal Wetland
Upland Watershed
Secondary Wetland Watershed
Diked Wetland
Peytonia Slough
Boynton Slough
Note: some contributing landscape features may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Data Sources: hillshade (USGS, 1984); sloughs, watershed polygons (WWR, 2012)
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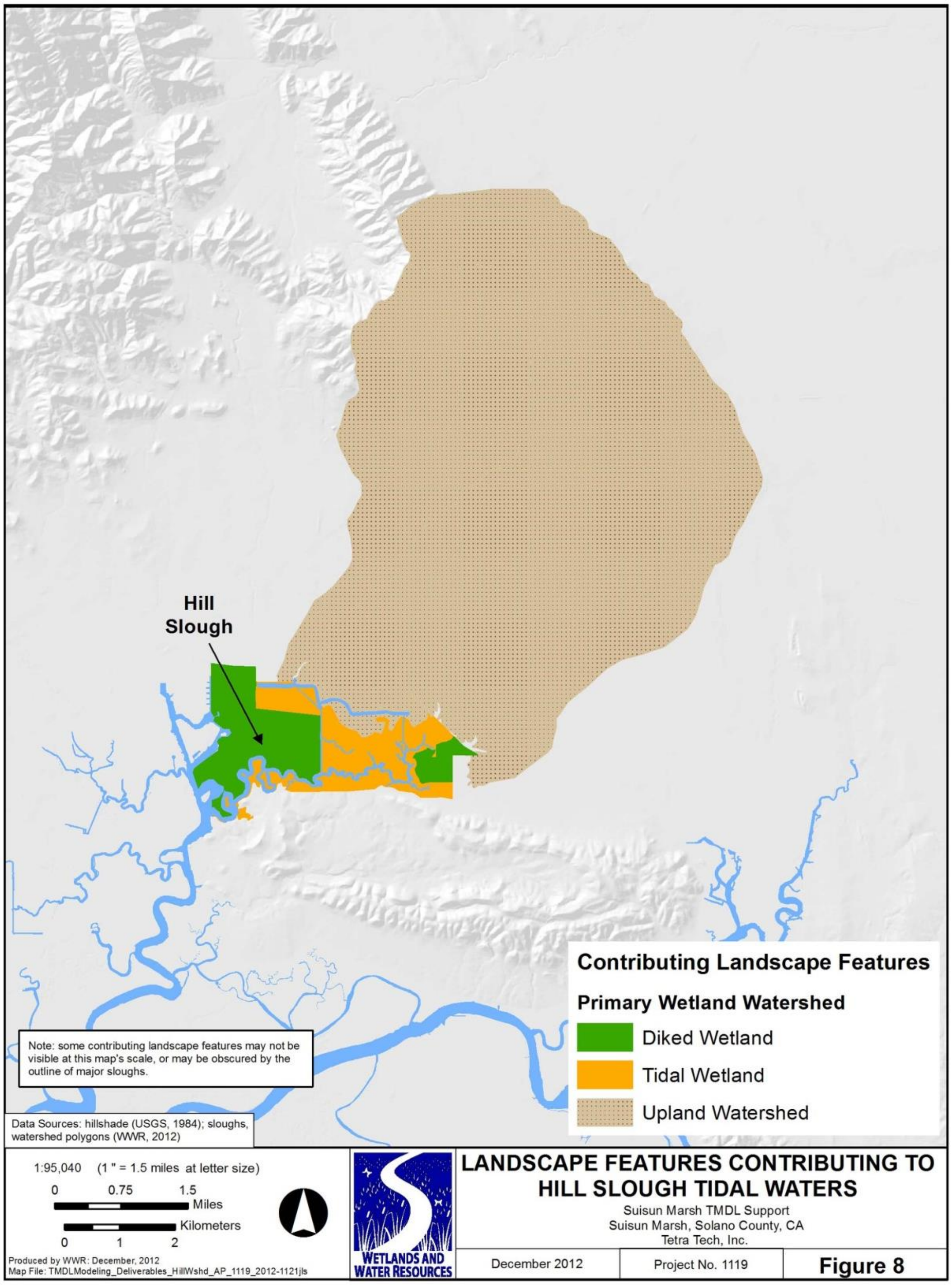
0 1 2 Kilometers
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_PeytoniaWshd_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO PEYTONIA SLOUGH TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 7


Hill Slough
Contributing Landscape Features
Primary Wetland Watershed
Diked Wetland
Tidal Wetland
Upland Watershed
Note: some contributing landscape features may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Data Sources: hillshade (USGS, 1984); sloughs, watershed polygons (WWR, 2012)
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0 0.75 1.5 Miles
0 1 2 Kilometers
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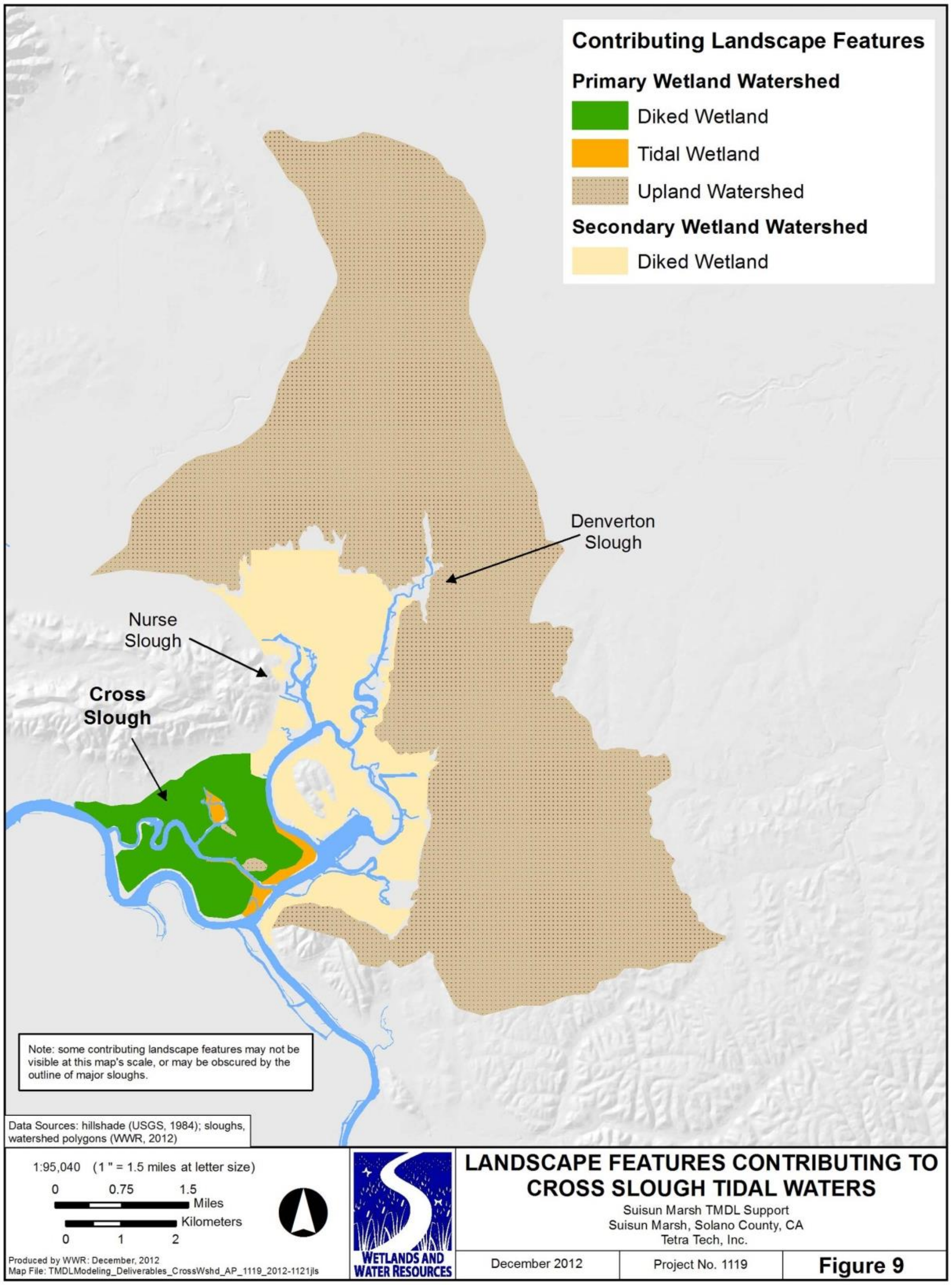
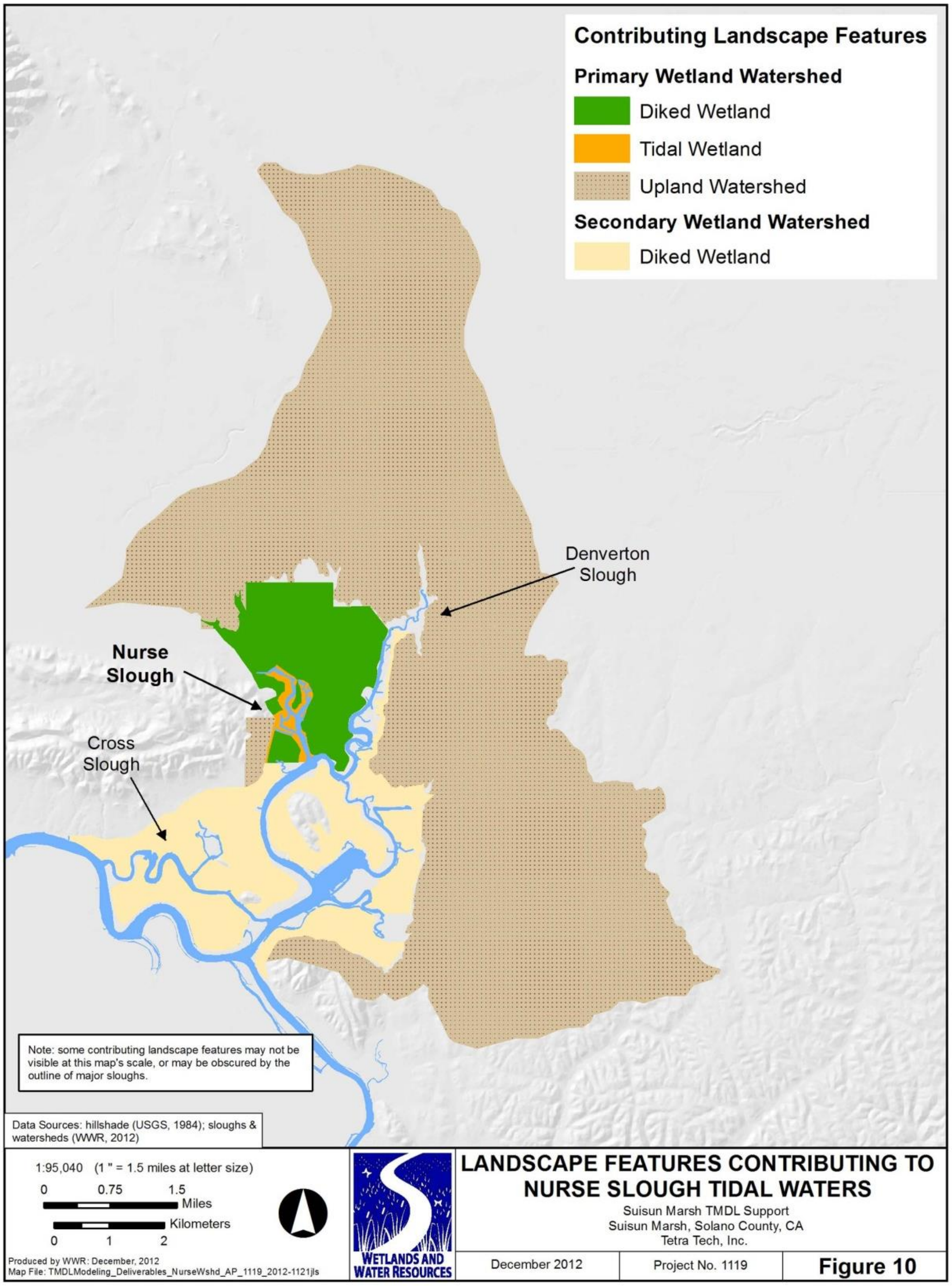
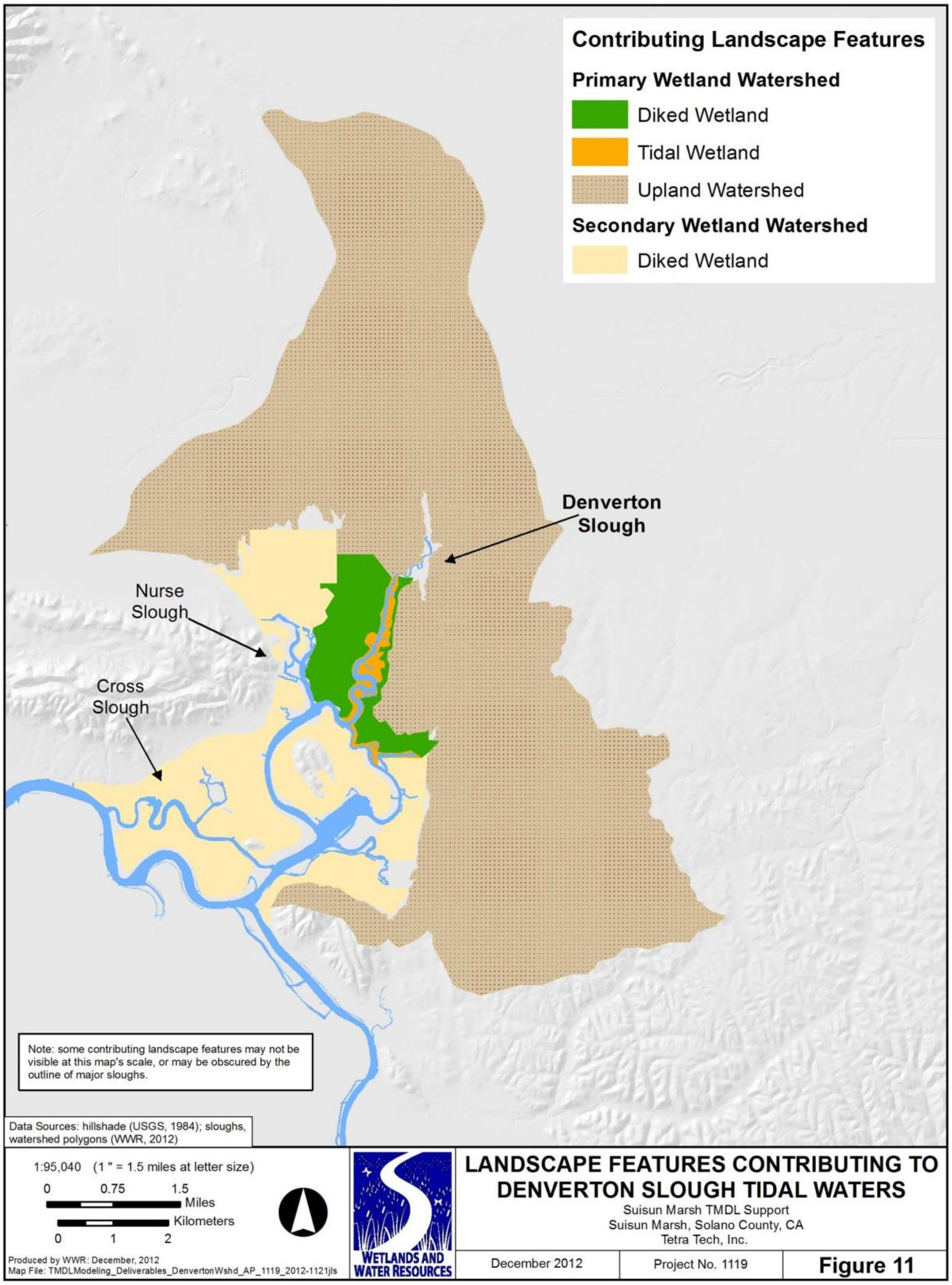
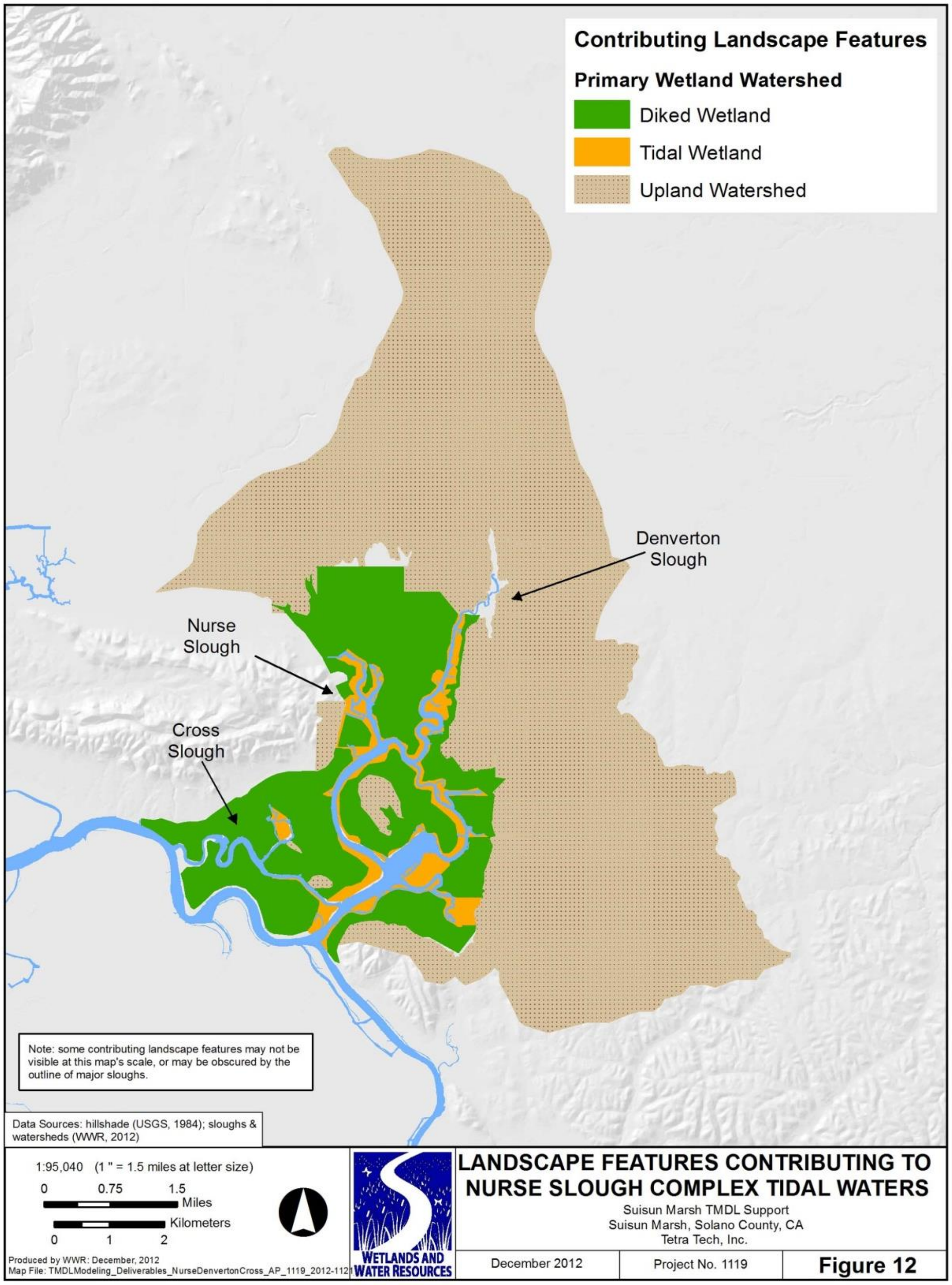
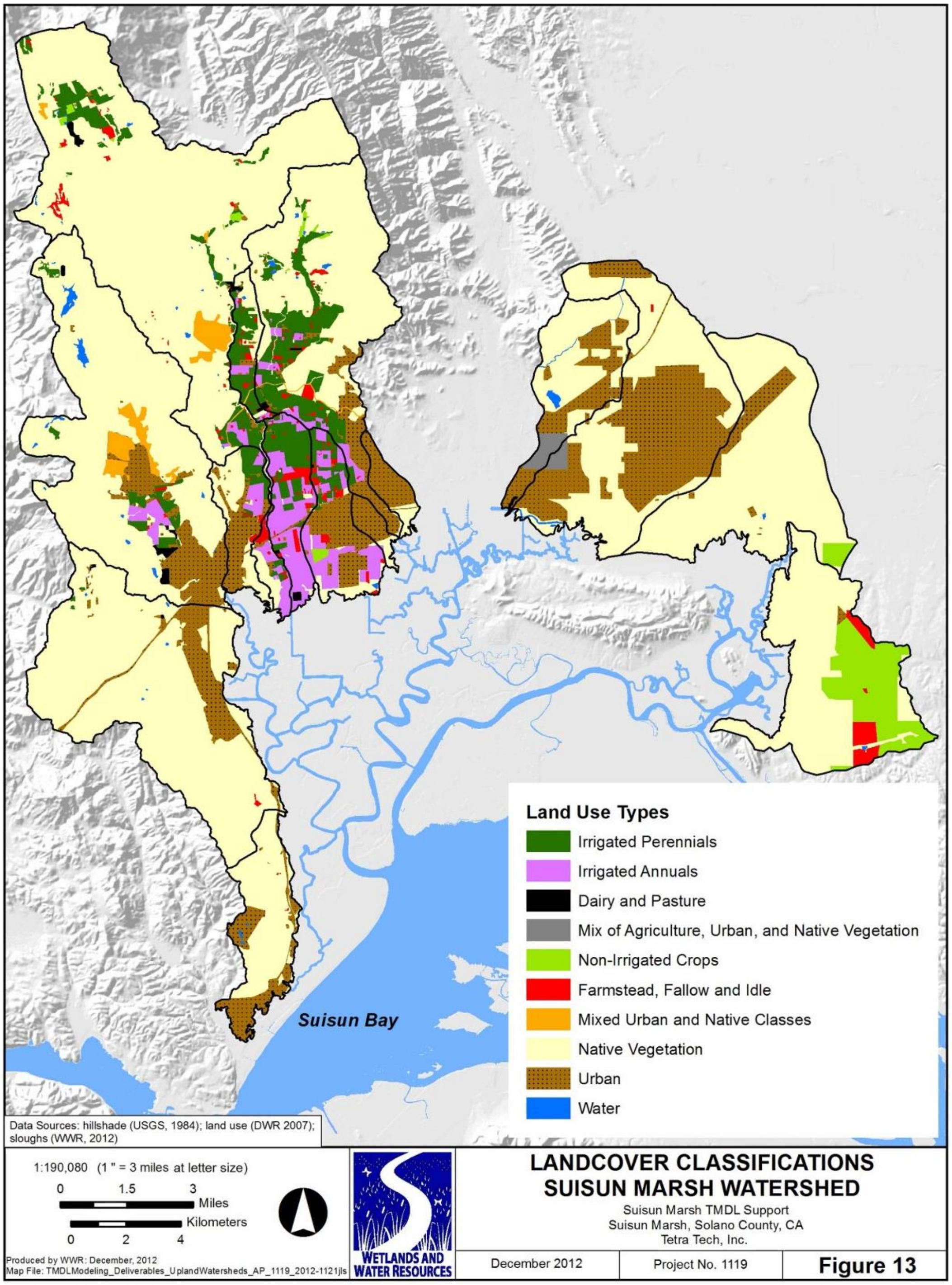
Map File: TMDLModeling_Deliverables_HillWshd_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO HILL SLOUGH TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 8


Contributing Landscape Features
Primary Wetland Watershed
Diked Wetland
Tidal Wetland
Upland Watershed
Secondary Wetland Watershed
Diked Wetland
Denverton Slough
Nurse Slough
Cross Slough
Note: some contributing landscape features may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Data Sources: hillshade (USGS, 1984); sloughs, watershed polygons (WWR, 2012)
1:95,040 (1 " = 1.5 miles at letter size)
0 0.75 1.5 Miles
Kilometers 0 1 2
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_CrossWshd_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO CROSS SLOUGH TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 9


Contributing Landscape Features
Primary Wetland Watershed
Diked Wetland
Tidal Wetland
Upland Watershed
Secondary Wetland Watershed
Diked Wetland
Denverton Slough
Nurse Slough
Cross Slough
Note: some contributing landscape features may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Data Sources: hillshade (USGS, 1984); sloughs & watersheds (WWR, 2012)
1:95,040 (1 " = 1.5 miles at letter size)
0 0.75 1.5 Miles
0 1 2 Kilometers
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_NurseWshd_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO NURSE SLOUGH TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 10


Contributing Landscape Features
Primary Wetland Watershed
Diked Wetland
Tidal Wetland
Upland Watershed
Secondary Wetland Watershed
Diked Wetland
Denverton Slough
Nurse Slough
Cross Slough
Note: some contributing landscape features may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Data Sources: hillshade (USGS, 1984); sloughs, watershed polygons (WWR, 2012)
1:95,040 (1 " = 1.5 miles at letter size)
0 0.75 1.5 Miles
0 1 2 Kilometers
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_DentonWshd_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO DENVERTON SLOUGH TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 11


Contributing Landscape Features
Primary Wetland Watershed
Diked Wetland
Tidal Wetland
Upland Watershed
Denverton Slough
Nurse Slough
Cross Slough
Note: some contributing landscape features may not be visible at this map's scale, or may be obscured by the outline of major sloughs.
Data Sources: hillshade (USGS, 1984); sloughs & watersheds (WWR, 2012)
1:95,040 (1 " = 1.5 miles at letter size)
0 0.75 1.5 Miles
0 1 2 Kilometers
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_NurseDenvertonCross_AP_1119_2012-1121
WETLANDS AND WATER RESOURCES
LANDSCAPE FEATURES CONTRIBUTING TO NURSE SLOUGH COMPLEX TIDAL WATERS
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 12


Suisun Bay
Land Use Types
Irrigated Perennials
Irrigated Annuals
Dairy and Pasture
Mix of Agriculture, Urban, and Native Vegetation
Non-Irrigated Crops
Farmstead, Fallow and Idle
Mixed Urban and Native Classes
Native Vegetation
Urban
Water
Data Sources: hillshade (USGS, 1984); land use (DWR 2007); sloughs (WWR, 2012)
1:190,080 (1 " = 3 miles at letter size)
0 1.5 3 Miles
Kilometers 0 2 4
Produced by WWR: December, 2012
Map File: TMDLModeling_Deliverables_UplandWatersheds_AP_1119_2012-1121jls
WETLANDS AND WATER RESOURCES
LANDCOVER CLASSIFICATIONS
SUISUN MARSH WATERSHED
Suisun Marsh TMDL Support
Suisun Marsh, Solano County, CA
Tetra Tech, Inc.
December 2012
Project No. 1119
Figure 13

** Slough systems: Goodyear, Cordelia, Chadbourne, Boynton, Peytonia, Hill, Nurse/Denverton/Cross*

6. TABLES

Table 1
Suisun Tidal Slough Landscape Characteristics and BMP Implementation Priority

Contributing Area Landscape Features	Units	Slough									
		Goodyear	Cordelia	Chadbourne	Boynton	Peytonia	Hill	Upper Nurse	Upper Denverton	Cross	Nurse/ Denverton/ Cross Complex
Diked Managed Wetlands											
# Clubs	No.	10	19	14	6	4	2	5	2	3	19
# Diversions	No.	32	41	40	22	7	11	12	5	4	39
Diked Area	Acre	3,070	5,050	5,080	1,910	960	860	1,450	860	1,400	4,300
Secondary contributing diked managed wetlands, via linked sloughs	Acre	5,050	7,020	5,740	4,480	1,570	0	3,490	4,090	3,550	0
Tidal Slough Geometry											
Slough length (including tributaries)	Miles	6	15	9	4.5	5.5	10.5	2.5	3.5	3	9
Slough avg. width	Feet	65	72	56	61	45	87	88	130	135	256
Tidal Marshlands											
Area: Clubs polygons	Acre	310	60	0	150	460	950	150	230	140	980
Area: EcoAtlas	Acre	80	65	70	30	15	0	0	0	0	0
Area: Total	Acre	390	125	70	180	475	950	150	230	140	980
Terrestrial Watershed Land Use											
Total Area	Acre	3,322	28,490	23,361	2,629	11,346	14,651		See total to right -->		16,075
Land Uses that May Contribute to Adverse Water Quality Conditions											
Urban	Acre	1,017	3,799	235	971	1,881	6,495		See total to right -->		643
Irrigated Perennials	Acre	0	659	2,490	355	1,902	0		See total to right -->		0
Irrigated Annuals	Acre	0	442	1,559	867	317	0		See total to right -->		0
Dairy Pasture	Acre	0	131	119	3	21	0		See total to right -->		0
Land Uses Less Likely to Contribute to Adverse Water Quality Conditions											
Mix of Ag, Urban, & Native Veg	Acre	0	23	147	0	0	403		See total to right -->		0
Non-Irrigated Crops	Acre	0	0	75	56	49	0		See total to right -->		2,429
Farmstead: Fallow & Idle	Acre	3	81	511	142	185	6		See total to right -->		417
Mixed Urban and Native	Acre	0	558	457	0	45	0		See total to right -->		0
Native Veg.	Acre	2,290	22,612	17,727	227	6,910	7,643		See total to right -->		12,575
Water	Acre	12	185	41	8	36	104		See total to right -->		11

Table 1 (continued)
Suisun Tidal Slough Landscape Characteristics and BMP Implementation Priority

			Slough									
	Contributing Area Landscape Features	**Units**	**Goodyear**	**Cordelia**	**Chadbourne**	**Boynton**	**Peytonia**	**Hill**	**Upper Nurse**	**Upper Denverton**	**Cross**	**Nurse/ Denverton/ Cross Complex**
Indices of Poor Water Quality Potential												
1	Slough Length/Avg. Width	mi/ft	0.09	0.21	0.16	0.07	0.12	0.12	0.03	0.03	0.02	0.04
2	Percent of primary wetlands as tidal marsh	%	11%	2.4%	1.4%	8.6%	33%	52%	9.4%	21%	9.1%	19%
3	Watershed land uses (urban, irrigated agriculture, pasture) that may contribute to adverse water quality conditions in Suisun Marsh tidal sloughs											
3A	Percent of watershed	%	31%	18%	19%	84%	36%	44%		See total to right -->		4%
3B	Area of watershed	Acre	1,017	5,031	4,403	2,196	4,121	6,495		See total to right -->		643
3C	Ratio of total watershed lands to primary wetlands along slough	%	29%	97%	85%	105%	287%	359%		See total to right -->		12%
4	Past records of poor water quality	NA	Yes	No data	No data	Yes	Yes	No	No	No	No	No
Recommendations												
	BMP Implementation Priority	NA	High	Need Data	Need Data	High	High	Low	Low	Low	Low	Low
	New Data to ID Extent of Issue	NA	No	Yes	Yes	No	No	No	Maybe	Maybe	Maybe	Maybe

Table 2
Best Management Practices Summary

				Evaluation Criteria							
				Slough Water Quality			Upstr Slough	Wet		Further	Avoid
BMP No.	Description	Intended Outcomes	Field Tried	DO	DOC	MeHg	Flow	Mgmt	Discussion	Study	Use
Key to Outcomes Ratings											
	Desired			↑	↓	↓	↓	Help		Yes	
	Intermediate			NC	NC	NC	NC	Neut.		Maybe	
	Undesired			↓	↑	↑	↑	Hinder		No	Yes
Water Management-Based BMPs: Baseline											
	Baseline: flood and circulate	Business as usual	NA	NC	NC	NC	NC	Neut.	Existing practices	No	Yes
Water Management-Based BMPs: Initial Fall Flood-Up Period											
H-1	Pre-flood to shoot level, drain, immediate reflood	Used in 2007 at 112 and 123	Yes	↓	↑	NC	↑	Neut.	High 'first flush' pulse of DOC into sloughs reduces DO. Neutral on MeHg prod? Neutral or improve wetland WQ.	No	Yes
H-2	Pre-flood to field saturation level, drain, delayed reflood	Used in 2008 at 112 and 123	Yes	↓	↑	NC	↑	Neut.	Allows time to offgas decomposing organic matter relative to H-1	No	Yes
H-3	Pre-flood to field saturation level, drain, immediate reflood	Used in 2000s at some locations in attempt to reduce low DO	Yes	↓	↑	NC	↑	Neut.	Lower pre-flood stage may reduce DOC pulse quantity relative to H-1	No	Yes
H-4	Flood and hold with minimal exchange	Avoid poor WQ dsicharges to sloughs during sensitive periods (fall)	No	↑	↓	?	NC	Hinder ???	Reduces slough loadings from wetland 'first flush' low DO/high DOC waters and reduces circulation during fall when wetland WQ is poorest. Mercury effect unclear. Will produce "blackwater" nuisance to hunters and complicate vector control.	Maybe	

Table 2 (continued)
Best Management Practices Summary

BMP No.	Description	Intended Outcomes	Field Tried	Evaluation Criteria: Slough Water Quality DO	DOC	MeHg	Upstr Slough Flow	Wet Mgmt	Discussion	Further Study	Avoid Use
H-5	Delay flood-up as late as possible before hunt season	Initial flood up occurs with cooler temps	Ltd	↑	↓	↓	↓	Hinder ???	May compress time when wetlands flood up, spiking upstream slough flows; would require mgmt integration across wetlands.	Maybe	
H-6	Reroute wetland drain events to large sloughs	Reduce BOD loading to sloughs with lower DO capacity	Yes	↑?	↓	NC	↑	Neut.	Increased net upstream slough flows reduce mixing which promotes low DO in sloughs; model before try further	Maybe	Yes
H-7	Stagger flood/drain events across multiple wetlands	Spread out WQ and hydrologic effects temporally	No	↑	↓	↓	?	Neut?	Requires multi-party coordination; effects on wetland management may be complex	Yes	
H-8	Coordinate drain events across multiple wetlands using DO-based discharge scheduling	Base operational decisions on real-time data of slough water quality	No	↑	↓	↓	NC	Hinder	May complicate vector control and wetland management but potential water quality improvements could be significant	Yes	
H-9	Maximize use of FSSD water for initial flood up	Provide higher DO wetland inflows, reduce upstream slough flows	No	↑	↓	NC	↓	Neut.	Requires FSSD active participation and coordination, maybe infrastructure changes	Yes	
H-10	Maximize FSSD water discharge into Boynton and/or Peytonia sloughs during drain events	Dilute low DO/high DOC water in Boynton Slough; minimize net upstream flow	No	↑	↓	↓	↓	Neut?	Requires FSSD active participation and coordination, maybe infrastructure changes; may have wetland salinity effects	Yes	

Table 2 (continued)
Best Management Practices Summary

BMP No.	Description	Intended Outcomes	Field Tried	Evaluation Criteria: Slough Water Quality: DO	Evaluation Criteria: Slough Water Quality: DOC	Evaluation Criteria: Slough Water Quality: MeHg	Evaluation Criteria: Upstr Slough Flow	Evaluation Criteria: Wet Mgmt	Discussion	Further Study	Avoid Use
Water Management-Based BMPs: Circulation period (winter, hunting season)											
H-11	Minimum exchange between wetlands and sloughs	Avoid poor WQ discharges, allow photo-demethylation and wind mixing	No	↑	↓	↓	NC	Hinder	Reduced slough loadings. Likely to create poor wetland conditions including blackwater (low DO within wetland)	Maybe	
H-12	High exchange rates	Minimize residence time in wetlands to avoid development of poor water quality	Ltd	↑	↑?	↓	Vary	Help	High DOC diffusion could increase BOD load, perhaps offset by high dilution rates. May require pumps to achieve circulation rates. Could increase upstream flows. May worsen conditions due to high DOC loading rates	Maybe	
H-13	Maximize internal wetland circulation	Eliminate stagnant areas	Yes	↑	?	↓	NC	Help	Requires physical improvements to internal circulation infrastructure that may prove difficult to achieve	Maybe	
Water Management-Based BMPs: Salinity and vegetation management period (spring and summer)											
H-14	Summer irrigation, no drainage	Compact soils, accelerate labile organic decomposition	Ltd?	↑	↓	↓	↑	Hinder	Potential challenges of mosquito production, diversion limitations, weed growth, and reduced time for wetland management	Maybe	

Table 2 (continued)
Best Management Practices Summary

BMP No.	Description	Intended Outcomes	Field Tried	Evaluation Criteria: Slough Water Quality: DO	DOC	MeHg	Upstr Slough Flow	Wet Mgmt	Discussion	Further Study	Avoid Use
Vegetation and Soil Management-Based BMPs											
VS-1	Manage for less leafy green vegetation	Reduce labile organic matter	Yes	↑	↓	↓	NC	Help	Important practice	Yes	
VS-2	Mow vegetation earlier in the Season	Allow longer vegetation decomposition period	No	↑	↓	↓	NC	Neut?	Decomp mostly requires wetting which may complicate mgmt.	Yes	
VS-3	Remove mowed vegetation from wetlands	Reduce labile organic matter from dead vegetation	No	↑	↓	↓	NC	Neut?	Ability may depend on wetland soils ability to support baler (may not work on peat soils)	Yes	
VS-4	Graze wetlands to remove unwanted vegetation	Reduce labile organic matter from dead vegetation	No	↑	↓	↓	NC	Neut?	Yolo Bypass shown benefits. May be logistically challenging. Integrate w/ veg mgmt.	Maybe	
VS-5	Reduce soil disturbance (disking) activities	Reduce soil organic matter content available for decomposition	No	↑	↓	↓	NC	Hinder ???	Could be key strategy to reduce main carbon pool that contributes to water qualit problems; may complicate site management	Yes	