San Francisco Estuary Wetland Regional Monitoring Program: Monitoring Plan

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Executive Summary

The San Francisco Estuary Wetlands Regional Monitoring Program (WRMP) delivers coordinated regional monitoring of the San Francisco Estuary's wetlands to (1) inform science-based decision-making for wetland restoration and adaptive management and (2) increase the cost-effectiveness of permit-driven monitoring associated with tidal wetland restoration projects. The goal of this Monitoring Plan is to identify and recommend a suite of monitoring actions that integrate key tidal wetland indicators across regional, subregional, and site-specific scales. The Monitoring Plan is intended to serve as a visionary framework for program monitoring and describes activities essential to understanding the health, function and persistence of established and restoring tidal wetlands in the SFE. The Monitoring Plan identifies and explains monitoring activities that:

- Span regional (remotely-sensed mapping products), subregional (environmental sensors in locations central to multiple WRMP Network sites), and site-based monitoring
- Develop information to
    - Answer the Program's Guiding and Management Questions
    - Contextualize restoration project monitoring
    - Reduce investment in monitoring by restoration project proponents
    - Inform future restoration investment and adaptive management of existing wetlands
- Can be initiated and adjusted over time to respond to shifts in science and/or program partner information needs

The monitoring framework described in this Plan builds upon the science framework that was first described in the WRMP Phase 1 Program Plan (WRMP 2020a), as well as the geographic framework described in the WRMP Priority Monitoring Site Network Memo (WRMP 2023a). This Plan will serve as the foundation for the WRMP's first Implementation Work Plan, expected in 2024 (see Figure ES-1, below). The Work Plan will detail which subset of activities from this Monitoring Plan the WRMP has funding to implement, and how those activities will be implemented.

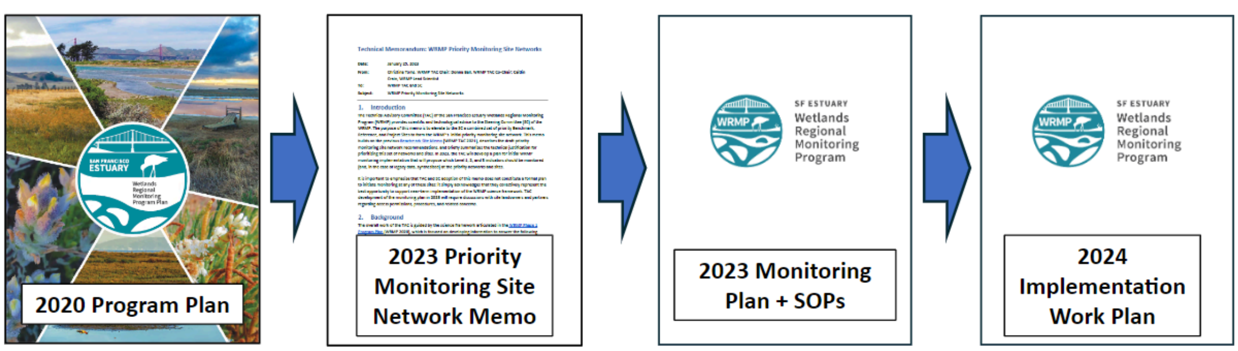

Figure ES-1. Relationship between the WRMP's 2020 Program Plan, 2023 Priority Monitoring Site Network Memo, this Monitoring Plan, and anticipated Implementation Work Plan.

This first iteration of the WRMP Monitoring Plan operationalizes the WRMP science framework, and describes an ambitious vision of proposed monitoring activities over the very near-term (next 1-2 years) and near-term (next 3-5 years) time frames. The WRMP science team, including the WRMP

Technical Advisory Committee (TAC) and its workgroups, produced this Monitoring Plan in parallel with standard operating procedures (SOPs) for data collection, analysis, synthesis, and interpretation. The SOPs serve as appendices to this Plan. The WRMP has limited initial funds to implement very-near-term monitoring, and is primarily using these funds to leverage and add value to existing ambient monitoring, project-specific monitoring, and special studies (see Section 2.2 and Figure ES-2, left). Specifically, the WRMP is (1) utilizing existing NAIP imagery to develop the first iteration of the Baylands Landmark Map 2020 (see Section 3.2), (2) synthesizing historical CRAM (California Rapid Assessment Method) data and implementing a new round of CRAM monitoring at select WRMP priority monitoring sites (see Section 5.1), and (3) expanding the network of sediment elevation tables-marker horizons (SET-MHs) in the region (see Section 5.2). Over time, the WRMP will grow its implementation funding, help realign funding for existing monitoring projects and programs, work to align WRMP monitoring with permit-required monitoring, fund/implement an increasing proportion of ambient monitoring, project monitoring, and special studies, and coordinate these efforts at a regional scale (Figure ES-2, right).

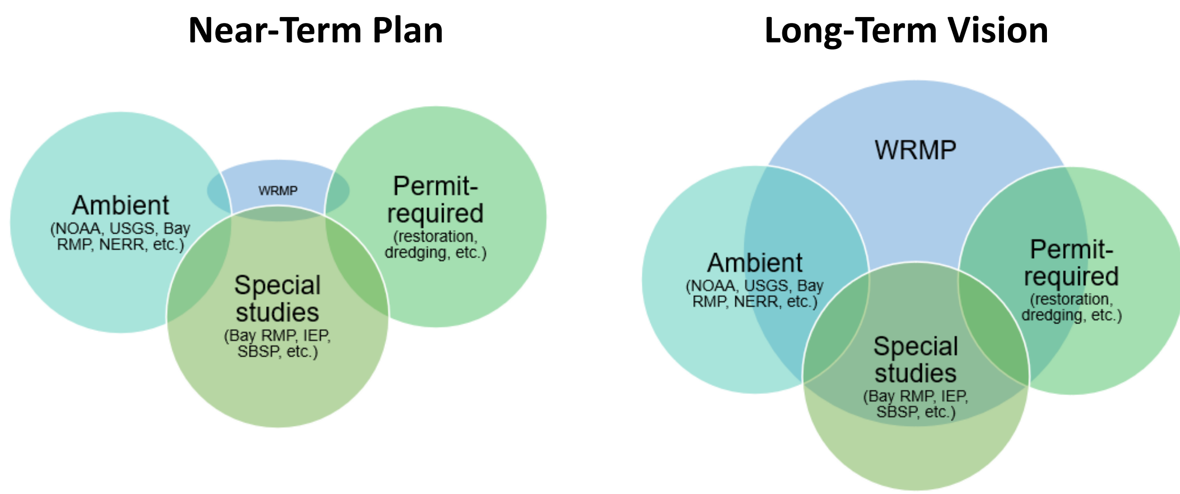

Figure ES-2. Near-term (left) and longer-term (right) vision of how the WRMP intends to fund, manage, and coordinate ambient monitoring, project monitoring, and special studies.

Consistent with the WRMP science framework, this Monitoring Plan proposes efforts at three spatial scales: regional, subregional, and site:

- **Regional** (Section 3): This Monitoring Plan proposes regional, estuary-wide remote sensing and mapping of the distribution and abundance of four key WRMP indicators:
    - Bayland habitats (including tidal wetlands, mudflats and channels, shallow and deep subtidal waters, beaches, and non-tidal wetlands) and landscape features
    - Bayland elevations, including elevations relative to local tidal datums (elevation capital)
    - Bayland dominant vegetation alliances
    - Bayland shoreline change

These maps will serve as foundational science products of the WRMP; repeated remapping efforts will facilitate an understanding of status and trends across all of the region's tidal baylands, including all Benchmark, Reference, and Project Sites. The new map of bayland habitats currently being developed is called the Baylands Landmark Map 2020[1], and is funded by the USEPA Region IX.

- **Subregional** (Section 4): This Monitoring Plan proposes to expand subregional monitoring of key abiotic drivers of tidal bayland habitat distribution, abundance, and condition:
    - Water levels, inundation, and rates of sea level rise
    - Surface water salinity
    - Suspended sediment

  Monitoring of these indicators is intended to capture conditions in tidal rivers, sloughs, and channels that serve as "feeder" channels to multiple priority WRMP monitoring sites. Information from subregional monitoring will enhance understanding of changes in ambient estuarine conditions over time, and allow for observations of dependent abiotic and biotic conditions in Benchmark, Reference, and Project sites to be appropriately contextualized. In most cases, WRMP monitoring of these indicators will be designed to fill key spatial and temporal gaps in existing monitoring programs that are implemented by program partners (e.g,. USGS, NOAA, SFBNERR). The Monitoring Plan also discusses how the WRMP could build upon existing and proposed efforts to monitor dissolved oxygen in SFE baylands.

- **Site** (Section 5): This Monitoring Plan proposes site-scale monitoring of key biotic and abiotic indicators at select Benchmark, Reference, and Project sites:
    - California Rapid Assessment Method (CRAM) to capture changes in overall wetland condition, and the factors driving those changes
    - Sediment elevation tables with marker horizons (SET-MHs) to capture accretion and elevation change
    - Elevation transects to capture changes across key elevation gradients and ground-truth remotely sensed observations of elevation
    - Vegetation transects to capture changes across key gradients of elevation, inundation, and salinity, and ground-truth remotely sensed observations of dominant vegetation alliances
    - Fish and fish habitat monitoring to characterize the composition and abundance of estuarine fish communities, including the presence/absence of special-status species

  Site-scale monitoring efforts will be carefully coordinated and, where necessary and/or practicable, co-located to most efficiently and effectively monitor individual tidal baylands and gain an improved understanding of regional status and trends. Site-scale monitoring of birds, mammals, and carbon sequestration are included as additional indicators of interest to be

[1] Formerly known as the Baylands Change Basemap

further developed in the near future. Using conceptual models, empirical models, and best professional judgment, monitoring at priority WRMP sites can in some cases substitute for less coordinated, more ad hoc monitoring across a suite of locations. This can reduce and in some cases potentially eliminate the need for project proponents to fund and implement specific monitoring activities.

Where practicable, this Monitoring Plan provides cost estimates for proposed monitoring activities. In 2024, the WRMP science team, in conjunction with the WRMP Technical Advisory Committee (TAC) and Steering Committee (SC), will develop an Implementation Work Plan that will detail which subset of activities from this Monitoring Plan the WRMP has funding to implement, and how those activities will be implemented. The Monitoring Plan is a living document that will change over time as the WRMP grows, the science framework is ground-truthed, and to reflect shifts in program science priorities, management information needs, funding resources, geographies, and other factors. The science team, with guidance from the TAC, will revise these documents in coordination with the Steering Committee, consistent with the WRMP charter.

1 Introduction

Tidal baylands - including tidal wetlands, mudflats, and shallow open waters - provide crucial ecosystem services to the San Francisco Estuary's (SFE) natural and built communities. These formerly abundant habitats provide habitat for native plants, fish, and wildlife, improve water quality, buffer shoreline communities from storms and floods, and provide recreational and public health benefits for the Bay Area's more than 7 million residents. The region's tidal wetland conservation community comprises a broad spectrum of institutions, agencies, and advocates with fiduciary, technical, and regulatory interests in maintaining and increasing the distribution, abundance, and condition of the region's tidal wetlands. For decades, this community has attempted to reconcile the growing and occasionally competing needs for monitoring data to inform conservation and restoration project planning, implementation, and permitting. More recently, climate change threatens to derail efforts to fulfill the region's goal of establishing 100,000 acres of tidal wetlands in the estuary (Goals Project 1999 and 2015), and has highlighted the need for innovative, cost-effective monitoring approaches that allow information to be synthesized across multiple scales of space and time.

The SFE's Wetlands Regional Monitoring Program (WRMP) represents the most recent, robust, and collaborative attempt by the region's tidal wetland community to bridge the gap between (1) the ambient monitoring necessary to assess the influence of landscape-scale drivers such as climate change and watershed management on tidal wetlands across multiple spatial and temporal scales, and (2) the site-specific monitoring that is typically required of tidal wetland restoration project implementers by regulatory and resource agencies. To accomplish the WRMP mission to deliver coordinated regional monitoring of the San Francisco Estuary's wetlands to (1) inform science-based decision-making for wetland restoration and adaptive management and (2) increase the cost-effectiveness of permit-driven monitoring associated with wetland restoration projects, this program will develop information to support decision-making by a broad range of tidal wetland conservation partners, including land managers, funders, restoration designers, and regulators. By re-aligning and leveraging the region's considerable investments in existing monitoring projects and programs, the WRMP will reduce the amount of time, money, and effort that restoration project implementers must invest in permit-required monitoring. It will help the region's tidal wetland conservation partners understand the evolution of the estuary's existing tidal wetland restoration projects, support effective adaptive management in a changing estuary, and provide the information they need to design projects that will be resilient to likely future conditions.

1.1 Summary of the WRMP Science Framework

The geographic scope of the WRMP encompasses tidal baylands within the SFE downstream of Broad Slough in the Sacramento-San Joaquin Delta, and encompasses "complete" tidal marsh ecosystems as defined by the Baylands Ecosystem Habitat Goals Update, or BEHGU (Goals Project 2015). The complete tidal marsh ecosystem includes subtidal areas to a depth of 12 ft below local Mean Lower Low Water (MLLW), channels, tidal flats, fully tidal and muted tidal marshes, and adjoining estuarine-terrestrial and estuarine-fluvial transition zones. This emphasis on connected subtidal, intertidal, and supratidal habitats reflects scientific consensus on the importance of landscape connectivity to the long-term resilience of the estuary's tidal marshes in the face of climate change.

The scope for this iteration of the monitoring plan does not currently include managed marshes, such as duck clubs in Suisun Marsh, or diked non-tidal wetlands and waters within the historical limits of the San Francisco baylands. However, it is important to note that ponds and recently restored pond areas are important for wildlife (particularly for important bird species on the Pacific Flyway) both as critical pond habitat for foraging, nesting, and roosting, and as areas transitioning to tidal marsh. When these latter systems are restored to tidal action (either by purposeful restoration or by levee failure), or as funding is identified to enable monitoring of these areas and species, they can be incorporated into the monitoring scope of the WRMP.

The WRMP science framework is broadly described in the WRMP Phase 1 Program Plan (WRMP 2020a), and is based on the Wetland and Riparian Area Monitoring Plan (WRAMP) framework established by the California Water Quality Monitoring Council. The WRAMP framework integrates cost-effective project and ambient monitoring within local and regional contexts, based on management questions that have been articulated and prioritized by program partners. The framework describes how to integrate Level 1 (remote sensing), Level 2 (rapid field assessment), and Level 3 (intensive field assessment) data to develop information products that answer key questions from partners. Accordingly, the WRMP science framework is built around the following Guiding Questions and associated Management Questions, which have been approved by the Steering Committee and are described at length in the WRMP Program Plan:

- **Guiding Question 1:** ***Where are the region's tidal wetland ecosystems, including tidal wetland restoration projects, and what net landscape changes in area and condition are occurring?***
    - Management Question 1A: *What is the distribution, abundance, diversity, and condition of tidal marsh ecosystems, and how are they changing over time?*
    - Management Question 1B: *Are changes in tidal marsh ecosystems impacting water quality?*
- **Guiding Question 2:** ***How are external drivers, such as accelerated sea level rise, development pressure, and changes in runoff and sediment supply impacting tidal wetlands?***
    - Management Question 2A: *How are tidal marshes and tidal flats, including restoration projects, changing in elevation and extent relative to local tidal datums?*
    - Management Question 2B: *What are the regional differences in the sources and amounts of sediment available to support accretion in tidal marsh ecosystems?*
- **Guiding Question 3:** ***What new information do we need to better understand regional lessons from tidal wetland restoration projects, advance tidal wetland science, and ensure the continued success of restoration projects?***
    - Management Question 3A: *Where and when can interventions, such as placement of dredged sediment, reconnection of restoration projects to watersheds, and construction of living shorelines, help to sustain or increase the quantity and quality of tidal marsh ecosystems?*

- **Guiding Question 4: *How do policies, programs, and projects to protect and restore tidal marshes affect the distribution, abundance, and health of plants and animals?***
    - Management Question 4A: *How are habitats for assemblages of resident species of fish and wildlife in tidal marsh ecosystems changing over time?*
    - Management Question 4B: *How are the distribution and abundance of key resident species of fish and wildlife in tidal marsh ecosystems changing over time?*
- **Guiding Question 5: *How do policies, programs, and projects to protect and restore tidal wetlands benefit and/or impact public health, safety, and recreation?***
    - Management Question 5A: *What mosquito and vector control strategies need to be considered in restoration design and management to understand the effects that restoration can have on mosquito and vector populations?*
    - Management Question 5B: *What monitoring data are needed to optimize the relationship between tidal marsh restoration, fish and wildlife support, mosquito and vector control, and public access?*
    - Management Question 5C: *How are the benefits of wetlands (such as flood risk reduction, water quality, public access, opportunities for community stewardship, knowledge production & transmission, and cultural & spiritual experiences) distributed regionally and among different demographic groups?*
    - Management Question 5 D: *How does the provision of benefits (such as flood risk reduction, water quality, public access, opportunities for community stewardship, knowledge production & transmission, and cultural & spiritual experiences) progress over time at existing and restored wetland sites?*

The 2020 Program Plan includes foundational elements of the program's science framework, including a matrix of program management questions, monitoring questions, and indicators (Appendix A of the Program Plan), a spatial and temporal framework for monitoring and analysis (Appendix D of the Program Plan), and a compendium of conceptual models that describe the relationships between a broad suite of physical and ecological indicators in tidal wetlands and their associated bayland habitats (Appendix F of the Program Plan). These conceptual models are broadly summarized in Figure 1 below, and they inform the central logic of the program's science framework:

- Wetlands subject to different sources of fresh and marine water and sediment, and at different stages of evolution, respond differently to changing sea level and sediment supply, and to adaptive management designed to counteract undesired responses.
- Responses to external drivers occur at different spatial and temporal scales.
- Tracking responses at different scales is necessary to identify thresholds that trigger management actions.
- Therefore, the WRMP should support long-term data collection of leading indicators in order to define a numerical threshold at which a management or regulatory action could be triggered, to prevent/minimize tidal wetland loss or otherwise enhance tidal wetland conservation and recovery.

- The WRMP science framework must provide the minimum organization necessary to define non-linear relationships and changes in tidal marsh distribution, abundance, diversity, and condition at different scales of space and time.

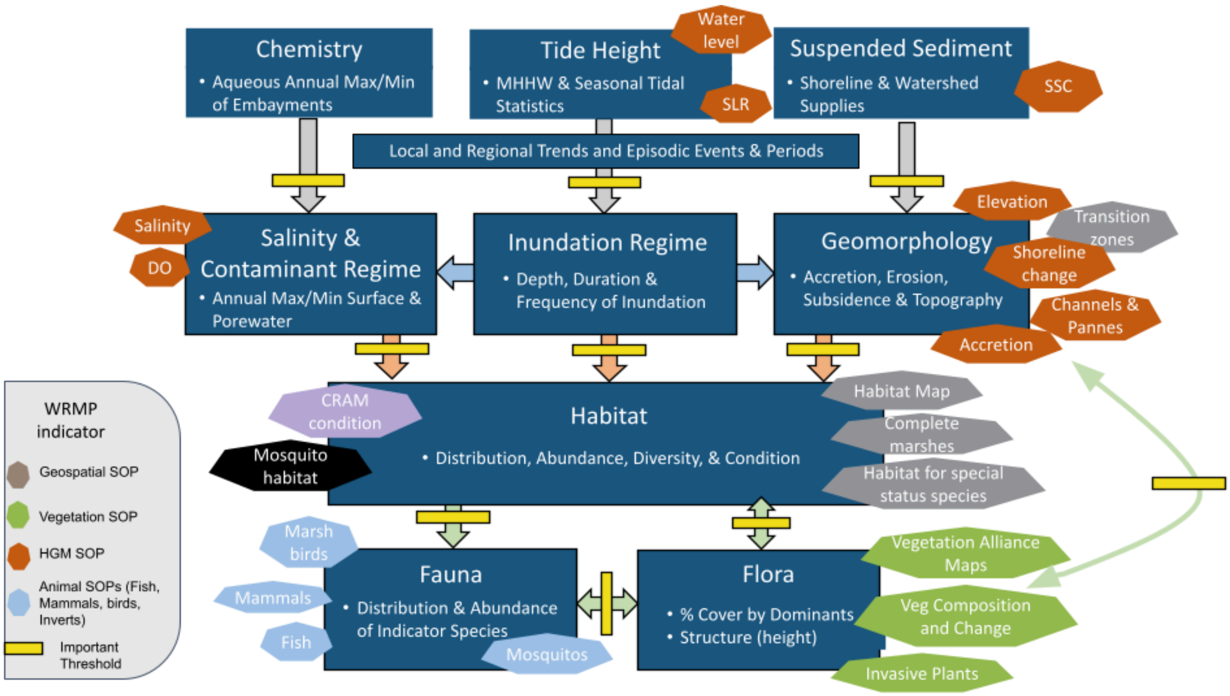

Figure 1. Overall conceptual model of the relationships between abiotic and biotic drivers and features of wetlands and corresponding WRMP indicators. The indicators are described in more detail in Standard Operating Procedures (SOPs) grouped by topics including Geospatial, Vegetation, Hydrogeomorphic (HGM) and Animal/Fauna. (Note CRAM in figure refers to California Rapid Assessment Method)

Based on this logic, the 2020 WRMP Program Plan established numerous science priorities for near-term (3-5 year) implementation that reflect the WRMP Guiding Questions. These priorities have guided the subsequent work of the TAC and its workgroups:

1. **Conduct regional baseline and subsequent routine surveys and inventories of the distribution, abundance, diversity, and condition of tidal wetlands throughout the region**, using existing tools and metrics to the extent practicable and new tools and metrics where necessary.

    - Status: In December 2023, the WRMP released a Baylands Landmark Map 2020 that represents the first updated mapping of the abundance and distribution of bayland habitats in the lower SFE since 2009. The WRMP will re-map bayland habitats every five years according to the procedures established in the WRMP SOP for Indicators 1 and 3 (Geospatial SOP, see Section 3.1.1 below). This monitoring plan and its associated SOPs describe how the WRMP will assess tidal wetland diversity and condition.

2. **Establish the WRMP Monitoring Site Network** to guide the collection of new data (and synthesis of existing data) to address the Guiding and Management Questions, especially science priorities 3-5 below.

    ○ Status: In January 2023, the WRMP TAC released the WRMP Priority Monitoring Site Network Memo, which elaborates upon the spatial monitoring framework in the Program Plan and describes and maps out the Benchmark, Reference, and Project Sites that form the WRMP's initial priority near-term monitoring site network. The monitoring activities proposed in this Monitoring Plan largely reflect the geographic priorities, sites, and networks in that memo.

3. **Conduct repeated surveys (detect change) of living organisms and their habitats (indicators)**, and standardize the metrics and reporting for indicators that are common to projects and baseline/subsequent ambient monitoring, across the range of project designs and restoration practices.

    ○ Status: As of December 2023, the WRMP has developed SOPs for the monitoring of geospatial, hydrogeomorphic, vegetation, fish & fish habitat, and people & wetlands indicators developed by the TAC and its workgroups. This Monitoring Plan proposes a strategy for where and how these SOPs should be implemented over the next 3-5 years.

4. **Analyze data on the relative roles of estuarine and upland/watershed sources of sediment** to counter the threats of marsh drowning, mudflat loss, and shoreline erosion driven by sea level rise.

    ○ Status: The WRMP is coordinating with the Sediment Workgroup of the SF Bay Regional Monitoring Program (Bay RMP) to identify, review, and fund sediment studies that bridge the management questions of both programs. These studies include work by the USGS to assess how tides, waves, and currents mediate sediment flux between marshes and adjacent mudflats/shallows, modeling to estimate sediment loads from key watersheds, and estimates of accretion volumes along a spectrum of WRMP sites.

5. **Assess the broad range of interactions between people and wetlands that should be monitored for the safety of people and the health of the wetlands.** This process should ensure integration of flood control and mosquito and disease vector control into project planning and assessment, and similarly integrate wetland restoration into flood control planning. This science priority will be modified in the near future to include priorities identified through the People and Wetlands Workgroup, which will integrate the priorities of frontline communities and tribes.

    ○ Status: In October 2022, the WRMP established a People & Wetlands Workgroup to help align program science with the priorities of vulnerable environmental justice and frontline communities. As of July 2023, the workgroup has identified wetland benefits and human/wetland interactions that are key for the WRMP to monitor for human safety and well-being. These are shoreline protection, water quality, public access, opportunities for stewardship, knowledge production and transmission, and cultural and spiritual activities. The workgroup will develop SOPs for monitoring aspects of these benefits/interactions, including the information needed to integrate them into a future iteration of the monitoring plan. The People & Wetlands Workgroup also produced two new and one revised Management Question, regarding these benefits/interactions that will guide SOP development. These questions were approved by the Steering Committee in June 2023.

1.2 Purpose and Duration of the Monitoring Plan

The Monitoring Plan proposes and describes the what, why, how, where, and when of program monitoring will begin over the very-near-term (1-2 year) and near-term (3-5 year) time frames, in addition to some topics that will be explored and expanded depending on resource availability. It forms the foundation of near-term WRMP implementation strategies for funding, administration, and regulatory alignment, as well as longer-term (5+ years) strategies to expand the program's spatial and temporal coverage. The intended audience for implementation of this Monitoring Plan is the WRMP TAC and Steering Committees, science and program partners including land managers, project proponents and funders, and regulatory and resource agencies. Over time, iterations of the Monitoring Plan are expected to reflect shifts in management needs, monitoring questions, program science priorities, restoration geography, and more.

- **WHAT**: The Monitoring Plan describes the information products that the WRMP will develop to support science-based decision-making by the region's tidal wetland conservation and restoration participants. These products include interactive online maps of tidal wetland abundance, distribution, and condition; status and trends analyses of key wetland indicators across multiple scales of space and time; and assessments of how tidal wetland restoration projects are evolving towards target functions.

- **WHY**: The Monitoring Plan provides the technical justification for proposed monitoring activities, including how the information products address the WRMP's guiding, management, and monitoring questions. It provides examples of information products that can be used by program partners including but not limited to land managers, project funders, regulators, and frontline communities.

- **HOW, WHERE, and WHEN**: The Monitoring Plan describes how the WRMP will develop the information products, including through SOPs (Standard Operating Procedures) developed by the TAC and its workgroups to guide new data collection and analyses of new and legacy/existing data. It proposes specifics for where and when new data should be collected and legacy/existing data should be leveraged to support proposals for future program funding and monitoring permissions from land owners. The Monitoring Plan is designed to be used in concert with the SOPs which provide recommended methods for different tiers of effort to measure indicators; **it is important to note that those SOPS are not intended and should not be interpreted as prescribed monitoring for regulatory permits**.

1.2.1 Types of Questions Addressed by Monitoring

In addition to the Guiding and Management questions described above, the WRMP is designed to address a range of related questions:

- **WRMP Monitoring Questions**: Consistent with the WRAMP framework, the WRMP Monitoring Questions are derived directly from the WRMP Guiding and Management Questions, and are meant to be answered by (usually) quantitative and (less frequently) qualitative measurements of indicators. Some monitoring questions can help answer multiple Guiding and Management Questions, especially if they address key drivers of tidal wetland abundance, distribution, and condition. For example, the frequency, depth, and duration of inundation in tidal wetlands is a fundamental driver that helps to govern sediment flux between the wetland and tidal waters, hydrologic residence time, surface and subsurface salinity and biogeochemistry, vegetation establishment and succession, support for aquatic biota, and other key functions of management interest (see the conceptual models in Appendix A of the WRMP Program Plan). Therefore, answering the question "*How do tidal inundation regimes differ throughout the estuary's tidal wetlands, and are they muted, choked, or otherwise different from source tides?*" by monitoring tidal inundation helps to address a broad suite of Guiding and Management questions. The updated WRMP Monitoring Matrix shows the relationships between Guiding/Management questions, Monitoring Questions, Indicator name and numbers, and approach. This nomenclature is adopted in the Monitoring Plan to reflect which Management and Indicator numbers are addressed in each section.

- **Questions from regulators**: In the lower SFE, projects that could result in impacts to tidal wetlands, waters, and biota (including tidal wetland restoration projects) typically require permits from six regulatory agencies: the US Army Corps of Engineers, US Fish and Wildlife Service, National Marine Fisheries Service, SF Bay Regional Water Quality Control Board, SF Bay Conservation and Development Commission, and California Department of Fish and Wildlife. Each agency has distinct and often overlapping authorities and frequently conflicting priorities related to environmental concerns such as fill placement, hydrologic alterations, habitat conversion, water quality, and the protection and recovery of native and special-status plants, fish, and wildlife. In order to issue permits, these agencies need answers to questions about how proposed projects will change environmental conditions within a site and its landscape. The answers to these questions help inform permit findings and conditions related to impact analysis, performance measures, compensatory mitigation requirements (if necessary), and other regulatory concerns. WRMP staff have developed a Regulatory Needs Assessment (Appendix 1) that outlines how the program can help improve the efficiency and efficacy of permit-required monitoring through standardized methods of data collection, management, and analysis.

- **Questions from tidal wetland restoration project sponsors and funders:** Public agencies such as the USEPA, California Coastal Conservancy, and San Francisco Bay Restoration Authority fund the majority of tidal wetland restoration projects in the region. These agencies typically disburse funds through competitive grant programs that must assess the relative strengths and weaknesses of numerous project proposals (the sum of money requested by applicants typically exceeds available funds). Typical criteria for proposal funding include the likelihood and timeframe within which a project will achieve its intended restoration targets, if the project is in a landscape position that is well-suited for habitat restoration, and how the project is likely to affect adjacent built/natural communities and past/likely future projects. In the absence of coordinated regional monitoring of the region's baylands landscapes and the factors that drive their distribution, abundance, and condition, it can be difficult for project funders and sponsors to make well-informed decisions about how proposals address these criteria. Once projects are in the ground, this absence also creates challenges for adaptive management by making it difficult for implementers to assess if observed changes are due to site-specific conditions or more regional drivers. The WRMP will help fill this gap, and increase the return on public investment in habitat restoration through improved science-based decision-making.

1.2.2 Relationship Between the WRMP and Existing Regional Ambient Monitoring, Project/Permit-Required Monitoring, and Special Studies

Partners in the SFE tidal wetland conservation, management, and restoration enterprises invest considerable resources of time, personnel, and funds into existing monitoring programs and projects throughout the region. These investments generally fall into three distinct categories, with limited overlap: ambient monitoring, project/permit-required monitoring, and special studies:

- *Ambient monitoring:* Ambient monitoring tracks the long-term status and trends of key background (external to project) conditions, often across broad spatial scales. Examples of ambient monitoring in SFE include monitoring of tidal water levels (NOAA) and suspended sediment concentrations (USGS) along the spine of the estuary, water chemistry and toxicity within SFE (Bay RMP), and regular satellite imagery/data collection of the region through platforms such as Landsat (NASA) and Sentinel-2 (ESA). The drivers of ambient monitoring can vary, and are often tangential to how the resulting products are utilized by end users. For example, the US Department of Agriculture implements the National Agriculture Imagery Program (NAIP) program to track acreages of crop production, but the imagery is often used by SFE tidal wetland conservation colleagues as a source of aerial imagery. Since ambient data are not usually collected for the express purpose of monitoring tidal wetlands, it can complicate the use of these data to track changes in wetland distribution, abundance, and condition across different scales of space and time. The WRMP will expand ambient monitoring in the region via targeted collection of key regional-scale (Section 3), subregional-scale (Section 4), and site-scale (Section 5) biotic and abiotic indicators. By filling key spatial and temporal gaps in ambient monitoring, the WRMP will facilitate more cost-effective monitoring of existing tidal wetlands and tidal wetland projects. For example, regular remote sensing and mapping of regional tidal bayland habitats, elevations, and vegetation will allow for these conditions to be tracked across multiple tidal wetlands (including restoration projects) at the same time, which can in many cases reduce or eliminate the need for land managers and projects to fund and implement their own remote sensing and mapping. The WRMP's expansion of ambient monitoring will also provide program partners with a more comprehensive and nuanced perspective on how climate change and other landscape-scale drivers are affecting physical and ecological conditions throughout the estuary.

- *Project/permit-required monitoring:* Project monitoring typically tracks the status and trends of select indicators across limited scales of space and time. In SFE tidal wetlands, the scope of project monitoring is often governed by provisions in permits granted by regulatory agencies, CEQA documents, and related environmental documents (see "questions from regulators'' in Section 1.2.1 above). The goal of these provisions is to ensure that projects that impact and/or restore tidal habitats achieve their intended outcomes. For example, tidal wetland restoration projects in the region are frequently required to monitor hydrology, sediment accretion, and vegetation communities within a project site for five to ten years after implementation. Since projects are implemented by different partners with varying resources, and can have different regulatory requirements and performance measures, monitoring is typically not coordinated between projects. This makes it difficult to compare projects to each other, and to assess projects against a backdrop of changing ambient conditions. The WRMP is intended to reduce the amount of time, money, and effort that individual projects must invest in site-specific monitoring by implementing coordinated, consistent monitoring across multiple spatial scales that can fulfill permit requirements. As documented in the WRMP Regulatory Needs Assessment (Appendix 1), permit-driven project monitoring almost always requires collection of several metrics (e.g., relative area of habitat types, vegetation cover, marsh elevation) that the WRMP will collect at a regional scale and can provide to projects to fulfill their project monitoring needs. In addition to this enhanced ambient monitoring/mapping, the WRMP will implement new coordinated data collection at select existing and new tidal wetland restoration projects. Using conceptual models, empirical models, and best professional judgment, monitoring at targeted locations can substitute for monitoring across a suite of locations. This can reduce and in some cases potentially eliminate the need for project proponents to fund and implement specific monitoring activities. For example, WRMP monitoring of suspended sediment within a tidal channel that feeds several tidal wetland restoration projects can reasonably represent suspended sediment concentrations at those sites.
- *Special studies:* Special studies also typically track the status and trends of select indicators across limited scales of space and time, but often do so in a manner that attempts to link observations between particular locations and ambient conditions, and/or answer specific questions distinct from long-term, regional analyses of status and trends. Special studies can address specific project types (e.g,. SFBRA projects, beneficial reuse projects) or geographies

(e.g., frontline communities, areas with high wave action). They can also address specific events that can have a significant influence on tidal baylands abundance, distribution, and condition, including but not limited to:

- Wet winters, atmospheric rivers, Yolo Bypass activation, high Delta outflows
- Unplanned breaches of large diked baylands (levee failures)
- Significant fires in watersheds that contribute major amounts of freshwater and sediment to the baylands
- Major earthquakes or other seismic events

In some cases, special studies may be proposed to pilot a monitoring SOP to determine its utility and efficacy in tracking a particular indicator (or indicators) before implementation at a broader spatial or temporal scale. In other cases, special studies may be triggered by baseline monitoring, to identify specific drivers of change. Special studies in SFE tidal wetlands are often funded by opportunistic sources of funding (federal and state grants, regulatory enforcement funds, etc.) or programs such as the Bay RMP that sets aside funds each year for high priority studies. Examples of special studies include efforts by USGS to assess how waves and tides influence sediment flux between tidal wetlands and adjacent mudflats at China Camp and Whale's Tail South, periodic efforts by the State of the Birds consortium to assess the distribution and abundance of listed species such as Ridgway's rail (*Rallus obsoletus*) within SFE, and monthly monitoring of aquatic communities in the South Bay (UC Davis/City of San Jose). The WRMP will help coordinate special studies so that they can help fill key data gaps across space and time, and leverage existing and ongoing investments in regional, subregional, and site-specific monitoring. For example, the WRMP is working with the Bay RMP Sediment Workgroup to align USGS studies of sediment sources, transport, and loadings with WRMP indicators and priority monitoring sites. The WRMP is also coordinating with multiple special studies in the region, including the MAture REstoration Assessment (MAREA) Project funded by the National Estuarine Research Reserve Science Collaborative (Janousek et al. in-progress), and a national USGS project on coastal wetland vulnerability to climate change and sea-level rise (Osland et al. in-progress). In the longer term, the WRMP TAC will evaluate proposals for special studies through a standardized process similar to that of the Bay RMP.

The WRMP has limited initial funds to implement very-near-term monitoring, and is primarily using these funds to leverage and add value to existing ambient monitoring, project-specific monitoring, and special studies (see Section 2.2 and Figure 2, left). Specifically, the WRMP is (1) utilizing NAIP imagery to develop the first iteration of the Baylands Landmark Map 2020 (see Section 3.2), (2) synthesizing historical CRAM (California Rapid Assessment Method) data and implementing a new round of CRAM monitoring at select WRMP priority monitoring sites (see Section 5.1), and (3) expanding the network of sediment elevation tables-marker horizons (SET-MHs) in the region (see Section 5.2). Over time, the WRMP will grow its implementation funding, help realign funding for existing monitoring projects and programs, fund/implement an increasing proportion of ambient monitoring, project monitoring, and special studies, and coordinate these efforts at a regional scale (Figure 2, right).

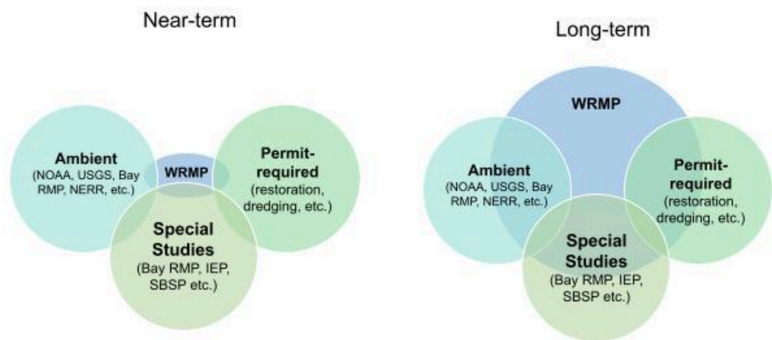

Figure 2. Near-term (left) and longer-term (right) vision of how the WRMP intends to fund, manage, and coordinate ambient monitoring, project monitoring, and special studies.

1.2.3 Relationship between WRMP Monitoring & Regional Modeling Efforts

With the increasing costs of monitoring coupled with the refinement of management questions that extend outside the spatial and temporal coverage of field data, a coupled modeling and monitoring program is needed to help hone model accuracy and identify areas where additional monitoring data are needed. Integrating modeling and monitoring can help the WRMP be more cost efficient, more adaptable, and allow for more timely answers to pressing questions.

For example, incorporating sediment data into a sediment model could simulate how sediment accretion/erosion might vary within/around different habitats/Bay regions under a range of changing conditions (for example future watershed flow and sediment loads, sea level rise, evolving tidal marsh area, and shifting Bay hydrologic regime). Due to time and expense, these types of management questions cannot be addressed through monitoring alone. In areas where the model uncertainty is highest, monitoring resources could be allocated to those locations to help improve the model.

<u>Nutrient Management Strategy</u>

The WRMP will benefit from ongoing collaboration and coordination with the San Francisco Bay Nutrient Management Strategy (NMS) and generally with the Bay RMP Sediment Workgroup to ensure that WRMP work products are coordinated with other regional efforts and to take advantage of the strengths of the various organizations in helping to answer the Guiding and Management questions for the WRMP.

The San Francisco Bay Nutrient Management Strategy (NMS) is a regional initiative for developing the science needed for informed decisions about managing nutrient loads within the Bay in response to the apparent changes in the Bay's resilience to nutrient loading. Some examples of the work of the NMS includes water quality monitoring and sediment monitoring and modeling using both field methods and remote sensing to estimate turbidity throughout the Bay. The NMS regularly collects data from a network of sensors in the South Bay to measure turbidity, salinity, and dissolved oxygen.

Bay RMP Sediment Workgroup

The efforts of the Bay RMP Sediment Workgroup are focused on increasing our understanding of sediment processes to inform management practices into the future. Tidal wetland restoration can utilize natural processes to mobilize and redeposit emplaced sediment to vertically build marshes, mudflats, and baylands. Consequently, the Bay RMP Sediment Workgroup places a high priority on monitoring and modeling processes that will inform management and restoration of tidal wetlands.

The Bay RMP Sediment Workgroup formulated five Sediment Management Questions to guide and prioritize future modeling and monitoring studies on sediment transport processes within the Bay. Of these questions, the first two focus on dredging and sediment placement, sediment quality, and their effects on habitats and species. The other three questions focus on the physics of sediment in the Bay—quantity, movement, and deposition, particularly on tidal marshes—and are the primary questions relevant to this monitoring plan. Table 1 shows a crosswalk between the WRMP guiding and management questions and the RMP Sediment Workgroup management questions 3-5.

Table 1. Crosswalk between WRMP management questions and RMP Sediment Workgroup management questions 3-5

		RMP Sediment Working Group Management Questions		
WRMP Management Questions		MQ3 - What are the sources, sinks, pathways, and loadings of sediment and sediment-bound contaminants to and within the Bay and subembayments?	MQ4 - How much sediment is passively reaching tidal marshes and restoration projects and how could the amounts be increased by management actions?	MQ5 - What are the concentrations of suspended sediment in the Estuary and its subembayments?
WRMP GQ2 - How are external drivers (sea-level rise, development, changes in runoff/sediment supply) impacting tidal marshes?	WRMP MQ 2A - How are the elevations of tidal marshes and tidal flats, including restoration projects, changing relative to local tidal datums?		✔	
	WRMP MQ 2B - What are the regional differences in the sources and amounts of sediment available to support the accretion and tidal marshes and adjacent habitats?	✔		✔
WRMP GQ3 -What information do we need to better understand regional lessons from tidal marsh restoration projects in the future?	WRMP MQ 3A - Where/when can interventions, such as placement of dredged material, reconnection to watershed sediment supplies, and construction of living shorelines, help sustain or increase tidal marshes + flats?	✔	✔	✔

One example of an ongoing modeling project that is relevant to both Bay RMP and WRMP management questions is the expansion of the Delft Flexible Mesh (DFM) hydrodynamic model to dynamically model PCBs, contaminants of emerging concern (CECs), and sediment in San Francisco Bay (Jones et al. 2022). Under the current work plan, there are two anticipated outputs from this model that pertain to sediment information needs of the WRMP:

a. 3-D water column sediment concentrations near tributary mouths (distribution fields)
b. Rates of sediment accumulation in areas of interest on the margins

The model work plan includes efforts to compile data for the boundary conditions for sediment, and comparing bed elevation predictions with measured sediment accumulation rates.

The WRMP focuses on processes that occur within the marsh and on the mudflat itself with the assumption that the Bay RMP Sediment Workgroup will provide data on suspended sediment processes in the adjacent subtidal shallows. WRMP Benchmark sites can be associated with the complementary network of Bay RMP stations that monitor salinity and suspended sediment in the major subembayments.

A number of marsh models to predict the effects of sea level rise have been developed and applied in the SFE. A few examples include SLAMM (Mogensen and Rogers 2018) which uses functions of land elevation, tide range, and sea level rise to predict long term shoreline and habitat changes; CWEM (Morris et al. 2022) which uses a cohort model to estimate changes in elevation; and the Wetland Accretion Rate Model for Ecosystem Resilience (WARMER) is a 1-D model of elevation that incorporates both biological and physical processes of vertical marsh accretion (Swanson et al. 2014; Buffington et al. 2020).

In addition to ongoing modeling efforts, USACE is exploring strategic sediment placement using a combination of field observation and dynamic modeling for potential lessons and data sharing opportunities. Furthermore, the USGS conducts monthly cruises throughout the SFE to collect turbidity and salinity data.

2 Monitoring Plan Development

2.1 Relationship to Previous and Future WRMP Science Products

This Monitoring Plan operationalizes the WRMP science framework, which was first proposed in the Program Plan (WRMP 2020a) and expanded through the subsequent Benchmark Site Memo (WRMP 2021a), Fit-Gap Analysis Report (2021), and Priority Monitoring Site Network Memo (WRMP 2023a). The WRMP science team, including the TAC and its workgroups, produced this Monitoring Plan in parallel with SOPs for data collection, analysis, synthesis, and interpretation.

As the WRMP grows its funding resources and transitions from program planning to program implementation over the next three to five years, the Monitoring Plan and associated SOPs may have to be revised to reflect “ground-truthing” of the science framework. The TAC will revise these documents in coordination with the Steering Committee, consistent with the WRMP charter. In the longer-term, the TAC may also decide to revise the Monitoring Plan and SOPs to reflect shifts in program science priorities, information needs of the Steering Committee, funding resources, geographies, and other factors.

2.2 Near-Term Monitoring

To initiate program implementation, address key information needs, and fulfill SFBRA grant requirements, the WRMP science team (including the TAC) identified a suite of priority near-term monitoring activities for the program to implement over the next 1-2 years. The science team used numerous criteria to identify these activities, including but not limited to their ability to:

- Support broad regional assessment of the distribution, abundance, and condition of SFE tidal wetlands
- Address funder and regulator interest in evaluating restoration projects within a regional context
- Identify opportunities to develop WRMP monitoring methods and strategies to address required project monitoring and regulatory permitting requirements
- Address the near-term science priorities that are articulated in the 2020 Program Plan
- Leverage legacy data and existing data from ongoing ambient monitoring, project monitoring, and special studies
- Fill key data and information gaps across space and time
- Support a high return on investment and develop key information products with relatively minimal additional funds/effort (i.e., "picking the low-hanging fruit")
- Inform planned tidal wetland restoration and nature-based adaptation projects
- Pilot data collection and interpretation at various scales (regional, aerial imagery; rapid-assessment; and site-based)

The science team, in collaboration with the SC (and with approval from the TAC) selected three near-term monitoring activities that fulfilled these criteria, which are described at length in the WRMP Near-Term Monitoring Priorities Memo:

- Standardized analyses of regional wetland characteristics from the Baylands Landmark Map 2020, including calculations of:
    - Marsh habitat change, calculated by comparing Baylands Landmark Map 2020[2] (BCB) habitat coverage with 2009 BAARI mapping, with a focus on calculating gains due to restoration and losses in vegetated centennial marsh (strip/infill marsh) such as at SR 37 Strip Marsh East
        - Tracking where wetlands are located and how they are changing over time is a primary goal (Guiding question 1) of the WRMP.
    - Percent vegetated cover at Benchmark, Reference and Project Sites
        - Tracking decline in vegetated cover at Benchmark and Reference Sites has historically been an important indicator of marsh stability in the region. In contrast, tracking growth in vegetation is an important indicator at Project

[2] Name subject to change

Sites of restoration success. Methods for mapping change in unvegetated and vegetated habitats are outlined in the Hydrogeomorphic and Vegetation SOPs.

- Subregional- and Operational Landscape Unit (OLU)-scale maps of complete marshes (Indicator 4, defined in the Baylands Ecosystem Habitat Goals Update) and where projects can make key improvements in hydrological and ecological connectivity (e.g. infrastructure re-alignment)
    - Complete marshes connect across mudflat and marsh habitats to upland transition zones, allowing vertical migration space as sea-levels rise. Identifying complete marshes and opportunities for complete marshes aid in prioritization of highest return upland protection and marsh restoration and protection efforts in the region.

- Conduct California Rapid Assessment Methods (CRAM) assessments of WRMP Priority Monitoring Network Sites to:
    - Establish a baseline understanding of marsh condition at WRMP Network Sites
    - Facilitate change detection in scores over time (for sites that have been previously assessed using CRAM)
    - Evaluate WRMP Network Site CRAM scores relative to regional trends using established Cumulative Distribution Function estimates (CDFs) of regional wetland condition
    - Compare WRMP Project Sites to established Habitat Development Curves (HDCs) and see how they compare to Benchmark and Reference Sites
- Deploy Sediment Elevation Tables-Marker Horizons (SET-MHs) in underrepresented sub-regions and conduct region-wide SET-MH data collection at existing sites to assess where marsh elevations are and are not keeping pace with rising sea levels.

The monitoring described below in Sections 3, 4, and 5 will build upon these activities as funding allows.

2.3 Process with TAC, SC, and Working Groups

The WRMP Workgroups and the TAC are tasked with developing both monitoring methods/Standard Operating Procedures (SOPs) and a monitoring strategy/plan in order to answer the Guiding and Management Questions previously developed by the SC as part of the Science Framework. Monitoring questions were also previously developed as part of the Science Framework and referenced in the Program Plan's Monitoring Matrix.

In the future, the hope is that the Workgroups will continue to function to support the WRMP by providing scientific support to advise and prioritize ongoing scientific monitoring, similar to the function of workgroups in the Bay RMP.

SOP Development and Approvals. The science team comprising WRMP, SFEP, and RWQCB staff assembled workgroups specific to major topic areas and indicators (Geospatial, Vegetation, Hydrogeomorphic, and Fish and Fish Habitat) to develop monitoring methods/SOPs to answer the monitoring questions, and the Guiding and Management Questions. Workgroup members included science experts within the SFE with expertise in each of the topic areas. As the workgroups delved into monitoring questions for specific indicators, they made minor adjustments as needed to better address the Guiding and Management Questions. Each of the SOPs were developed by smaller subgroups within the workgroup with input and discussion, review, and approval by the larger workgroup. SOPs were then presented to the TAC for input, review, and approval and submitted to the SC for discussion and ratification. All TAC meetings are open to the SC and some SC members also participated in SOP input, review, and discussion.

The SOPs are companion documents to this Monitoring Plan in that they provide regionally agreed upon methods (the 'how') to accomplish the various monitoring activities described herein. Contents of the Monitoring Plan also include recommendations that have been derived from the SOP workgroups and the TAC as part of robust discussions about data gaps and opportunities to leverage existing monitoring. The Monitoring Plan was developed by the science team, workgroup members, and the TAC with input, review, and approval from both the TAC and the SC. A subsequent Implementation Plan will prioritize elements of this Monitoring Plan based on available funding and will be approved by the TAC and SC.

2.4 Product Summary

To answer the management and monitoring questions of the WRMP, the science team has identified a suite of indicators that can be monitored in SFE tidal marshes over time. Monitoring these indicators will generate data that can be interpreted and visualized in a variety of ways to answer various questions. For instance, geospatial data describing habitat distributions, landscape features, and change over time will be mapped across the region and can be visualized through an interactive online map. Alternatively, sub-regions or OLUs can be evaluated individually for analysis within a sub-scale or compared between scales. For instance, change in the marsh edge can be evaluated regionally to look at large-scale trends, within OLU's to look for correlations between edge- change and potential drivers, or between OLU's to identify localities at greater risk for marsh edge erosion. This monitoring plan points to priority information products that will be supported by the proposed monitoring activities, but the list of potential analyses and products can be much greater.

Along similar lines, the indicators the program plans to monitor can be summarized, synthesized and packaged into indices that can relate a variety of information in a condensed format. Interest in marsh function or services can be evaluated by summarizing metrics that relate to a common function. For instance, the California Estuarine MPA Monitoring Program has developed a functional condition assessment for sea-level rise amelioration and resiliency that combines across vegetation cover, marsh plain topography, sedimentation rates, CRAM scores, and upland migration area. Since these metrics will be monitored by the WRMP, it can derive a similar functional assessment. Similarly, monitoring data collected at Project and Reference Sites could be synthesized in a Restoration Performance Index similar to that developed for the National Estuarine Research Reserve system. The State of the San Francisco Estuary Report also utilizes numerous composite indices to describe estuarine condition; for example, the Bay Fish Index uses ten indicators to assess the condition of fish community health within SF Bay. The WRMP can use a similar approach for data collected in wetlands.

3 Regional-scale Monitoring Activities

3.1 Background

The goals of regional monitoring are to track patterns and trends in variables such as species and habitat distributions that may be responding to large-scale external drivers such as climate change, shifts in freshwater flows and sediment delivery, and other major shifts in resources. Though all data generated by the WRMP can be analyzed at multiple spatial scales, for purposes of this Monitoring Plan, "regional-scale" monitoring refers to Level 1 remote sensing and mapping activities as described in the WRAMP framework. Monitoring wetlands at the regional scale differs from site-scale (Level 2 and 3) monitoring in the breadth of coverage, data resolution, and types of information generated. This Monitoring Plan proposes regional, estuary-wide remote sensing and mapping of the distribution and abundance of three key WRMP indicators:

- Bayland habitats (including tidal wetlands, mudflats, and channels, shallow and deep subtidal waters, beaches, and non-tidal wetlands) and landscape features: (Funded, estimated completion Winter 2023)
- Bayland elevations, including elevations relative to local tidal datums (elevation capital)
- Bayland dominant vegetation alliances
- Bayland shoreline change analysis

Repeated, consistent remote sensing and mapping of regional tidal bayland habitats, elevations, and vegetation by the WRMP will allow for these conditions to be tracked across multiple tidal wetlands (including restoration projects) at the same time, which can in many cases reduce or eliminate the need for land managers and project proponents to fund and implement their own remote sensing and mapping. Due to their broad spatial scale, the WRMP expects the regional habitat, elevation, and vegetation maps to be utilized by a broad range of partners within and outside the program, such as flood managers, frontline communities, municipal planners, and decision-makers from transportation and utility infrastructure sectors.

3.2 Regional Habitat Map

The absence of regularly updated data describing habitat distribution and abundance makes it extremely difficult to track where wetland habitats are changing (e.g. growth, loss, migration), track regional progress towards bayland habitat restoration goals, or understand site-scale monitoring observations in the absence of regional context. The region's bayland habitats were last mapped in 2009, and since then, multiple large tidal habitat restoration projects have come online (e.g. Sears Point, Hamilton Wetlands, and thousands of acres of former commercial salt ponds in the North and South Bays). To fill this key information gap, the WRMP will develop an updated regional habitat map, known as the Baylands Landmark Map 2020, that will serve as the primary dataset for assessing change in tidal bayland typology, abundance, distribution, and diversity over time. This new map will provide a foundation for restoration practitioners, regulators, funders, and other program partners to measure progress against the region's tidal habitat recovery goals. It will enable them to assess site-specific restoration effectiveness over time, and account for localized impacts to tidal habitats from sea-level rise and other long-term, landscape-scale processes. Regular, consistent updates of this mapping will allow for site-scale observations of habitats and biotic/abiotic indicators to be considered within broader spatial contexts and enable the assessment of change in acreage and distribution over time. Regional habitat mapping and analyses will address a broad suite of WRMP monitoring questions approved by the Steering Committee, including:

- ***What is the distribution, abundance, diversity, and condition of tidal marsh ecosystems, and how are they changing over time? (All MQs, Indicators 1 and 3)***
- ***What are the elevations and elevation capital of the estuary's existing and restoring tidal wetlands? (All MQs, Indicator 2)***
- ***Where do tidal wetlands have space to migrate upslope? (MQs 1-3, Indicator 3)***
- ***Where do tidal wetlands support habitat diversity and connectivity, including "complete" marshes as defined by BEHGU? (All MQs, Indicator 4)***
- ***What is the distribution and abundance of tidal wetland habitats that can support special-status species? (All MQs, Indicator 5)***
- ***Where are tidal wetlands eroding landward and/or growing seaward? (MQs 2-4, Indicator 6)***

3.2.1 Approach and Methods

The WRMP is mapping bayland habitats consistent with v1.0 of the WRMP SOP for Indicators 1 and 3 (Geospatial SOP), which was approved by the WRMP TAC in March 2022. The BCB is funded by USEPA and scheduled for completion by the end of 2023; since it largely reflects conditions on the ground as of 2020, the WRMP will refer to it as the "2020 Baylands Landmark Map 2020." Consistent with the Geospatial SOP, the 2020 BCB will be considered a "Landmark Baylands Map" of entirely new mapping. Landmark mapping efforts will alternate every 5 years with a Baylands Change Update Map, where change detection methods will be used to capture changes from the most recent Landmark Baylands Map and update those areas with new mapping. In other words the WRMP will develop a Baylands Change Update Map representing the status of the baylands in 2025, followed by a new Landmark Baylands Map representing the status of the baylands for 2030, and so on.

3.2.2 Data Analysis and Products

The WRMP is using BCB data to develop a broad spectrum of related geospatial products to address specific information needs of program partners. For instance, early partnership with the Baylands Resilience Framework (BRF) is leading to the development of indicators of shoreline resilience that can be calculated for tidal wetland sites across the SFE upon release of the BCB. The BRF, funded by the Water Board, USACE, and Google, is deriving a suite of indicators calculated across all wetland sites in the SFE to support analyses of baylands resilience and guide planning for the beneficial reuse of dredged sediment to support tidal wetland enhancement and restoration. These indicators, based on outputs from the BCB, are of interest and utility to the WRMP and will be scripted for repeat analysis over time based on BCB updates. These indicators and analyses include mapping the distribution and abundance of:

- Tidal wetlands, including the classification of tidal wetlands into discrete units (sites) to facilitate site-scale analyses
- Connectivity between marsh patches and between marshes and upland transition zones
- Tidal mudflats and their characteristics
- High tide refugia within and adjacent to tidal wetlands such as marsh islands, mounds, and natural tidal channel levees
- Ponds/pannes in tidal wetlands

Further coordination and review of the BRF metrics by the WRMP TAC will lead to incorporation and repeat mapping of these metrics going forward. In addition, the WRMP will expand the analyses listed above of BCB data and hydrogeomorphic variables to derive additional products, including:

- Subregion/OLU-scale maps of the locations and distribution of tidal wetland habitat change, relative to previous mapping efforts (e.g. 2009 mapping for BEHGU). In particular, maps can illustrate habitat gains due to tidal wetland restoration projects, clarifying restored vegetated marsh, restored and still evolving into marsh and planned restoration
- Percent vegetated cover (and the related indicator UVVR, or unvegetated to vegetated ratio) at Benchmark, Reference and Project sites
- Regional and subregional analyses of changes in shoreline location within San Pablo Bay since the 1993 Shifting Shorelines Report (Beagle et al. 2015) and in the future at the regional scale with regions-wide mapping data (see Hydrogeomorphic (HGM) SOP and subsection therein on Shoreline Change Mapping)
- Identification of "Complete" marshes as defined by BEHGU, with a focus on connectivity between tidal wetlands, estuarine-terrestrial transition zones, and subtidal habitats
- Tidal channel network characteristics per site including network length and channel density
- Panne and pond dimensions and rates of change (and potential correlations with changes in marsh elevations)

Due to differences between the methods used to produce the BCB and the methods used to produce earlier SFE habitats maps (e.g., mapping done for the 1999 and 2015 Baylands Goals reports), comparisons between these data sets will provide useful estimates of the magnitude and direction of change, but may not support precise "apples to apples" comparisons, especially at finer spatial scales. Moving forward, the repeated implementation of the WRMP Geospatial SOP will allow for more precise change detection, comparison, and analyses.

3.2.3 Data Management, Reporting, and Visualization

The BCB data layers will be uploaded to the WRMP geospatial database, and made accessible to end users through an updated, dynamic EcoAtlas interface that will facilitate data queries across user-selected spatial scales of interest (e.g., parcel, polygon, shape, network, OLU, subregion, region). The interface will allow users to calculate metrics of interest, export these calculations in tabular form, and in select instances develop data visualizations such as charts and graphs (see Figure 3 below) to describe indicators of interest.

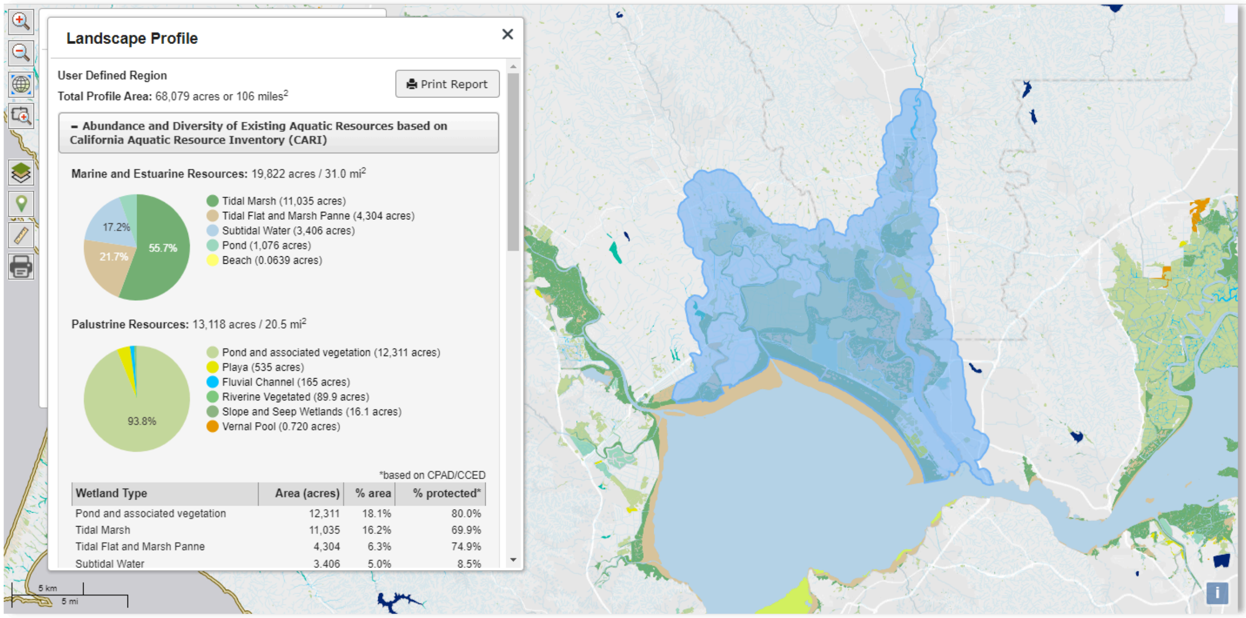

Figure 3. Example visualization of interface within EcoAtlas to show landscape habitats within the SFE.

3.3 Regional Elevation Map

Elevation is a fundamental driver of habitat distribution, abundance, and condition in tidal bayland habitats. Broad-scale elevation monitoring in the region's baylands is primarily done by municipal entities such as cities and counties that use the data to inform municipal planning, flood management, fire resilience, and related purposes. Municipal elevation data collection does not always consider tidal stage, vegetation height, and other confounding factors that can limit how useful the data are for WRMP partners. As the HGM SOP indicates, the most recent date of broad-scale elevation mapping varies throughout the region, resulting in a patchwork quilt of elevation data that creates challenges for accurate elevation mapping and analysis. To fill this key information gap, the WRMP will develop an updated regional map of tidal bayland elevations that will serve as a primary input into the regional habitat map (Section 3.2 above) and allow program partners to assess change in tidal bayland elevations and geomorphology over time. This new map will help support lines of inquiry from regulators and other project partners into observed changes in tidal bayland habitats (e.g., habitat drowning/downshifting), and allow for site-scale observations of indicators such as accretion, erosion, elevation change, vegetation, and sediment supplies to be considered within broader spatial contexts. Regional elevation mapping will address WRMP monitoring question: ***What are the elevations and elevation capital of the estuary's existing and restoring tidal wetlands? (All MQs, Indicator 2)***

3.3.1 Approach and Methods

The WRMP HGM SOP recommends the use of vegetation-corrected LiDAR to develop a Digital Elevation Model (DEM) of topography within SFE baylands. To develop the map of elevation relative to tidal datums (elevation capital), the WRMP will process this DEM using the tidal datums described under Section 4.2 below. The WRMP will develop maps of elevation and elevation capital every 5 years, concurrent with the development of the Baylands Landmark Map 2020.

3.3.2 Data Analysis and Products

In order to develop the Baylands Landmark Map 2020, the WRMP produced a DEM of bayland elevations throughout the entire lower estuary. This DEM is based on numerous LiDAR (Light Detection and Ranging) flights that cover different portions of the estuary, were collected at different times, and have different resolutions (see the Geospatial and Hydrogeomorphic SOPs for additional details). The BCB used this composite DEM and available tidal datum data to develop a map of elevation capital in the lower estuary's baylands. However, since these initial BCB maps of elevation and elevation capital are based on heterogeneous DEMs and incomplete tidal datum data (especially in the more upstream/landward portions of the estuary, where tide gauge data are limited), the precision with which they can be used to track elevation change is limited.

Moving forward, future BCB re-maps will utilize the SOP for Level 1 elevation mapping in the Hydrogeomorphic SOP to develop a unified, consistent DEM and elevation map of all lower SFE baylands. The BCB will apply updated tidal datums for the whole estuary (see Section 4.2) to this DEM to generate a unified, consistent map of bayland elevation capital. From the existing and new maps of elevation and elevation capital, the WRMP can derive estuary-wide maps of elevation-related metrics such as the percentage of sites that are below MHW, elevation skewness, and relationships between site elevations and mapped plant communities (see Section 3.3).

3.3.3 Data Management, Reporting, and Visualization

Due to the complex nature of the composite DEM used to develop the initial (2020) BCB, it is not a suitable product to share with the general public on the EcoAtlas platform or the WRMP geospatial database. However, once the WRMP develops its own DEM of the baylands consistent with the protocols described in the Hydrogeomorphic SOP, it can be made accessible on EcoAtlas and the geospatial database, and subject to data queries across user-selected spatial scales of interest (e.g. parcel, polygon, shape, network, OLU, subregion, region, etc.).

3.4 Regional Vegetation Map

Vegetation communities in SFE tidal wetlands are driven by numerous factors, though elevation, inundation, and salinity exert primary controls on the abundance, distribution, and composition of these communities. Vegetation is itself a fundamental driver of tidal bayland habitat condition and function, and is especially important for understanding habitat use by dependent wildlife. CDFW has been regularly mapping bayland vegetation in Suisun Marsh (VegCamp) since the late 1990s, but in the lower SFE, most vegetation mapping has been done on a site-by-site basis using a variety of techniques. In the last few years, with funding from NOAA, the Pacific VegMap team has developed county-scale maps of dominant vegetation alliances in the baylands of Marin, San Mateo, and Santa Clara counties; efforts to expand this mapping to Alameda, Solano, Napa, and Sonoma counties are ongoing. The South Bay has a more comprehensive mapping effort (Habitat Evolution Mapping Project,HEMP), with a decadal repeat analysis to track vegetation change over time, however mapping methods here differ from that of Pacific VegMap or VegCamp (Fulfrost 2021). Overall, the region lacks regularly updated, regionally consistent vegetation data to inform habitat restoration planning, regulatory policy-making, and other information needs. The WRMP will fill this key information gap by developing an updated regional map of tidal bayland vegetation that will serve as a primary input into the regional habitat map (Section 3.2 above) and allow program partners to assess change in dominant vegetation communities over time. This new map will help support lines of inquiry from regulators and other project partners into observed changes in tidal bayland habitats and dependent wildlife communities, and allow for site-scale observations of biota to be considered within broader spatial contexts. Regional vegetation mapping will address the WRMP monitoring question: ***What is the current distribution, extent, and diversity of dominant vegetation communities in the estuary, and how do these change over time? (All MQs, Indicator 7)***

3.4.1 Approach and Methods

The WRMP will use the methods recommended in the Vegetation Monitoring SOP to develop a regional map of dominant vegetation alliances and associations within SFE (not yet funded as of December 2023). The Vegetation SOP pairs remote sensing data with field data and machine learning to map dominant vegetation alliances and associations. The WRMP will use the same remote sensing data used to develop the Baylands Landmark Map 2020 (i.e. aerial imagery and LiDAR) for the vegetation alliance and association mapping.

3.4.2 Data Analysis and Products

The WRMP will develop a vector (polygon) map of the distribution and abundance of the 23 SFE estuarine wetland vegetation alliances and associations described by the Manual of California Vegetation. In subsequent re-maps timed with the BCB, the WRMP will calculate change in vegetation communities at the subregional/OLU scales and site-scale. Changes in vegetation alliance distributions will be tracked across elevational gradients within sites and across salinity gradients in the estuary and correlated with corresponding hydrogeomorphic data (e.g. inundation) to examine trends. The WRMP will map the vegetation alliances and associations every 5 years, concurrent with updates of the BCB. Repeated mapping will facilitate change detection and the identification of trends in vegetation cover, distribution, and abundance.

3.4.3 Data Management, Reporting, and Visualization

The WRMP will upload the regional vegetation map to the WRMP geospatial data catalog. The WRMP will also upload derived products such as vector/rasters describing vegetation change to the data catalog. Like the BCB and DEM, EcoAtlas will facilitate queries of vegetation data across user-selected spatial scales of interest (e.g. parcel, polygon, shape, network, OLU, subregion, region, etc.).

3.5 Regional Shoreline Change Map

Lateral changes in the position of the marsh edge are extremely important to monitor because marsh retreat is thought to be the chief mechanism by which coastal wetlands worldwide are being lost. While processes can be monitored at a site scale for more detailed accuracy, remote sensing is more appropriate for a regional scale and is an important indicator for highlighting locations in need of more site-specific monitoring. Regional mapping of shoreline change over time answers the monitoring question: ***Where are tidal wetlands eroding landward and/or growing seaward? (MQs 2-4, Indicator 6)***

3.5.1 Approach and Methods

In the longer term, the HGM SOP recommends converting the shoreline edge within the BCB to a line feature and mapping change with each mapping update using a tool such as the Digital Shoreline Analysis System (Himmelstoss et al. 2021).

Using the Baylands Landmark Map 2020, a bay-wide regional map of the shoreline can be estimated using methods outlined in the HGM SOP (WRMP 2023b). The shoreline is defined here as the vegetated edge using a combination of LiDAR and aerial imagery and object-based classification (WRMP 2021b). The WRMP will leverage a broad range of existing data sources to execute the SOP, including but not limited to:

- SFEI library of orthoreferenced historic aerials and UAV data
- 2003 Coastal Conservancy high-resolution air photo collection
- NAIP aerial photographs (2005, 2009, 2010, 2012, 2014, 2016, 2018, 2020, 2022, ongoing)
- Existing analysis of shoreline retreat at Whale's Tail (Alameda Creek Network) by Brian Fulfrost and USGS
- Existing analysis of shoreline retreat at Dotson Family Marsh (Wildcat Creek Network) by ESA
- Baylands Landmark Map 2020 products

A site-level map of shoreline change can also be mapped by using LiDAR, structure from motion (SfM), or RTK GNSS surveys to map the shoreline (WRMP 2023b).

Special Studies: In select site networks (Wildcat, Alameda Creek, Corte Madera), the TAC may consider analyzing shoreline change together with Level 3 marsh topography and wave data to develop finer-scale models of the mechanisms of marsh edge change. The TAC may also consider special studies of shoreline change during non-BCB years if environmental conditions (stormy winters with extreme wave action, high Delta outflow, etc.) indicate the potential for significant shoreline retreat.

3.5.2 Data Analysis and Products

Where are tidal wetlands eroding landward and/or growing seaward? The WRMP will answer this question by developing subregional- and OLU-scale maps of changes in shoreline location from remaps of the BCB. Site based estimates of shoreline change will be based on sequential mapping of the shoreline at the site-scale.

3.5.3 Data Management, Reporting, and Visualization

Like the BCB, the geospatial data layers describing shoreline position (polylines) will be accessed by end users through an updated, dynamic EcoAtlas interface that will facilitate data queries across user-selected spatial scales of interest (e.g. parcel, polygon, shape, network, OLU, subregion, region, etc.). The interface will allow users to visualize, calculate, and export metrics of interest, such as rates and directions of shoreline change.

4 Subregional-scale Monitoring Activities

4.1 Background

While SFE is a relatively shallow, partially-mixed estuary, dominant physical gradients (e.g., salinity) and localized features (e.g., local topography or riverine inputs) create variation in important physical parameters (Conomos et al. 1985). Monitoring these parameters at the subregional scale (representative locations of estuarine and watershed gradients proximate to WRMP priority monitoring sites) can provide information about conditions across the SFE and can additionally be related to parameters at various specific sites. Because the focus of the WRMP is improving management and restoration of tidal wetlands and because other programs focus on monitoring physical parameters in the main channel of the Estuary (e.g., Bay RMP), the WRMP will focus physical monitoring in the tidal sloughs and channels connected to the network of priority wetland sites identified in the WRMP Priority Monitoring Site Network Memo. As described in the Memo, the priority sites are nested within Operational Landscape Units (OLUs), thus sharing common watershed conditions, and distributed in OLUs throughout the estuary in the various subembayments, reflecting differences in estuarine position and physical attributes. Concentrating certain monitoring activities in a subregional location, central to an OLU network (e.g., tidal channels that flow into multiple WRMP monitoring sites) efficiently distributes monitoring effort that can both 1) fill gaps in regional monitoring that tracks ambient conditions over time and 2) contextualize and develop relationships between estuarine parameters and metrics monitored at individual sites (e.g., porewater salinity and marsh surface sedimentation; see methods below). Table 2 Below is a summary table of the various gauges and sensors locations and proposed locations within the SFE that are relevant to the WRMP.

This Monitoring Plan proposes subregional-scale monitoring of key abiotic indicators of tidal bayland habitat distribution, abundance, and condition including:

- Water levels (or water surface elevation)
- Surface water salinity
- Suspended-sediment concentration

This Monitoring Plan also discusses how the WRMP could build upon existing and proposed efforts to monitor dissolved oxygen SFE baylands in the future.

- Dissolved oxygen

Table 2. Existing and proposed multi-sensor gauges in WRMP priority monitoring sites at Benchmark and Reference and select Project site locations.

Network Name	Site Name	WRMP Site Type	Existing Data Collection Coverage				Proposed New Long-Term
			Water	Surface	SSC/Turbidi	DO	

			Surface Elevations	**Salinity**	**ty**		**WRMP Multi-Sensor Installation**
Suisun: Suisun Slough	**Rush Ranch**	Benchmark	X	X	X	X	
	Hill Slough (Existing)	Reference	X	X	?	?	
	Peytonia Slough Marsh	Reference					
	Hill Slough (Restoration)	Project	covered by existing Hill Slough installation				
	Wings Landing	Project	X	X	?	?	
San Pablo Bay: Napa-Sonoma	**Older Raccoon Island**	Benchmark					W
	Newer Raccoon Island	Reference					
	Bull Island	Reference					covered by new Brazos Bridge installation
	Brazos Bridge	Feeder Channel	X				W
	Pond 6A	Project					
	Napa Plant Site	Project					
	Dutchman Slough	Feeder Channel					W
	Cullinan Ranch	Project					covered by new Dutchman Slough installation
	Pond 3	Project					
	Pond 2A	Project					

	Steamboat Slough/Ringstrom Bay	Feeder Channel/Benchmark Site					W
	Tolay Creek	Feeder Channel					?
San Pablo Bay: Novato-Gallinas/West San Pablo Bay	**China Camp**	Benchmark	X	X	X	X	
	Outer McInnis Marsh	Reference					
	Hamilton Wetlands	Project	X	X	X	X	
	Novato Creek Mouth	Feeder Channel	X				W
	Carl's Marsh	Project	potentially covered by Novato Creek Mouth tide gauge				
	Sonoma Baylands	Project					
	Sears Point	Project					
San Pablo Bay: Wildcat Creek	**San Pablo Creek Marsh**	Benchmark					W
	Wildcat Creek Marsh	Reference					
	Dotson Family Marsh (Existing)	Reference					covered by new San Pablo Creek Marsh installation
	Dotson Family Marsh (Restoration)	Project					
South Bay: Alameda Creek	**Whale's Tail South**	Benchmark					W
	Cargill Mitigation Marsh	Reference					

	North Creek Marsh	Project					W
	Pond E9	Project					
Lower South Bay: Santa Clara Valley	**Older Warm Springs Marsh**	Benchmark					W
	Warm Springs Marsh	Project					
	Calaveras Point	Reference	X	X	X	X	
	Coyote Triangle Marsh	Reference					
	Pond A21	Project					
	Pond A17	Project					
	Pond A6	Project	X	X	X	X	

4.2 Water Surface Elevations, Inundation, and Rates of Sea Level Rise

Inundation is the difference between water surface elevations (WSEs) and ground surface elevations at a given location. The frequency, depth, and duration of inundation in tidally-influenced baylands is a fundamental driver of their condition, function, and resilience. Inundation mediates the movement and net flux of salt, sediment, nutrients, food, and other key environmental constituents between tidal wetlands and adjacent mudflats and open estuarine waters. It serves as a primary control of habitat access and availability for aquatic and terrestrial organisms, and together with salinity and substrate governs the distribution and composition of vegetation communities. Inundation therefore drives multiple key outcomes of interest to the WRMP, including but not limited to the evolution of tidal wetland restoration projects, ability of tidal wetlands to keep pace with rising sea levels, changes in the distribution/abundance/health of wetland biota, and where management and restoration activities

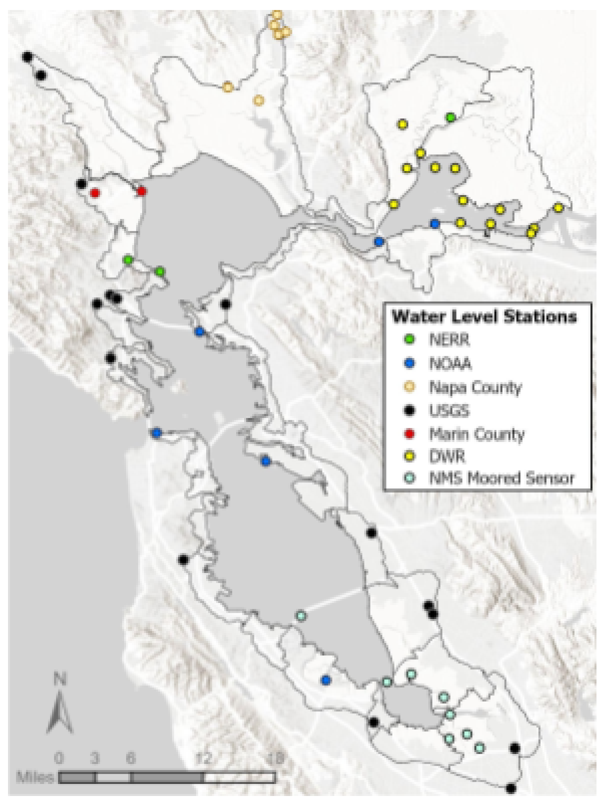

Figure 4. Map of active tide gauges/water surface elevation stations within the San Francisco Estuary.

can support tidal wetland resilience and ecosystem services.

Increases in WSEs and tidal inundation are expected as sea levels continue to rise. In the absence of adequate sediment supplies, rising sea levels can drive marsh edge erosion/retreat, marsh downshifting (conversion from high marsh to low marsh) and drowning (conversion of low marsh to mudflat), and prevent tidal wetland restoration sites from achieving their desired ecosystem functions (Stralberg et al. 2011; Schile et al. 2014; Swanson et al. 2014; Buffington et al. 2021). These changes in marsh functions can affect ecological functioning of marshes, and also result in the loss of protective functions that marshes can provide to upland habitats and communities. The ability to identify marshes susceptible to erosion, downshifting, and drowning may provide opportunities to apply early management actions to prevent further impacts.

Expanded monitoring of WSE within tidal wetland complexes off of the main stem of the SFE are essential for improving models of tidal datums that drive much of our regional-level mapping products (see sections above). Current estimates of tidal datums spanning tidal wetland complexes are interpolated from hydrodynamically modeled outputs ringing the SFE. These interpolated surfaces lack consideration of unique hydrodynamics and surface friction encountered as tidal action moves across the landscape. Accurate measures of WSE are needed to ground-truth and improve these models that underpin our ability to map relative tidal elevations in wetlands and accurately predict wetland habitat types.

Long-term monitoring of WSEs (and therefore inundation and rates of SLR) in SFE is primarily limited to NOAA-operated and maintained stations along the spine of the estuary, where timely and accurate data is necessary to support commercial shipping operations and public safety, with minimal data collection near shorelines and intertidal baylands. As of 2023, NOAA implements real-time data collection at six tide gauges in deep shipping channels along the main axis of SFE: Port Chicago, Martinez-Amorco Pier, Richmond, San Francisco at Golden Gate, Alameda, and Redwood City (Figure 4). As of 2023, continuous, long-term WSE monitoring in shallow tidal baylands outside the main estuarine axis is currently limited to:

- A network of tide gauges in Suisun Marsh managed by DWR to support water and salinity management operations
- A network of multi-parameter (WSEs, salinity, DO) gauges in the South Bay managed by SFEI to support the Nutrient Management Strategy
- A USGS tide gauge on Coyote Creek near Alviso
- Tide gauges operated by the SF Bay National Estuarine Research Reserve at China Camp and Rush Ranch
- Tide gauges on Novato Creek and the Napa River operated by the Marin and Napa County Flood Control Districts, respectfully

Multiple tidal wetland restoration projects also have tide gauges installed, but for the most part these deployments are intended to be temporary, with planned gauge removal once their permit-required monitoring periods are complete. Most of these bayland gauges reflect relatively recent (post-2017) installations, and utilize different procedures for data QA/QC, management, processing, and publication.

The geographic coverage provided by the estuary's network of existing tide gauges excludes many regions with significant acreage of existing tidal baylands and/or planned and existing tidal wetland restoration projects, such as the Napa-Sonoma baylands, Novato Creek and Petaluma River baylands, and the Richmond shoreline. The absence of reliable, continuous WSE, inundation, and SLR data in these areas creates challenges for tidal wetland restoration project planners, designers, regulators, and monitors, by obscuring one of the fundamental drivers of tidal wetland condition and function. Water surface elevation data gaps in the baylands can also create challenges for the region's flood management agencies, who must increasingly anticipate and respond to flood events driven by the confluence of extreme watershed storm flows on top of rising sea levels. Therefore, the overall goal of WRMP monitoring of WSEs, inundation, and SLR is to expand the spatial and temporal coverage of monitoring throughout the region's baylands, generate more accurate information for use by program partners, and address WRMP monitoring questions related to water levels, inundation, and sea level rise (SLR): ***How do tidal inundation regimes differ throughout the estuary's tidal wetlands, and are they muted, choked, or otherwise different from source tides? What are regional rates of sea level rise, and how do they vary throughout the estuary? (All Management Questions and Indicators 14,15)***

4.2.1 Approach and Methods

Table A4.1 in Appendix 4 describes existing and proposed new WRMP deployments of tide gauges throughout the estuary. Existing and proposed tide gauges within SFE are highlighted in table 4. New proposed WRMP deployments should be installed consistent with the protocols described in the HGM SOP, either as inundation-only installations or co-located with sensors for other priority indicators (e.g., salinity, temperature, dissolved oxygen, suspended sediment). Some new, permanent deployments are proposed for priority WRMP site networks that are poorly represented by the region's existing gauge network, where more local data is necessary to accurately assess inundation and SLR rates. Other deployments are proposed to be temporary/rotating special studies, to support calculating tidal datums within a WRMP monitoring site/network, establishing quantitative relationships between existing long-term water level sensors and a WRMP monitoring site/network, and/or assessing tidal exchange at new and evolving Project Sites. The precise length of temporary deployments will vary based on the use case. The justification for proposed new tide gauge installations in priority WRMP monitoring site networks is described in Appendix 4.

4.2.2 Data Analysis and Products

By expanding the spatial and temporal coverage of WSE data collection into SFE baylands, data from new long-term WRMP tide gauge installations will help answer the WRMP monitoring question: ***What are regional rates of sea level rise, and how do they vary throughout the estuary?*** By expanding data collection into numerous WRMP Benchmark, Reference, and Project Sites (and/or their tidal feeder channels), data from new long-term and short-term WRMP tide gauge installations will help answer the question: ***How do tidal inundation regimes differ throughout the estuary's tidal wetlands, and are they muted, choked, or otherwise different from source tides?*** WSE, inundation, and SLR products and requisite data analysis procedures are detailed in the HGM SOP, and comprise:

- **Calibrated time series WSE data** from all new WRMP tide gauge installations, accessed from a queryable database through the interactive map (see Section 4.6). This will allow users to directly query and download WSE data of interest, including temporal trends such as rates of sea-level rise or seasonal patterns due to freshwater flows.
- Calculation of **tidal datums** for all new WRMP tide gauge installations, especially upstream/landward bayland regions. These tidal datums will support restoration planning as well as regional geospatial analyses such as future revisions of the Baylands Landmark Map 2020 (see Section 3). See the HGM SOP for details about tidal datum calculation procedures.
- A **data collection report** for each new WRMP tide gauge installation that presents methods for stilling well installation, topographic surveying to establish NAVD88 elevations including QA/QC data, instrumentation deployed including specifications sheets, deployment descriptions (install dates, download dates, retrieval dates), field methods and records for converting water depth data to water surface elevation (including barometric adjustments if using non-vented pressure transducers) including QA/QC, photographs of stations, and other relevant installation and deployment attributes.

4.3 Surface Water Salinity

Estuaries such as SFE are distinguished from other coastal habitats by the mixing of freshwater and saltwater. Salinity is therefore a fundamental component of estuarine water quality that influences numerous physical and biological processes and is one of the primary drivers of the distribution, abundance, and condition of estuarine habitats and biota. Salinity plays an important role in the flocculation of suspended sediment, and drives patterns of estuarine circulation. Together with inundation, salinity helps determine the types of vegetation that can establish within tidal baylands, the composition of aquatic (benthic and demersal) communities (including native and listed fish species), food web resources for shorebirds and waterfowl, and other biotic responses of interest to land managers, resource regulatory agencies, and restoration practitioners. For these reasons, one of the near-term science priorities of the WRMP is to assess the influence of watershed flows of freshwater and sediment on tidal bayland habitats, especially regarding the ability of these habitats to keep pace with rising sea levels.

In the northern reach of the SFE, freshwater flow from the Sacramento and San Joaquin rivers results in a spatially and temporally variable salinity gradient that stretches from full marine conditions at the Golden Gate to tidal freshwater conditions in the Delta, with vertical stratification in deeper channels such as the Carquinez Strait. In contrast, the southern reach of SFE receives less than a tenth as much freshwater inflow as the northern reach, so salinities there are more uniform throughout and can be even greater than ocean water in summer due to evaporation. In both the northern and southern regions of SFE, large local watershed inputs can create subgradients of salinity off of the main estuarine axis; examples of these can be observed at the Napa River, Walnut Creek, Alameda Creek, and Coyote Creek among others.

Surface water salinity in a given tidal wetland is a product of numerous factors, including but not limited to its position along the estuary's main axis and any subgradients, its volume/frequency/duration of freshwater inputs, mixing patterns due to inundation/winds/currents, and evapotranspiration on the marsh surface. Since these factors can change over different scales of space and time, continuous (time series) salinity data is generally more useful than periodic grab samples in characterizing salinity status and trends. Like WSEs, (see Section 4.3 above), since it is neither logistically feasible nor cost-effective to continuously monitor salinity at every single individual wetland, salinity is typically monitored at key locations that can represent conditions throughout a broader area. This approach allows scientists to establish baselines and track change due to large-scale drivers such as shifts in freshwater inflow or saltwater intrusion due to SLR.

Like WSE data, most continuous salinity data collection in SFE is concentrated along the estuary's main axis, with the exception of Suisun Marsh and the South/Lower South Bay subembayments. USGS operates 13 continuous salinity gauges in SFE downstream of Broad Slough. Seven of these gauges are in Suisun Marsh/Bay and near the confluence of the Sacramento and San Joaquin Rivers to support water operations in Suisun and the Delta. The remaining six USGS gauges are located on the lower estuary's major bridges (Benicia, Carquinez, Richmond-San Rafael, San Mateo Bridge, Dumbarton Bridge) and at Pier 17 in San Francisco. CA DWR operates 28 continuous salinity gauges in tidal channels throughout Suisun Marsh/Bay, again to support water operations in Suisun and the Delta. Finally, the SFBNERR operates continuous salinity gauges at China Camp and Rush Ranch. With the exception of Suisun Marsh, salinity trends in most of the estuary's shallow baylands are poorly characterized, even in areas that support significant estuarine subgradients such as those listed above. Again, as with tide gauges, the relative lack of data from these areas creates challenges for the tidal wetland conservation and restoration communities, by obscuring one of the fundamental drivers of tidal wetland condition and function. Expanding the spatial scope of regional salinity data collection is critical to help modelers understand how rising sea levels, changes in watershed flows, shifts in water operations, and other impacts of climate change will influence salinity fields in SFE in tidal baylands outside the main estuarine axis. Therefore, the overall goal of WRMP monitoring of salinity is to expand the spatial and temporal coverage of monitoring in the region's baylands, generate more accurate information for use by program partners, and address WRMP monitoring questions related to salinity: ***How do surface water salinity fields differ throughout the estuary's tidal baylands? How are the primary and secondary salinity gradients in the estuary's tidal baylands changing over time? (Corresponding mainly to Management Questions 2-4 and Indicator 16)***

4.3.1 Approach and Methods

Salinity can be monitored via salinity-only gauges, or as part of a multi-parameter installation such as a CTD that simultaneously measures conductivity (which can be translated into salinity[3]), temperature,

[3] Electrical conductivity (typical units microsiemens/centimeter or uS/cm) is a normalized form of electrical conductance to account for measurement cell size. Specific conductance (typical units uS/cm at 25 degrees Celsius) is a normalized form of electrical conductivity to account for water temperature (additional details available in resources listed in the Appendix). Widely available sensors that measure electrical conductivity and temperature report these two parameters, which can then be related to salinity via various algorithms (e.g., Fofonoff and Millard Jr 1983).

and depth (WSEs). Table A4.2 in Appendix 4-2 describes existing and proposed new WRMP deployments of salinity gauges throughout the estuary. New WRMP salinity gauge deployments will be installed consistent with the protocols described in the HGM SOP, co-located with sensors for other priority indicators (e.g., salinity, temperature, dissolved oxygen, suspended sediment). This co-location approach increases the efficiency of field efforts to deploy and maintain these stations. New, long-term deployments are proposed for priority WRMP site networks that are poorly represented by the region's existing salinity monitoring network, where more local data is necessary to accurately assess the influence of changing watershed inputs of freshwater on bayland habitats. Proposed new salinity gauge installations in priority WRMP monitoring site networks are described in detail in Appendix 4.

4.3.2 Data Analysis and Products

By expanding the spatial coverage of salinity data collection into SFE baylands and along some of its major estuarine subgradients, the WRMP will help answer the questions ***How do surface water salinity fields differ throughout the estuary's tidal baylands?*** and ***How are the primary and secondary salinity gradients in the estuary's tidal baylands changing over time?*** Data from this monitoring will also help support modeling of future changes in salinity fields within the region's tidal baylands, to support conservation planning and help contextualize observations of biota at WRMP monitoring sites. Salinity products and requisite data analysis procedures are detailed in the HGM SOP, and mirror those for WSE data and other water quality indicators:

- **Time series salinity data** from all new WRMP salinity gauge installations, accessed from a queryable database through the interactive map (see Section 4.6). Users will be able to download data to analyze spatial and temporal trends, such as comparisons between wet and dry season hydrology (e.g. impact of watershed flows on freshwater delivery to baylands).
- Multiple TAC members have requested **raster files describing seasonal/annual salinity conditions** within SFE tidal baylands as a helpful tool to assess the response of biota such as fish and birds to changes in salinity. The WRMP science team will work with these TAC members and other interested program partners to develop procedures for developing these products.

4.4 Suspended Sediment Concentrations

The concentration of suspended sediment in the estuarine water column is one of the essential building blocks for accretion and vertical growth in tidal wetlands, helping to support their diversity and resilience in the face of rising sea levels. The SFE experienced heavy sediment loads throughout most of the 20th century due to watershed land-use changes, especially the legacy of hydraulic gold mining in the Sierra Nevada. In the 1990s, the estuary experienced a step decrease in suspended-sediment delivery from the Delta, likely due to the cumulative effects of watershed-derived sediment becoming trapped behind reservoirs in the Sierra (Schoellhamer 2011, Schoellhamer et al. 2018). Currently, roughly one third of the estuary's total supply of suspended sediment comes from the Delta, with the remaining two thirds coming from local tributaries such as the Napa River, Walnut Creek, Sonoma Creek, Alameda Creek, and San Francisquito Creek (Schoellhamer et al. 2018, Dusterhoff et al. 2021). Future supplies of sediment to the estuary are uncertain, though available data indicate that there will likely not be enough sediment to support the resilience of the region's tidal wetlands and existing/future restoration projects against rising sea levels (Dusterhoff et al. 2021).

For these and related reasons, one of the near-term science priorities of the WRMP is assessing the relative influences of estuarine- and watershed-derived sediment supplies on accretion rates in SFE tidal wetlands, and identifying where sediment supplies are and are not sufficient for tidal wetland elevations to keep pace with rising sea levels. This information can help program partners understand observed changes in tidal bayland morphology and ecology, develop tidal wetland restoration projects that are more likely to be resilient to climate change, adaptively manage existing wetland restoration projects, and support planning and permitting of wetland restoration and strategic sediment placement projects. Proposed WRMP monitoring of suspended sediment builds upon and leverages decades of investment by partners (especially participants in the San Francisco Bay RMP Sediment Workgroup) in monitoring the sources, sinks, and pathways of sediment in the estuary. To date, most of this work has focused on sediment dynamics along the estuary's main channel in deeper waters, and within its subtidal shallows and intertidal mudflats. More recently, this work has expanded to include special studies of sediment flux and elevation change between and within tidal wetlands and offshore tidal flats (Lacy et al. 2015, 2018, and 2019; Lacy and Thorne in-progress) at the China Camp and Whale's Tail South Benchmark Sites. The Bay RMP Sediment Workgroup is coordinating these projects with the WRMP science team, in recognition of the fact that the two monitoring programs have overlapping monitoring, modeling, and science questions related to sediment in tidal baylands (McKee et al. 2023). Bay RMP Sediment Workgroup monitoring questions include:

- *Are SFE marsh edges and shorelines undergoing net erosion or progradation?*
- *What actions can we undertake to increase deposition rates in restoration sites?*
- *Is large-scale marsh restoration likely to erode mudflats?*
- *What are the accretion/erosion rates and fluxes between individual existing marshes, mudflats, and shallow subtidal shoals?*

Multiple WRMP TAC members participate in the Sediment Workgroup, and the two programs will continue to coordinate suspended-sediment monitoring and related activities. Avenues of program alignment include, but are not limited to:

- Selecting monitoring indicators and locations that are of interest to both the WRMP and Bay RMP
- Utilizing shared SOPs (e.g., the HGM SOP) for data collection, analysis, and synthesis
- Bringing legacy and current Bay RMP sediment data into the WRMP data management platform
- Identifying funding opportunities for suitable studies
- Pooling funding resources to support priority monitoring activities

The overall goal of WRMP monitoring of suspended-sediment concentrations is to answer these questions: ***Where is there adequate suspended sediment to support rates of accretion that are equal to or greater than SLR?*** and ***How is sediment delivery to marshes mediated by storms, waves, and related factors? (These correspond to Management Questions 2-4 and Indicator 13)***

4.4.1 Approach and Methods

In most of SFE, time series measurements of suspended-sediment concentrations (SSC) are calculated from continuous observations of surrogate parameters. Because SSC is a measure of the mass of sediment contained in a known volume of water, continuous SSC measurement is intractable and surrogate parameters are used. Surrogate parameters include optical or acoustic properties of the water which are simpler to measure and can be related to SSC through statistical methods. The most-common surrogate parameter employed in SFE is turbidity, an optical measure of the relative clarity of the water. Turbidity sensor output must be calibrated to in-situ (i.e., site-specific) SSC using a robust calibration program of water samples and laboratory analysis. Because the WRMP and RMP seek to understand the movement and fate of sediment throughout SFE, measuring turbidity alone is insufficient and the additional steps to estimate SSC are necessary. As has been shown in the body of research on sediment dynamics in SFE (e.g., Schoellhamer et al. 2007, Lacey et al. 2020), SSC is heterogeneous (i.e., not constant) in space or time, and measurement of SSC in tidally influenced channels near the periphery of SFE is essential because (1) SSC varies between the main channel of the estuary and within the near-shore baylands and (2) sediment accretion in wetlands is affected by sediment delivery processes that can be measured.

The WRMP will monitor SSC through surrogate measurements of turbidity as described in the SSC SOP (Appendix 9 of the HGM SOP). Table A4.3 in Appendix 4 describes existing and proposed WRMP SSC monitoring locations throughout the estuary. New WRMP SSC monitoring sites will be co-located with sensors to measure other priority indicators (e.g., water-surface elevation, salinity, temperature, dissolved oxygen) to optimize maintenance costs. The WRMP has identified high-priority SSC monitoring sites that feature robust physical connections to watersheds that are poorly represented by the region's existing network. These proposed sites necessitate local data to accurately assess the influence of changing watershed delivery of sediment into bayland habitats. Some proposed turbidity monitoring locations also provide the opportunity to leverage legacy/historic monitoring by entities such as the Bay RMP, to help assess change in sediment concentrations over time. The proposed new SSC monitoring sites using turbidity sensors are detailed in Appendix 4 and include:

- Napa-Sonoma Network:
  - Brazos Bridge (co-located with an existing tide gauge and proposed salinity gauge)
  - **Older Raccoon Island** Benchmark Site (co-located with proposed tide and salinity gauges)
  - Dutchman Slough (co-located with proposed tide and salinity gauges)
  - Tolay Creek? Sonoma Creek?
- Wildcat Creek Network:
  - **San Pablo Creek Marsh** Benchmark Site (co-located with proposed tide and salinity gauges)
- Alameda Creek Network:
  - **Whale's Tail South** Benchmark Site (co-located with proposed tide and salinity gauges)
  - **North Creek Marsh** Project Site (co-located with proposed tide and salinity gauges)
- Santa Clara Valley Network:

- ○ Coyote Creek at Alviso Slough/Calaveras Point?? re-occupy and/or calibrate to SSC?

All of these new deployments are proposed to be co-located with tide and salinity gauges, and are intended to be close enough to proposed new or existing SET-MH installations (see Section 5.2) to facilitate site- and network-scale observations and analysis of how inundation, watershed flows, and SSC influence accretion and elevation change in tidal wetlands. The WRMP science team will coordinate with the Bay RMP Sediment Workgroup to align proposed SSC monitoring at these locations with the monitoring and modeling elements described in McKee et al. 2023.

4.4.2 Data Analysis and Products

By expanding the spatial coverage of SSC data collection into key estuarine subgradients and tidal wetland restoration regions, and by co-locating SSC data collection with tide gauges, salinity gauges, and SET-MHs, the WRMP will help answer the questions ***Where is there adequate suspended sediment to support rates of accretion that are equal to or greater than SLR?*** and ***How is sediment delivery to marshes mediated by storms, waves, and related factors?*** Data from this monitoring will also help support modeling of future changes in sediment sources, sinks, and pathways within the region's tidal baylands, to support tidal wetland restoration, strategic sediment placement, and related habitat enhancement/climate adaptation projects. SSC data products and analysis procedures are detailed in the HGM SOP; expected products include:

- **Time series turbidity and SSC data** from all new WRMP SSC installations, accessed from a queryable database through the interactive map (see Section 4.6). Users will be able to download data to analyze spatial and temporal trends, such as comparisons between wet and dry season hydrology (e.g. impact of watershed flows on sediment delivery to baylands, impact of summer wave climates on estuarine-derived SSC).
- Regional and site-scale analyses of **change in wetland bed elevations and accretion rates** (Indicator 12) in relation to SSC (Indicator 13) over multiple temporal scales (e.g. storm, season, water year)
- Improved estimates of **sediment delivery from select watersheds** (as presented in Dusterhoff et al. 2021)

4.5 Dissolved Oxygen

Adequate dissolved oxygen (DO) concentrations within tidal baylands in SFE is vital for aquatic life. A number of factors influence DO concentrations in SFE including spatial and temporal variability within the SFE due to air and water temperature variations, seasonal freshwater inputs, tidal cycles, nutrient inputs, and local geomorphic conditions. Many species, such as fish and aquatic invertebrates rely on DO for respiration, and low DO can result in impacts to biota such as the widespread marine mortality event associated with a harmful algal bloom in SFE during the summer of 2022. Low DO levels can be driven by numerous factors, including point and nonpoint source pollution, hydrologic manipulation of tidal wetlands and channels, and eutrophication. Limited tidal flushing in sloughs and channels can lead to low oxygen levels as the oxygen is consumed and not replenished; this effect can be exacerbated by elevated temperatures which can increase respiration rates and further contribute to low DO. The SFBRWQCB enforces a Total Maximum Daily Load (TMDL) for low DO and methylmercury in Suisun Marsh associated with duck club operations (SFBRWQCB 2019).

DO monitoring in SFE is implemented by numerous program partners including SFEI, USGS, and DWR. Outside Suisun, much of this monitoring is coordinated by the Bay RMP, which collects point-based samples within the SFE and reports the data online (ceden.waterboards.ca.gov). The USGS also has monthly cruises within SFE and measures DO through submersible sensors and discrete water samples at pre-established locations along the cruise route. SFEI operates numerous DO sensors in the Lower South Bay as part of the Bay RMP's Nutrient Management Strategy, and DWR operates numerous sensors in Suisun and portions of San Pablo Bay through its Environmental Monitoring Program (EMP). Outside of these regions, there is limited monitoring of DO in tidal wetlands and associated habitats around the SFE margins, and thus limited understanding of where inadequate DO may be impacting aquatic biota in and near tidal wetlands.

In 2024, the WRMP science team (including the TAC) will coordinate with the Bay RMP and discuss establishing a DO/water quality workgroup. Future iterations of this Monitoring Plan will reflect the recommendations of that workgroup. This work could include monitoring DO at the same subregional multi-parameter hubs identified in the WSE and salinity sections above, as well as special studies to better understand the spatial and temporal variability of DO within various channel and site types within a network. This work will address the WRMP Monitoring Question ***Where do tidal wetlands and channels provide adequate water quality to support fish and other aquatic life?*** **(Corresponding to Management Question 1, 3 and 5, and Indicator 18).**

4.6 Subregional Data Management, Reporting, and Visualization

Though the WRMP has yet to develop a complete data management strategy with associated infrastructure, there are certain key elements that will be necessary for the program to manage, analyze, and visualize subregional WSE, salinity, and SSC data. The first of these is an online **interactive map** that links to the data access portals for all currently operating tide gauges, salinity gauges, and turbidity/SSC sensors in the estuary (including new WRMP installations). This map will allow interested users to easily access data portals from WRMP partners such as NOAA, USGS, SFBERR, the region's flood control districts, and others from one central location. When users select a WRMP monitoring station, they will be able to view and download data from a new **queryable database** designed to manage WRMP data (and associated calibration/metadata). The database will allow users to view, select, and download data across the temporal and spatial scales of interest to the user. The database will support a limited suite of data visualizations that allow users to observe status and trends of selected indicators.

Relevant examples of interactive maps and queryable databases include SFEI's EcoAtlas and EnViz platforms, respectively. The WRMP will develop a data management strategy in 2024, in parallel with development of the first WRMP Implementation Work Plan. Over time, the data management system can be expanded to include direct access to external (e.g. USGS, NOAA, etc.) data and more powerful data analysis/synthesis/visualization tools.

5 Site-Scale Monitoring Activities

A fundamental component of a regional monitoring program is collecting monitoring metrics at a site-scale, and relating them across sites within a regional monitoring site network to develop a landscape-scale understanding of the function, variability and overall health of the system. For instance, while remote sensing of vegetation alliances can provide insights into the landscape-scale distribution and abundance of dominant vegetation over time, having "eyes on the ground" to track site-scale vegetation composition within dominant alliances, record shifts in distribution patterns that aren't evident through remote sensing, or observe other indicators of stress such as an early invasion is essential to inform restoration and adaptive management. Site-scale monitoring can be coordinated with and related to sub-regional and regional monitoring to most efficiently target monitoring metrics that must be observed at a site and are most useful for understanding patterns at broader scales.

In addition, the majority of monitoring currently underway in the estuary and required by permits at restoration sites occurs at the site-scale. By encouraging projects to monitor using consistent protocols and by leveraging data already gathered to comply with permits, the WRMP can benefit ongoing monitoring efforts and potentially alleviate monitoring burdens at individual project sites going forward to make monitoring more efficient while also improving regional understanding. The site-level monitoring described in this Monitoring Plan is intended for WRMP implementation within our Monitoring Site Network. However, it can be applied at other locations for additional benefits.

Finally, another goal of site-scale monitoring is to establish qualitative and quantitative relationships between metrics operating and measured at different spatial scales. For instance, site-scale monitoring can be used to ground-truth remotely sensed metrics. Co-locating sub-regional and site-scale monitoring can help identify predictive relationships between metrics such as suspended sediment concentrations and elevation change, inundation and vegetation communities, and many more.

There are a variety of techniques that can be used to answer WRMP Guiding and Management Questions at the site scale. This Monitoring Plan proposes site-scale monitoring of the following WRMP indicators:

- California Rapid Assessment Method (CRAM)
- Accretion/elevation Change
- Elevation distribution
- Vegetation cover
- Porewater/groundwater salinity
- Fish communities and fish habitats
- Bird communities

Though the site-scale monitoring metrics are outlined individually below, we envision co-locating and coordinating monitoring of these metrics within and across sites. Co-locating monitoring of multiple metrics will provide comprehensive information at the site-scale while helping to minimize monitoring costs by improving the efficiency of data collection. For instance, within a site, the WRMP proposes to establish replicate transects from the bayward edge to the upland transition with permanently-marked quadrats for monitoring vegetation cover (see the Vegetation SOP regarding transect distribution). In some cases, these quadrats would also be regularly monitored for elevation and porewater salinity and periodically monitored for accretion rates using marker horizons and sediment pads. At the start of a transect, groundwater wells will be continuously monitored for groundwater salinity and pressure transducers on the marsh surface will record inundation times. Data from this suite of point-based and transect level monitoring would then be related with data from nearby sub-regional gauges that measure water surface elevations, salinity, and other water quality parameters. Table 3 summarizes the suite of proposed site-based monitoring activities and how they can be co-located and distributed within and across different types of WRMP Monitoring Sites.

Table 3. Recommended site-scale monitoring activities and distribution at WRMP priority monitoring sites.

<table>
<tr><th></th><th>Benchmark</th><th>Reference</th><th>Project</th><th>Special study</th></tr>
<tr><td>CRAM</td><td>X</td><td>X</td><td>X</td><td></td></tr>
<tr><td rowspan="2">Point-based</td><td>SET-MH</td><td></td><td>sediment pins</td><td rowspan="2">temporary water level gauge - project sites</td></tr>
<tr><td>groundwater well: continuous salinity, water level</td><td>groundwater well: continuous salinity, water level</td><td>groundwater well: continuous salinity, water level</td></tr>
<tr><td rowspan="7">Transect-based</td><td>photo-points</td><td>photo-points</td><td>photo-points</td><td rowspan="7">transition zone veg cover - Benchmark Sites</td></tr>
<tr><td>vegetation cover</td><td>vegetation cover</td><td rowspan="6">initiated once minimum vegetation threshold met and/or coordinated with project</td></tr>
<tr><td>elevation (Total Station or RTK)</td><td>elevation (Total Station or RTK)</td></tr>
<tr><td>MH</td><td>MH</td></tr>
<tr><td>Sediment deposition</td><td>Sediment deposition</td></tr>
<tr><td>porewater salinity</td><td>porewater salinity</td></tr>
<tr><td>inundation (pressure transducer)</td><td>inundation (pressure transducer)</td></tr>
<tr><td>Fish</td><td>large-bodied, small bodied and marsh plain species sampling with abiotic indicators</td><td>large-bodied, small bodied and marsh plain species sampling with abiotic indicators</td><td>large-bodied, small bodied and marsh plain species sampling with abiotic indicators</td><td></td></tr>
<tr><td>Birds</td><td>TBD</td><td>TBD</td><td>TBD</td><td></td></tr>
<tr><td>Mammals</td><td>TBD</td><td>TBD</td><td>TBD</td><td></td></tr>
</table>

5.1 California Rapid Assessment Method (CRAM)

The California Rapid Assessment Method (CRAM) for Estuarine Wetlands is a scientifically robust Level 2 assessment tool. CRAM was developed by the California Wetland Monitoring Workgroup (CWMW) of the California Water Quality Monitoring Council to support cost effective, standardized stream and wetland condition monitoring for mitigation and restoration projects, and to support local and regional program monitoring across the state. CRAM has been subject to extensive peer review and iterative refinement since its development in the early 2000s. It is an established statewide program with an online public data management system that supports data transparency and public access to scientific information. It is managed by the Level 2 Committee of the CWMW, which meets quarterly to manage the technical and scientific aspects of the program.

CRAM assessments are conducted through field observations by trained practitioners who evaluate four universal attributes of wetland condition: buffer and landscape context, hydrology, physical structure, and biotic structure. Each attribute is assessed using two or three metrics, some of which have sub-metrics. The four Attribute Scores roll up into an Index Score of overall condition. CRAM condition scores can be compared within a wetland site and across many wetlands including at a sub-embayment, Bay wide, eco-regional, or statewide scale. CRAM assessments also identify key stressors that may be affecting conditions, and compile them in a Stressor Checklist.

The WRMP is using the CRAM module for estuarine wetlands to (1) establish a baseline condition assessment of its priority wetlands sites, (2) evaluate restoration project performance over time, and (3) assess the status and trends of overall ecological condition of wetlands across the SFE. To begin, the program is conducting a retrospective analysis of existing, historical CRAM data to characterize the overall ecological conditions of estuarine wetlands across the SFE by the WRMP's sub-embayment and priority wetland site types. This analysis will help program managers evaluate information gaps that will help them plan, refine, and adjust the near-term monitoring plans presented below. In the longer term, the WRMP intends for CRAM assessments to help resource managers evaluate the success of mitigation and restoration projects across the estuary by (1) comparing these projects to the expected habitat development curve for estuarine wetlands, and (2) serving as a tool to set management goals and track the relative proportions of estuarine wetlands in good, fair, or poor condition over time across sub-regional and regional scales.

Where practicable, the WRMP will co-locate CRAM assessment areas with other site-scale monitoring activities (such as vegetation transects) to help identify relationships between CRAM scores and other metrics. Once identified, these relationships can be used to glean information about non-CRAM Level 3 metrics at locations where a CRAM assessment has been conducted but other metrics have not been directly measured. Using these relationships, CRAM can serve as a triage mechanism that can trigger additional Level 3 monitoring when CRAM scores suggest undesirable conditions or a deviation from regional norms.

CRAM assessments will address the monitoring question: ***What is the condition of tidal marsh ecosystems, and how are they changing over time?*** (**Corresponding to Management Questions 2-4, and Indicator 11).**

5.1.1 Approach and Methods

Building upon the retrospective analysis of historical CRAM data (conducted during Fall 2023), the WRMP will collect 30 new CRAM assessments over the next 1-2 years, with a focus on assessing conditions at Project and Reference sites within the Priority Monitoring Site Network. These new assessments will in many cases establish baseline conditions at many marshes that have never been CRAMed before, and help fill spatial and temporal data gaps in the historical data set to capture a more robust picture of regional conditions.

The WRMP anticipates refining and adjusting the near-term monitoring plans over the next 3-5 years to optimize CRAM data collection to evaluate baseline conditions, project performance over time, and the status and trends of wetlands across the SFE. For example, a portion of future data collection could focus exclusively on Project sites, including Restoration Authority project sites, to better understand the condition of projects compared to ambient conditions, and to understand how wetland conditions within these projects change over time. Another potential data collection focus could be sites with existing CRAM data, to understand how condition at these sites changes through time, and help identify drivers of change. Another data collection focus could be capturing the status and trends of wetlands across the SFE, through a probability-based ambient survey sample frame and sample draw. Data from this effort could develop a new cumulative distribution function (CDF) estimate curve, which could be compared to the previous (2008) curve and compared to any future curves to evaluate change in condition at the regional scale. This approach would also provide the ability to compare any CRAM site to ambient regional conditions, and determine what percentile of condition that site is in at any given point in time.

These examples of future potential uses of CRAM data are not comprehensive, but are intended to illustrate the versatility and utility of CRAM within a broader monitoring framework. It is important to note that any of the data collection approaches described above can occur at any of the spatial scales described in this monitoring plan (site-scale, sub-embayment scale, or regional scale), and can be used to support ambient monitoring, project/permit-required monitoring, and to answer specific questions from special studies. For example, a special CRAM study might investigate how wetland condition changes in response to an environmental perturbation such as an extended period of drought, a period of extreme stream/river flows, or to sea level risen. As another example, CRAM could be partnered with Level 1 analyses, so that when Level 1 monitoring indicates a significant change (e.g. in area, elevation, vegetation cover), a CRAM assessment can quantify condition within the wetland, and help direct corrective action or additional detailed data collection.

5.1.2 Data Analysis and Products

The WRMP has identified CRAM as one of three priority near-term monitoring activities (see Section 2.2). This monitoring activity will utilize both existing historical data (entered in the eCRAM database) as well as new assessments collected by the WRMP and other agencies/organizations over the near term. CRAM data analyses and products over the next five years will focus on addressing the following priorities:

- **Analysis: Establishing a baseline understanding of marsh condition at WRMP Network Sites**
    - **Products:** Bar graphs that display the proportion of CRAM assessments in good/fair/poor condition for the wetland type (Benchmark, Reference, and Project) and for each sub-embayment, as a series of maps illustrating the spatial distribution of

assessments color-coded by good/fair/poor condition, and as a series of box-and-whiskers plots that illustrate the full range of scores, including the mean, median, 25th and 75th percentiles, and any outliers.

- **Analysis: Detecting change in condition over time (for sites that have been previously assessed using CRAM)**
    - **Products:** Graphical presentation of numeric CRAM scores (Index and Attribute scores) for each time period and identification of site-specific or spatial trends.
- **Analysis: Evaluating CRAM scores at WRMP priority monitoring sites relative to regional conditions using established Cumulative Distribution Function estimates (CDFs) of regional wetland condition (SCCWRP 2008)**
    - Products: Plots comparing CRAM scores for individual sites or for wetland types (Benchmark, Reference, and Project) against the CDF to visualize and quantify how the sites of interest compare to conditions across the region.
- **Analysis: Comparing WRMP Project Sites to established estuarine Habitat Development Curves (HDCs) to assess how they compare to Benchmark and Reference Sites**
    - Products: Plots comparing CRAM scores for WRMP Project Sites against the HDC to identify if each project is meeting the expected rate of improvement or maturation that is expected, and identify those projects where adaptive management is needed (Figure 5). The HDC tool can be used to evaluate if project sites are on track to reach tidal wetland condition goals relative to the age of the project. The program can also plot Reference and Benchmark assessment scores against the HDC to assess the distribution in score by site age.

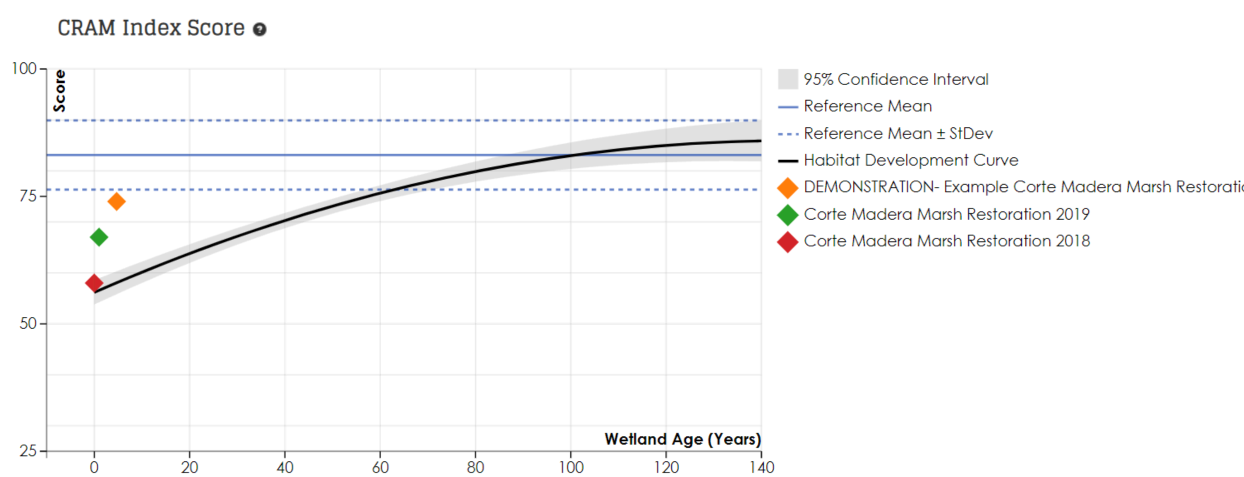

Figure 5. Statewide Estuarine Wetland Habitat Development Curve with example repeat assessment scores from an individual project plotted. The scores in this example all plot on or above the curve, indicating that this site is likely to continue to improve in condition, and ultimately reach reference condition (horizontal line).

5.1.3 Data Management, Reporting, and Visualization

The collection and management of CRAM data will follow the established statewide protocols for QA/QC, data management, and analysis, as these have all been well established and documented in the CRAM User's Manual (CWMW 2013b), the CRAM Technical Bulletin (CWMW 2019), and the CRAM QAPP (CWMW 2018)(CWMW, 2018). After field data collection, new CRAM data will be entered into the online eCRAM database (www.cramwetlands.org) and made publicly available (as allowed), enabling it to be visualized, queried and downloaded through EcoAtlas (www.ecoatlas.org), in addition to the WRMP data catalog. The newly-collected data will join the existing legacy data (collected between 2005 to present; see Appendix 3) that already is available on EcoAtlas.

5.2 Accretion/Erosion/Elevation Change - Sediment Elevation Tables - Marker Horizons (SET-MH)

Monitoring elevation change is key to assessing the ability of SFE tidal wetlands to keep pace with rising sea levels and other impacts of climate change and to answer the questions, ***How are the elevations of marsh plains (including high tide refugia) changing over time?*** and ***Where in the estuary are tidal wetland accretion rates keeping up with rates of sea level rise?*** **(Management Questions 2-4 and Indicator 12).**

There are a number of ways to measure how elevations in tidal wetlands change over time, including digital levels, total stations, and SET-MHs. Each of these methods provides similar levels of accuracy, but vary in cost, impacts to the marsh during sampling, and the ability to detect fine-scale change (Lynch et al. 2023). The HGM SOP (WRMP 2023b and link) outlines these considerations and in Benchmark Sites recommends the use of Surface Elevation Table–Marker Horizons (SET-MH) and networks, and proposes a nationally and regionally standardized approach for site-level installation and monitoring. Individual SET-MH sites measure total elevation change and accretion (Cahoon and Turner 1989; Cahoon et al. 2002) (Figure 6) and when individual sites are included as part of a regional network, they can provide broader-scale information on accretion, elevation change, and shallow subsidence (compaction or expansion). This approach facilitates site-scale change detection as well as regional comparisons between marshes to better understand the relationship between biogeomorphic conditions and relative sea-level rise rates (Callaway et al. 2012; Thorne et al. 2022; Saintilan et al. 2022).

Formalizing the existing network of SET-MH sites in the SFE and ensuring the funding for their consistent monitoring will increase regional, sub-regional, and project-level understandings of vertical accretion and elevation change. Data collected from individual SET-MH Benchmark and Reference sites can inform the expectations for accretion at nearby Project sites. The establishment of a broad network of SET-MHs could provide information that over time could decrease the need for individual projects to monitor these processes.

Near-Term Monitoring Priority :

The WRMP TAC and SC identified regional SET-MH monitoring at Benchmark Sites as a near-term priority of the WRMP, and are funding the installation of a new SET-MH at Older Racoon Island in the Napa-Sonoma Priority Monitoring Site Network. The program is also funding a new round of data collection at all SET-MHs in the region (Table 4).

In the longer term, the WRMP will integrate this SET network into a broader monitoring approach for understanding accretion using marker-horizon transects and total station leveling/RTK transects (see Section 5.3, Elevation Transects, below). Through this integrated network, the WRMP will assess trends in local accretion rates as well as relationships between elevation, vegetation cover, sediment supply and accretion rates. These relationships can help restoration projects anticipate likely accretion rates at their sites based on correlations with parameters that are easier to measure or already monitored (such as elevation, vegetation cover, and/or suspended sediment concentrations).

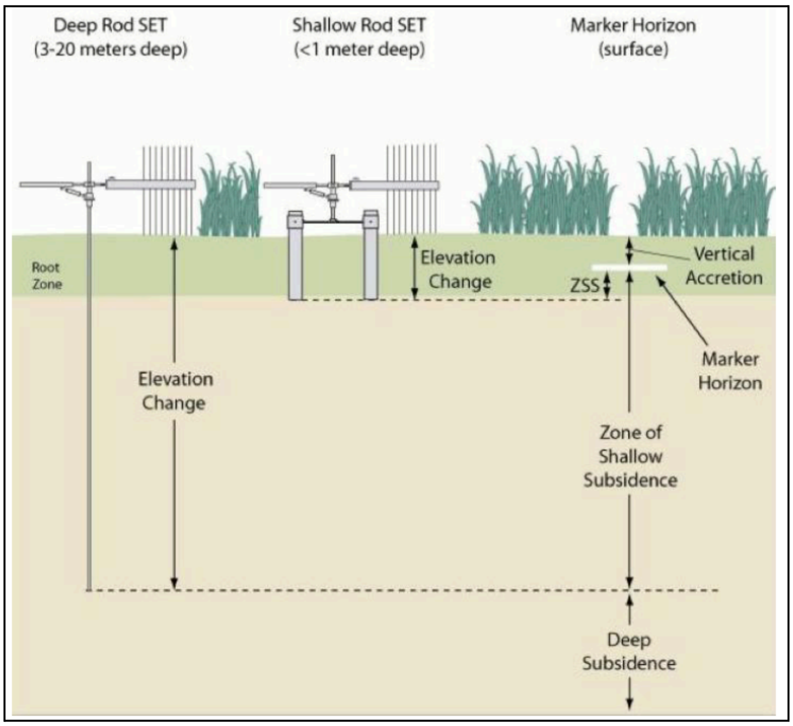

Figure 6. Diagram of Rod Surface Elevation Table (Callaway et al. 2013).

5.2.1 Approach and Methods

Consistent with the goals of this monitoring plan, the WRMP will leverage existing SET-MH sites established by the USGS, NERR, EBRPD, USFWS, and others. Detailed methods for the installation and monitoring of SET-MH sites are included in the HGM SOP (WRMP 2023b). The WRMP may monitor SET-MHs concurrently with other Level 3 data collection activities (e.g., elevation surveys, vegetation surveys, photopoint monitoring, etc.). The WRMP proposes to read each SET-MH annually, ideally in the fall outside the breeding season for special-status wildlife (e.g., Ridgway's rail, salt marsh harvest mouse) and with permissions and permits from relevant land managers and resource agencies.

The locations and status of existing and potential future SET-MHs in SFE are shown in Table 4 and Figure 7. Recommended future SET-MHs within and outside of the Priority Monitoring Site Network are included for reference pending further discussions with the TAC/SC, landowners, and as opportunities arise and funding becomes available. Additional sites for consideration in the future may include Central Bay sites such as Dumbarton Marsh, Whale's Tail, Oro Loma Marsh, Arrowhead Marsh, as well as the Highway 37 Strip Marsh, Southampton Marsh, Point Edith, and sites in Richardson Bay.

Table 4. Location of known existing and proposed SET-MH sites in the San Francisco Estuary.

WRMP Site Network	Wetland Site	WRMP Site Type	Monitoring Entity, Landowner	Status
Alameda Creek	Whale's Tail South	Benchmark	CDFW	Proposed
Belmont Redwood Creek	Greco Island	Benchmark	USFWS	Proposed and Existing (Callaway), USFWS
Belmont Redwood Creek	Ravenswood Pond R4	Other project site	USGS, USFWS	Existing (Dec 2023)
Corte Madera	Heerdt Marsh	Benchmark	Marin Audubon Society	Proposed
Montezuma - Cache Slough	Brown's Island	Benchmark	USGS, EBRPD	Existing
Mowry	Mowry Outboard Marsh	Other project site	USGS, USFWS	Existing
Napa Sonoma	Older Raccoon Island	Benchmark	CDFW	New WRMP installation (March 2024)
Novato - Gallinas	China Camp	Benchmark	USGS, SFBNERR	Existing (Fall 2023)
Novato - Gallinas	Hamilton Wetlands	Project	ESA, SCC, USACE	Existing
Petaluma	Petaluma Marsh	Benchmark	USGS, CDFW	
Santa Clara Valley	Coyote Triangle Marsh	Reference	USGS, USFWS	Existing
Santa Clara Valley	Calaveras Point	Reference	USGS, USFWS, John Callaway	Existing
Santa Clara Valley	Guadalupe Marsh	Other project site	USGS, USFWS	Existing
San Francisquito	Laumeister	Benchmark	USGS, USFWS	Existing
Suisun Slough	Rush Ranch	Benchmark	USGS, SFBNERR	Existing
Wildcat Creek	Dotson Family Marsh-Existing	Reference	USGS, EBRPD	Existing

Wildcat Creek	Dotson Family Marsh-Restoration	Project	USGS, EBRPD	Existing

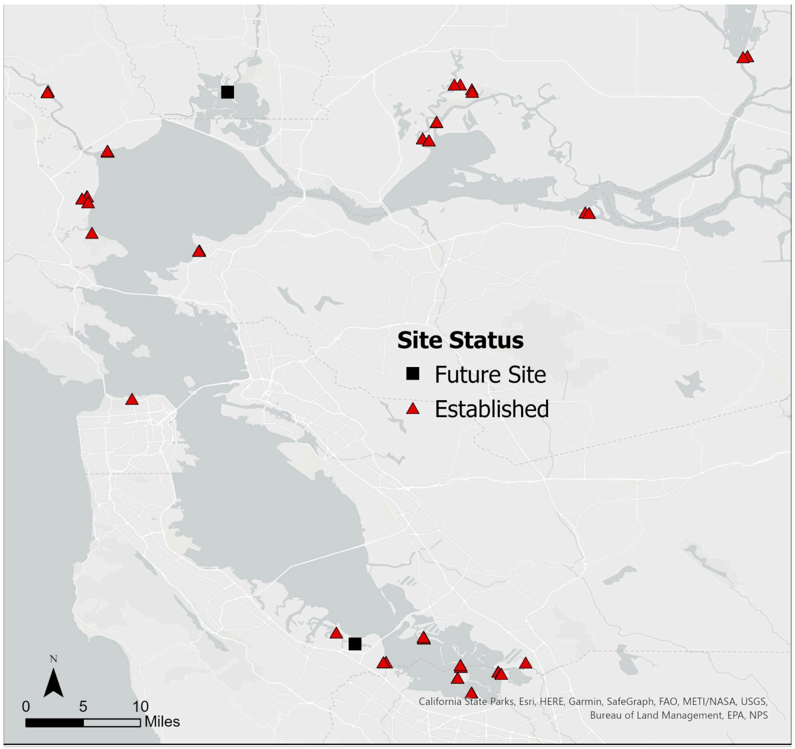

Figure 7. Map of known existing SET-MH installations in the estuary.

5.2.2 Data Analysis and Products

WRMP monitoring of SET-MHs will utilize the standard approaches for data collection, analysis, and QA/QC described in the HGM SOP (WRMP 2023b). For the near-term re-surveying of all SET-MHs, the WRMP is using a Leica survey-grade GNSS rover (GS15 and GS14 models) using GPS real-time kinematic (RTK) corrections (manufacturer-published horizontal precision ±1 cm and vertical precision ±4 cm; Leica Geosystems Inc., Norcross, GA). Data corrections are streamed to the rover via an internet connection to GNSS base-station networks (Leica Smartnet, www.smartnetna.com), with the average measured vertical error being within the ±2 cm error of the RTK at local benchmarks. The WRMP will calculate total elevation change and accretion for each SET-MH, and summarize statistics by edge/interior sites and for the overall marsh. Anticipated information products include:

- Map and graphs displaying accretion and wetland surface elevation trends at SET-MH sites relative to SLR rates and (where data are available) inundation regimes.
- Analyses of the relationships between observed elevation change and shoreline retreat/progradation, unvegetated to vegetated ratio (UVVR), and/or other Level 1 indicators.

5.2.3 Data Management, Reporting, and Visualization

The WRMP will publish raw data and metadata from the near-term SET-MH re-survey in a USGS data release (sciencebase.gov) within six months after data collection is complete, and update this database annually with new data collection. The WRMP will make these data available through the WRMP Geospatial Database, and present an annual summary report to the WRMP TAC, SC, and other interested groups. The needs of the TAC and SC will guide SET-MH data visualization; some examples are shown below in Figure 8.

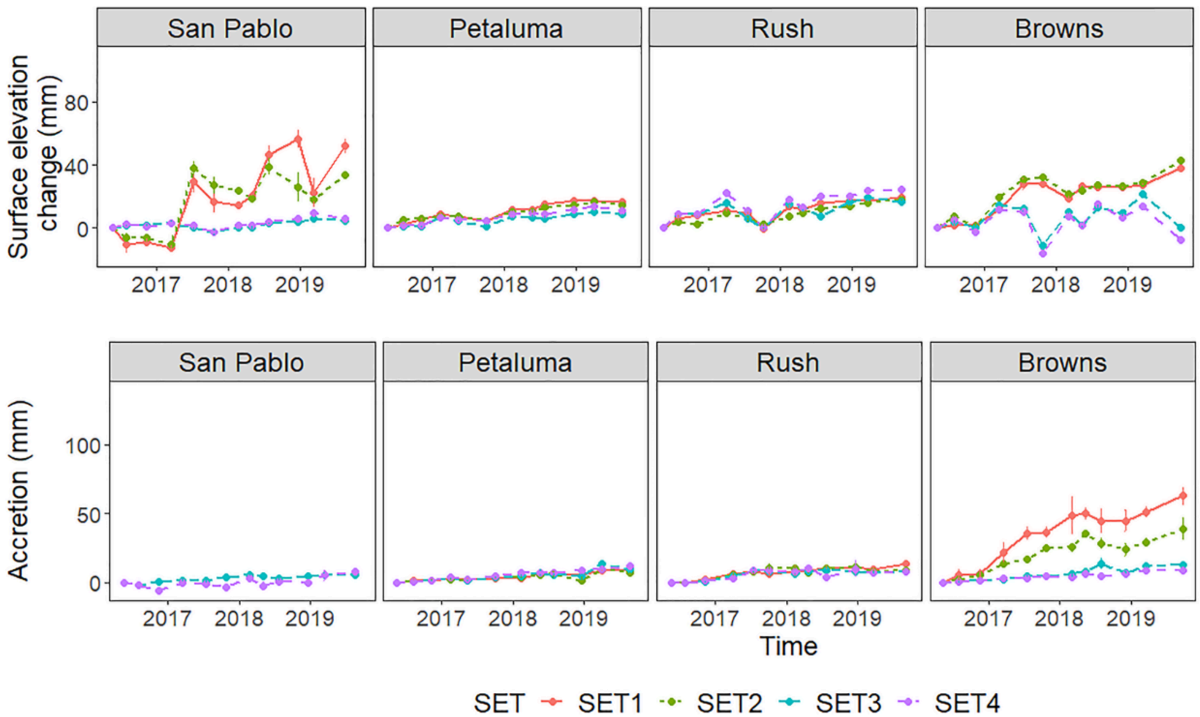

Figure 8. Examples of accretion and surface elevation change (mm ± standard error) over time from Surface Elevation Table (SET)-marker horizon (MH) sites across SFE (note missing data for low SET-MH accretion at San Pablo; From Thorne et al. 2022). WRMP-funded monitoring will enable partners to create similar graphics with extended time periods and more sites across the region.

5.3 Elevation Transects

Marsh surface elevation, relative to tidal flooding, exerts a primary control on many tidal marsh ecosystem processes. For example, marsh species have unique tolerances to flooding and tend to organize into zones characterized by elevation (Pennings et al. 2005; Janousek et al. 2019). Rates of sediment deposition are inversely correlated with elevation, as areas higher in the tidal frame are flooded for shorter durations and less frequently than areas lower in the tidal frame. The concept of elevation 'capital' is also key for understanding vulnerability of marshes to sea-level rise; the higher a marsh is in the tidal frame, the longer it will take to transition or submerge, while marshes with less elevation capital are low in the tide frame and more susceptible to sea-level rise (Cahoon et al. 2019).

While monitoring elevation at a region-wide scale over time is best done vie LiDAR and creation of digital elevation models (see Regional Elevation Mapping section above), monitoring elevation at a site-scale is important for ground-truthing aerial-based products, tracking elevation change more frequently or with greater accuracy, and for discerning relationships between elevation data and other site-scale indicators. The elevation transects can help determine accretion rates across the transect (at a coarser resolution than SET-MHs, but finer than LiDAR), which can help identify how accretion differs within a site and how accretion rates vary with features such as distance from marsh edge. Monitoring elevation across dominant marsh gradients at all network sites can help expand our understanding of elevation and accretion processes developed through the SET-MH network described above. Elevation transects can also help identify subtle changes in the elevations and morphology of important tidal wetland landscape features, such as channels and bayward edges, that are in many cases too fine to be effectively captured by remote sensing approaches. These changes can illuminate key processes such as bayward edge erosion, marsh plain subsidence/drowning, and the expansion/contraction of channel networks. Capturing tidal channel cross-sections is especially important, as changes in channel geometry are indicative of changes in tidal prisms within a marsh. In addition, by co-locating elevation transects with vegetation monitoring, we will improve our understanding of the distributional drivers and limits of wetland vegetation, improving regional mapping and predictive understanding of range shifts and migration potential under future SLR scenarios. Elevation transects will help answer: **How are the elevations of high and low marsh (including high tide refugia) changing over time? (Management questions 2-4 and Indicator 2)**

5.3.1 Approach and Methods

The WRMP will establish elevation transects according to the procedures outlined in the HGM SOP (WRMP 2023b), often (but not always) co-located with vegetation transects (see Section 5.4 below) to maximize data collection during field campaigns. Where practicable, the WRMP will establish elevation transects in locations that can be tied into existing geodetic control, to maintain the horizontal and vertical accuracy of survey readings. At sites selected for elevation monitoring, the WRMP science team will work with the TAC to identify key landscape gradients and lay out proposed transects. Key gradients include, but are not limited to:

- Along interior marsh drainage divides from a marsh's estuarine-terrestrial transition zone, across the marsh plain, to its bayward edge
- Perpendicular from interior marsh plain drainage divides, across tidal channels, to opposite drainage divides
- Across ponds/pannes, interior high tide refugia, fringing bayfront beaches, and other key habitat features

As outlined in the Accretion and Erosion section of the HGM SOP (WRMP 2023b), staff will collect elevation measurements along transects using Real-time Kinematic GNSS Surveying. At each site, transect layout should consider the need for replication (to increase confidence in change detection), the level of effort needed to collect data along the transect, and the potential for data collection along a transect to disturb sensitive plant/wildlife species. An example of a potential elevation/vegetation transect layout at a WRMP priority monitoring site is shown in Figure XX.

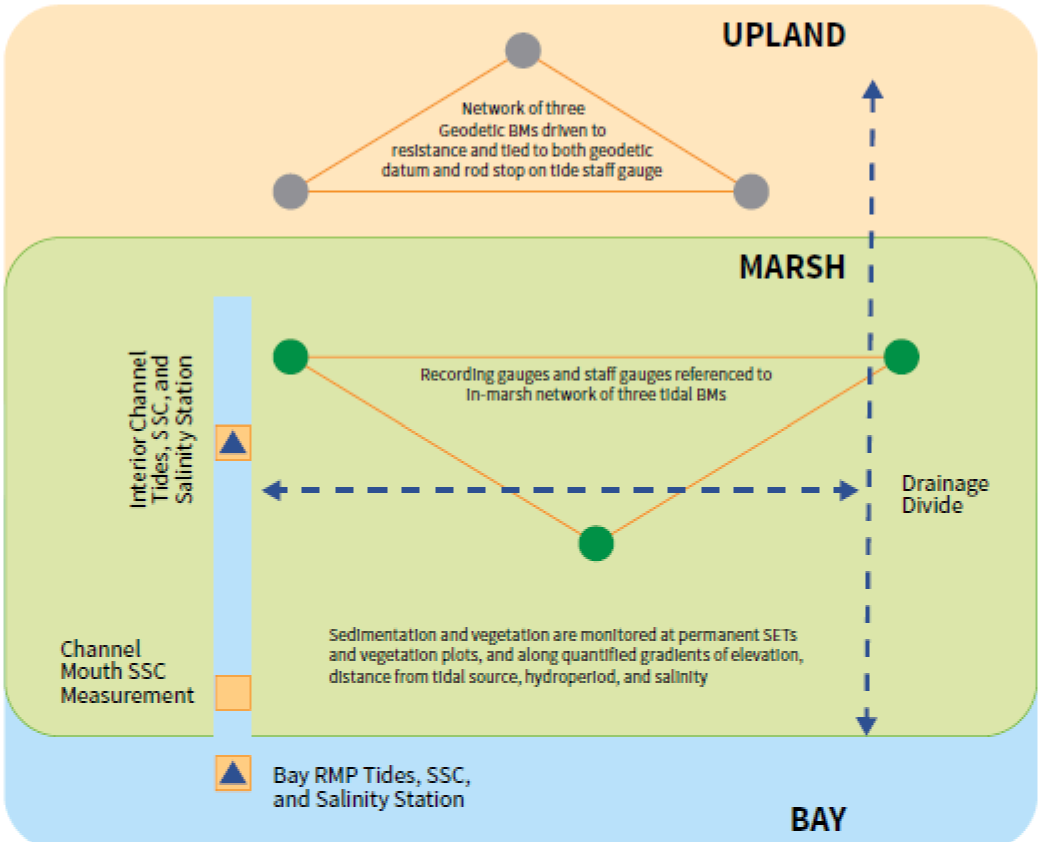

Figure XX. Conceptual arrangement of Level 3 monitoring elements at a site, including elevation transects (dashed lines).

5.3.2 Data Analysis and Products

Elevation transect data is intended to be analyzed in conjunction with other Level 3 data such as inundation, accretion/elevation change, and vegetation. For example, transect data can indicate how marsh vegetation communities are responding to changes in elevation, and how those communities may continue to change in the future. Transect data can be analyzed together with inundation data to determine if/how changes in hydrology (e.g. from sea level rise or prolonged seasonal inundation in wet years) are driving changes in marsh elevation and morphology. Over time, repeated transect data can indicate if measurements of elevation change at nearby SET-MHs are indicative of elevation change at broader site- and landscape-scales.

5.3.3 Data Management, Reporting, and Visualization

The WRMP will store QA/QC'd elevation transect data and relevant metadata in an online data visualization platform that allows viewers to select established transects at sites of interest and view/download data. Section 4.6 contains additional detail about this proposed database.

5.4 Vegetation Transects

Vegetation monitoring is one of the most common approaches to assess ambient wetland health and functions as well as restoration project success. Monitoring of percent cover and species composition is almost always required by permits for restoration projects, often in conjunction with photo-point monitoring and hydrologic monitoring. The vegetation monitoring proposed in this Plan is designed to be consistent with typical current permit-driven monitoring requirements.

In order to assess percent cover and composition of vegetation across dominant elevation gradients at various types of WRMP Network Sites (Benchmark, Reference and Project) and to complement and calibrate/validate the remote sensing of vegetation alliances at regional scales, the WRMP Vegetation SOP (WRMP 2023c) recommends field-based (Level 3) vegetation monitoring. The Vegetation SOP recommends field-based monitoring to track percent cover and composition of vegetation to answer the following monitoring questions:

- How does vegetation cover and composition at restoration Project Sites develop and compare to Benchmark and Reference sites along key hydrogeomorphic gradients such as inundation/elevation and salinity?
    - **Percent cover of vegetation across elevational gradients in Project, Reference and Benchmark sites (Management Questions 1-4 and Indicator 24)**
- How does site-specific vegetation cover and composition at Benchmark and Reference Sites relate to environmental shifts due to climate change such as sea-level rise and changes in salinity?
    - **Percent cover and composition of vegetation across transition zones in Benchmark and Reference sites (Management Questions 1-4 and Indicator 24)**

5.4.1 Approach and Methods

The Vegetation Monitoring SOP outlines three approaches to field-based vegetation monitoring, differentiated by the levels of funding and programmatic resources that are available to inform and answer the monitoring questions above. Photo-point monitoring is a relatively low investment, non-invasive approach that is particularly useful for monitoring vegetation succession at project sites. Photo-points at Project Sites can be compared with photo-point monitoring stations at Benchmark and Reference Sites to compare shifts in species composition and habitat structure over time. As more programmatic resources become available, transect monitoring across elevational gradients at Benchmark, Reference and Project (that meet a minimum % cover threshold) sites can track vegetation percent cover and composition. The Vegetation Monitoring SOP explains the ideal distribution of replicate transects where permanent quadrats for quantifying vegetation cover are spaced across the elevational gradient of the marsh (WRMP 2023c). A special study across transition zones (upland/marsh plain, channel edges, and low marsh/marsh plain) at a subset of Benchmark sites can track fine scale changes in vegetation cover in species rich, narrow marsh zones, and indicate early responses of vegetation to varying environmental drivers such as rising sea levels and shifts in salinity.

5.4.2 Data Analysis and Products

The WRMP's initial monitoring investment will develop a baseline dataset describing vegetation patterns; repeat surveys over time will enable change detection in parameters of interest. These data can be used to compare vegetation cover at Project Sites with Reference and Benchmark Sites.

Repeated photo-point monitoring of the same location can help document quantitative and/or qualitative change in wetland vegetation composition, phenology, and other indicators. Digital images can be fed into software to help measure indicators such as percent vegetation cover, assess changes in channel geomorphology, or quantify changes within each grid cell of an image. Images may be qualitatively analyzed to assess spatial patterns of vegetation growth, the presence of invasive species, and large-scale erosion/deposition. Ultimately, the primary objective of this photo-point monitoring is to document landscape change and provide valuable insights into the evolving dynamics of the tidal wetland ecosystem.

In field transect monitoring, the primary vegetation metric collected in each sampling plot is percent cover for each individual species present in the plot. Using these data, the following derived metrics can be computed at the following scales for a single sampling period:

- Mean (±SD) percent cover by species at the transect and site scale
- Total plant cover (±SD) of all species per site at the plot, transect, and site scale (total cover is a measure of canopy complexity)
- Mean (±SD) species richness at the plot and transect scale
- Frequency of occurrence of each species at the site scale
- Species composition
- Estimates of total plant species richness at the site scale (by species accumulation curves or Chao metrics)

Additionally, the following derived metrics can be computed at the following scales when data are combined for two or more sampling periods/locations:

- Change in percent cover at the transect, site, or sub-region scale for all plant species
- Change in frequency of occurrence at the site or sub-region scale for all species
- Change in species richness at the plot, transect, site, or sub-region scale
- How accurately does Level 1 vegetation mapping reflect Level 3 vegetation data?

By co-locating vegetation transects with Level 3 monitoring of elevation, porewater salinity, tidal inundation, and other indicators, we can correlate patterns in vegetation percent cover and species richness with key physical parameters, and investigate relationships between physical drivers and vegetation change over time. For example, we can ask:

- How sensitive are different vegetation communities to these changes, and what are the leading thresholds of change in hydrogeomorphic factors that can lead to early actions?
- How does vegetation species distribution relate to elevation?
- How does vegetation species distribution relate to pore water salinity?

Products for vegetation transects include site-scale maps and analyses:

- Quantifying vegetation assemblages along the transects and calculating the change in vegetation cover across the transects.
- Species presence within elevation ranges and salinity within the site, OLU and across the region
- How percent vegetation cover changes with elevation, inundation and salinity at the site and OLU-scale
- Calculate modified Restoration Performance Index (RPI) that summarizes vegetation and hydrogeomorphic metrics for linked Benchmark, Reference, and Project sites within each network (Raposa et al. 2018)

The Vegetation SOP proposes a special study to monitor vegetation within transition zones (e.g. estuarine-terrestrial transition zones, high marsh-low marsh transition zones, etc.). Vegetation transition zone monitoring can help detect fine-scale, long-term shifts in species composition due to landscape-scale drivers such as sea level rise and shifts in salinity fields. Detecting change at Benchmark sites can serve as a leading indicator of change at Reference and Project sites, and provide valuable context for interpreting observations of change at the latter.

5.4.3 Data Management, Reporting, and Visualization

The WRMP will store QA/QC'd vegetation transect data and relevant metadata in an online data visualization platform that allows viewers to select established transects at sites of interest and view/download data. Section 4.6 contains additional detail abFish and Fish Habitat (FFH) Monitoring

In the SFE, monitoring of aquatic communities can provide valuable information regarding the status and trends in water quality and ecosystem health, both of which are critical for guiding management and restoration. The diversity and structure of fish communities, for example, reflect the overall ecological integrity (i.e., chemical, physical, and biological integrity) of an ecosystem. Thus, in addition to providing information to help manage individually regulated fish populations, the monitoring of fish and aquatic communities can also be important for understanding broader integrated patterns of biotic integrity (Whitfield and Elliott 2002; Cooper et al. 2018). This is because the cumulative effects of multiple factors such as eutrophication, pollutants, temperature, and sediment loading are integrated by biological communities over time, with changes in aquatic communities reflecting how well a habitat can support aquatic life. The FFH SOP recommends fish monitoring to track fish populations and abundance over time and to to answer the following monitoring questions:

What are long-term trends in the estuary's tidal wetland fish communities? Are the region's tidal wetlands and tidal wetland restoration projects contributing to the recovery of listed fish species? How can the estuary's tidal wetlands and tidal wetland restoration projects be adaptively managed to support rare and common fish taxa? (Management Question 2-4 , Indicator 21)

5.4.4 Approach and Methods

The WRMP's FFH Workgroup conducted a rigorous literature review of existing fish data from prior surveys conducted in wetlands of the lower SFE, and used this information to inform the development of the WRMP FFH SOP (see Appendix 2 of FFH SOP). The FFH SOP and its appendices identify where and how sampling has previously been conducted, sampling options for aquatic taxa, common and best practices, and key information gaps. This information guided the development of FFH sampling recommendations in the SOP to inform future coordinated monitoring of fishes in brackish and saline wetland habitats throughout the lower SFE.

The FFH SOP recommends quantifying the abundance and size structure of 3 focal groups (large-bodied species, small bodied species, and marsh-plain species) using 3 sampling approaches (otter trawls, trammel nets, and beach seines) that can be implemented depending on the available funding. Along with biological metrics, physical environmental data should be collected during monitoring efforts, including dissolved oxygen (concentration, mg/L), dissolved oxygen (saturation, %), temperature (degrees Celsius, °C), specific conductance (µS/cm at 25 °C), salinity (practical salinity units, psu), Secchi depth (m), and turbidity (nephelometric turbidity unit, ntu). The pairing of biological and physical environmental metrics with each sample will facilitate quantification of suitable water quality parameters for a variety of wetland-associated taxa.

The UC Davis Otolith Chemistry & Fish Ecology Laboratory received independent funding to pilot implementation of the FFH SOP in sloughs and restored ponds within the Alviso Marsh complex in summer-fall 2023 and 2024. UC Davis has also received funding from the SBSPRP to develop a subregional meta-analysis of fish community data from over a decade of monitoring in the Santa Clara Network that can inform monitoring of future tidal wetland restoration projects in the region. In 2024, the WRMP science team (including the TAC) will work with UC Davis, NMFS, CDFW, USFWS, and other program partners to integrate additional FFH monitoring into the Implementation Work Plan. Based on the results of the regional meta-analysis completed by the FFH workgroup in 2022 and the 2023 pilot implementation, additional implementation of the FFH SOP in relatively under-sampled regions with existing and planned tidal wetland restoration projects, such as the Napa-Sonoma and Alameda Creek networks, could be beneficial.

5.4.5 Data Analysis and Products

Likely analyses include assessments of the long-term trends in wetland fish communities throughout the SFE, including presence/absence, local abundance/biomass (index/CPUE), and community structure of juvenile and adult stages of select focal species and functional groups at Benchmark, Reference, and Project sites (Indicator 21). Further analyses could include:

- Site-specific and network-specific synthesis of geospatial habitat metrics with corresponding fish community data
- Spatial and temporal analysis of presence/absence of FESA/CESA listed fish species in tidal wetland and associated habitats
- Spatial and temporal analysis of how aquatic communities (including key native and special status fish species) respond to tidal wetland restoration activities
- Spatial and temporal analysis of how physical environmental metrics vary and how aquatic communities respond to environmental variation

Data analyses and products can also be aligned with the State of the San Francisco Estuary Report (e.g. calculation of a wetland fish index).

5.4.6 Data Management, Reporting, and Visualization

Maps, analysis, and linked reports from the Appendix 2 of the FFH SOP will be uploaded online through a Shiny dashboard, EcoAtlas, or the WRMP Geospatial Catalog. New fish data will be added to the WRMP Geospatial Catalog and the online database described above in Section 4.6.

5.5

5.6 Bird Monitoring

The Monitoring Questions listed in the Monitoring Matrix of the WRMP Program Plan focus on the response of resident tidal marsh birds to tidal wetland restoration, climate change, and other drivers of tidal wetland distribution/abundance/condition. While a formal Bird Workgroup of the WRMP has not yet convened, members of the SC, TAC and other interested parties have expressed interest in monitoring bird populations that use tidal wetlands and associated habitats more broadly. As a critical stop on the Pacific Flyway for a variety of bird groups, it is also important to understand how tidal flats, managed ponds, restoring marshes, and other habitats support these SFE bird populations. Therefore, monitoring how marshes provide habitat for waterbird and ground nesting birds as restored former ponds develop into marsh habitat is also critical.

At the time of the writing of this Monitoring Plan, a WRMP Workgroup focused specifically on birds does not exist, but can be formed in 2024 at the direction of the Steering Committee. The following Guiding and Management Questions from the Program Plan can guide the initial work of the Workgroup to develop a monitoring strategy and SOPs for monitoring protocols. The SC will direct the Workgroup on the level of effort for different types of bird monitoring based on available funding.

How do projects to protect and restore tidal marshes affect the distribution, abundance, and health of plants and animals? (GQ4). How are habitats for assemblages of resident species of fish and wildlife in tidal marsh ecosystems changing over time? (MQ4A). How are the distribution and abundance of key resident species of fish and wildlife of tidal marsh ecosystems changing over time? (MQ4B).

Additional Questions specific to tidal wetland birds: What are long-term trends in the estuary's tidal wetland bird communities? Are the region's tidal wetlands and tidal wetland restoration projects contributing to the recovery of listed bird species? How can the estuary's tidal wetlands and tidal wetland restoration projects be adaptively managed to support rare and common bird taxa?

5.6.1 Approach and Methods

TBD - topic should be addressed in 2024. The Bird Workgroup will be tasked with developing or incorporating existing methods to form the basis of the Bird Monitoring SOP. The existing tidal marsh bird monitoring effort comprises two complementary efforts representing two distinct field protocols: 1) tidal marsh bird species of special concern and 2) secretive marsh birds (rails). There are also existing protocols for monitoring pond-associated birds that also utilize tidal marshes/restoring marshes. The Bird Workgroup will take these into account in developing monitoring recommendations and SOP/methods.

5.6.2 Data Analysis and Products

TBD - topic should be addressed in 2024

5.6.3 Data Management, Reporting, and Visualization

TBD - topic should be addressed in 2024

5.7 Mammal Monitoring

Section in progress. Will be completed in the future when a Mammal Workgroup is convened.

5.8 Carbon Sequestration

Section in progress: While Carbon Sequestration is not featured as an indicator in the initial WRMP Monitoring Matrix, this section is included here due to TAC and other partner interest, importance for climate change mitigation and stabilization, its potential value as Carbon markets invest in sequestration, and the unique opportunity regional monitoring could offer. The inclusion of carbon sequestration here is intended as a place-holder to capture ideas, and will be expanded, elevated and implemented in the future should there be interest, funding, and guidance from program directors.

Coastal wetlands are an important sink for carbon due to their high annual productivity, anoxic soils that limit decomposition, and their ability to trap and accrete sediments and organic material and grow vertically. Because of these properties, coastal wetlands have become known as Blue Carbon sinks with focus on understanding and accounting for their ability to sequester carbon dioxide from the atmosphere and store it in belowground biomass. Carbon sequestration is of particular interest to restoration practitioners who could potentially use the Carbon markets to fund restoration of stable Blue Carbon wetlands. Due to the importance and monetary value of Blue Carbon stocks, monitoring Carbon sequestration at marshes across the SFE that vary in their age, species composition and salinity could aid the region in understanding carbon storage dynamics, stability and restoration potential.

What are rates of carbon sequestration in the estuary's tidal wetlands, and how are they changing over time? How are rates of carbon sequestration in the estuary's tidal wetlands affected by shifts in ecogeomorphic factors such as inundation, salinity, sediment supplies, and vegetation communities?

5.8.1 Approach and methods

Methods are in development but should leverage existing data such as trace gas flux data available at towers located in Eden Landing, Rush Ranch and Hill Slough (available at https://ameriflux.lbl.gov/). Existing SET-MH data and dated sediment cores are also useful for carbon sequestration measurements since accretion is related to belowground carbon storage through recalcitrant roots and rhizomes. Furthermore, remote sensing can be paired with carbon flux models such as PEPRMT to estimate gross primary production (Oikawa et al. 2017; Miller et al. 2019). Additional flux towers, cores or SET-MH measurements can be useful to get a higher spatial resolution. Should funding and interest arise, a more throughout and thorough methods and approach section can be developed with an accompanying SOP.

5.8.2 Data Analysis and Products

Products can include regional and site-scale estimates of short-term carbon sequestration estimated from SET-MH data, loss on ignition (LOI), biological demand, and local LOI-%C relationship. Note that short-term carbon sequestration rates overestimate ecosystem-atmosphere carbon exchange because they don't account for turnover of new, labile carbon.

Regional and site-scale analyses of long-term carbon sequestration can be estimated from:

- Method 1: modeled from long-term vertical accretion and carbon sequestration using CWEM (Morris et al. 2022) or another accretion model
- Method 2: measured as net ecosystem exchange (from tower data) minus lateral carbon losses

A comparison of multiple metrics includes an analysis of carbon sequestration rates relative to inundation, salinity, SSC, and vegetation communities. This can be evaluated across space, longitudinally at specific sites, or both. Again, if funding and interest arise in monitoring carbon sequestration this section can be more thoroughly described and expanded.

5.8.3 Data Management, Reporting, and Visualization

TBD - If funding and interest arise in monitoring carbon sequestration, this section can be described.

6 Conclusions and Next Steps

The initial WRMP Monitoring Plan (v.1), completed December 31, 2023 will serve as an initial guiding document for WRMP monitoring activities. This Monitoring Plan is intended as a framework for the program and provides a holistic vision for monitoring in the SFE to address WRMP Guiding and Management questions and enable the program to begin to systematically initiate monitoring activities to reach this goal. The Monitoring Plan is thus aspirational and inclusive of a large suite of potential monitoring activities, but also attempts to provide a holistic model that is achievable over time. Using this Monitoring Plan as a guiding framework, the WRMP science team in collaboration with the TAC and SC will next be developing a short-term Implementation Plan/work plan that will prioritize the monitoring activities identified in this Plan for early implementation.

The WRMP continues to strive for integration and coordination with regulatory agencies. Near-term work in this regard will incorporate findings from coordination with regulatory agencies into WRMP monitoring efforts and program development. We will continue work with agencies and project proponents to look for opportunities to align WRMP monitoring with permitting requirements, streamline monitoring efforts for projects, leverage historic monitoring data, and support restoration projects by providing regional context with the goal of alleviating monitoring requirements.

This Monitoring Plan is a living document that will be regularly updated and revised. In addition to the planned revisions in the coming phases of the WRMP grant cycles, the Monitoring Plan will be updated as new workgroups establish and identify monitoring protocols and plans (such as birds and mammals), as monitoring is initiated and existing SOPs need to be modified, as new technologies and approaches alter the best practices for accomplishing monitoring, as Guiding and Management questions are answered and new questions rise in priority, and as other unforeseen needs of the program emerge.

Appendix 1: Regulatory Alignment

The WRMP charter states, "The WRMP will improve wetland restoration project success by putting in place regional-scale monitoring to increase the impact, utility, quality, cost effectiveness, consistency, and application of permit-driven monitoring to inform science-based decision-making." To realize this vision, WRMP program staff are working to identify opportunities to support effective and efficient permit-driven wetland monitoring and to design regional wetland data collection so that it can inform decision-making, including at regulatory agencies.

The WRMP enlisted the Consensus Building Institute (CBI) to assist in advancing regulatory agency alignment and monitoring recommendations by conducting a regulatory needs assessment, drafting and refining findings, and finally, developing recommendations for a Regulatory Engagement Strategic Roadmap, to map out key decision points, define roles and responsibilities, and identify approaches, commitments, and next steps. CBI's work on this goes through June 2023.

As a first step, CBI conducted a Regulatory Needs Assessment through focus groups and interviews with regulatory agency staff and restoration project practitioners, which was completed in June 2023. The Regulatory Needs Assessment identified ways in which current permit-driven monitoring does and does not meet the needs of regulatory agencies, and pinpointed opportunities for the WRMP to meet some of those needs while providing regional efficiencies. The Regulatory Needs Assessment found widespread agency interest in, and WRMP opportunities for, improving data consistency, quality, and sharing of project-based monitoring data, thereby contributing to better science and information to inform stewardship and adaptive management for conserving, restoring, and enhancing the San Francisco Bay's wetlands.

The Regulatory Needs Assessment also found that some regulatory agencies are skeptical about the potential for substitution of site-based permit driven monitoring with WRMP regional monitoring in the short term. Some agencies expressed that some permit-driven, site-specific monitoring is essential for ensuring that wetland restoration projects achieve their intended goals, comply with all relevant regulations, and avoid negative impacts to listed species and water quality. Regional data are unlikely to be able to provide this level of information.

The WRMP SOPs outline a suite of methods for data collection that may eventually facilitate standardized data collection and regional analysis. The WRMP may select all or part of the SOPs for monitoring activities in the region or at a site, based on the monitoring plan and available funding. It is important to note that the WRMP SOPs in their entirety are not immediately suitable for adoption by regulatory agencies to be written into permit monitoring requirements.

If regulatory agencies were to require all the monitoring procedures in the SOPS to be written into permits, it would increase rather than reduce the current permit-driven monitoring required of project implementers. Ongoing discussion between the WRMP and regulatory agencies will clarify whether specific portions of the SOPs may be suitable for meeting permit-driven monitoring requirements while also providing relevant data for regional analysis.

Most regulatory agencies:

- Agreed that current permit-driven monitoring faces challenges in data consistency, comparability, quality, and sharing, and that it did not necessarily serve the needs of regional scientific understanding.
- Welcomed the addition of regional-scale science and topic-specific SOPs to better inform understanding of tidal wetlands.
- Were generally open to suggestions on more standardized sampling protocols and monitoring methodologies as well as opportunities for better data sharing, as long as the WRMP could ensure high quality of data and address proprietary data issues.

The WRMP Regulatory Engagement Strategic Roadmap will be complete by June 2024.

Appendix 2: Preliminary Costs Estimates

Costs of labor and materials change over time; the information presented below represent preliminary estimates for 2023. To be made into a Table.

Regional

For the regional habitat map, the mapping and interpretation relies on several component parts: 1) obtaining appropriate imagery, 2) obtaining LiDAR (see estimates on regional elevation map below), 3) staff time for data management and processing (training and validating e-Cognition software), and 4) conducting relevant analyses using mapping results.

- The cost estimate for obtaining imagery for 4 band 60 cm spatial resolution (~ $175/sq mile) tide controlled and collected in the summer is $120,000. Alternatively the frequency of remapping could be shifted to an even number of years (e.g. 4 or 6 years vs 5 years) in order to use free NAIP imagery collections (4 spectral bands and 60 cm spatial resolution, but likely without tide controlled collection). Opportunities to coordinate aerial imagery collection with partners (e.g. Bay-area Counties, NASA, others) for cost-sharing benefits can be explored.
- Cost estimates for staff time to manage habitat map: (e.g. number of hours x average rate)
- The regional elevation map cost estimate is based on past NOAA Coastal Geospatial Services Contracts. It is estimated that a tide-controlled LiDAR collection and delivery of QL1 LiDAR products would cost roughly $280/square mile. Assuming a study area of 678.6 square miles

that is approximately $190,000. Ideally LiDAR data will be collected as close in time to imagery collected for the bayland habitat mapping effort.

- Additional costs (staff time for processing, other?) associated with creating updated DEM using LiDAR and best available tidal datums (see section below):
- Cost estimates for staff time to analyze maps for change detection and analysis of interest: particularly Shoreline Change Detection and other early analyses such as UVVR.
- Cost estimates for vegetation mapping is based on both Pacific VegMap and HEMP-type vegetation mapping. Upper cost estimate is $2M, with an estimated cost of $3-$5 per acre for detailed classification. These cost estimates include field work, software and staff time, while leveraging free multispectral imagery and LiDAR. Between 1⁄3 and ½ of the budget could be spent on a field campaign for calibration/validation, which potentially could be reduced if paired with other field campaigns.

Subregional

Many sensors collecting subregional data are hosted by larger organizations such as USGS, NOAA or a county's Flood Control and Water Conservation District. Costs can include the equipment, installation, maintenance and if applicable costs to read the instrumentation (such as with SET-MHs).

- For tide gauges, installation costs for each new WRMP tide gauge are estimated at roughly $11,000 per site. Long-term installations will have estimated annual costs for maintenance/calibration at roughly $600 per site. Installation costs include field time for staff that can simultaneously be used to support installation of other field sampling equipment to measure salinity (see Section 4.3 above), suspended sediment (see Section 4.4 above), and other WRMP indicators. See the HGM SOP for additional details.
- Costs for water quality sensors such as DO, SSC, and surface water salinity can be bundled together within a sensor. Multiparameter sondes such as a YSI EXO2 Multi-parameter water quality sonde costs roughly $20,000 with 6 sensors and a wiper port. Costs for a multi-parameter sonde depends on the number of sensors included. Costs estimates for instrumentation maintenance, sample collection and analysis is $9,400.
- For porewater salinity or groundwater salinity, either a shallow well with an electrical conductivity sensor or a porewater sampling device (eg., sipper or a Rhizon sampler) needs to be used. The cost for Rhizon samplers is about $200 for a pack of 10 with an accompanying syringe. A conductivity, temperature and depth sensor, which can be used for groundwater monitoring, cost in the range of $500 - $1000. Costs for processing pore water salinity is estimated at $100.

Site-scale

Site-scale cost estimates involve considering factors such as equipment procurement, personnel training and field time, data collection frequency, and laboratory analysis, with a focus on ensuring comprehensive coverage and accurate representation of ecological dynamics. Cost estimates are originally taken from (WRMP 2020b) and have subsequently been updated where possible/necessary.

- CRAM practitioners have proposed an initial cost estimate of $90,000 to implement CRAM at roughly 30 AAs at WRMP sites during the first year of monitoring. This estimate includes startup time for experts to coordinate with the TAC to outline the initial goals of the Level-2 monitoring for the WRMP. Other costs include: (1) developing a detailed near-term sampling and analysis plan, (2) executing the CRAM assessments in the field, (3) conducting data entry, QA/QC and data analysis, and (4) reporting back to the TAC with a brief summary memorandum of the WRMP's CRAM monitoring effort. It is expected that future annual monitoring costs may be reduced once the WRMP establishes a long-term plan for Level-2 assessments within the program. For now, however, startup and science advisory planning costs are included in this initial annual cost estimate.
- Estimated costs for new SET-MH installation are approximately $13,000 per site. Estimated costs for annual reading of the regional SET-MH network and associated data analysis/reporting with the current number of network sites are roughly $20,000 per year with those costs increasing as sites are added.
- Costs for vegetation transects include purchasing and pre-programming tablets for data collection, which can cost $1,000. If vegetation transects are done concurrently with elevation transects, a high precision GPS unit is not required since latitude and longitude can be recorded with an RTK-GNSS. However if a high precision GPS unit (centimeter accuracy) is required they range from $6,000 - $15,000. Ongoing field work costs for gradsects or standard vegetation surveys can range from $1,500 to $3,500 per site. Elevation transects Costs of a new RTK-GNSS system can cost upwards of $15,000 however these systems can be rented or bought used. Costs to do field transects alone for elevation cost roughly $1,900 - 2,300 per site. If concurrently conducting vegetation surveys with elevation transects, the cost per site is reduced.
- Fish survey costs depend significantly on the sampling methods and frequency; therefore, the cost estimate is a wide range. Costs for monthly fish sampling for abundance, community composition, and distribution is between $50,000 - 200,000.
- Cost for a site-visit is estimated at $2,000 and ongoing surveys between $2,500 and $9,500 for two tidal marsh bird surveys or for a secretive marsh bird survey (mainly focused on the endangered California ridgway's rail) that require boat access. TBD (separate estimates for tidal marsh birds at regional, sub-regional, and project levels).
- For mammal surveys such as the salt marsh harvest mouse, costs include initial start-up time. This includes about 8 hours of setting up a survey grid (2 people/4 hours), and an ongoing cost of $5,000 for one survey by a consulting firm. However, some marsh mammal monitoring, mainly focused on the endangered salt marsh harvest mouse, currently occurs throughout the Estuary
- Carbon sequestration - costs estimates for carbon sequestration are not yet available, however in the future if there is more interest and funding available this section can be expanded and a cost estimate developed.

Appendix 3: CRAM Analysis in WRMP Sites

Using historic and existing CRAM data collected from 2010 through 2023, the WRMP will analyze results of CRAM assessments in the WRMP priority monitoring network. This analysis will assist in developing the strategy for new CRAM sampling in 2024. This report will be included as an appendix upon completion of the initial study in early 2024.

Appendix 4: Justification for Subregional Monitoring Installations

4-1: Water Surface Elevations

- **Suisun Slough Network:** WAITING ON INFO FROM DWR/CDFW.

- **Napa-Sonoma Network:** The only tide gauge near the vast marshes of the Napa-Sonoma baylands is the one installed by the Napa County Flood Control District in 2017 at the Brazos bridge. This gauge is more than a mile upstream of Older Racoon Island (Benchmark Site), roughly three quarters of a mile downstream of Bull Island (Reference Site), and many miles from Project Sites at Pond 2A, Pond 3, Cullinan Ranch, and other CDFW and USFWS tidal wetland restoration sites. The nearest tide gauges with long-term records are the NOAA gauges at Port Chicago and Richmond, which are roughly 19 and 20 miles away (as the crow flies), respectively).

    - **Proposal:** This region represents a considerable spatial and temporal gap in regional monitoring of water levels, inundation, and sea level rise. This gap makes it challenging for land managers and project proponents such as CDFW, USFWS, Ducks Unlimited, and the Sonoma Land Trust to understand if/how the region's many existing restoration projects are achieving target conditions, and to plan for future restoration and adaptive management. To fill these gaps, the WRMP proposes two new long-term tide gauge installations, and numerous short-term tide gauge installations. The opportunity to re-occupy former IRWM WSE monitoring sites at Older Racoon Island, Bull Island, and Pond 2A is relatively unique among WRMP sites, and provides a valuable opportunity to leverage legacy data to develop new analyses of change over time.

        - **New long-term installations:** The WRMP will install a new long-term gauge at **Older Raccoon Island** in order to link proposed site-specific observations of accretion/elevation change, vegetation, and other key indicators (see Section 5) to inundation. Data from this sensor can also be compared to data from the Integrated Regional Wetland Monitoring (IRWM) deployment almost 20 years ago, to support analyses of multi-decadal trends in conditions at the site. The program will also install a new long-term gauge in **Dutchman Slough** to represent water levels in the lower Napa River basin, to provide an inundation reference for multiple existing and future Project Sites including **Pond 3** and **Cullinan Ranch**. This gauge will eliminate the need for those projects to install their own reference gauges to compare how tides in those sites compare with source tides. Finally, the WRMP will also install a long-term gauge at **Steamboat**

Slough, to support planning and monitoring of tidal wetland restoration projects that are likely to result from implementation of the Sonoma Creek Baylands Strategy.

        - **New short-term installations:** The WRMP tide gauges at the **Bull Island** Reference Site and **Pond 2A** Project Site. These installations will be temporary, with an aim of collecting enough data to (1) compare data from the Bull Island and Pond 2A sensors to the former IRWM sensors to support analyses of multi-decadal trends in conditions at the site, and (2) determine if data from Napa Flood Control's Brazos gauge can serve as a surrogate for data from Bull Island.
        - **Installations at anticipated future Project Sites:** The beneficial reuse (eastern) portion of **Cullinan Ranch** is expected to be restored to tidal action sometime in late 2024/early 2025. The WRMP will work with the Coastal Conservancy, USFWS, and Ducks Unlimited to install a tide gauge at this site before it's restored to tidal action. Data from this gauge will be compared with data from the proposed Dutchman Slough gauge to assess post-restoration hydrology.

- **Novato/Gallinas/West San Pablo Bay Network:** This network currently supports four long-term tide gauges: two at the China Camp Benchmark Site operated by SFBNERR, and two along Novato Creek (one at its mouth, one at the Rowland bridge) operated by the Marin County Flood Control District. Environmental Science Associates (ESA) also periodically installs tide gauges at the Hamilton Wetlands Project Site as part of permit-required monitoring for that project. Whenever ESA deploys gauges at Hamilton, they also deploy a gauge at the historic railroad bridge at the mouth of the Petaluma River to represent background water levels within San Pablo Bay.
    - **Proposal:** For the most part, existing monitoring at China Camp and Hamilton Wetlands provides suitable coverage for the Gallinas OLU and the southern portion of the Novato OLU. Existing monitoring along Novato Creek provides suitable coverage for the northern portion of the Novato OLU. Together, these gauges can represent reference WSEs for planned tidal wetland restoration projects at Bel Marin Keys Unit V and Inner McInnis Marsh. However, coverage for the many existing and proposed restoration projects in the lower Petaluma baylands is lacking. In addition, regulatory/resource agencies will likely require site-specific monitoring of WSEs within tidal restoration projects that have yet to be implemented.
        - **New short-term installation:** The WRMP will install a new short-term gauge at the **Carl's Marsh** Project Site to (1) assess mathematical differences between tides at the mouths of Novato Creek and the Petaluma River, and (2) support analyses of multi-decadal trends in conditions at the site through comparison with data from the site's Integrated Regional Wetland Monitoring (IRWM)

deployment almost 20 years ago. Short-term installations at Carl's Marsh can be timed with ESA's deployment of gauges at Hamilton Wetlands, and eliminate the need for ESA to install a reference gauge for Hamilton at the railroad bridge. If the TAC determines that tides at Carl's Marsh reflect tides at the Novato Creek mouth, then the latter can support monitoring of Project Sites at **Sonoma Baylands**, **Sears Point**, and perhaps even at **Bahia**, as well as select future tidal wetland restorations that may result from implementation of the Petaluma River Baylands Strategy. If the TAC determines that tides at Carl's Marsh are sufficiently different from tides at the Novato Creek mouth, then the TAC may decide to convert Carl's Marsh into a long-term installation.

        - **Installations at anticipated future Project Sites:** The **Bel Marin Keys Unit V** and **Inner McInnis Marsh** Project Sites are still in their planning stages; the timelines for implementation of both are unclear. When these projects move forward, the WRMP will work with Marin County Parks, the Coastal Conservancy, and other partners to install tide gauges at these sites. Data from the BMKV and Inner McInnis gauges can be compared to data from the Carl's Marsh and China Camp gauges, respectively, to assess post-restoration hydrology.

- **Wildcat Creek Network:** The Wildcat Creek network of WRMP sites is separated from the long-term NOAA tide gauge at Richmond by the Potrero Hills of the Richmond shoreline, and is hemmed in by Point San Pablo to the south and Point Pinole to the north. The network does not currently support any long-term gauges of its own, despite significant tidal wetland restoration and living shoreline projects at the Dotson Family Marsh Project Site, and plans to restore and enhance tidal wetlands near the Wildcat Creek Marsh Reference Site. A USGS tide gauge at Point San Pablo installed in 1989 was discontinued in 2006.

    - **Proposal:** Tidal wetlands play an important role in protecting economically disadvantaged and environmental justice-impacted communities in North Richmond from flooding, so this network represents an important spatial and temporal gap in WSE monitoring that the WRMP can fill.

        - **New long-term installation:** The WRMP will install a new long-term tide gauge at the **San Pablo Creek Marsh** Benchmark Site in order to link site-specific observations of accretion/elevation change, vegetation, and other key indicators (see Section 5) to inundation. By comparing these data to data from the Richmond gauge, the WRMP can help to identify how flows from San Pablo Creek influence hydrology at the site. Data from this gauge can also help land managers and other WRMP partners to understand how sea level rise and related long-term landscape processes are affecting the Richmond shoreline.

        - **New short-term installation:** The WRMP will work with the Coastal Conservancy, East Bay Regional Parks, local NGOs, and other partners to periodically deploy a tide gauge at the **Dotson Family Marsh (Restoration)** Project Site. The duration and frequency of deployments will be tailored to address the specific needs of this site, including assessing the effects of offshore subtidal habitat enhancement actions on nearshore waves and WSEs. These installations will also be designed to assess post-restoration hydrology at the site (tidal datums, etc.), and determine if data from the proposed San Pablo Creek Marsh gauge can serve as a surrogate for WSE data from the restoration site.

        - **Installations at anticipated future Project Sites:** A broad coalition of program partners including the West County Wastewater District, East Bay Regional Parks District, San Francisco Estuary Partnership, and local NGOs are partnering to develop the North Richmond Shoreline Living Levee Project, an effort to expand the footprint of the Wildcat Creek Marsh Reference Site and design and build a subsurface wastewater seepage or "horizontal" levee between the West County Wastewater District's treatment plant and the marsh. When this project is implemented, the WRMP can work with the living levee team to install a tide gauge in the restored tidal wetland and monitor its development over time.

- **Alameda Creek Network:** The Alameda Creek network is home to CDFW's 5,500-acre Eden Landing Ecological Reserve, one of the three areas that comprise the South Bay Salt Pond Restoration Project (SBSPRP). Phase 1 of SBSPRP restored roughly 1,700 acres of former salt ponds north of the Old Alameda Creek channel to tidal action from 2006 through 2010; Phase 2 proposes to restore another 2,200 acres south of the creek to tidal action beginning in (hopefully) 2024. In 2020, to support the Nutrient Management Strategy (NMS), SFEI installed three multi-parameter (WSEs, salinity, DO, and more) sensors offshore of Eden Landing. Since 2020, USGS has periodically installed multiple tide gauges at the Whale's Tail South Benchmark Site as part of a special study into tidally- and wave-mediated transport of sediment between the marsh and offshore tidal flats.
    - **Proposal:** The Alameda Creek network represents a considerable opportunity for the WRMP to add value to the many monitoring efforts being implemented by the SBSPRP and NMS, and reduce the amount of time, money, and staff resources that SBSPRP and CDFW invest in monitoring. To support monitoring and adaptive management of earlier Phase 1 restorations, and implementation/monitoring of Phase 2 restorations, the WRMP proposes two new long-term tide gauge installations at the **Whale's Tail South** Benchmark Site and the **North Creek Marsh** Project Site. These two locations should roughly bracket tidal ranges and the influences of waves/storms within the Eden Landing complex, and will help provide context for site-specific observations of elevation change, vegetation, and other WRMP indicators at these marshes.

- **Santa Clara Valley Network:** The Santa Clara Valley network is home to the Alviso Ponds of USFWS's Edwards National Wildlife Refuge[4], another of the three areas that comprise the South Bay Salt Pond Restoration Project (SBSPRP). Phase 1 of the SBSPRP restored 480 acres of tidal habitat within Ponds A19, A20, and A21 (the Island Ponds) in 2006, and 462 acres of tidal habitat within Ponds A6 and A17 in 2010 and 2012, respectively. Phase 2 of the SBSPRP proposes further enhancement of tidal connections at the Island Ponds, as well as tidal restoration of 710 acres of tidal habitat within Ponds A1 and A2W (within the Stevens Creek OLU) beginning in 2023. The SBSPRP is also working with Valley Water on planned full tidal restoration of Pond A8 (currently muted tidal). Finally, the South Bay Shoreline Protection Project proposes to restore 2,900 acres of tidal habitats within Ponds A9 through A13, A15, and A18 over roughly 30 years. In 2015, SFEI installed three multi-parameter (WSEs, salinity, DO, and more) sensors in this network, at Alviso Slough, Guadalupe Slough, and the Pond A8 feeder channel.
    - **Proposal:** Like the Alameda Creek network, the Santa Clara Valley network represents a considerable opportunity for the WRMP to add value to the many monitoring efforts being implemented by SBSPRP, NMS, the South Bay Shoreline Protection Project, and other program partners in support of tidal restoration planning, implementation, and adaptive management. Given the already considerable investment in WSE monitoring in this region, the WRMP is proposing just one additional tide gauge installation, at Coyote Creek near the **Older Warm Springs Marsh** Benchmark Site and **Warm Springs Marsh** Project Site. Data from this site can help support site-scale observations of accretion, vegetation, and other WRMP indicators at these marshes.

Table A4.1. Existing and proposed WRMP tide gauge deployments. Blue cells reflect priority WRMP monitoring site networks; white cells reflect Operational Landscape Units (OLUs) that could comprise future priority monitoring networks.

Network or OLU	Site	WRMP Site Type	Existing Tide Gauge Installation	Proposed WRMP Tide Gauge Installation
Alameda Creek Network	North Creek Marsh	Project Site		New long-term tide gauge
	Whale's Tail South	Benchmark Site		New long-term tide gauge
Belmont Redwood OLU	Port of Redwood City		NOAA	
Carquinez South OLU	Martinez-AMORCO Pier		NOAA	
Corte Madera OLU	Corte Madera Creek		Marin Flood Control	

[4] Pond A18 is owned by the City of San Jose.

Golden Gate OLU	San Francisco @ Golden Gate		NOAA	
Montezuma Network	Montezuma Wetlands		Montezuma Wetlands LLC	
	Beldon Landing	feeder channel to potential future Project Sites	DWR	
	Blacklock	Project Site	DWR	
	Montezuma Slough at National Steel	feeder channel to potential future Project Sites	DWR	
	Montezuma Slough at Roaring River	feeder channel to potential future Project Sites	DWR	
Napa-Sonoma Network	Napa River (at Brazos and Napa downtown)		Napa Flood Control	
	Older Raccoon Island	Benchmark Site		New long-term tide gauge
	Dutchman Slough	feeder channel for multiple Project Sites		New long-term tide gauge
	Steamboat Slough	feeder channel for multiple future Project Sites		New long-term tide gauge
	Bull Island	Reference Site		New short-term tide gauge
	Pond 2A	Project Site		New short-term tide gauge
	Cullinan Ranch (east)	future Project Site		New short-term tide gauge
Port Chicago OLU	Port Chicago		NOAA	
	Mallard Island		DWR	
Point Richmond	Richmond Inner		NOAA	

OLU	Harbor			
Richardson OLU	Coyote Creek		Marin Flood Control	
San Francisquito OLU	Dumbarton Bridge		SFEI*	
Mowry OLU	Mowry Slough		SFEI*	
	Newark Slough		SFEI*	
San Leandro OLU	Alameda		NOAA	
San Mateo OLU	San Mateo Bridge		SFEI*	
Santa Clara Valley Network	Coyote Creek near Older Warm Springs Marsh and Warm Springs Marsh restoration	feeder channel to Older Warm Springs Marsh Benchmark Site and Warm Springs Marsh Project Site		New long-term tide gauge
	Coyote Creek at Alviso	feeder channel to Calaveras Point (Reference Site) and Pond A6 (Project Site)	USGS	
	Coyote Creek near Calaveras Point	Reference	SFEI*	
	Alviso Slough	feeder channel to existing Project Site (Pond A6) and multiple future Project Sites (Ponds A7-A12)	SFEI*	
	Guadalupe Slough	feeder channel to existing Project Site (Pond A6) and multiple future Project Sites (Ponds A5, A8)	SFEI*	
	Pond A8 feeder channel	feeder channel to future Project Site	SFEI*	

		(Pond A8)		
Suisun Slough Network	Rush Ranch	Benchmark Site	SFBNERR	
	Hill Slough	feeder channel to Hill Slough (existing) Reference Site and HIll Slough (restoration) Project Site	DWR	
	Goodyear Slough	feeder channel to potential future Project Sites	DWR	
	Cordelia Slough	feeder channel to potential future Project Sites	DWR	
	Hunter Cut	feeder channel to potential future Project Sites	DWR	
	Sunrise Cut	feeder channel to potential future Project Sites	DWR	
Gallinas/Novato/ West San Pablo Bay	China Camp	Benchmark Site	SFBNERR	
	Novato Creek - Mouth and Rowland Bridge		Marin Flood Control	
	Hamilton Wetlands	Project Site	ESA	
	Carl's Marsh	Project Site		New short-term tide gauge
	Bel Marin Keys Unit V	future Project Site		TBD
	Inner McInnis Marsh	future Project Site		TBD
Wildcat Creek Network	San Pablo Creek Marsh	Benchmark		New long-term tide gauge

	Dotson Family Marsh (restoration)	Project		New short-term tide gauge
	North Richmond Living Levee	future Project Site		TBD

*SFEI moorings for the Nutrient Management Strategy measure WSEs, salinity, temperature, chlorophyll a, dissolved organic matter (DOM) fluorescence, dissolved oxygen, and turbidity at 15-minute intervals.

4-2: Salinity

- **Suisun Slough Network:** The Suisun Slough network of WRMP sites has excellent salinity data coverage due to the suite of sensors deployed and managed by DWR, USGS, and SFBNERR. The WRMP is not proposing new sensors in this network in the near-term. If new tidal restoration projects come online in this OLU that are not adequately covered by the existing suite of sensors, the WRMP will work with DWR, USGS, SFBNERR, and other partners to develop proposals for new salinity gauges.

- **Napa-Sonoma Network:** The Napa-Sonoma Network does not currently support any salinity gauges, despite the fact that the Napa River - Sonoma Creek estuarine subgradients are among the largest in SFE, and support regionally significant acreages of existing tidal wetlands, tidal habitat restoration projects, and future/planned restoration projects.

    - **Proposal:** This region represents a considerable spatial and temporal gap in regional monitoring of salinity, and like WSEs, this gap makes it challenging for land managers and project proponents such as CDFW, USFWS, Ducks Unlimited, and the Sonoma Land Trust to understand if/how the region's many existing restoration projects are achieving target conditions, and to plan for future restoration and adaptive management. To fill these gaps, the WRMP proposes new long-term salinity gauges at the following locations, co-located with tide gauges: Napa River at Brazos Bridge, **Older Raccoon Island** (Benchmark Site), Dutchman Slough, and Steamboat Slough. These locations will provide data coverage throughout the Napa River and Sonoma Creek estuarine subgradients, including for the **Bull Island** Reference Site, existing Project Sites at Napa Plant Site, **Napa Ponds 3, 4, and 5**, and **Cullinan Ranch**, as well as anticipated future Project Sites within the Sonoma baylands.

- **Gallinas/Novato/West San Pablo Bay Network:** The only current salinity gauge in this network is at the **China Camp** Benchmark Site. This monitoring location provides adequate salinity coverage for the **Outer McInnis** Reference Site and **Hamilton Wetlands** Project Site, which like the China Camp tidal marshes are largely disconnected from upland watershed sources and have hydrology dominated by San Pablo Bay tides. However, the China Camp salinity gauge will likely not provide adequate coverage for planned tidal wetland restoration projects in the Novato Creek baylands, including at the **Bel Marin Keys Unit V** and **Deer Island Basin** Project Sites that will receive significant freshwater inputs from the Novato Creek watershed. It also may not be adequate to describe salinity in the future **Inner McInnis** Project Site, which will be directly connected to Gallinas Creek and possibly Miller Creek.

  - **Proposal:** The WRMP will install a long-term salinity gauge at the **mouth of Novato Creek** (co-located with the existing tide gauge) to provide salinity data coverage for existing restoration projects in the region including **Carl's Marsh, Sonoma Baylands, and Sears Point,** as well as future restoration projects at **BMKV** and **Deer Island Basin**. When the Inner McInnis restoration project is implemented, the WRMP will work with partners including the Coastal Conservancy and Marin Parks to discuss the need for a short- or long-term salinity gauge at this site.

- **Wildcat Creek Network:** This network is relatively close to the continuous USGS salinity gauge at the Richmond-San Rafael (RSR) bridge, however, due to the local influence of runoff from Wildcat and San Pablo Creeks, it's unclear how well data from this gauge reflects conditions at WRMP monitoring sites within the Wildcat Creek Network (**San Pablo Creek Marsh** Benchmark Site, **Wildcat Creek Marsh** and **Dotson Family Marsh [Existing]** Reference Sites, and **Dotson Family Marsh [Restoration]** Project Site).

  - **Proposal:** The WRMP will co-locate a salinity gauge with the proposed tide gauge at the **San Pablo Creek Marsh** Benchmark Site to assess if/how local salinity conditions (including at the nearby **Dotson Family Marsh Existing** and **Restoration** sites) deviate significantly from conditions at the USGS RSR gauge. If not, then the WRMP will discontinue monitoring salinity at this location.

- **Alameda Creek Network:** The restoring tidal wetlands of Phase 1 of the SBSPRP are directly connected to freshwater flows from Old Alameda Creek, and planned restoration in Phase 2 is expected to eventually include direct connections to the considerable freshwater flows in the Alameda Creek flood control channel. Though these freshwater sources likely exert a considerable influence on the condition and evolution of the OLU's tidal habitats, this network currently supports no continuous salinity gauges. This network therefore represents a considerable opportunity for the WRMP to add value to the many monitoring efforts being implemented by the SBSPRP and NMS, and reduce the amount of time, money, and staff resources that SBSPRP and CDFW invest in monitoring.

  - **Proposal:** The WRMP will install two continuous salinity gauges in this network, both co-located with proposed WSE gauges: One at the **Whale's Tail South** Benchmark Site, and one at the **North Creek Marsh** Project Site. These gauge locations will help bracket the relative influences of estuarine-derived (more saline) and watershed-derived (more freshwater) flows on the network's tidal baylands, and provide context for site-specific observations of accretion, vegetation, and other WRMP indicators.

- **Santa Clara Valley Network:** This network receives continuous freshwater inputs from the San Jose-Santa Clara Wastewater Pollution Control Plant at Artesian Slough, as well as winter storm flows and year-round urban runoff from Coyote Creek, Guadalupe River/Alviso Slough, San Tomas Aquino + Calabazas Creeks/Guadalupe Slough, and other local flood control channels. The salinity sensors installed by SFEI in the Lower South Bay in support of the NMS provide adequate spatial coverage for Reference Sites at **Calaveras Point** and **Coyote Triangle Marsh**, as well as Project Sites at **Ponds A6, A21, and A17**. The only priority locations in this network that are not well-represented by existing salinity gauges are the **Older Warm Springs** Benchmark Site and the **Warm Springs Marsh** Project Site, which represent an area with considerable freshwater influence from Coyote Creek.

- **Proposal:** The WRMP will co-locate a salinity gauge with the tide gauges proposed for Coyote Creek near the **Older Warm Springs** Benchmark Site and the **Warm Springs Marsh** Project Site. These gauge locations will help bracket the influence of freshwater flows from Coyote Creek on the network's tidal baylands, and provide context for site-specific observations of accretion, vegetation, and other WRMP indicators.

Table A4.2. Existing and proposed continuous salinity loggers in SFE. Blue cells reflect priority WRMP monitoring site networks; white cells reflect Operational Landscape Units (OLUs) that could comprise future priority monitoring networks.

WRMP Site Network or OLU	Site	WRMP Site Type	Existing Salinity Gauge Installation	Proposed WRMP Salinity Gauge Installation
Suisun Slough Network	Rush Ranch	Benchmark Site	SFBNERR & USGS	
	SUISUN CREEK AT CORDELIA RD		DWR	
	Hill Slough		DWR	
	First Mallard Branch		USGS	
Montezuma Network	Montezuma Wetlands	Project Site		
	GRIZZLY BAY A SUISUN SLOUGH NR AVON CA		USGS	
Port Chicago OLU	SUISUN BAY A BUOY 19 NR PORT CHICAGO CA		USGS	
	SUISUN BAY AT CHANNEL MARKER 24A		USGS	
	SACRAMENTO R A CHANNEL MARKER 5 A COLLINSVILLE CA		USGS	

	SUISUN BAY AT VAN SICKLE ISLAND		USGS	
Carquinez North/South OLUs	Carquinez Bridge		USGS	
Napa-Sonoma Network	Brazos?			
	Older Racoon Island	Benchmark Site		New long-term salinity gauge
	Dutchman Slough	feeder channel to multiple Project Sites		New long-term salinity gauge
	Steamboat Slough	feeder channel to potential future Project Sites		New long-term salinity gauge
Novato/ Gallinas/West San Pablo Bay Network	China Camp	Benchmark Site	SFBNERR	
	Gallinas Creek	Benchmark Site	SFBNERR	
	SAN PABLO BAY A PETALUMA R CHANNEL MARKER 1 CA		USGS	
San Rafael OLU/Point Richmond OLU/Corte Madera OLU/Wildcat Creek Network	Richmond-San Rafael Bridge		USGS	
	San Pablo Creek Marsh	Benchmark Site		New long-term salinity gauge
Mission - Islais OLU	SF Pier 17		USGS	
	SF Pier 24			
Golden Gate OLU	SAN FRANCISCO BAY A NE SHORE ALCATRAZ ISLAND CA		USGS	
Alameda Creek Network	Whale’s Tail South	Benchmark Site		New long-term salinity gauge
	North Creek Marsh	Project Site		New long-term salinity gauge

Belmont-Redwood OLU/San Mateo OLU	San Mateo Bridge at Foster City		USGS	
	San Mateo Bridge at Foster City		SFEI*	
San Francisquito OLU	Dumbarton Bridge		USGS	
	Dumbarton Bridge		SFEI*	
Mowry OLU	Mowry Slough		SFEI*	
Santa Clara Valley Network	Alviso Slough		SFEI*	
	Guadalupe Slough		SFEI*	
	Pond A8		SFEI*	
	Alviso Slough Feeder Channel		USGS	
	Older Warm Springs Marsh	Benchmark Site		New long-term salinity gauge

*SFEI moorings for the Nutrient Management Strategy measure WSEs, salinity, temperature, chlorophyll a, dissolved organic matter (DOM) fluorescence, dissolved oxygen, and turbidity at 15-minute intervals.

4-3: Suspended Sediment Concentrations

Table 4.3. Existing and proposed WRMP turbidity/SSC sensor deployments. Blue cells reflect priority WRMP monitoring site networks; white cells reflect Operational Landscape Units (OLUs) that could comprise future priority monitoring networks.

Network	Site	Site Type	Existing Sensor Deployment	Proposed WRMP Sensor Deployment
Carquinez North/South OLUs, Walnut OLU	Benicia and Carquinez Bridge		USGS - Time series turbidity w/ SSC calibration	
Alameda Creek Network	Whale's Tail South	Benchmark		Time series turbidity w/ 36 SSC calibration samples
	North Creek Marsh	Project		Time series turbidity w/ 36 SSC calibration

				samples
Napa-Sonoma Network	Older Raccoon Island	Benchmark		Time series turbidity w/ 36 SSC calibration samples
	Brazos Bridge	Feeder channel to multiple sites (relatively more fluvial)		Time series turbidity w/ 36 SSC calibration samples
	Dutchman Slough	Feeder channel to multiple sites (relatively more estuarine)		Time series turbidity w/ 36 SSC calibration samples
	Tolay Bridge? Sonoma Creek?			
Belmont-Redwood OLU/San Mateo OLU	San Mateo Bridge at Foster City		USGS - Time series turbidity w/ SSC calibration	
San Francisquito OLU, Mowry OLU	Dumbarton Bridge	Other	USGS - Time series turbidity w/ SSC calibration	
Santa Clara Valley Network	Coyote Creek at Hwy 237	Feeder channel to Older Warm Springs Marsh Benchmark Site	USGS - Time series turbidity w/ SSC calibration	
	Coyote Creek at Alviso Slough/Calaveras Pt	Feeder channel to multiple sites	SFEI - Time series turbidity deployment from 2015-2020	Re-occupy and calibrate to SSC?
	Alviso Slough		SFEI - Time series turbidity	
	Guadalupe Slough		SFEI - Time series turbidity	
	Pond A8		SFEI - Time series turbidity	
	Alviso Slough Feeder Channel		SFEI - Time series turbidity	
Suisun Slough	Rush Ranch	Benchmark	SFBNERR - Time	

Network			series turbidity	
Gallinas/Novato/ West San Pablo Bay Network	China Camp	Benchmark	SFBNERR - Time series turbidity	
Wildcat Creek Network	Richmond San Rafael Bridge	Other	USGS - Time series turbidity w/ SSC calibration	
	San Pablo Creek Mouth	Benchmark		Time series turbidity w/ 36 SSC calibration samples

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