WRMP Cost Estimates

Jillian Burns

Final Draft – 02/28/2020

Note to reader: These cost estimates will be refined in Phase 2.

1. Introduction

The San Francisco Estuary Wetland Regional Monitoring Program (WRMP) will advance and coordinate science to inform estuarine wetland management and regulation. Phase 1 of WRMP development concluded in early 2020 and focused on developing the technical foundation for three main program components (Figure 1): science content, data management, and administration and program governance. Science content is guided by a space-time framework for the WRMP that describes how and what data should be collected and/or synthesized to answer management and monitoring questions determined by the WRMP Steering Committee (SC). Costs were estimated to advance science content development into Phase 2 and inform the funding amount required for program start up and initial data collection (i.e. science content and administration and governance components). The data management component is also being developed in Phase 2 and those costs are not included in this analysis.

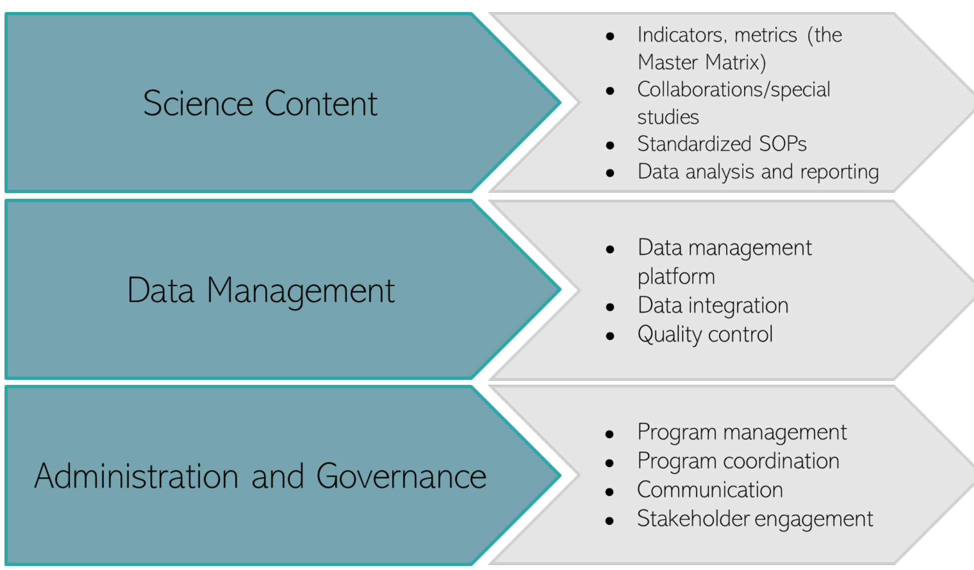

Figure 1. Program components.

Through science content development in Phase 1 described above, the following five science priorities emerged:

- Baseline Assessment: Conduct regional baseline and subsequent routine surveys.

- Benchmark Site Network: Establish the WRMP monitoring site network (dependent on available funding and resources), starting with the Benchmark Site Network.
- Standardize SOPs: Repeat 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.
- Sediment: Analyze existing data on the relative roles of estuarine and upland/watershed sources of sediment to counter the threat of sea level rise. Other drivers will be addressed in later WRMP phases.
- People and Tidal Marshes: Consider the broad range of interactions between people and tidal marshes that should be monitored for the safety of people and health of the marshes. This process should better integrate flood control and mosquito and disease vector control into project planning and assessment.

To achieve these priorities and answer the management and monitoring questions, the space-time framework includes over 20 proposed indicators that would monitor wetland physical processes, vegetation, wildlife, and mosquitoes (i.e. the Master Matrix, linked in Appendix A). The indicators were developed over two years through multiple workshops, a Science Advisory Team and science synthesis meetings that brought together wetland stakeholders from throughout the region. Indicator development was guided by the Wetland and Riparian Area Monitoring Plan (WRAMP). WRAMP is a framework and toolset developed through the California Wetlands Monitoring Workgroup of the California Water Quality Monitoring Council to improve the quality and consistency of local and regional wetland monitoring programs. WRAMP incorporates the 3-Level data classification system provided by USEPA as part of its guidance for state wetland program development:

- Level 1, or regional map-based inventories that collect data across a broad region at the same time;
- Level 2, or regional probabilistic surveys that collect certain types of data at representative subsets of sites across a region or sub-region; and
- Level 3, or site-specific monitoring.

Refer to the WRMP Program Plan for more detail on the science content development process and the space-time framework. According to this framework, indicators are measurable aspects of wetland condition and metrics are the methods of measurement. The indicators will enable the WRMP to evaluate conditions at various spatial and temporal scales of management. The indicators comprise a system of empirical observation designed to identify and forecast thresholds of condition that should trigger management actions. The framework integrates monitoring at restoration and mitigation projects and other fixed sites with regional ambient monitoring to improve project planning and assessment in the context of climate change and other external drivers of marsh ecosystem condition. Besides projects, there are two categories of fixed sites. Reference sites represent the expected or planned condition of projects after their initial period of natural maturation. Benchmark sites represent the mature conditions.

The reference sites and benchmark sites, as described in the program plan, serve multiple purposes. They will be used to detect thresholds of wetland response to external factors driving wetland condition. Monitoring at these sites will help managers and regulators understand how project conditions are affected by external versus project-specific factors. The benchmark sites will also be used to develop and calibrate indicators, test the functional relationships among indicators, explore marsh dependence upon the bay and its watersheds, and develop predictive models of future marsh ecosystem condition. Figure 2 shows a possible schematic of the distribution of monitoring efforts at a benchmark site. The plan for benchmark site monitoring will be further developed in Phase 2.

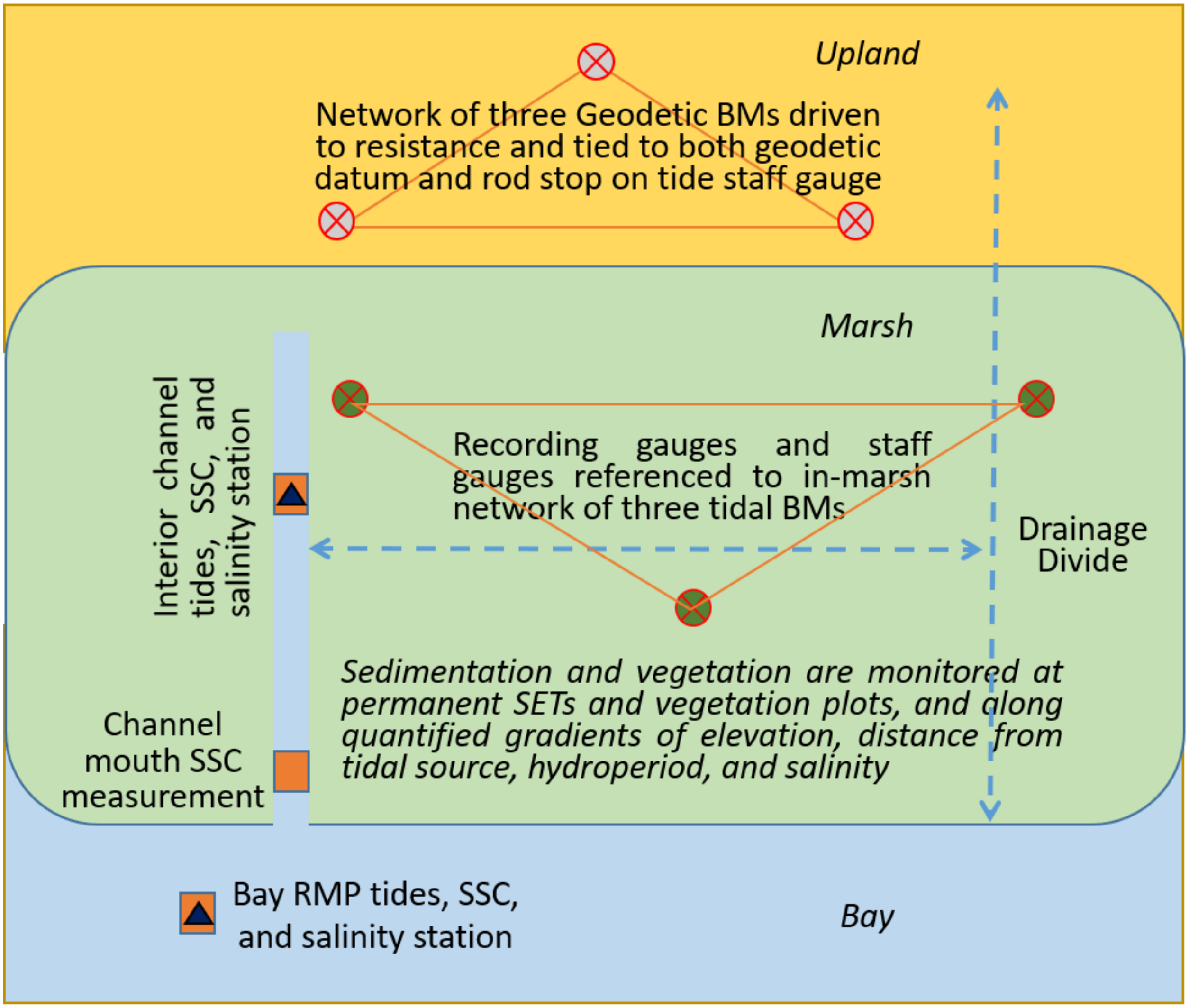

Figure 2. Schematic of possible benchmark site monitoring. Source: WRMP Plan.

The program plan documents the work completed and decisions made in Phase 1 and guides continued program development into Phase 2. The main components of Phase 2 include developing the funding plan, an institutional relations plan/charter, and the data management system and associated outreach. A Technical Advisory Committee (TAC) will be formed to advise and review WRMP science and technology. The TAC's recommendations in Phase 2 will greatly inform costs. Recommendations made by the TAC will consider phasing of implementation to assure that the WRMP establishes a scientifically sound foundation for program expansion and growth, and to cost-effectively address the guiding management questions. The SC and its TAC recognize that costs will be a primary control on implementation.

The program will be implemented in phases and start small with select priorities. The TAC will provide recommendations to the SC for science priorities and the SC will make the final decisions on science, administration, and governance priorities. For program start-up and implementation planning, it is important to understand the anticipated costs of the program's management structure and data collection. Cost estimates will be one of several prioritization criteria used by the SC to define initial steps for data collection and methods. This analysis provides a starting point for consideration of costs and is a foundation to build from for future decisions. The approach to this analysis was presented to the SC on October 15th, 2019 and modified by the Core Team. This document is organized by the two main program components that costs were estimated: **science content** and **administration and governance**. Each section includes methods, results, and discussion.

2. Science Content

2.1 Methods

To develop cost estimates, the Core Team interviewed practitioners from academia, private consulting, non-profits, and government agencies throughout the region who conduct monitoring relevant to the prioritized science content and indicators (see Appendix A). Brenna Mahoney, the coordinator for NOAA's San Francisco Bay and Outer Coast Sentinel Site Cooperative, assisted with the interviews. As described above, this analysis provides preliminary cost estimates associated with the WRMP start up tasks, including science content, administration, and governance. Data collection will be implemented in three main phases: baseline, start-up, and ongoing (see Table 1). Cost estimates were organized based on these three phases and general examples of costs associated with each phase include:

- Baseline: gathering existing data, developing a baseline map
- Start-up: site visit, planning/coordination for set-up, site set-up, equipment rental, field time, special studies to investigate methods
- Ongoing: surveys, instrument maintenance, lab analysis, data analysis and reporting

In the future, multipliers can be applied to these estimates to help understand expected funding required for larger scale implementation (e.g. multiple benchmark sites or region-wide surveys). Some economies of scale will apply, because it will be more cost-effective to collect data in one consolidated effort rather than multiple separate smaller efforts. Additionally, there are differences in wage and salary rates depending on the type of entity who will conduct the monitoring. The type of cost and scale of time and place for each phase is captured in Table 1 below.

Table 1. Cost organization for science content data collection.

Phase	Cost Type	Spatial Scale	Unit

Baseline	existing and new data	region-wide	NA; part of WRMP Phase 2
	baseline map		one-time cost
Start-up	equipment	one site	one-time cost/indicator
	fieldwork		
	special studies	varies by study	cost/study
Ongoing	fieldwork	one site	cost for one year/indicator
	Lab work		
	data analysis and reporting		
	special studies	varies by study	cost/study
	baseline map update	region-wide	TBD; frequency not determined yet

Embedded in Table 1 are three main categories that span some or all the three phases. The science content *Results* and *Summary* sections describe indicators, the baseline map, and special studies separately because these categories have different types of costs. Data analysis and reporting are not further discussed because the data management system is being developed in Phase 2, as essential information unknowns about the metrics of the indicators and indicator phasing is developed. The costs of data management can be revised as Phase 2 planning is completed.

Indicators

This analysis includes ballpark estimates of expected costs to implement an indicator. The Core Team developed a framework for cost estimates based on implementing that indicator at one hypothetical benchmark site for one year. The benchmark site network was decided upon for initial costings because it is a science priority and it allows for comparison of cost estimates between different indicators at similar scales. The start-up and baseline phases are one-time costs for one benchmark site, and the ongoing category describes one year of implementation. In the future, multipliers can be applied to each cost in order to visualize costs at multiple benchmark sites or as a region-wide survey. Each cost associated with an indicator was itemized in a detailed spreadsheet (Appendix A). This spreadsheet can be updated as program development progresses.

For the analysis of indicator costs, the baseline cost phase was examined separately from the start-up and ongoing phases. This is because baseline data collection will occur in the WRMP Phase 2 during the fit-gap analysis, as part of data management system development. The fit-gap analysis will examine the available and scientifically-validated datasets or existing data relevant to the science content and identify any data needs for each indicator. Gathering the existing data will help develop an appropriate data management system.

Baseline Map

Cost estimates for the baseline map, from the baseline phase, includes costs associated with developing a map of existing wetlands in the San Francisco Estuary. This baseline map also addresses multiple indicators but is not included in the indicator discussion above. Remote sensing will be used to create the baseline map, as well as address more site-specific questions. Like the indicators, remote sensing experts from across the region were interviewed to understand costs associated with acquiring and processing remotely sensed data and images and the various available methods. In Table 1, the baseline map is also included as an ongoing cost because the map will need to be updated periodically. Frequency of the update has not been determined.

Special Studies

Special studies are occurring in parallel to WRMP program development to help inform what monitoring methods (metrics) are best to evaluate each indicator. As more special studies occur, costs for implementing each indicator will be refined. There are currently multiple ongoing and future planned special studies associated with the WRMP to help inform SOPs. Current special studies include:

- Marin County vegetation baylands mapping with remote sensing: The WRMP is collaborating with a Golden Gate National Parks Conservancy team to pilot an alliance-scale vegetation mapping of Marin baylands. Vegetation alliances are classified by dominant species within polygons visible via remote sensing. Aerial imagery and Lidar were acquired by Marin County for a terrestrial vegetation map. The WRMP can use this imagery at no cost to conduct this mapping effort. Once a vegetation base map of the baylands is created, it is probable that future change analysis can be tracked by remote sensing and provide a valuable indicator for the WRMP. Mike Vasey, SF Bay NERR and WRMP SC member, is leading this special study.
- Remote Sending Special Study: The Montezuma Wetlands Restoration Project in Solano County is currently analyzing the best use of remote sensing methods (e.g. UAS, satellite, aerial imagery, lidar) for monitoring different aspects of the wetlands. Josh Collins, SFEI and WRMP SC member, is involved in this analysis and will ensure coordination with the WRMP. The results of this special study will inform remote sensing SOPs for the WRMP.
- There is concerted effort to understand sediment dynamics between the bay and marshes. The WRMP is keeping track of or are part of these efforts, which will greatly inform monitoring.

There are additional new and potential special studies and collaborations and other restoration projects the WRMP will learn from. Special studies are not included in this cost analysis but are recognized as an important component of program development. However, special studies are identified as a category of cost (Table 1). It is expected that special studies will be funded mainly through grants and partnerships, especially during early implementation.

2.2 Results

This analysis serves as the first step to developing cost estimates. More refined cost estimates will be developed as more information becomes available. The accuracy of the cost estimates presented here is subject to multiple factors, including not limited to: site location, site size, site access, specific data collection method (metric), level of effort, and frequency of data collection. These factors exist because the location of the monitoring sites, monitoring metrics, indicator prioritization, and frequency and level of effort of data collection have not been finalized. These unknowns be will be addressed in Phase 2 of program development. Other factors or unknowns specific to each indicator are further described below. More details can be found in the interview notes here.

Indicators

All indicators described below are from the Master Matrix of indicators. The Master Matrix is a “living document” that currently reflects consensus on a scientific framework for a wetlands regional monitoring program for San Francisco Bay. It will be updated as the program and science evolve. Table 2 summarizes the expected costs by implementation phase for the indicators that represent the prioritized science indicators that assess wetland physical response to changing sea lever and sediment supplies.

Table 2. Summary of indicator cost estimates by phase.

Phase	Spatial Scale	Unit	Estimate		Description
			Low ($)	High ($)	
Start-up	one benchmark site	one-time cost	~56,000	~180,000	Installing infrastructure to monitor elevation, water level, and sediment
Ongoing	one benchmark site	cost for one year/indicator	11,920	12,280	Ongoing monitoring and surveys elevation, water level, and sediment

Physical Processes

The proposed physical processes indicators include monitoring of marsh elevation, sediment, tidal inundation, and sea-level rise in the Estuary.

Table 3. Physical processes indicator cost estimates.

Indicator # from Master Matrix (metric)	Phase	Estimates			
		Low ($)		High ($)	
2 Change in elevations (ft NAVD) and elevation capital (Z*relative to local MHHW); 12 (Marsh plain and tidal flat accretion rates (relative to local tidal datums and NGVD)	start-up	27,720	purchase equipment for and install SETs and benchmarks	79,640	purchase new RTK GPS system; purchase equipment for and install SETs and benchmarks
	ongoing	1,920	conduct RTK GPS survey and monitor SETs	2,280	Rent RTP GPS system; conduct RTK GPS survey and monitor SETs
12 (marsh plain and tidal flat accretion rates relative to local tidal datums and NGVD); 13 (suspended sediment concentrations in tidal marsh channels)	start-up	15,000	SSC site set-up	20,000	Purchase new fully equipped multi-parameter sonde (addresses other indicators)
	ongoing	9,400	Fieldwork for Instrument maintenance, sample collection and analysis	9,400	Fieldwork for Instrument maintenance, sample collection and analysis
14 (tidal inundation regime); 15 (annual mean sea level rise.)	start-up	13,650	Tide gauge (low cost), installing a stilling wells, equipment rental	23,650	Tide gauge (high cost)
	ongoing	600	Repeated monitoring (1 person/6 hours; $100/hr)	600	Repeated monitoring (1 person/6 hours; $100/hr)

16 (Aqueous (in-channel) and porewater salinity	start-up	750	Salinity/conductivity hobo logger	20,000	Fully equipped multi-parameter sonde (addresses other indicators)
	ongoing	100	soil sample processing for porewater salinity	100	soil sample processing for porewater salinity

Marsh elevation indicators require the most significant start-up costs but are vital to monitoring wetland resiliency with the required precision to answer the WRMP guiding, management, and monitoring questions.

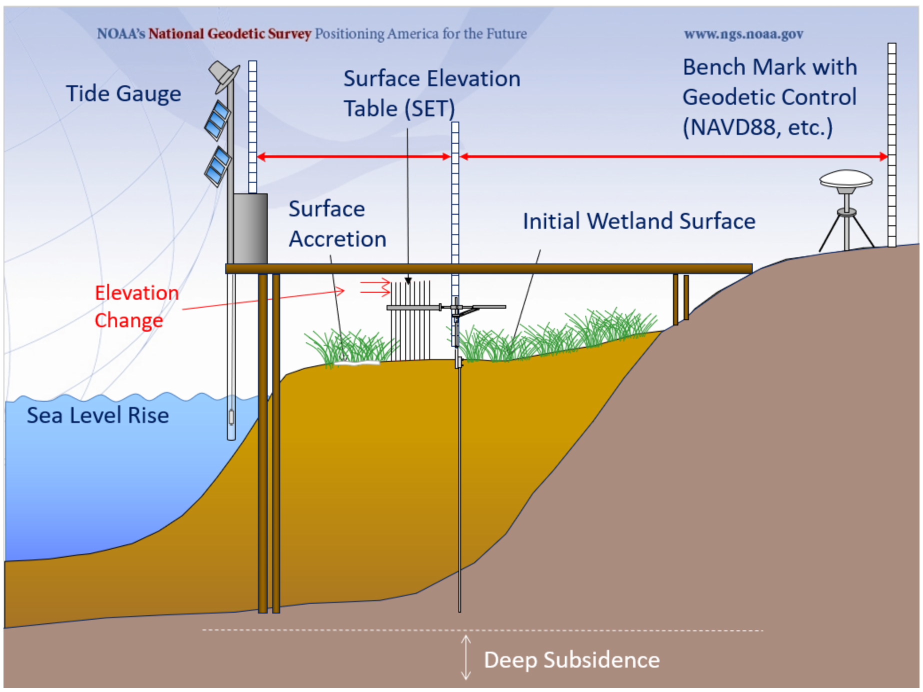

Figure 3. Wetland elevation capital monitoring (Indicator 2). Source: Philippe Hensel (National Geodetic Survey/NOAA) presented this schematic a the WRMP Physical Processes Workshop on August 28, 2018.

The start-up costs for Indicators 2 and 12 in the Table 3 represent establishing infrastructure to evaluate wetland elevation capital. Wetland elevation capitol is vital to understanding a wetland's ability to sustain elevation in the face of sea level rise. Currently in the Estuary, this monitoring already occurs at Rush Ranch and China Camp by the SF Bay NERR and Petaluma Marsh, a site south of Sears Point Wetland Restoration Project, Browns Island, and Minor Slough on the Sacramento River by USGS. The WRMP may be able to reduce costs by utilizing these locations for the benchmark site network.

Some of the above locations are already identified by the WRMP as potential benchmark sites. However, they rely on local elevation control networks that are not connected to the National Spatial Reference System (NSRS), which has been discussed as a priority of the WRMP. In other words, some the existing monitoring infrastructure in the Estuary does not have benchmarks with geodetic control, as shown in

Figure 3. The SF Bay NERR benchmarks do have geodetic control. The NSRS, maintained by NOAA's National Geodetic Survey, is a consistent and accurate coordinate system of marked points that define latitude, longitude, height, scale, gravity, and orientation in the country. Local control networks only allow elevation change to be monitored relative to the specific site, while benchmarks with geodetic control allow elevation change to be monitored based on the site's actual position on earth, and this controls for vertical land motion. Land uplift can decrease relative sea level rise and help mediate its impacts, whereas land subsidence can accentuate the impacts. Connecting WRMP benchmark sites to the NSRS will require more investment and frequent monitoring, especially because the San Francisco Estuary is in a tectonically active region.

Assessing sediment delivery to tidal marsh ecosystems is one of the identified science priorities approved by the SC. At benchmark sites, the WRMP proposes to continuously monitor suspended sediment concentration in marsh channels, in coordination with in-bay measurements, to help understand tidal marsh sediment supply, demand, and delivery. Indicators 12 and 13 are needed to monitor the resulting marsh accretion rates, as a function of suspended sediment concentration (SSC). Start-up costs for SSC monitoring involve installation of sonde. Ongoing costs include field time to download data, and to calibrate and maintain the sonde.

Indicator 14 and 15 require site set-up costs associated with installing a tide gauge at the benchmark site and a stilling well with a staff gauge and rod stop to calibrate the gauge and correct water level measurements for vertical gauge movement. Ongoing costs include repeated monitoring for instrument maintenance and downloading data. Indicators 12 and 13 also require field time for ongoing sediment monitoring, and therefore, it would be efficient for one monitoring team to cover all the physical process indicators during the same field visit. This cost sharing will apply to many of the indicators that require field visits for instrument maintenance, sample collection, and data retrieving and will require careful logistical planning.

Indicator 16 is needed to measure both in-channel and porewater salinity. In-channel salinity includes start-up costs for installing a sonde in the channel. This cost ranges from $750 for a salinity/conductivity logger to $20,000 for a fully equipped multi-parameter sonde that would also cover multiple indicators. Porewater salinity is measured from water extracted from a soil sample. In the Estuary, to measure pore water salinity, soil samples need to be collected at the marsh and put in a centrifuge to separate the water and soil. Then, using a refractometer, measure conductivity of the water. The samples would be collected during a vegetation survey, and therefore would not likely require additional field costs.

Marsh Vegetation and Condition

The proposed vegetation indicators include monitoring how vegetation structure and composition respond to the physical processes presented above, namely based on duration of inundation and a combination of aqueous and porewater salinity. Utilization of groundwater wells can also help to understand the rooting environment in which the vegetation is situated.

Table 4. Marsh vegetation and condition survey indicator cost estimates.

Indicator # from Master Matrix (metric)	Phase	Estimate			
		Low ($)		High ($)	
7 and 8 (Likely to include acres and location of dominant tidal wetland vegetation alliances, patchiness, total % cover, veg height, etc.)	start-up	1,000	pre-programmed tablets for data collection	1,000	pre-programmed tablets for data collection
	ongoing	1,440	gradsect or standard vegetation survey (2 ppl/2-3 days; 30$/hour)	3,360	gradsect or standard vegetation survey (2 ppl/2-3 days; 70$/hour)
10 (distribution and abundance of selected non-native, invasive plant species); 11 (CRAM Index and Metric scores relative to regional CRAM CDFs)	start-up	NA	NA	NA	NA
	ongoing	1,120	CRAM survey including survey, travel time, and field preparation (2 ppl/ one day; 70$/hour)	1,120	CRAM survey including survey, travel time, and field preparation (2 ppl/ one day; 70$/hour)

Indicators 7, 8, 10, 11, and 16 are all related to monitoring marsh vegetation and condition (Table 4). Indicators are needed to measure the percent cover, height, and patch characteristics of major dominant species assemblages, and Indicator 8 assesses the magnitude and direction of change of those measurements over time. To valuate these indicators, a vegetation survey at a benchmark site is expected to cost between $1,440 and $3,360. As a start-up/one-time cost, iPads used for data collection cost about $1,000 each. These vegetation indicators also highlight the opportunity to use remote sensing paired with the field surveys to track vegetation change. Field surveys provide ground truthing for remotely sensed images, while remote sensing decreases the amount of field work. Figure 4 shows available remote sensing methods. The first row shows the wide range of costs associated with each method. Numbers associated with these methods are listed in Table 8. The Remote Sensing Special Study, described above, and the TAC will develop an SOP for WRMP use of remote sensing to monitor vegetation and other indicators.

Considerations	Satellite sensors	Aerial manned including LiDAR	Aerial unmanned including LiDAR	In situ sensors & sensor networks
General cost of data acquisition	Varies but open-source options exist	Typically high	Low after instrument purchase	Relatively low
Spatial extent of coverage	Large	Moderate	Moderate to small	Very small (local)
Repeated data collection	Common	Very costly	Possible as needed	Possible at high temporal frequency
Customized timing of data collection	Typically not possible	Possible but very costly	Possible as needed	Possible as needed
Technical & data quality constraints	Clouds may affect image usability	Typically addressed by vendors	Flight logistics, wind, data stitching	Minimal
Sensitivity to spectral contrasts among veg. types	Often relatively high, depends on sensor	Depends on sensor, but high sensitivity options are costly	Depends on sensor, but high sensitivity options are costly	Often not very high
Spatial detail & ease of human expert recognition	Low to moderate	Moderate to high	High	High

Figure 4. Strengths and limitations of different remote sensing methods for vegetation monitoring. Source: Iryna Dronova (UC Berkeley) presented "Opportunities & Limitations of Remote Sensing Techniques to Assess Vegetation Change Over Time" at the WRMP Vegetation Workshop on October 30, 3018.

Indicator 11 is needed to assess overall wetland condition or health. The proposed method to evaluate the indicator is the California Rapid Assessment Method (CRAM). CRAM allows sites to be compared to each other and over time based on standardized assessment of landscape context, buffer, hydrology, physical structure, and biotic structure of standard size assessment area. A CRAM survey at one benchmark site is expected to take two field scientists one day, however the actual costs will mostly depend on site size and access. These scientists must be CRAM certified (i.e. complete a 5-day training for $1,500). There will be start-up costs associated with determining the assessment area. During CRAM or other vegetation surveys, the field scientists can also record other observations or measurements like the presence of non-native or invasive species (Indicator 10) or take soil samples (Indicator 16).

Wildlife

The proposed wildlife indicators include monitoring of mercury and dissolved oxygen in the food web, distribution and abundance of tidal marsh and secretive marsh birds, and resident marsh mammals and fish.

Table 6. Wildlife indicator cost estimates.

Indicator # from Master Matrix (metric)	Phase	Estimate	
		Low ($)	High ($)

17 (Hg concentrations in blood or tissue of bio-sentinel species representing tidal flats)	start-up and ongoing	3,500	coordination meetings, field survey, lab work and analysis	4,000	coordination meetings, field survey, lab work and analysis
18 (dissolved oxygen concentrations)	start-up	4,000	sonde with only DO and salinity	20,000	sonde with all water quality parameters
	ongoing	1,000	sonde maintenance	1,000	sonde maintenance
19 (tidal marsh and secretive marsh bird abundance, trends in abundance)	start-up	NA	NA	2,000	site visit
	ongoing	2,500	two tidal marsh bird surveys	9,500	secretive marsh bird survey; boat required for access
20 (SMHM, perhaps California Vole)	start-up	NA	NA	8 hours	set-up survey grid (two people/4 hours)
	ongoing	NA	NA	5,000	one survey by a consulting firm
21 (Abundance of longjaw mudsucker; community composition, abundance, and distribution of estuarine fish (pelagic/larval and marsh plain), and anadromous fish (Chinook salmon and steelhead trout))	start-up	NA	NA	NA	NA
	ongoing	50,000	monthly fish sampling	200,000	monthly fish sampling

Proposed wildlife indicators include monitoring mercury and dissolved oxygen levels to understand their impact on the marsh food web and conducting surveys for tidal marsh and secretive marsh birds, fish, and mammals to understand the status of select populations (Figure 5). Wildlife indicators are not identified as priorities from Phase 1, but do not require start-up costs and can be added to the program later as funding becomes available.

Figure 5. Some species the WRMP may monitor. A. From left, California ridgway's rail, song sparrow, salt marsh common yellow throat, California black rail, Julian Wood (Point Blue Conservation Science). B. Salt marsh harvest Mouse. Source: Isa Woo (USGS). C. Longjaw mudsucker caught in pond A21 of the South Bay Salt Ponds. Source: Jim Ervin ("Fish in the Bay").

The main start-up costs associated with the wildlife indicators would include site visits and sampling design; these are not reflected in Table 5 because there are too many unknowns at this time. The fish survey costs depend significantly on the sampling methods and frequency; therefore, the cost estimate is a wide range. A tidal marsh bird survey at one benchmark site is expected to cost $2,500 and a secretive marsh bird survey is expected to cost $3,000 (Indicator 19). These costs could double if a boat is required for access. Secretive marsh bird surveys, mainly focused on the endangered California ridgway's rail, are already conducted throughout the region due to regulatory requirements for the Invasive Spartina Project. A salt marsh harvest mouse survey is expected to cost over $5,000. However, some marsh mammal monitoring, mainly focused on the endangered salt marsh harvest mouse, currently occurs throughout the Estuary. The WRMP will need to coordinate with this existing wildlife monitoring to foster data sharing and coordinate survey locations. Costs can be greatly reduced if the WRMP can utilize existing monitoring for many of the wildlife indicators.

Mosquito and Vector Control

The proposed mosquito and vector control indicators include monitoring of mosquito habitat and production of mosquito larvae and adults.

Table 7. Mosquito and vector control indicator cost estimates.

Indicator # from Master Matrix (metric)	**Phase**	**Estimate**			
		Low ($)		**High ($)**	
22 (total area and patch size of known and	start-up	NA		NA	

potential areas of mosquito production)	ongoing	546	UAS aerial imagery acquisition and post processing (1 person/7 hours; low hourly rate)	700	UAS aerial imagery acquisition and post processing (1 person/7 hours; high hourly rate)
23 (counts of mosquito adults and larvae by species)	start-up	NA	NA	NA	NA
	ongoing	NA	NA	NA	NA

The WRMP recognizes the importance of coordinating wetland restoration and monitoring with the Mosquito Abatement Districts (MADs). Indicator 22 proposes monitoring of mosquito habitat with remote sensing. Mosquito production can occur at any standing water; therefore, the MADs thoroughly monitor existing surface waters throughout the Estuary. Remote sensing, mostly UAS (i.e. drones) with a camera can more efficiently identify surface water. One UAS survey to assess standing surface water costs between $500-700, including data acquisition and post-processing. This assumes the surveyor already has the UAS equipment and is properly trained. At the Mosquito and Vector Control Workshop, the Alameda County MAD reported their use of this technology in conjunction with field surveys (Figure 6).

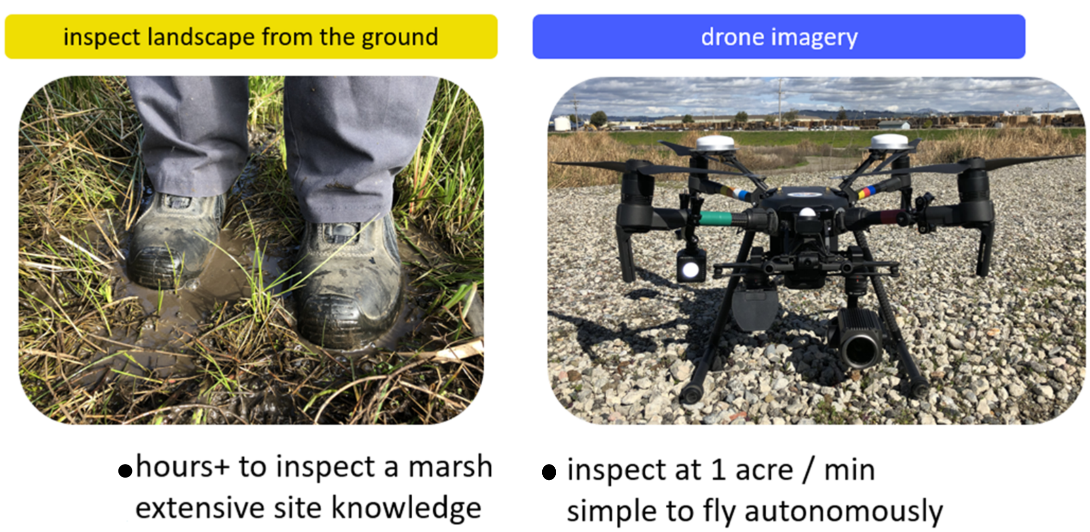

Figure 6. Alameda County Mosquito Abatement District is using a UAS multi-spectral camera, paired with field surveys, to monitor mosquito habitat. They are also developing an artificial intelligence method to count mosquito

larvae in a marsh. Source: Miguel Barretto presented "Assessing mosquito breeding sites from above" at the WRMP Mosquito and Vector Control Workshop on March 21, 2019.

Indicator 23 includes counts of mosquito larvae and adult species. The MADs already monitor marshes throughout the Estuary for mosquito adults and larvae. It is not expected that the WRMP would require additional mosquito monitoring at this time. Costs associated with these indicators will be related to coordination and data sharing. Opportunities to coordinate mosquito monitoring and other WRMP monitoring will be explored.

Baseline Map

The baseline map directly addresses Indicator 1 (map of baylands habitat types and elements) and indicator 4 (map of "complete marshes" as defined by BEHGU and fluvial/upland/riparian connectivity) and partially addresses indicator 3 (map of estuarine-terrestrial transition zones and migration space), indicator 5 (map of tidal wetland special-status species habitats), Indicator 6 (map of changes in the lateral extents of natural foreshores (tidal marsh and beach)), and Indicator 9 (changes in unvegetated areas of the marsh). There are extra costs associated with indicators 3, 5, 6, and 9 because staff will need to perform geospatial analysis using the baseline map to fully evaluate each indicator. Depending on the best remote sensing method(s) determined by the special study, TAC, and SC for the baseline map (i.e. satellite imagery, aerial imagery, lidar, etc.), the map will also be evaluated to significantly reduce the error of lidar elevation data due to the presence of moisture in marsh vegetation. the indicators for vegetation, elevation, and mosquito habitat.

Table 7 documents the cost estimates provided by each interviewed practitioner. More consideration of different remote sensing methods for the baseline map will occur in Phase 2, in consultation with the San Francisco Estuary Geospatial Working Group and through the Remote Sensing Special Study. A parallel effort to update the Bay Area Aquatic Resources Inventory is in the early stages of proposal planning and will help address the indicators described in the previous paragraph. The State of California is purchasing lidar for the entire state. The WRMP is tracking this in the hope it will benefit the program. It is important for the WRMP to keep track of opportunities to partner with other entities and cost-share remote sensing data collection.

Table 8. Remote sensing cost estimates gathered from interviews.

Indicator # from Master Matrix	Method	Description	Projects	Scale	Cost Estimate
1, 2, 3, 4, 5, 6, 7, 8, 9, 10 ,14	Non-UAS lidar and aerial imagery	Data acquisition	county vegetation mapping	NA	Q1 lidar: $600/sq mile; 6-inch 4-band aerial imagery: $200/sq mile
	Non-UAS lidar and aerial	Data acquisition and post-	Delta Lidar 2017	Delta boundary	$750,000

	imagery	processing			
	Non-UAS lidar and aerial imagery	Data acquisition and post-processing	ballpark estimate for the WRMP	WRMP area	Up to $1,000,000
	Satellite imagery	Data acquisition	ballpark estimate for the WRMP	WRMP area	$50,000
	Non-UAS aerial Imagery	Data acquisition	ballpark estimate for the WRMP	Various	10 cents – one dollar/acres depending on size of total site
	Satellite imagery	Data acquisition and post-processing	ballpark estimate for the WRMP	WRMP area	Significantly less than $1,000,000
	UAS aerial imagery	Data acquisition and post-processing	Corte Madera Marsh	One marsh	$12,000
	UAS aerial video and imagery – multi-spectral camera	Data acquisition and post-processing	Alameda Mosquito Abatement District surveys	One marsh	Less than $1,000
	UAS lidar	Equipment purchase	NA	NA	$80,000
	Set Benchmark Control Network	Fieldwork	Set benchmarks for aerial imagery collection	One marsh	2,450
	Aerial imagery (drone or fixed-wing)	Data acquisition and post-processing	ballpark estimate for the WRMP	One marsh	2,300-6,800
	Photogrammetry	Data acquisition and post-processing	ballpark estimate for the WRMP	One marsh	3,300-6,800

Remote sensing data can be acquired in many ways. There are open-source websites with access to satellite, lidar, and aerial data at minimum cost for downloading and storage. However, these data are not customizable and require post-processing costs. Satellites and occupied-aircrafts can provide customizable imagery and lidar at a higher cost. The imagery can provide a lot of types of data to map habitat areas or multi-spectral images to track vegetation change. Overall, lidar is the most expensive method to acquire data but unlike satellite or other aerial images, it can provide data on both vegetation and elevation. These comparisons are also reviewed in Figure 4.

The USGS has developed a method, termed the Lidar Elevation Adjustment with NDVI (LEAN)-corrected model, to significantly reduce the error of lidar elevation data resulting from the moisture in marsh vegetation. However, to achieve the accuracy and precision of elevation data needed to evaluate thresholds of sea level rise or sediment supply that trigger ecological change, the corrected lidar data will need to be calibrated against field-based elevation monitoring (i.e. SETs and optical surveys referenced to a network of stable tidal and geodetic benchmarks with very low closure values). Another important consideration is the stage of tide during which remote data are collected. Remotely sensed data for tidal marshes and flats must be collected during low-tide. This eliminates the suitability of many existing data and raises the costs for new data collection. However, costs should decrease as the technology improves and becomes more broadly used. is improving and have steadily been

2.3 Summary

Costs are divided into three phases of program implementation including baseline, start-up, and ongoing. The indicators either require start-up (e.g. instrument installation) and ongoing costs (e.g. instrument maintenance, data retrieval), or just have ongoing costs (e.g. conducting a survey). These ongoing cost-only indicators do not require infrastructure at a benchmark site and can be added to the monitoring program later depending on indicator prioritization by the TAC and SC and available funding. For example, the wildlife indicators mainly propose surveys to understand the distribution and abundance of a certain taxa. Wildlife surveys do not require start-up costs like installing instruments at a benchmark.

Some indicators related to the science priorities determined from Phase 1 require start-up costs that need to be prioritized in the initial phases of program implementation in order to begin collecting data to assess the marsh response to climate change and sediment availability, as highlighted in the prioritized science content. For example, elevation monitoring will cost tens of thousands of dollars to install the SETs, benchmarks, and other equipment initially. Once the infrastructure is installed, the ongoing monitoring costs are low and only require monitoring teams to return to the site periodically to collect data and maintain equipment. As discussed in the Results section, the start-up costs can be reduced by selecting benchmark sites where similar monitoring is already occurring and the start-up costs will only include coordination with existing monitoring teams and connecting the benchmarks to the NSRS. These decisions will be made by the SC, with recommendations from the TAC.

The TAC, to be formed in late-Spring/early-Summer 2020 will be the main venue to weigh different options related to the science content. The TAC will make recommendations of the best methods for prioritized science indicators to the SC. Examples of topics that need to go through the TAC include level of effort, frequency, and locations of monitoring, frequency of reporting, event-based monitoring, details SOPs for each active indicator, continued re-evaluation of methods and metrics, use of emerging technologies, level of ground truthing for remote sensing, methods for data analysis and visualization, and many more.

Costs can be reduced through logistical coordination with existing monitoring and cost-sharing with other indicators. Extensive coordination will be required to efficiently manage the monitoring activities proposed in this program and to track outside efforts and opportunities to partner on projects that will benefit the WRMP. The costs of coordination should not be underestimated.

3. Administration and Governance

3.1 Methods

Administration and governance will require significant funding across various phases of program development. Currently, the WRMP is exploring funding and program management models, including examination of other monitoring programs in the region and nationally both for program startup costs as well as long term program management costs. The Regional Monitoring Program for Water Quality in San Francisco Bay (Bay RMP) and Delta Regional Monitoring Program (Delta RMP) are water quality monitoring programs managed by the San Francisco Estuary Institute, and though the programs have differences from the WRMP (i.e. data type, funding, stakeholders) the program budgets provide helpful examples that will inform costing analysis for the WRMP.

3.2 Results

Figure 7 shows the proportion of the Bay RMP's 2019 detailed workplan and budget and Delta RMP's fiscal year 2019-2020 detailed workplan and budget allocated for each task relevant to the WRMP. The figure shows proportions because the two monitoring programs' actual budget numbers are not directly applicable to the WRMP.

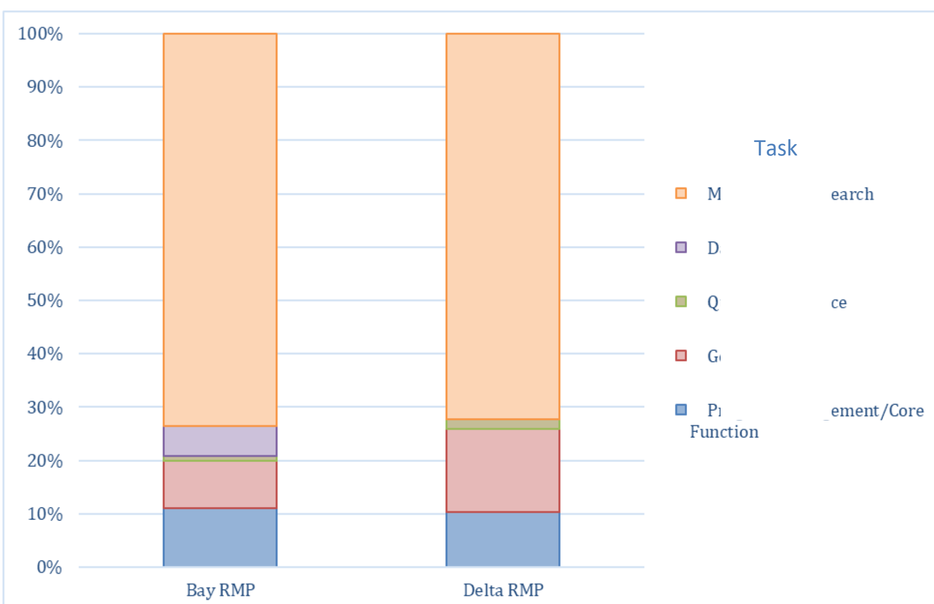

Figure 7. Proportions of allocated for each task of the Bay RMP and the Delta RMP.

The Bay RMP allocates approximately 23% for program management (program management, governance, and QA and data services), 10% for annual reporting and communications, 65% for status and trends monitoring and special studies, and about 2% is unallocated. The Delta RMP allocates approximately 28% for program management (core functions, governance, and administration, and quality assurance) and 72% for water quality monitoring and special studies. The data management is embedded in the monitoring and special studies. The Bay RMP is larger and more established than the Delta RMP, but both programs allocate roughly a third of the budget to administration and governance tasks. The rest of the budget funds monitoring and special studies.

3.3 Summary

The WRMP's governance will potentially be more complicated than the processes associated with the programs mentioned above. Data management will also be more complicated because the WRMP will be managing and synthesizing multiple types of data sources. Most of the data collected and managed from the Bay RMP and Delta RMP consist of discrete sampling data and are accordingly of a similar form. Unlike the WRMP, both the Bay RMP and Delta RMP are currently implemented and operational programs so their budgets will not completely reflect the funding that will be required to start up the WRMP. In addition, it is expected the funding required to start up the WRMP's administration and governance and data management may be up to 40% of the total budget.

Where the data management practices, processes, technologies, and tools are already established by the Bay and Delta RMPs, the WRMP could recognize a significant savings over the long-run when managing their data in a regional data center. Quality control / quality assurance strongly benefits from routine and experience. The WRMP will overlap in geography and potentially in topics with the already established water quality programs. The WRMP will accordingly be in a good position to leverage preexisting data and information pertinent to program indicators. More importantly, the WRMP can make use of staff, processes, scripts, and tools that represent an investment by each RMP of multiple years.

Appendix A. Supplemental Information

Master Matrix: shorturl.at/qDV26
Cost estimates folder:
https://drive.google.com/drive/u/0/folders/1Atoo95o8EdkgjQw9DIt2MEqC3t1xoQyf

The following table lists the practitioners I interviewed for this analysis. I did not get permission from everyone share their name publicly, so please keep for internal purposes.

Table 9. List of practitioners interviewed for this analysis.

Name	Affiliation	Topics Discussed
April Robinson	SFEI	mercury
Brian Fulfrost	Brian Fulfrost and Associates	Remote sensing, vegetation
Dan Gillenwater	GillenH2O Consulting	Marsh elevation, vegetation
Danny Franco	Golden Gate National Parks Conservancy	Remote sensing, vegetation
Invasive Spartina Project	Olofson Environmental	Site access, birds, vegetation
Iryna Dronova	UC Berkeley	Remote sensing, vegetation
Jared Lewis	Applied technology and Science	Remote sensing, vegetation
Jimmy Kulpa	Cinquini & Passarino, Inc.	Marsh elevation, vegetation
Joel Dudas	CA Department of Water Resources	Remote Sensing
Julian Wood	Point Blue Conservation Science	Birds
Karen Thorne	USGS	Marsh elevation
Kass Green	Kass Green and Associates	Remote sensing, vegetation
Katie Smith	WRA	Marsh mammals
Levi Lewis	UC Davis	Fish
Matt Ferner	SF Bay NERR	marsh elevation, vegetation, water quality

Maureen Downing-Kunz	USGS	sediment
Melissa Foley	SFEI	sediment, dissolved oxygen
Melissa Foley	SFEI	Sediment, dissolved oxygen
Mike Vasey	SF Bay NERR	Vegetation, marsh elevation,
Nina Garfield	NOAA	Marsh elevation, tidal inundation
Sarah Lowe	SFEI	CRAM
Sarah Pierce	SFEI	CRAM
Scott Jones	USGS	Porewater salinity