REGIONAL MONITORING PROGRAM FOR WATER QUALITY IN SAN FRANCISCO BAY

sfei.org/rmp

RMP Sediment Workgroup Meeting

May 7, 2019
9:30 AM – 5:00 PM

LOCATION
San Francisco Estuary Institute
4911 Central Ave, Richmond, CA

REMOTE ACCESS
Audio by Phone: (415) 594-5500, Access Code: 943-326-397#
Slides: https://join.me/sfei-conf-cw1

AGENDA

1.	**Introduction and Goals for Today's Meeting** The goals for today are to: ● Review results from completed and ongoing Sediment Workgroup Studies ● Rank special study proposals for funding in 2020 and provide advice to enhance those proposals ● Determine which SEP study proposals should be considered for funding ● Discuss Workgroup funding priorities for the next several years	9:30 am Scott Dusterhoff (SFEI)
2.	**Information: Review of March 19 Meeting** On March 19, 2019, the Sediment Workgroup had a 3-hr meeting focused on reviewing the Workgroup Multi-Year Plan and the funding priorities for 2020 and beyond, and discussing the	9:45 am Scott Dusterhoff (SFEI)

	proposals to submit for 2020 funding. This item a brief summary of the meeting discussion and outcomes. <u>Meeting materials</u>: March 19 Meeting Notes <u>Desired outcome</u>: Informed committee	
3.	**Information: Presentations on 2018 and 2019 Sediment Workgroup Studies** Workgroup member will give short presentations on studies being conducted under the auspices of the Sediment Workgroup. These will include presentations providing final results from studies completed in 2018 and presentations providing progress updates for studies that will be completed in 2019. This will be an opportunity for Workgroup members to be informed about completed studies and provide feedback on studies still in progress. The studies that will be presented are: ● Mallard Island Suspended Sediment Concentration Monitoring ● Lower South Bay Suspended Sediment Flux Study ● Napa River and Sonoma Creek Sediment Transport Monitoring ● PCB Synthesis Study of Measurements in Dredged Sediments Compiled in the Dredged Material Management Office (DMMO) Database ● Workshop on Sediment Screening and Testing Guidelines for Beneficial Reuse of Dredged Sediments ● Sediment Bulk Density Study <u>Meeting materials</u>: Lower South Bay Suspended Sediment Flux Measurements Year 1 Report, DMMO PCB Synthesis Study Report <u>Desired outcome</u>: Informed committee, feedback on in-progress studies	10:00 am Maureen Downing-Kunz (USGS) Daniel Livsey (USGS) Scott Wright (USGS) Don Yee (SFEI) Melissa Foley (SFEI) Jeremy Lowe (SFEI)

4.	**Information: Update on BCDC Sediment Management Efforts** BCDC is in the process of developing a sediment monitoring strategy that addresses recommendations in their 2016 Science of Sediment Report, and a science framework for guiding in-Bay sand mining permits. This presentation will provide an update on these efforts and discuss next steps. Meeting materials: None Desired outcome: Informed committee, feedback on study	11:40 am Brenda Goeden (BCDC)
	LUNCH (provided)	Noon
5.	**Information: Update on the Conceptual Understanding of Sediment Dynamics & Sediment Monitoring Strategy Development** In 2018, the Sediment Workgroup received funds to develop a conceptual understanding of Bay sediment dynamics and a sediment monitoring strategy to help guide the Workgroup's efforts over the next several years. This presentation will provide an update on conceptual understanding and strategy development and discuss next steps. Meeting materials: None Desired outcome: Informed committee	12:30 pm Jeremy Lowe (SFEI)
6.	**Information: Presentations of 2020 Proposed Special Studies** The study proposals being put forth for 2020 funding will be presented to the Workgroup. These proposals have already been identified as "high priority" by the Workgroup. Meeting materials: ● Sediment modeling strategy (SFEI) ● Sediment bioaccumulation guidance (SFEI) ● Bathymetric analysis - Year 2 (USGS) ● Golden Gate sediment flux modeling (Anchor QEA) Desired outcome: Opportunity for clarifying questions about proposed studies.	1:15 pm Scott Dusterhoff (SFEI) Diana Lin (SFEI) Bruce Jaffe (SFEI) Michael MacWilliams (Anchor-QEA)

<table>
<tr><td>7.</td><td>Closed Session

Decision: Ranking of 2020 Special Studies Proposals

RMP Special Studies are identified and funded through a three-step process. Workgroups recommend studies for funding to the Technical Review Committee (TRC). The TRC weighs input from all the workgroups and then recommends a slate of studies to the Steering Committee. The Steering Committee makes the final funding decision. For this agenda item, the Workgroup is expected to prioritize the list of proposed special studies to recommend to the TRC. To avoid an actual or perceived conflict of interest, the Principal Investigators for proposed special studies are expected to leave the room during this agenda item.

Meeting Materials:
● RMP Charter (describes process for funding decisions)
● RMP Multi-Year Plan that includes the Sediment Workgroup Multi-Year Plan

Desired Outcome: Ranking of the Sediment Workgroup proposed 2020 Special Studies for the TRC</td><td>2:45 pm

Bridgette DeShields (TRC Chair)</td></tr>
<tr><td>8.</td><td>Report Out of Proposal Ranking and Recommendations to Principal Investigators</td><td>3:15 pm

Bridgette DeShields (TRC Chair)</td></tr>
<tr><td></td><td>BREAK</td><td>3:30 pm</td></tr>
<tr><td>9.</td><td>Discussion & Decision: SEP Study Ideas

Each RMP Workgroup has been asked to develop three study ideas to place on the list for possible Supplemental Environmental Project (SEP) funding. These studies should be of interest to the Workgroup and considered priority projects, but require funds beyond the Workgroup’s allotted budget. This discussion will include a brief description of all ideas submitted and a decision on which ones to move to the SEP list at this time.

Meeting materials: SEP Study Idea Table</td><td>3:45 pm

Scott Dusterhoff (SFEI)</td></tr>
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	Desired outcome: Decision on the three SEP study ideas to submit for SEP funding consideration	
10.	**Discussion: Strategic Planning for the next 5 years** The Sediment Workgroup Multi-Year Plan is a living document that needs to be updated as new Workgroup priorities are established. During this discussion, the Workgroup will identify funding priorities for special studies over the next 5 years (drawing upon the discussion in Agenda Item 5) and decide on Multi-Year Plan updates to reflect these priorities. The Workgroup will also discuss ideas for seeking additional funds to pay for high priority studies and working with partner organizations to complete studies. Meeting materials: none Desired outcome: Decision on updates to the Sediment Workgroup Multi-Year Plan	4:00 pm Scott Dusterhoff (SFEI)
11.	**Wrap Up: Review Action Items and Decisions**	4:45 pm Scott Dusterhoff (SFEI)
12.	**Adjourn**	5:00 pm

RMP Sediment WG Meeting

March 19, 2019
San Francisco Estuary Institute
4911 Central Avenue, Richmond, CA

Meeting Summary

Attendees:

PRESENT		PHONE	
Name	**Affiliation**	**Name**	**Affiliation**
Tawny Tran	USACE	Lester McKee	SFEI
Dave Halsing	South Bay Salt Pond Restoration Project (SCC)	Carol Foster	SCVWD
Bruce Jaffe	USGS	Judy Nam	SCVWD
Brian Ross	EPA	Beth Christian	SFBRWQCB
Brenda Goeden	BCDC	Roxanne Grillo	SCVWD
Luisa Valiela	EPA		
Jennifer Siu	EPA		
Jeremy Lowe	SFEI		
Letitia Grenier	SFEI		
Aaron Bever	Anchor QEA		
Daniel Livsey	USGS CA WSC		
Richard Looker	SFBRWQCB		
Jay Davis	SFEI		
Josh Gravenmier	Arcadis		
Melissa Foley	SFEI		
Scott Dusterhoff	SFEI		
Tom Mumley	SFBRWQCB		
Christina Toms	SFBRWQCB		
Jing Wu	SFEI		
Paul Work	USGS		
Steve Hagerty	SFEI		

The last page of this document has information about the RMP and the purpose of this document.

1. Introductions and Goals for Today's Meeting

- Melissa Foley (SFEI) welcomed the workgroup and led a round of introductions.
- Scott Dusterhoff (SFEI) gave an overview of the meeting agenda and goals.
- Tom Mumley gave a brief background and history of the RMP.

2. Information: Management Questions and Processes to Develop Proposals for 2019 Special Studies

Scott gave a presentation that covered the overall RMP structure, the origin of the Sediment WG, the WG Mission and Guiding Management Questions, recently completed studies and currently funded studies.

Key points include:

- In 2018, WG developed a list of potential study ideas, tiered by priority. Study proposals were then developed for 2019 funds guided in large part by survey results. Most proposals submitted for 2019 funds were funded.
  - Study ideas that did not get voted on and prioritized included: mudflat mapping, sediment provenance, data collection to fill bathymetric datagaps.
- 2019 funded studies included:
  - Sediment WG funded: Conceptual understanding of sediment dynamics and sediment monitoring strategy (SFEI), Bathymetric Change Analysis-Year 1 (USGS), Develop Recommendations for Updated Beneficial Reuse Thresholds (SFEI), Sediment Bulk Density Study (SFEI).
  - Supplemental Environmental Project (SEP) funded: Dumbarton Bridge (lower South Bay) Sediment Flux Study-Year 2 (USGS), Synthesis of DMMO Data (PCBs) (SFEI)

3. Information: Multi-Year Plan Review

Scott presented an overview of the Sediment WG Multi-Year Plan that includes funded studies and study ideas for 2020-2022. Some key notes include:

- The studies included revolve around Strategy, Screening Values, Impact studies, Data mining, Beneficial reuse, Sediment budgets, and General elements.
- Reasons for study ideas being included in the Multi-Year Plan (2020 and beyond)
  - Ranked as a high priority 2019 study idea but not funded in 2019
  - Year 2 of 2-year study that received 2019 funding
  - Sediment-related study idea from the Exposure & Effects Workgroup (which is currently inactive)
  - Considered important to include based on the conversations during the May 2018 WG meeting and follow-up conversations

Discussion points included:

- Note that years are describing calendar (January to December) rather than fiscal years
- Tom Mumley and others describe/emphasize the finite resources of the RMP, but also the importance of the WG idea bank; tabled ideas can be funded in later years, through SEP funds or via alternate entities.
- Two studies described in more detail by Brenda Goeden:

- Essential Fish Habitat (EFH) study: This relates to the programmatic consultation process for dredge effects on EFH and is designed to streamline permitting rather than consulting on every individual project. USGS (Susan De La Cruz & Isa Woo) looked at benthic habitat function for three years after dredging projects of 12 ft or less to understand benthic recovery. Final report should be complete this year
- Synthesis of light attenuation near dredging study: examines how dredging affects light and eelgrass bed health from disturbance of suspended sediment/increase in turbidity. Dredgers either opt for light monitoring or a silk curtain within a certain buffer. More data needed in order to evaluate if current regulations are appropriate.

- Additional information on the strategic placement framework: The finalization of the study has been put on hold due to lack of US Army Corps of Engineers funding to complete the document. The first phase of the concept was included in the State Coastal Conservancy proposal for the Water Resources Development Act (2016), Water Infrastructure Improvement for the Nation, Section 1122 Pilot Program. The proposal included direct beneficial reuse of four federal navigation projects at four restoration sites over ten years, and testing the concept of in-bay placement of dredged sediment to feed marshes through tidal action. The proposal was truncated, and awarded $3 million to do a portion of the work. The Coastal Conservancy and BCDC are working with the USACE on the next steps, which include developing a project management plan for submission to USACE Headquarters. Earliest anticipated funds for work is 2020.

4. Discussion: 2020 Special Study Proposals

Melissa gave an overview of the process and timeline for identifying studies to seek funding for 2020, and discussed special study proposals. Some of these key points include:

- WG was prompted with previously-agreed 2020 “Must Do” study ideas for the Multi-Year Plan, which will be developed into proposals for the May meeting.
- WG was told proposals would be ranked before submitting to TRC
- Roughly 70% of the “Must Do” projects will get funded (variable among workgroups and between years of this WG)
- SEP funds:
    - Unfunded or additional ideas can be used for potential SEP funds (each of these will need ½ to full page proposal)
    - SEP list has last year’s ideas; these can be added to or modified based on WG preferences/priorities

Points from discussion include:

- Jay points out that the total RMP special studies pot is $1.3m, while “must-do” proposals are $1.9m. “Must-do” is a terminology that will probably be transitioned to less pointed language, e.g., “high-priority.”
- Tom Mumley emphasizes the State Water Board endorses using SEP funds for RMP studies. Tom also points out that the SEP pot is highly variable, on average likely under $150k.
- New proposals are not emphasized at this time; goal is to focus on existing study ideas.

However, new ideas could be proposed and developed quickly into high priority ranking/proposal development with the blessing of the WG.
- Brief discussion of RMP link to regulatory outcomes or recommendations, including water quality standards, implementation, permit considerations improved efficiency of and confidence in monitoring. Jay will pass along more explicit information. Regular Pulse of Bay reports provide additional information. In context of Sediment WG, Brian Ross points out that dredgers historically contributed ~17% of RMP funding, desire to make studies more relevant to these regulations that more directly affect them.
- Jay and Scott discuss how “must do” items only add up to **$220k** (rather than the original $260k) because the DMMO study was assumed to be counted (when it actually has been dropped from the “must-do” list), meaning the WG has another potential **~$40k** to propose/rank/add to “must-do” list. Tom reminds group that it is unlikely WG will be funded 100% regardless.

Scott gave overview an overview of the of “must do” proposals. These include:
- Sediment Strategy/Workgroup ($10K) - needs to be written (SFEI lead)
- Sediment Modeling Strategy ($40K) - needs to be written (SFEI lead)
- Sediment Bioaccumulation Guidance ($48K) - already written
- Golden Gate Flux Modeling ($45K) - already written
- Bathymetric change study (year 2) ($77K) - does not need to be written

Discussion points included:
- Results from 2017 GG Flux monitoring showing inflow of sediment into the Bay are only part of the picture; desire to look over more than an 18-hour window for monitoring, to calibrate data, and improve the flux model.
- To clarify, the modeling strategy is not actual modeling but rather a plan/approach to identify data gaps, integrate models, etc. This is the only proposal not yet written.
- Beneficial reuse study will probably not get to numbers that can inform regulatory decisions
- Discussion of how RMP may favor proposals that benefit multiple WGs, though the flux modeling is farther along that what could be useful for the nutrients group at this time.
- Napa and Sonoma stream gauges are potentially continued but on non-RMP funds. Lester emphasized the importance of these stream gauges.
- The fates of DMMO, Strategic Placement and additional bathymetric gaps study ideas were debated:
    - DMMO:
        - Brian pointed out that Don Yee’s recent analysis of DMMO data shows that about ½ of the amount of PCBs in sediment encountered during dredging is removed from the Bay.
        - Desire for Don to present at next WG meeting to understand data application to WG.
        - Tom suggests this work may be somewhat outside scope of RMP and issue-specific; unlikely to fund, though open to consideration if prioritized by WG.
        - This particular proposal seems less time sensitive or higher priority that some of the other proposals, such as Strategic Placement.
    - Strategic Placement:
        - USACE funding for Strategic Placement project uncertain (discussed

previously)
        - Desire to be poised to deploy the strategic placement study as soon as funded
        - Would be good to study criteria for potential sites in advance of pilot.
    - Bathymetric change:
        - Some WG members think this should be a 2020 "must do" study
        - Big gaps in Central Bay, margins of San Pablo Bay and parts of Suisun.
        - While bathymetric data is better (more certain and consistent) done all at once, it can be done effectively piecemeal. Data collection and analysis of change steps needed to create new DEM.
        - Bruce Jaffe points out that the desire is to fill gaps where most change is happening.
        - Special emphasis for mudflat monitoring desired. Brenda Goeden points out that Laura Valoppi (USGS) did a mudflat study that could be of use.
            - There is some crossover to mudflats, especially adjacent to restoration sites, but not consistent. Need to integrate with WRMP on this topic.
            - Dave Halsing will try to acquire Laura's proposal on this topic.
    - Some options for funding these studies include adding to the "must-do" WG list, adding to the SEP list, using the "general fund" category, or combining with/cannibalizing from other proposal budgets.

5. Information: Preparation for the May 7 Meeting

Scott reviewed proposal development timeline:
- Mid-March to April 9 - draft proposal developed
- April 10 to April 22 - draft proposal reviewed by select WG members
- April 23 - April 29 - draft proposals revised
- April 30 - final proposals to all workgroup members in advance of May 7th WG meeting

Scott also reviewed the agenda planned at the May 7 Meeting. Scott introduced workgroup advisors for workgroup meeting: Pat Wiberg (UVA) and Dave Schoellhamer (USGS ret.).

6. Wrap Up: Review Action Items and Decisions

Some follow up items include:
- Miscellaneous:
    - Brenda will provide more information on the sand mining pieces
    - Bruce will provide more information on cores in San Pablo Bay by Brent Tipple (UCSC) and Renee Takesue (USGS)
    - Dave will ask Laura Valoppi for mudflats survey study
- 2020 proposals and SEP ideas:
    - Scott will work with WG members to write modeling strategy proposal and bathymetric mapping SEP study concept
    - Scott will coordinate with Don to get DMMO data synthesis SEP study concept

together
  - Scott will coordinate with selected WG members to review proposals
  - Proposals will be completed and sent in advance of May 7th WG meeting

About the RMP

RMP ORIGIN AND PURPOSE

In 1992 the San Francisco Bay Regional Water Board passed Resolution No. 92-043 directing the Executive Officer to send a letter to regulated dischargers requiring them to implement a regional multi-media pollutant monitoring program for water quality (RMP) in San Francisco Bay. The Water Board's regulatory authority to require such a program comes from California Water Code Sections 13267, 13383, 13268 and 13385. The Water Board offered to suspend some effluent and local receiving water monitoring requirements for individual discharges to provide cost savings to implement baseline portions of the RMP, although they recognized that additional resources would be necessary. The Resolution also included a provision that the requirement for a RMP be included in discharger permits. The RMP began in 1993, and over ensuing years has been a successful and effective partnership of regulatory agencies and the regulated community.

The goal of the RMP is to collect data and communicate information about water quality in San Francisco Bay in support of management decisions.

This goal is achieved through a cooperative effort of a wide range of regulators, dischargers, scientists, and environmental advocates. This collaboration has fostered the development of a multifaceted, sophisticated, and efficient program that has demonstrated the capacity for considerable adaptation in response to changing management priorities and advances in scientific understanding.

RMP PLANNING

This collaboration and adaptation is achieved through the participation of stakeholders and scientists in frequent committee and workgroup meetings (see Organizational Chart, next page).

The annual planning cycle begins with a workshop in October in which the Steering Committee articulates general priorities among the information needs on water quality topics of concern. In the second quarter of the following year the workgroups and strategy teams forward recommendations for study plans to the Technical Review Committee (TRC). At their June meeting, the TRC combines all of this input into a study plan for the following year that is submitted to the Steering Committee. The Steering Committee then considers this recommendation and makes the final decision on the annual workplan.

In order to fulfill the overarching goal of the RMP, the Program has to be forward-thinking and anticipate what decisions are on the horizon, so that when their time comes, the scientific knowledge needed to inform the decisions is at hand. Consequently, each of the workgroups and teams develops five-year plans for studies to address the highest priority management questions for their subject area. Collectively, the efforts of all these groups represent a substantial body of deliberation and planning.

PURPOSE OF THIS DOCUMENT

The purpose of this document is to summarize the key discussion points and outcomes of a workgroup meeting.

Improved Lower South Bay suspended-sediment flux measurements:
2018 data collection results

Daniel Livsey, Maureen Downing-Kunz, and David Schoellhamer
USGS California Water Science Center

ABSTRACT

This report details Lower South Bay suspended-sediment flux data collected by the USGS in calendar year 2018. Data are being collected as part of a two-year investigation conducted by the USGS California Water Science Center in cooperation with the Regional Monitoring Program for Water Quality in San Francisco Bay. Lower South Bay suspended-sediment flux monitoring and research began at Dumbarton Bridge in Water Year 2009 due to the importance of sediment supply to the success of the nearby South Bay Salt Ponds Restoration Project and transport of sediment-bound contaminants. Recent work on suspended-sediment flux measurements at Dumbarton Bridge has focused on reducing uncertainty in flux estimates by accounting for flocculation (i.e., aggregation of sediment particles into "flocs") in the water column (Livsey et al., in review[a]). When accounting for flocculation, net suspended-sediment flux computed from the mid-depth sensor changes direction for Water Years 2009-2011 and 2013-2016 and more closely agrees with flux estimates from previous numerical modeling efforts (Bever and MacWilliams, 2013). *In-situ* measurements of floc settling velocity collected during 2018 agree very well (R^2>0.95) with settling-velocity estimates used to correct suspended-sediment flux measurements, further validating the correction proposed by Livsey et al. (in review[a]). Flocculation is hypothesized to affect suspended-sediment flux measurements through a combination of the following: 1) influencing surrogate measurements of suspended-sediment concentration (SSC), specifically optical turbidity, or 2) adjustment of the sediment concentration profile to changes in flocculation that affects the relationship between SSC measured at a point and depth-averaged, cross-section SSC used to compute suspended-sediment flux. Additional data to be collected in 2019 will be utilized to further test this hypothesis. Results of this work are directly applicable to Lower South Bay but also have direct implications for suspended-sediment flux monitoring and modeling throughout San Francisco Bay.

INTRODUCTION

Lower South Bay suspended-sediment flux data are of interest to Federal, state, and local agencies given the influence of suspended sediment on estuary water quality, ecology, navigation, and marsh sustainability. Prior suspended-sediment flux monitoring from Water Years (WY, Oct 1 through Sep 30) 2009 – 2011 and 2013-2016 conducted by the USGS was aimed at informing the implementation of the South Bay Salt Pond Restoration Project, the largest tidal marsh restoration project on the west coast. The primary goals of the 2018-2019 data collection effort are:

1) Provide ongoing suspended-sediment flux measurements for Lower South Bay
2) Validate and further investigate the mechanisms for a newly proposed correction to estuarine suspended-sediment flux measurements needed to account for the effect of flocculation on suspended-sediment flux measurements (Livsey et al., in review[a]).
3) Investigate the influence of flocculation on optical and acoustic surrogate measurements of SSC used to compute suspended-sediment flux estimates.
4) Determine the added value of installing a vertical profiling instrument to reduce uncertainty in suspended-sediment flux estimates.

Although understanding of the controls of Lower South Bay suspended-sediment flux has increased (Shellenbarger et al., 2013; Livsey et al., in review[b]), large uncertainty in suspended-sediment flux computations remains (see discussion in Shellenbarger et al., 2013). Typical methods for measuring suspended-sediment flux use optical instruments to measure turbidity, a surrogate for SSC, paired with acoustic measurements of velocity to compute discharge and suspended-sediment flux (Edwards and Glysson 1999; Ruhl and Simpson, 2005; Shellenbarger et al., 2013). Large uncertainty in suspended-sediment flux measurements arises from scatter in the regression between optical turbidity measurements and velocity-weighted, depth-averaged, cross-section measurements of SSC (SSC_{xs}). SSC_{xs} is used to compute suspended-sediment flux within a cross-section. Scatter in the turbidity-to-SSC_{xs} regression arises from two mechanisms: 1) changes in the relationship between turbidity and SSC and 2) changes in the relationship between SSC estimated at-a-point and SSC_{xs}. Both mechanisms need to be addressed to reduce uncertainty in suspended-sediment flux measurements.

Flocculation, defined as the aggregation of individual sediment particles into a larger unit or "floc" (Eisma, 1986), is hypothesized to cause most of the scatter in the turbidity-to-SSC_{xs} regression. Changes in the relationship between optical turbidity and SSC arises from numerous environmental factors that affect optical turbidity measurements, such as particle size, shape, composition, flocculation, dissolved light-absorbing matter, bubbles, and biologic fouling (Downing, 2006). Of these, flocculation is hypothesized to cause most of the error in the turbidity–to-SSC_{xs} regression. Changes in the relationship between SSC estimated at-a-point and SSC_{xs} arises from changes in the sediment concentration profile that controls the relationship between SSC at fixed point in the water column and SSC_{xs}. The sediment concentration profile is influenced by vertical mixing driven by water velocity and downward settling of suspended particles (i.e., particle settling velocity). Vertical mixing systematically varies with the tides; while, in San Francisco Bay, variability in particle settling velocity is controlled primarily by flocculation (Manning and Schoellhamer 2013). Systematic changes in vertical mixing and/or particle settling velocity will result in systematic changes in the relationship between SSC estimated at-a-point and SSC_{xs}.

Numerous studies indicate that flocculation is prevalent throughout San Francisco Bay (Manning and Schoellhamer 2013; Huang 2017). Recent work has focused on reducing the uncertainty in suspended-sediment flux estimates by accounting for flocculation in the optical turbidity-to-SSC_{xs} regression (Livsey et al., in review[a]). Changes in floc size and density are estimated from settling velocity (W_s) computed from continuous, optical turbidity measurements taken at two elevations in the water column at Dumbarton Bridge and the Rouse-Vanoni-Ippen equation (herein "Rouse equation"; García, 2008). Accounting for flocculation in the turbidity-to-SSC_{xs} regression changed not only the magnitude but also the direction of cumulative suspended-sediment flux measurements (Livsey et al., in review[a]). Current methods for measuring and modeling suspended-sediment flux in estuarine settings do not account for the effect of flocculation on suspended-sediment flux (Edwards and Glysson 1999; Ruhl and Simpson, 2005; Shellenbarger et al., 2013; Sherwood et al., 2018); therefore, validation of the newly proposed correction to suspended-sediment flux measurements by Livsey et al (in review[a]) is critical for not only Lower South Bay suspended-sediment flux measurements but also, suspended-sediment flux measurements throughout San Francisco Bay.

Livsey et al. (in review[a]) did not directly consider how changes in the sediment concentration profile affect SSC_{xs} estimates from point measurements of optical turbidity. Below we present a slight modification to the equations utilized by Livsey et al. (in review[a]) to account for changes in the sediment concentration profile driven by changes in vertical mixing and particle settling velocity.

METHODS

Suspended-sediment flux measurements using the "index-quantity" method

Methods for computing suspended-sediment flux follow current USGS "index-quantity" techniques and methods (see Shellenbarger et al., 2013 and references therein) with the additional correction for the effect of flocculation on suspended-sediment flux measurements proposed by Livsey et al. (in review[a]). The index-quantity method utilizes regressions between the moored continuous "index" measurements of turbidity (T_b), flood-positive velocity (U_i), and stage (p) to cross-section averaged, velocity-weighted, suspended-sediment concentration (SSC_{xs}), cross-section averaged water velocity (U_{xs}), and cross-sectional area (A_{xs}), respectively, to develop continuous timeseries of discharge (Q_{xs}) and suspended-sediment flux (Q_s) with

$SSC_{xs}(T_b),\ U_{xs}(U_i), A_{xs}(p)$, and:

$$Q_{xs} = U_{xs}A_{xs}\ (eq. 1)$$

$$Q_s = Q_{xs}SSC_{xs}\ (eq. 2)$$

All directional quantities are defined as positive in the flood-tide direction. The optimum regression equation forms for $SSC_{xs}(T_b),\ U_{xs}(U_i), A_{xs}(p)$ were selected using the regression diagnostics of Helsel and Hirsch (2002) with regression data transformed as needed to reduce heteroscedasticity. Moored optical turbidity (sonde 6920, probe 6136, YSI, Inc., Yellow Springs, OH, USA) and acoustic Doppler current profiler (ADCP, Nortek Aquadopp 1 MHz, NortekUSA, Boston, MA, USA) sensors were utilized to continuously measure turbidity and water velocity and stage, respectively, at Dumbarton Bridge (Figs. 1 and 2). Continuous measurements with a 15-minute sampling interval were then related to boat-based measurements using the index-velocity method (Ruhl and Simpson, 2005; Levesque and Oberg, 2012). Boat-based measurements included a boat-mounted ADCP (RiverPro 1200 kHz, Teledyne Marine, Poway, CA, USA) used to measure cross-section averaged velocity and a US D-96 sampler (Davis, 2001) used to obtain SSC_{xs} measurements using the Equal-Discharge Increment method

(Edwards and Glysson, 1999). Q_{xs} and SSC_{xs} measurements were collected on four dates in 2018: February 28th, April 17-18th, and September 25th. The cross-section and sampling locations used for boat-based measurements are identical to those described in Shellenbarger et al. (2013).

As noted by Shellenbarger et al. (2013), cross-section measurements are limited by shallow intertidal mudflats (Fig. 1). To ascertain if the cross-section measurements captured most of the water flow and suspended-sediment flux in the cross-section, we utilized a 3-D hydrodynamic model from Elias (2013) without wind forcing to quantify the discharge occurring over the unmeasured shallow intertidal mudflats. The model results indicate that the measured cross-section captures 98% of the total water flow, with the remaining 2% over the unmeasured shoals. Although 2% of the total water flow occurs over the unmeasured shoals, SSC, and thus, suspended-sediment flux, may be much higher on the shallow intertidal mudflats where wind-waves are capable of resuspending sediment. Suspended-sediment flux measurements on intertidal mud flats north of Dumbarton Bridge from February – March 2009 indicate that SSC on the shoals ranged from 10 mg/L to 120 mg/L (Brand et. al., 2011), similar to the 0.05 – 0.95 quantile range of SSC_{xs}, 22 mg/L to 99 mg/L, observed at Dumbarton Bridge over the same period (Shellenbarger et al., 2013). Even if one assumes that SSC on the shoals is two to three times the measured SSC_{xs}, a conservative upper limit based on the comparison of measurements of Brand et al. (2013) and Shellenbarger et al. (2013) above, the sediment flux in the unmeasured area would represent no more than 4%-6% of the total cross-section flux. Because SSC on the shoals is similar to SSC_{xs} estimated in the channel, cross-section measurements that capture 98% of the total cross-sectional flow are expected to be representative of the net suspended-sediment flux for the entire cross section.

Calendar year 2018 sampling campaign deployments

In this study, water-quality sondes (sonde 6920, YSI, Inc., Yellow Springs, OH, USA) equipped with depth, turbidity, specific conductivity, and temperature sensors were deployed. For the entire study, sondes were positioned at two locations in the water column: at mid depth (7.6 m above the bed at ~0.5*H, where H is total water depth) and near bed (1.2 m above the bed at ~0.07*H). During two intensive sampling campaigns (April 16-18, 2018, and September 24-26, 2018), two additional sondes were deployed in the water column: upper (12 m above the bed at ~0.7*H) and lower (4 m above the bed at ~0.2*H) (Fig. 2). Together, these four sondes provided continuous measurements of turbidity, specific conductivity, and temperature at four locations in the water column to estimate vertical profiles of parameters. All measurements from the water quality sondes were computed from the average of 24 measurements sampled over a 12-second duration.

In addition to optical turbidity, measurements from a LISST ABS, LISST 100x, and "floc-cam" (Manning and Dyer, 2013) were collected at the mid-depth location (7.6 m above the bed) during the sampling campaigns. Because acoustic backscatter instruments are thought to be less prone to fouling and less sensitive to particle-size-changes than optical turbidity sensors, a LISST ABS, an acoustic backscatter (ABS) sensor, was installed alongside the mid-depth turbidity sensor on September 20, 2018. Deployment of the LISTT ABS sensor was delayed due to procurement processes. The LISST ABS will remain deployed into 2019 to collect data needed to investigate the effect of flocculation on acoustic backscatter. The LISST 100x, an *in-situ* laser grain-size analysis sensor, was deployed to continuously measure changes in particle size distribution. During the sampling campaigns the LISST ABS and LISST 100x sampled every 30 seconds for 12 seconds. For the long-term deployment the LISST ABS is set to measure every 3 minutes for 12 seconds. Floc-cam measurements were collected to provide *in-situ* measurements of floc size, density, and settling velocity approximately every 30 minutes. A total of thirty floc-cam measurements were collected: 15 on April 17th, 2018 (08:06 to 15:00 PST) and 15 on September 25th, 2018 (09:30 to 16:30 PST). A 1-L water sample was collected for every floc-cam measurement with a 25 mL aliquot used for the floc-cam analysis and the remainder used for SSC analysis. An automated water sampler for SSC measurements collected apart from floc-cam measurements was not deployed given concerns about consistent sampling of SSC through the tide given changes in floc size.

Continuous, cross-section estimates of SSC were computed from acoustic backscatter of the boat-based, ADCP discharge measurements to continuously measure SSC profiles in the channel where SSC_{xs} and Q_{xs} data are collected. Acoustic backscatter from the boat-based ADCP discharge measurements was converted to SSC using the SSC samples used for the computation of SSC_{xs}. Each SSC_{xs} measurement is the average of five depth-averaged SSC samples. At each depth-averaged SSC sample the ADCP is set to collect acoustic backscatter data through the duration of the sample. Velocity-weighted, depth-averaged, SSC measurements, R, and $\overline{W_s}$ estimates were computed from the boat-based acoustic backscatter converted to SSC for comparison to parameters computed at the bridge site.

Accounting for the effect of flocculation on suspended-sediment flux estimates

To account for the effect of flocculation on $SSC_{xs}(T_b)$, Livsey et al. (in review[a]) include estimates of W_s as an additional predictor variable in $SSC_{xs}(T_b)$. Two estimates were considered: depth-averaged settling velocity ($\overline{W}_s$) and point-estimated settling velocity (W_s^H , where H is sensor position, e.g., at the mid-depth sensor $W_s^{7.6\ m}$). These estimates were computed using point estimates of SSC (derived from optical turbidity) and the Rouse equation (for $\overline{W}_s$) , and the sediment transport equation (for $W_s^{7.6\ m}$), respectively. The Rouse equation can be written as (García, 2008):

$$SSC(z) = SSC(a)\left(\frac{h-z}{z}\frac{a}{h-a}\right)^{R} \ (eq. 3)$$

in which

$$R = \frac{\overline{W}_s}{\beta\kappa u_*} \ (eq. 4)$$

$$u_* = \sqrt{\frac{\tau_b}{\rho}} = \sqrt{\frac{C_d u^2}{2}} \sim \alpha u \ (eq. 5)$$

Where:
$SSC(z)$ = suspended-sediment concentration (mg/L) at elevation (z) (m)
$SSC(a)$ = suspended-sediment concentration (mg/l) at elevation (a) (m)
a = reference elevation above the bed, equal to 0.1 (m)
h = elevation of water surface above bed (i.e., depth) (m)
R = Rouse number (dimensionless)
$\overline{W}_s$ = Depth-averaged settling velocity (m/s)
β = the inverse Schmidt number (dimensionless, equal to 1)
κ = Von Karmen constant (dimensionless, equal to 0.4)

u_* = shear velocity (m/s)
τ_b = bottom shear stress (N/m^2)
ρ = density of fluid (kg/m^3)
C_d = drag coefficient (dimensionless)
u = fluid velocity (U_i; m/s)

To fit the Rouse equation (eq. 3) at least two $SSC(z)$ are needed to estimate R. R is computed by fitting an ordinary least squares regression to the $\log_{10}$-tranformed SSC value estimated from T_b readings at each senor, that is:

$$\log SSC = Rx + logSSC_a \ (eq. 6)$$

$$x = \frac{a}{h-a}\frac{h-z}{z} \ (eq. 7)$$

And

$$SSC = BCFx^R 10^{\log SSC_a} \ (eq. 8)$$

in which the bias correction factor (BCF) accounts for transformation between linear and logarithmic units. BCF is close to one and is the mean of the antilog of the residuals from eq. 6 (Helsel and Hirsh, 2002). $\overline{W}_s$ is computed using R in eq. 4 with a C_d value of 0.002 from Elias et al. (2013; see also further comment on C_d below). During the long-term deployment only two data points are available to fit eq. 6. The additional sondes deployed during the April and September 2018 sampling campaigns provided W_s estimates using 4 data points.

The sediment transport equation, used to compute point settling-velocity estimates at each sensor, considering only vertical mixing and longitudinal advection is:

$$\frac{\partial SSC}{\partial t} = W_s \frac{\partial SSC}{\partial z} + \frac{\partial}{\partial z} K \frac{\partial SSC}{\partial z} - \frac{\partial uSSC}{\partial x} \ (eq. 9)$$

Where:
SSC is suspended-sediment concentration (mg/L)
t is time
W_s is settling velocity (m/s)
z is elevation above the bed (m)
K is eddy diffusivity (m^2/s)
u is longitudinal (i.e., along the channel) water velocity, (flood positive, m/s)
x is the longitudinal coordinate (flood positive, m)

The first and second terms on the right-hand side are the settling and vertical mixing terms, respectively. The third term is longitudinal advection. Using the product differentiation rule, settling velocity from eq. 9 is:

$$W_s = \frac{\frac{\partial SSC}{\partial t} - K\frac{\partial^2 SSC}{\partial z^2} - \frac{\partial K}{\partial z}\frac{\partial SSC}{\partial z} + u\frac{\partial SSC}{\partial x}}{\frac{\partial SSC}{\partial z}} \ (eq. 10)$$

Eq. 10 provides W_s^H at each sensor elevation. Two forms of $K(z)$ were considered for eq. 10. The Rouse equation uses a parabolic eddy diffusivity, equal to zero at the bed and water surface, and is a maximum value at mid-depth where:

$$K = \beta\kappa u_* z\left(1 - \frac{z}{h}\right) \quad (eq. 11)$$

A more realistic $K(z)$ sometimes assumed for open channel flow is parabolic in the lower half of the water column and constant at the maximum value in the upper half (Geyer and MacCready, 2014):

$$K = \beta\kappa u_* z\left(1 - \min(\frac{z}{h}, 0.5)\right) \quad (eq. 12)$$

$\frac{\partial SSC}{\partial t}$ is computed from turbidity-estimated SSC timeseries estimated from regressions derived from SSC bottle samples taken at each sensor elevation. Because $\frac{\partial SSC}{\partial t}$ may change at a higher frequency than 15-minutes, a higher frequency sampling interval of 30 seconds was chosen during the sampling campaigns to ascertain if the 15-minute sampling interval used in the long-term deployment was sufficient to characterize the $\frac{\partial C}{\partial t}$ term of eq. 9. For comparison to the long-term deployment Rouse-based estimates of W_s were also computed using a sampling interval of 900 seconds by sub-sampling the 30 second timeseries every 15-minutes. The derivative of SSC with respect to x ($\frac{\partial SSC}{\partial x}$) is computed by fitting SSC over Lagrangian coordinates computed between slack tides. The derivatives of SSC with respect to z in eq. 10 can be calculated from SSC using finite differences; however, this approach was not taken since small errors in SSC are compounded when differences are taken and the assumption of linearity between measurement points is invalid. Our approach was to compute derivatives of SSC from the fit of the Rouse equation. Point estimates of W_s at each sensor elevation (z) can then be computed from the first (eqs. 13-14) and second (eq. 15) derivatives of SSC in eq. 10 with:

$$\frac{\partial SSC}{\partial z} = BCFx^{R-1}10^{\log SSC_a} R \frac{\partial x}{\partial z} \quad \text{(eq. 13)}$$

$$\frac{\partial x}{\partial z} = -\frac{a}{h-a} h \quad (eq. 14)$$

$$\frac{\partial^2 SSC}{\partial z^2} = BCFx^{R-1}10^{\log SSC_a} R \frac{\partial x}{\partial z}\left(\frac{R-1}{x}\frac{\partial x}{\partial z} - \frac{2}{z}\right) \quad \text{(eq. 15)}$$

The above approach requires point estimates of SSC at each sensor. Because there is uncertainty in point estimates of SSC, bootstrapped uncertainty estimates of SSC are utilized to compute uncertainty intervals for SSC and thereby bound W_s estimates with uncertainty. Bootstrapped uncertainty estimates of SSC at the mid-depth and near-bed sensors were developed from regressions between T_b and water-sample-derived SSC collected at each sensor from WY 2009 – 2016 (Buchanan et. al., 2018). Water samples for SSC analysis were not collected at the lower sensor (4 m above the bed) or the upper sensor (12 m above the bed); to estimate the turbidity-to-SSC regression parameters at these two sensors, the slope and intercept were interpolated from the mid-depth and near-bed turbidity-to-SSC regressions. Bootstrapped uncertainty estimates of SSC were computing using the methods of Rustomiji and Wilkinson (2008). Uncertainty in SSC timeseries is incorporated into W_s by computing quantiles on W_s estimates computed using all possible combinations of SSC quantiles at 0.05, 0.16, 0.5, 0.84, 0.95 (i.e., +/- 1 and 2σ and the median quantile).

Optical theory stipulates the slope of $SSC(T_b)$ is a function of D and ρ_f. Since the product of D and ρ_f (and D^2 and ρ_f) increase with particle diameter, we suggest the slope of $SSC_{xs}(T_b)$ is a function of W_s. Because the slope of the regression line, $\frac{SSC_{xs}}{T_b}$, is expected to increase with D and ρ_f (Downing, 2006) and W_s is proportional to $D^2(\rho_f - \rho_w)$ (Stokes Law, García, 2008), the effect of flocculation on $SSC_{xs}(T_b)$ can be computed using:

$$SSC_{xs}(T_b, D, \rho_f) = m_1(D, \rho_f)T_b(z_u) + b_1 \ (eq. 16)$$

Where:

$$m_1(D, \rho_f) = \frac{SSC_{xs}}{T_b}(W_s) = m_2 {W_s}^{c_1} + b_2 \ (eq. 17)$$

With eq. 17 arising from optical theory (Downing, 2006) and Stokes Law (Garcia, 2008).

Substituting eq. 17 into eq. 16 leads to:

$$SSC_{xs}(T_b, D, \rho_f) = b_2 T_b(z_u) + m_2 W_s{}^{c_1} T_b(z_u) + b_1 \ (eq. 18)$$

The exponent c_1 is not specified because the exact functional form between $\frac{SSC_{xs}}{T_b}$ and D and ρ_f is unknown. c_1 will be positive, and from previous studies (see references in Downing, 2006), c_1 is expected to be between 0.5 and 3. Since floc fractal dimension, floc size, and floc density are embedded in setting velocity, W_s, the effect of D, ρ_f, and floc particle packing on optical turbidity is accounted for in m_2 and c_1 of eq. 18.

Eq. 18 was utilized by Livsey et al. (in review[a]) with median W_s estimates to account for the effect of flocculation on $SSC_{xs}(T_b)$, but was not developed to directly account for possible changes in the sediment concentration profile that would affect the relationship of SSC at a fixed elevation (e.g., at the mid-depth sensor) and SSC_{xs}. Eq. 18 partially accounts for changes in sediment concentration profile with the W_s term but does not account for changes in the sediment concentration profile due to changes in vertical mixing induced by changes in water velocity. The shape of the sediment concentration profile described by the Rouse number, R, (eq. 4), is controlled by the settling of suspended particles and vertical mixing controlled by water velocity. To account for changes in the sediment concentration profile due to particle W_s and vertical mixing we propose to include R, the parameter that describes the sediment concentration profile with the following:

$$SSC_{xs} = m_3 \ SSC(T_b, D, \rho_f) + b_3 \ (eq. 19)$$

Where:

$m_3(R) = m_4 R^{c_2} + b_4 \ (eq. 20)$

And

$SSC(T_b, D, \rho_f, R) = b_2 T_b(z_u) + m_2 W_s{}^{c_1} T_b(z_u) + b_1 \ (eq. 21)$

With eq. 20 arising from the Rouse equation. Eq. 21 is the same as eq. 18 but with SSC point estimates substituted for SSC_{xs} to account for the effect of flocculation on point estimates of SSC. The exponent c_2 is a function of the sensor elevation in the water column relative to H and can be determined from the Rouse equation for a fixed height relative to H (e.g., 0.5*H). We note that R and and W_s are not independent but account for the separate effects of flocculation on suspended-sediment flux measurements. Combining equations 19, 20, and 21 to account for both mechanisms by which flocculation affects suspended-sediment flux measurements yields:

$$SSC_{xs}(T_b, D, \rho_f) = (m_4 + b_4 R^{c_2}) * (T_b(b_2 + m_2 W_s{}^{c_1}) + b_1) + b_3 \ (eq. 21)$$

For sediment computations below, we utilize eq. 18 since the primary goal of this report was to validate the correction proposed by Livsey et al (in review[a]). Including R in the computation of suspended-sediment flux computations will be the focus of future work and is expected to reduce uncertainty estimates but not affect the sign of suspended-sediment flux computations reported in Livsey et al. (in review). In addition to using the mid-depth turbidity sensor and $\overline{W_s}$ for estimates of cumulative suspended-sediment flux ($\sum Q_s$), the near-bed turbidity sensor, mid-depth LISST ABS sensor, and depth-averaged SSC computed from the Rouse equation ($\overline{SSC}$) were utilized. $\overline{SSC}$ is computed from the definite integral of the Rouse-equation fit to SSC estimates at the near-bed and mid-depth sensors (i.e., $\int_{1.2m}^{7.6m} C(a)\left(\frac{h-z}{z}\frac{a}{h-a}\right)^R dz$). $\overline{SSC}$ was considered as a predictor for SSC_{xs} (i.e., ($SSC_{xs}(\overline{SSC}) = m * \overline{SSC} + b$)) because this value utilizes the near-bed and mid-depth sensors to compute SSC_{xs}

For W_s estimates, we assume that C_D does not systematically covary with the tides and utilize a constant C_D of 0.002 computed from the calibrated hydrodynamic model of Elias et al. (2013). If C_D does not systematically covary with the tides, differences between the assumed C_D and actual C_D are corrected by the regression coefficient m_2 in eq. 18. A tidal asymmetry in C_D could complicate the use of a constant C_D in the channel only if C_D exhibits tidal asymmetry. C_D may vary with the influence of wave orbitals, bed sediment grain size, and bed-form geometry (Bricker et al., 2005). Wind waves would not affect C_D in the 15-m deep channel at Dumbarton Bridge. Further, the channel ~ 5 km north and south of Dumbarton bridge is composed of clay and fine silt (McGann, et al., 2013) thus bed grain-size changes and large-scale bedforms, (i.e., greater than ripples) that do not form on muddy beds, are not expected to induce systematic changes in C_D with the tide.

Uncertainty in suspended-sediment flux estimates

Uncertainty in suspended-sediment flux measurements arising from scatter in regression equations was quantified using bootstrap and Monte-Carlo resampling described in Rustomiji and Wilkinson (2008). Bootstrap resampling utilizes resampling with replacement of regression residuals to produce *n* possible synthetic regression data sets and thereby *n* possible regression equations and *n* possible SSC_{xs}, Q_{xs}, and Q_s timeseries realizations. Bootstrap confidence intervals at the median, 5%, and 95% confidence levels are computed from Monte-Carlo resampling (i.e., random resampling) of the bootstrapped realizations. For example, to compute uncertainty on the cumulative timeseries $\sum Q_s$, $m \sum Q_s$ timeseries are computed from *m* randomly selected bootstrap realizations of Q_s resulting in a distribution of *m* possible $\sum Q_s$ values at each observation *t.* Bootstrap confidence intervals are then computed at each observation *t.* Following Rustomiji and Wilkinson (2008) *n* = 10,000 and *m* = 2,000. Q_s was computed using each W_s quantile timeseries at the median, +/- 1σ, and +/- 2σ confidence intervals to account for uncertainty in the W_s timeseries. When computing Q_s using $\overline{SSC}$, the median, +/- 1σ, and +/- 2σ confidence intervals of $\overline{SSC}$ were also utilized to account for the uncertainty of $\overline{SSC}$ in Q_s.

Since the estimated W_s timeseries used to compute $\sum Q_s$ are based on only two measurements, the addition of more SSC estimates in the water column would presumably result in more precise estimates of W_s and thereby reduce uncertainty in $\sum Q_s$. To determine the added value of installing a vertical profiling instrument and/or additional sondes in the water column, a numerical approach was utilized to estimate the reduction in $\sum Q_s$ uncertainty as a function of decreased measurement spacing between the near-bed and mid-depth sensor elevations. The Rouse profiles and SSC timeseries computed from the near-bed and mid-depth turbidity sensors were considered to have no error for this analysis. This produced a synthetic sediment concentration profile dataset from which *n* measurements could be subsampled. Depth-averaged settling velocity with error was developed by adding normally-distributed random error added to the SSC profile timeseries. The standard deviation of the normally distributed random error was set equal to the 2σ confidence interval (i.e., 14 mg/l) of the mid-depth SSC timeseries. The Root Mean Squared Error (RMSE) for *n* measurements was computed by regressing the "error-free" depth-averaged setting velocity to depth-averaged setting velocity with error. Linearly spaced samples from the depth-averaged setting velocity estimates with error data set were taken between and including the near-bed and mid-depth sensor. Synthetic $\sum Q_s$ were computed using eq. 18 with no error assumed for the mid-depth SSC timeseries and with decreasing RMSE estimates for the $\overline{W_s}$ timeseries.

RESULTS

Discharge measurements and regressions for calendar year 2018 compare well with measurements from WY 2013 – 2016 (Figs. 3 and 4). More discharge measurements are needed during the ebb tide (Fig. 4). Ebb tides in April and September 2018 during spring tides primarily occurred during night. Ebb tides in April and September 2019 during spring tides occur primarily during daylight hours and will be targeted for additional sampling.

Turbidity and LISST ABS data at the mid-depth and near-bed locations covary, with turbidity higher near the bed (Figs. 5 and 6). Data gaps in the turbidity record resulted primarily from fouling. No LISST ABS data was lost to fouling. The data gap in turbidity and LISST ABS data in February 2019 was caused by power loss to the site. LISST 100x data from the April deployment have been analyzed, data from the September deployment have yet to be processed. LISST 100x data for the April deployment are plotted with respect to flood and ebb tides and cross-section water velocity (Fig. 7). Median particle sizes of the LISST 100x data were computed for the entire particle size distribution and microfloc and macroflocs size classes (Fig. 7B-D). The demarcation between microfloc and macroflocs was set at 160 µm following Manning and Schoellhamer (2013). Microflocs are comprised of organic and mineral particles that aggregate to form highly porous low-density macroflocs (Eisma, 1986).

Turbidity data for the near-bed, lower, mid-depth, and upper sensors from the April and September campaigns were converted to SSC timeseries and used to compute Rouse-estimated

W_s timeseries for comparison to floc-cam measurements (Figs. 8, 9). Seven of the fifteen floc-cam measurements collected on April 17, 2018 from late ebb into flood have been analyzed. Samples from the September 2018 dry-season sampling are still being analyzed. The seven floc - cam samples from the April 17th, 2018 sampled slack tide after ebb, through the flood tide, and nearly to peak ebb velocity (Fig. 8). The *in-situ* floc-cam measurements exhibit excellent agreement with Rouse-estimated W_s (Fig. 8, 9; all $R^2 > 0.96$). Inclusion of the near-surface sensor at 12 m above the bed resulted in Rouse W_s estimates that exhibit little to no correlation with floc-cam W_s measurements ($R^2 < 0.1$, *p*-values > 0.5) and is not utilized in the Rouse W_s estimates. The agreement between $W_s^{7\ m}$ computed using 4 sensors and floc-cam W_s did not improve by changing $K(z)$. The lack of agreement between $W_s^{7\ m}$ computed using 4 sensors and floc-cam W_s may be driven by vertical changes in the turbidity-to-SSC regression parameters and/or violation of the Rouse equation assumptions near the water surface.

$W_s^{7.6\ m}$ exhibit excellent agreement with floc-cam W_s measurements when using 2 (near-bed and mid-depth) or 3 (near-bed, lower, and mid-depth) sensors and a sampling interval of 30 seconds (for both: $R^2 > 0.96$, *p*-values < 0.0001; Fig. 9). However, when using 2 or 3 sensors and a sampling interval of 900 seconds, $W_s^{7.6\ m}$ did not correlate with floc-cam W_s measurements ($R^2 < 0.1$, *p*-values > 0.5). Depth-averaged W_s estimates ($\overline{W_s}$) were insensitive to the sampling interval and whether 2 or 3 sensors were chosen. All $\overline{W_s}$ estimates exhibited excellent agreement with floc-cam W_s measurements (Fig. 8; $R^2 > 0.96$, *p*-values < 0.0001). $\overline{W_s}$ and $W_s^{7\ m}$ timeseries, computed using 3 sensors and a sampling interval of 30 seconds, covary ($R^2 = 0.98$, *p*-value < 0.0001), with differences primarily occurring near slack tide (Fig. 8). Similar to data from WY 2009-2011 and 2013-2016 (Livsey et al., in review[a]) Rouse W_s estimates are larger on flood tide compared to ebb (Fig. 8). $\overline{W_s}$ computed from 2 sensors and 900 second sampling interval (i.e., the same as current long-term deployments) are a reasonable predictor of $W_s^{7\ m}$ computed using 3 sensors and a sampling interval of 30 seconds ($R^2 = 0.94$, *p*-value < 0.0001). The sensitivity of the $W_s^{7\ m}$ point-estimate to sampling interval suggests that the long-term deployment sampling interval of 900 seconds is not sufficient to characterize the $\frac{\partial SSC}{\partial t}$ term of eq. 9. Therefore, we utilize the $\overline{W_s}$ for the computation of suspended-sediment flux (eq. 18; Fig. 10) since $\overline{W_s}$ is a reasonable predictor of $W_s^{7.6\ m}$ and floc-cam W_s. A total of 11 SSC_{xs} measurements were collected in 2018 and used for the $SSC_{xs}(T_b)$ regression (Fig. 10). Advection was not included in $\overline{W_s}$ or $W_s^{7.6\ m}$ estimates because advection accounted for only 2% of the settling-velocity estimates and inclusion of the advection term did not affect the agreement between Rouse-based estimates of W_s and floc-cam W_s. All W_s estimates using the lower three sensors were insensitive to the form of $K(z)$ because these sensors are in the lower-half of the water column (i.e., below 7.5 m) where the two $K(z)$ models are equal. All fits to SSC profiles using the Rouse equation utilize SSC estimates from the lower half of the water column.

A total of 55 SSC samples from the 11 SSC_{xs} measurements collected in 2018 were utilized to calibrate the boat-based ADCP acoustic backscatter to SSC (Fig. 11). Sediment concentration profiles measured from boat-based ADCP measurements generally follow profiles predicted by the Rouse equation (Fig. 12). Representative SSC profiles collected during the wet season (i.e., ~Oct-May) and dry season (~June-Sept) are shown in figures 14B and 14D, respectively. During wet-season conditions, freshwater inflow and stratification resulted in increased SSC near the water surface (Fig. 12B). SSC profiles estimated from the Rouse equation, fit observations in the lower-half of the water column but did not fit observations in the upper-half of the water column. During dry-season conditions, the fit between the SSC profile estimated from the Rouse equation and the observed SSC profile improved for the entire water column relative to wet-season conditions (Fig. 12D). $\overline{W_s}$ estimated from the boat-based ADCP measurements covary with floc-cam measurements collected at the bridge and water velocity (Figs. 13A-B).

Inclusion of $\overline{W_s}$ in $SSC_{xs}(T_b)$ changed the magnitude and sign of $\sum Q_s$ timeseries during calendar year 2018 (Figs. 14), similar to results for WY 2009 – 2011 and 2013 – 2016 (Livsey et al., in review[a]). $\sum Q_s$ timeseries based on the near-bed turbidity sensor data and $\overline{SSC}$ generally agree with $\sum Q_s$ computed from the mid-depth turbidity sensor and $\overline{W_s}$ but estimates differ (Fig. 14A). These differences are thought to arise from changes in the sediment concentration profile induced by changes in water velocity and flocculation (see further comment in the discussion below). A primary objective of this report was to compare the results of $\sum Q_s$ timeseries based on the mid-depth turbidity and acoustic backscatter timeseries; however, because of the late deployment of the LISST ABS sensor in September 2018 only three SSC_{xs} measurements are available to compute $\sum Q_s$ based on acoustic backscatter (not shown). A preliminary comparison based on this small calibration data set is provided (Fig. 14B). Uncertainty intervals for the $\sum Q_s$ based on acoustic backscatter are not reliable given the small calibration data set; however, $\sum Q_s$ based on acoustic backscatter, like $\sum Q_s$ based on the mid-depth turbidity sensor data, both indicate a loss of sediment for Lower South Bay. This suggests that the LISST ABS data at the mid-depth elevation are also being affected by flocculation. Additional data collection in 2019 will be used to confirm this result.

Additional measurements between the near-bed and mid-depth sensors is estimated to reduce the RMSE of $\overline{W_s}$ estimates from +/- 1 mm/s to +/- 0.3 mm/s and reduce $\sum Q_s$ by up to 35% (Fig. 15A). The total $\sum Q_s$ uncertainty in Figure 15B was computed using the calendar 2018 data set, interpretation of the cumulative percent decrease in uncertainty is advised since the total $\sum Q_s$ uncertainty depends on the length of the $\sum Q_s$ timeseries. The relationship between the number of linearly spaced measurements and cumulative percent decrease in $\sum Q_s$ uncertainty is non-linear with decreased gains in reduced uncertainty near 30 measurements (Fig. 15B). This rate of decrease corresponds to measurements spaced at 0.25 m between the near-bed and mid-depth sensors and an estimated reduction in $\sum Q_s$ uncertainty of 20%.

DISCUSSION

Sampling during spring and neap tides during the wet and dry seasons was proposed for calendar year 2018-2019; however, further analysis of Rouse-estimated W_s timeseries from WY 2013-2016 indicated that most of the variation in estimated W_s timeseries occurred during spring tides and that maximum estimated W_s occurred during the spring (March-May). The sampling plan was redesigned to focus on the greatest variation in W_s. The agreement between *in-situ* floc -cam measurements and Rouse-estimated W_s (Figs. 8-9) substantiates the proposed flocculation correction for suspended-sediment flux measurements is needed to accurately compute $\sum Q_s$. Further the agreement of $\overline{W_s}$ computed from the ADCP transects and floc-cam measurements suggests that flocculation conditions observed at the bridge pier are similar in the channel where SSC_{xs} are collected.

$\sum Q_s$ computed using different sensors results in different estimates (Fig. 14). Especially note that $\sum Q_s$ computed from the near-bed sensor with no flocculation correction agrees with $\sum Q_s$ computed from the mid-depth sensor with flocculation correction. The difference in $\sum Q_s$ estimated from the mid-depth and near-bed sensors was first noted by (Bever and MacWilliams, 2013). Livsey et al (in review[a]) propose that the flocculation correction to the mid-depth sensor was needed because flocculation was affecting the optical turbidity response to SSC; however, comparison of the ratio of SSC point estimates to optical turbidity measurements ($\frac{SSC}{T_b}$, a measure of the optical response of the turbidity sensor to suspended sediment) shows no relationship with *in-situ* W_s measurements from floc-cam (*p*-value > 0.4). The lack of correlation between W_s and $\frac{SSC}{T_b}$ indicates that a single W_s value is not sufficient to characterize $\frac{SSC}{T_b}$. Since $\frac{SSC}{T_b}$ integrates the scattering from many different flocs with a range of W_s, future work will utilize particle-size distributions from the LISST 100x and floc-cam to investigate how changes in floc size affect $\frac{SSC}{T_b}$.

The lack of correlation between W_s and $\frac{SSC}{T_b}$ may indicate that the causal mechanism for the relationship between $\overline{W_s}$ and $\frac{SSC_{xs}}{T_b}$ is the adjustment of the sediment concentration profile to variation in $\overline{W_s}$ and/or vertical mixing that results in changes in the relationship between SSC measured at a fixed point and SSC_{xs}. To test the hypothesis that flocculation is primarily affecting suspended-sediment flux measurements through adjustment of the sediment concentration profile, the Rouse number was compared to the ratios of $\frac{SSC_{0.5*H}}{SSC_{xs}}$ computed from the ADCP cross-section measurements (Fig. 13D) and at the bridge site using the ratio of $\frac{SSC_{7.6m}}{\overline{SSC}}$ (Fig. 16). $SSC_{7.6m}$ is the median-estimated SSC at the mid-depth sensor and $\overline{SSC}$ is the depth-averaged SSC computed from the definite integral of the Rouse equation from the near-bed sonde to the water surface. The Rouse number exhibits excellent agreement with $\frac{SSC_{0.5*H}}{SSC_{xs}}$ and $\frac{SSC_{7.6m}}{\overline{SSC}}$, while W_s, exhibits more scatter (Figs. 13 and 16). This suggests that the Rouse number should be utilized in-lieu of $\overline{W_s}$ in eq. 18. We note that eq. 18 would remain the same if the Rouse number was utilized in-lieu of $\overline{W_s}$ and that the estimates of $\sum Q_s$ reported by Livsey et al (in review[a,b]) would be similar but are expected to exhibit reduced uncertainty. The above hypothesis would explain why the near-bed and mid-depth sensor data, uncorrected for flocculation, result in different $\sum Q_s$. As $\overline{W_s}$ increase and/or water velocity decreases more sediment is concentrated near the bed resulting in underestimates of SSC_{xs} at the mid-depth sensor (Fig. 16). At Dumbarton Bridge $\overline{W_s}$ and shear velocity are higher on flood tides and ebbs (Livsey et al., in review[a]). Rouse numbers are larger on flood tides than ebb tides despite larger shear velocity (the denominator of the Rouse number) indicating that the larger Rouse numbers on the flood tide are primarily due to enhanced flocculation on flood tides.

To illustrate how changes in the Rouse number result in different SSC_{xs} estimates, SSC at depths from the near-bed sensor (~0.07*H) to 0.9*H normalized to $\overline{SSC}$ integrated from 0.07*H to 0.9*H was computed over the range of observed Rouse numbers at Dumbarton Bridge during calendar year 2018 (Fig. 17). This analysis suggests that the use of one sensor to compute $\sum Q_s$ should be exercised with caution in tidal environments. $\frac{SSC_{0.3*H}}{SSC_{xs}}$ changes the least across the range of observed Rouse numbers (Fig. 17A). $\sum Q_s$ predicted from $\overline{SSC}$ integrated from the near-bed sensor to the mid-depth sensor exhibits the least uncertainty of $\sum Q_s$ estimates (Fig. 14); however, this integral includes depths that may overestimate SSC_{xs} by nearly 7-fold (see Fig. 17A at H*0.07). $\overline{SSC}$ integrated from 0.3*H to 0.5*H would result in < 5% change for 95% of the observed Rouse number range and may be a more appropriate surrogate for SSC_{xs} (Fig. 17B).

CONCLUSIONS

Additional data collection in calendar year 2019 will be utilized to further test the hypothesis that changes in water velocity and settling velocity are resulting in diverging cumulative suspended-sediment flux estimates at the near-bed and mid-depth sensors. We note that the large variability and systematic changes in sediment concentration over water depth with the tide may confound efforts to estimate suspended-sediment flux from surface estimates of suspended-sediment concentration (e.g., via remote sensing). Further, current sediment transport models for San Francisco Bay do not account for flocculation. Additional collaboration with sediment transport modelers is needed to ascertain the implications of this work for sediment transport models that aim to estimate suspended-sediment flux but ignore flocculation.

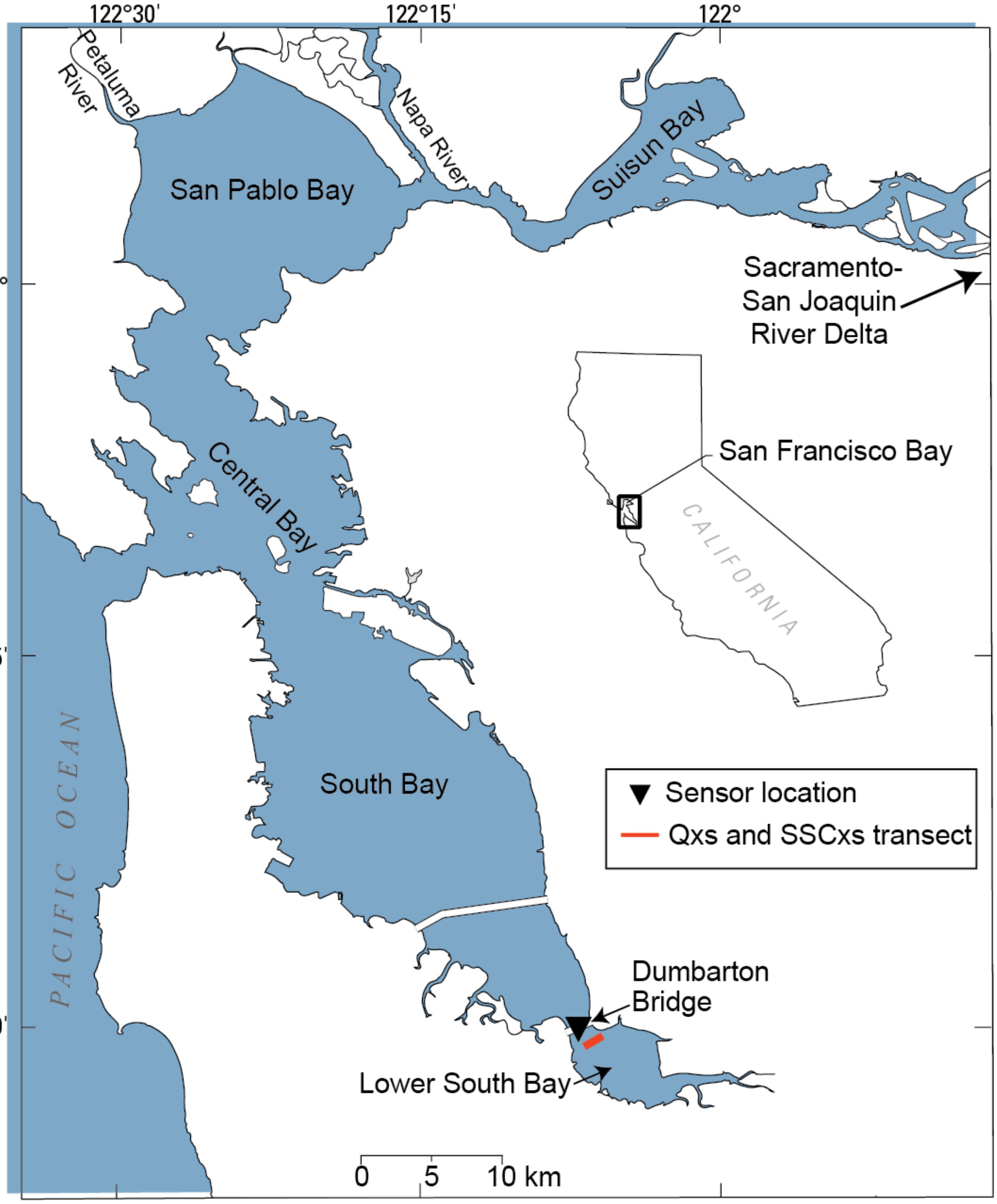

Figure 1. Map of study area indicating location of moored sensors at Dumbarton Bridge and location of boat-based discharge (Qxs) and cross-section averaged, suspended sediment concentration measurements (SSCxs).

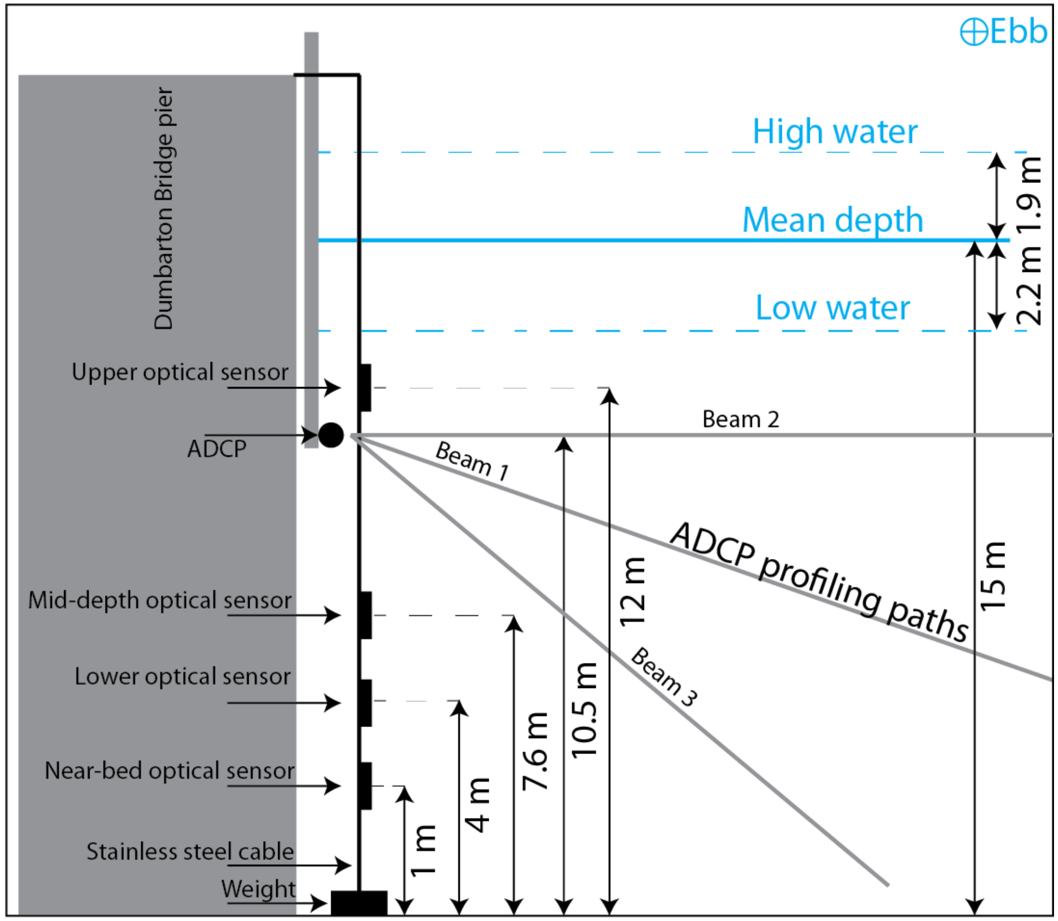

Figure 2. Deployment schematic of moored sensors at Dumbarton Bridge. The lower and upper sensors were deployed in addition to the long-term monitoring sensors near the bed and at mid-depth during two three-day sampling campaigns from April 17-18th, and September 25^{th,} 2018. An acoustic backscatter instrument, a LISST ABS, is collocated at the mid-depth optical sensor was installed in September 2018 and will be maintained into calendar year 2019. Floc-cam samples were collected at the mid-depth optical sensor. A LISST 100x laser particle size analyzer was collocated at the mid-depth optical sensor during the April and September 2018 sampling campaigns.

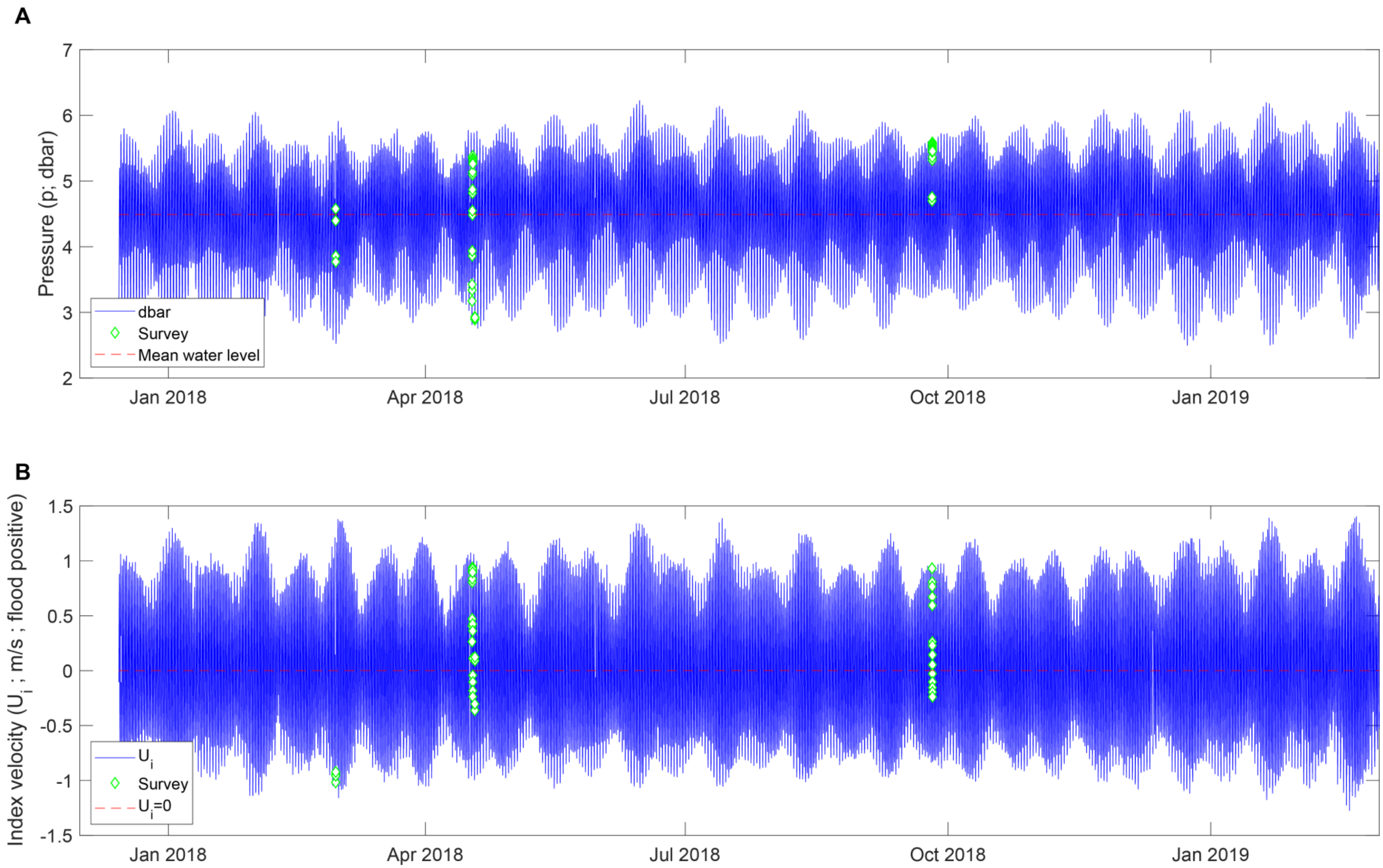

Figure 3. Timeseries of water depth (A) and velocity (B) from the Nortek ADCP deployed at 4.5 m from mean water level. Time of boat-based ADCP discharge measurements indicated by green diamonds.

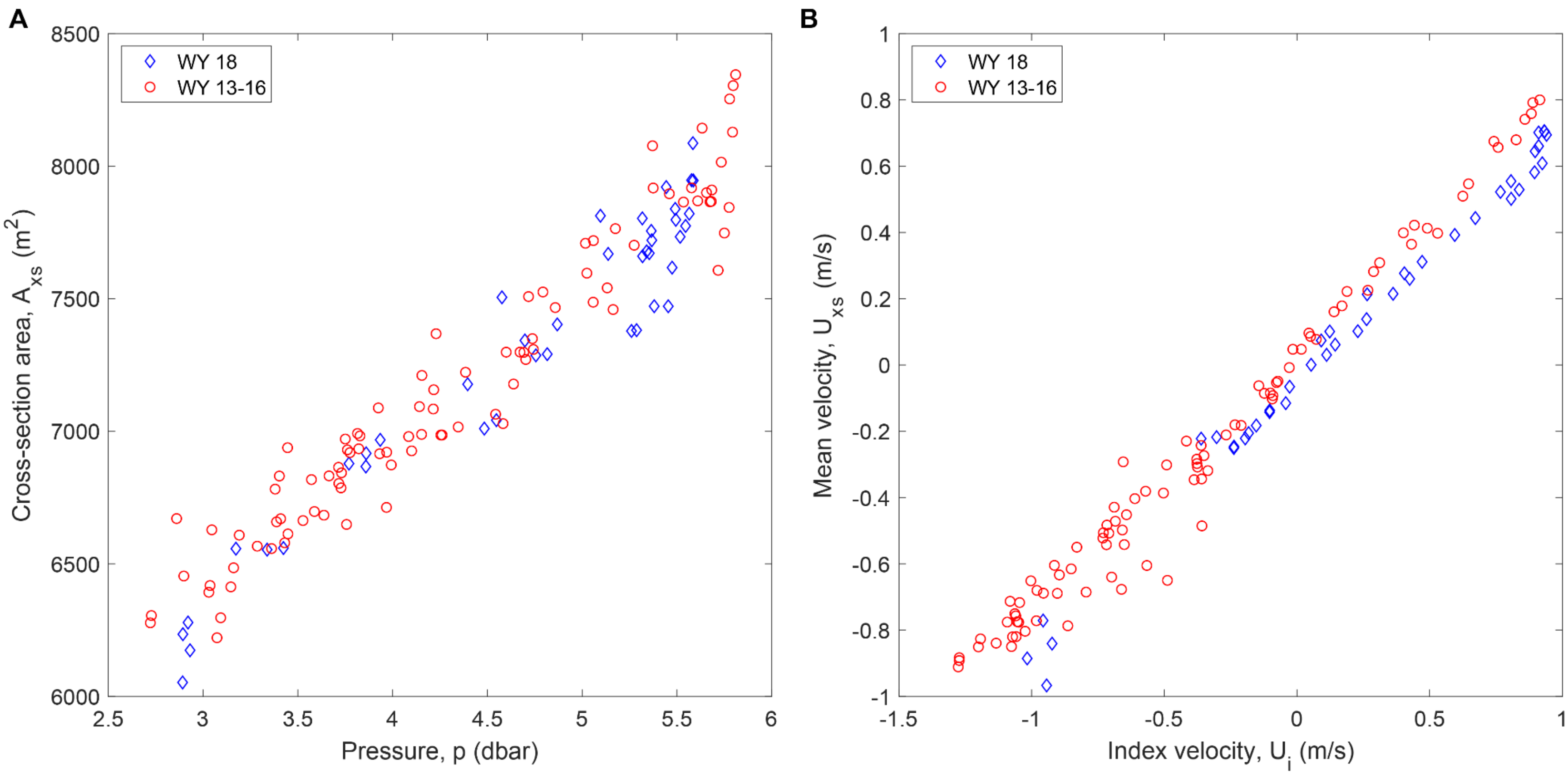

Figure 4. Pressure (A) and velocity (B) measured from the moored Nortek ADCP to related to boat-based discharge measurements of cross-section area (A) and average cross section velocity (B). Data from WY 2013-2016 (Livsey et al. in review[a]) shown for comparison.

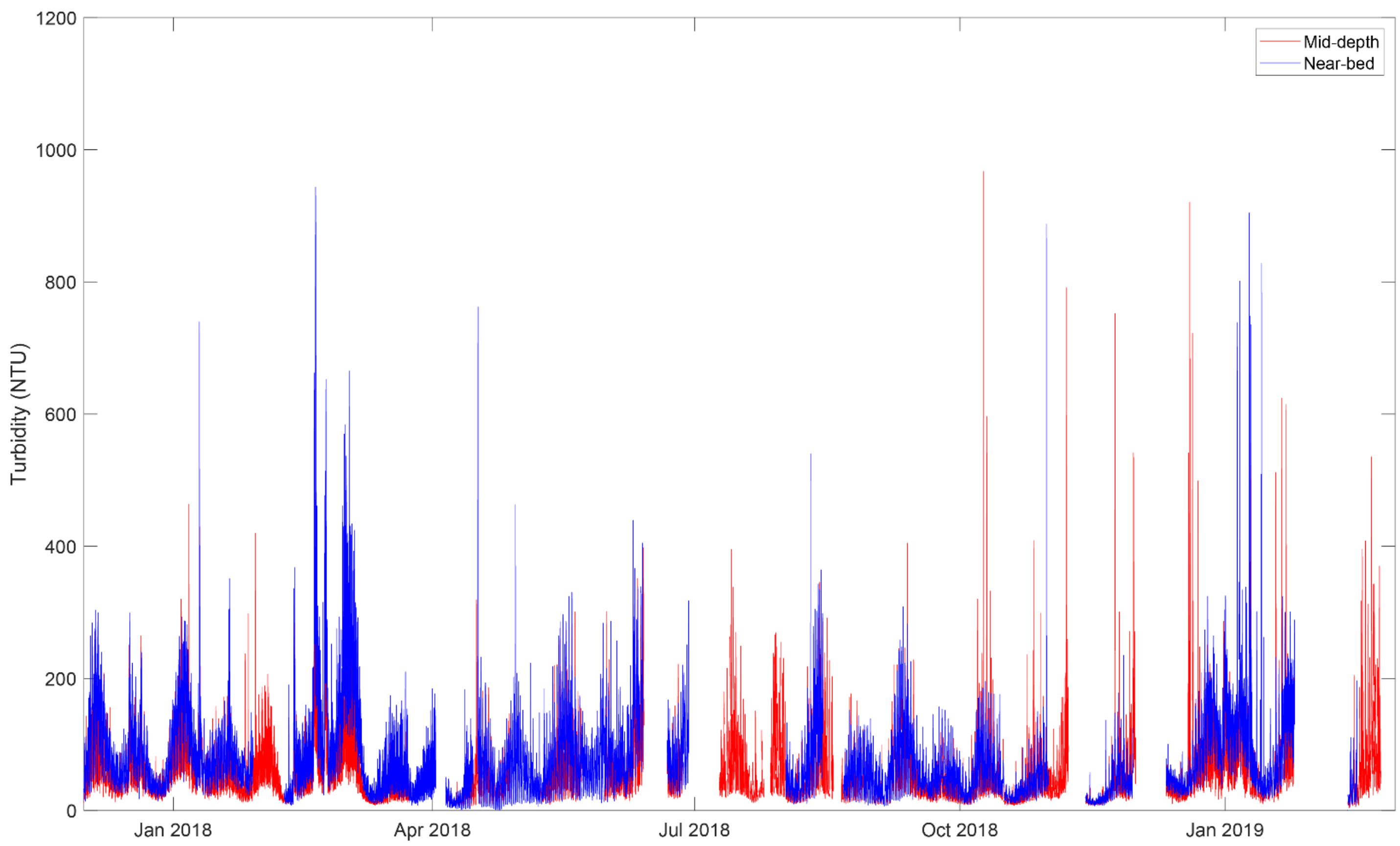

Figure 5. Turbidity timeseries used to compute suspended-sediment flux at Dumbarton Bridge. Data gaps arise from biologic growth on sensors.

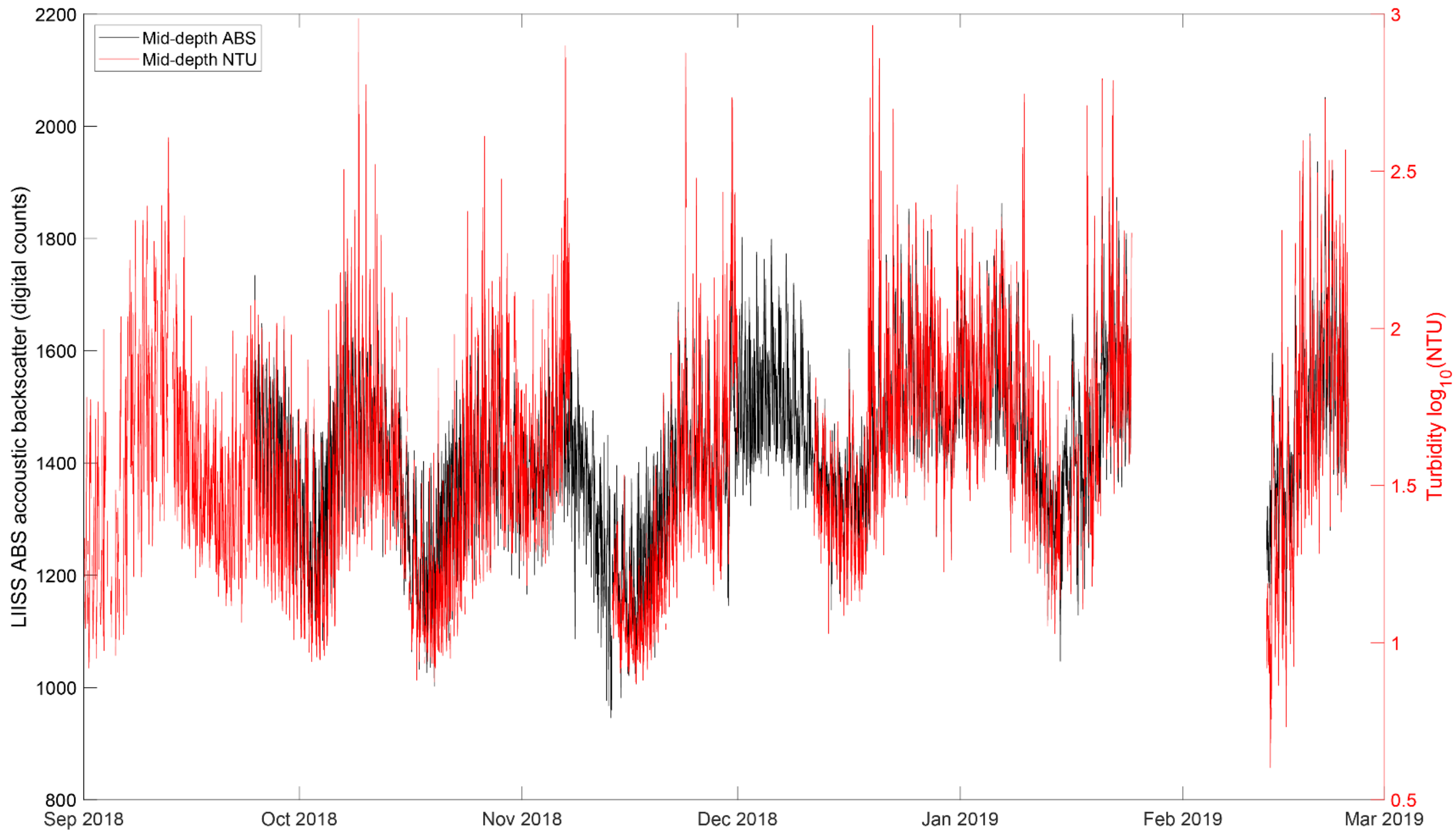

Figure 6. Acoustic backscatter from the LISST ABS sensor and collocated optical turbidity sensor at mid-depth. The data gap in LISST ABS data in February 2019 was caused by a power failure at the site. Turbidity data are plotted on $\log_{10}$ scale because acoustic backscatter is in $\log_{10}$ units.

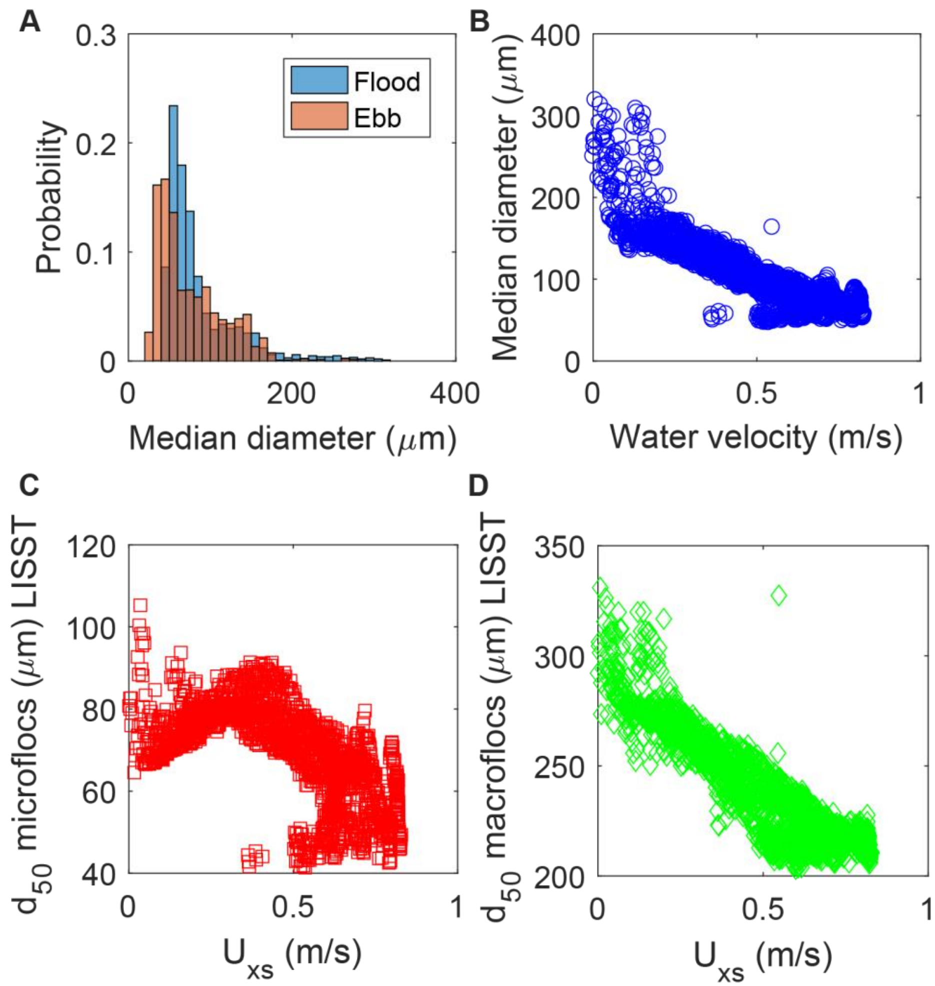

Figure 7. Median particle size of entire particle size distribution from the LISST 100x collected in April 2018 with respect to flood and ebb tides (A) and average cross-section water velocity (B). Median particle size of microfloc (particles ≤ 160 µm; C) and macrofloc (particles > 160 µm; D) populations with respect to velocity. Note median size of microfloc population increases with velocities up to ~ 0.4 m/s (C) while macrofloc median particle size decreased with increased water velocity (D).

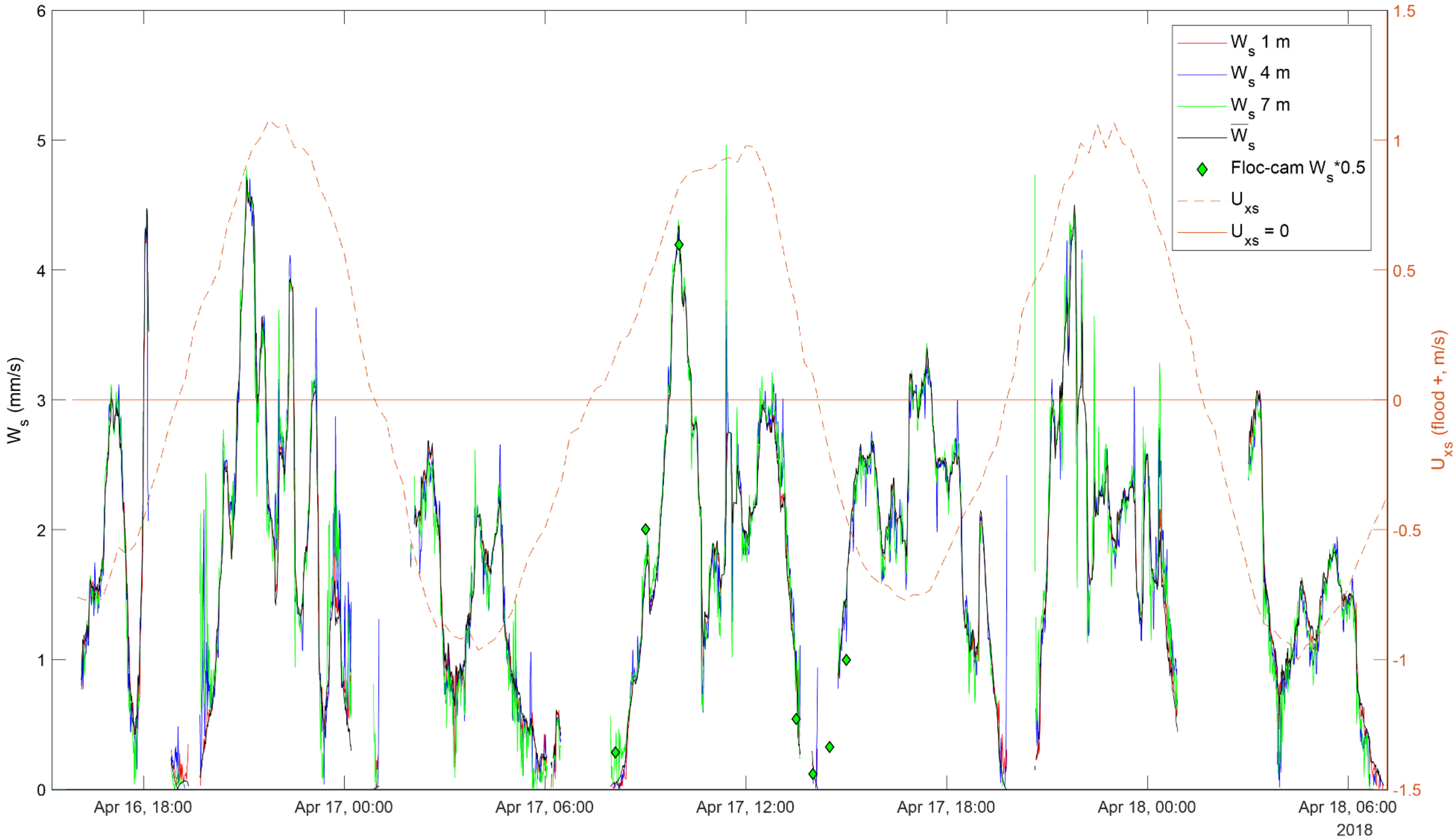

Figure 8. Timeseries of Rouse-estimated settling velocity (W_s) during the April 2018 sampling campaign. Point-estimated and depth-averaged settling-velocity estimates are shown along with *in-situ* floc-cam measurements scaled by 0.5. Note Rouse-estimated W_s and floc-cam measurements exhibit excellent agreement and covary with water velocity. Rouse-estimated W_s is larger on flood tides than ebb.

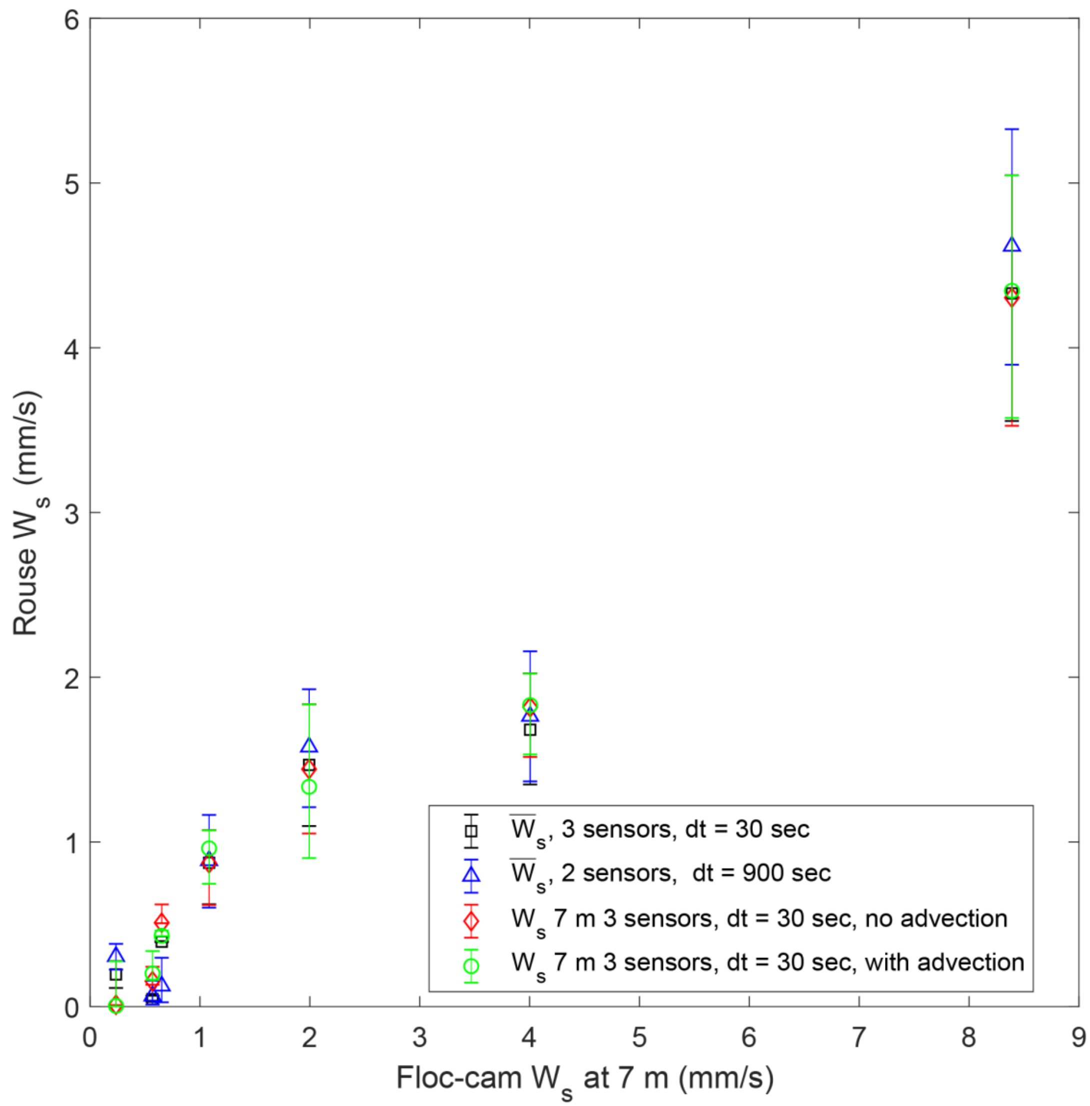

Figure 9. Comparison of *in-situ* floc-cam measurements from the mid-depth sensor and Rouse-estimated W_s. The floc cam may provide slightly higher W_s estimates than the Rouse-estimated W_s due to turbulence in the water column and/or small particles < 30 um not detected by the floc cam.

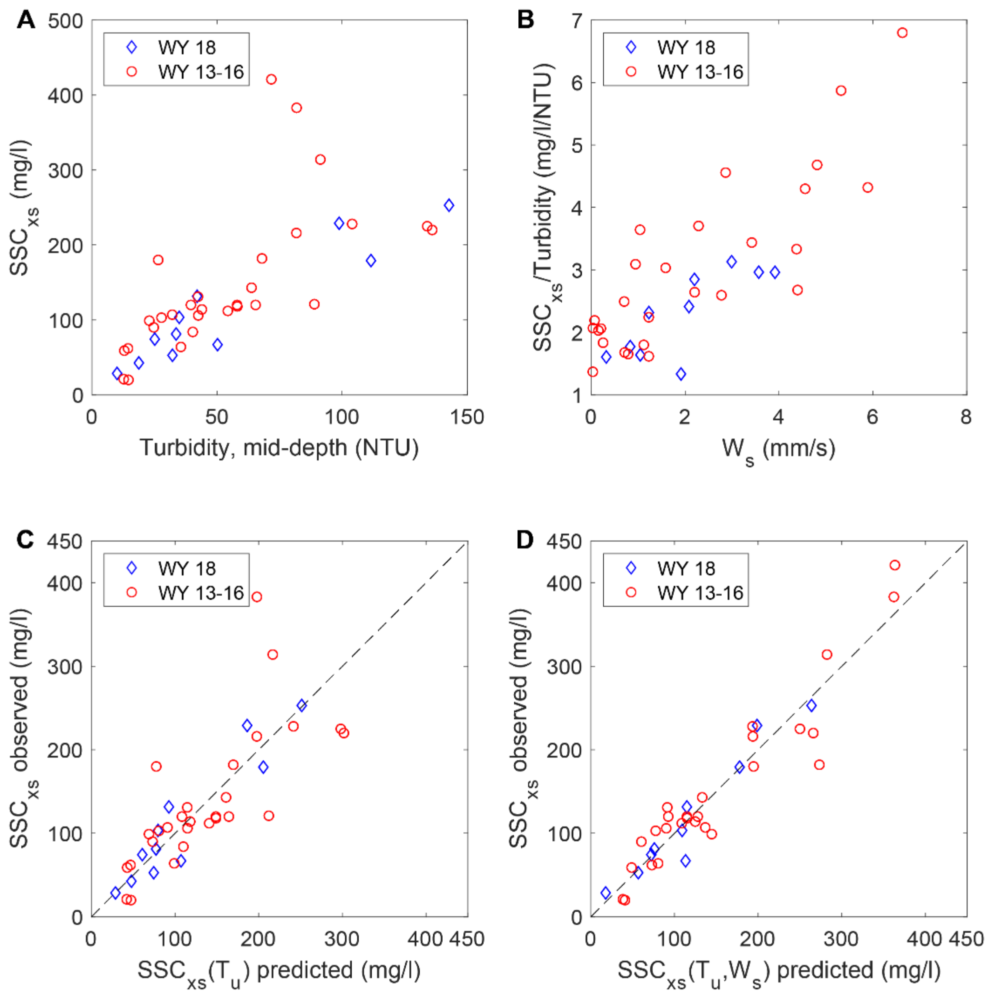

Figure 10. (A) Mid-depth turbidity compared to cross-section averaged SSC (SSC_{xs}). From optical theory the ratio of $\frac{SSC_{xs}}{T_b}$ is expected to increase with W_s (B). Predicted $SSC_{xs}(T_b)$ and $SSC_{xs}(T_b, W_s)$ and observed SSC_{xs} (C) and (D), respectively. Data from WY 2013-2016 shown for comparison.

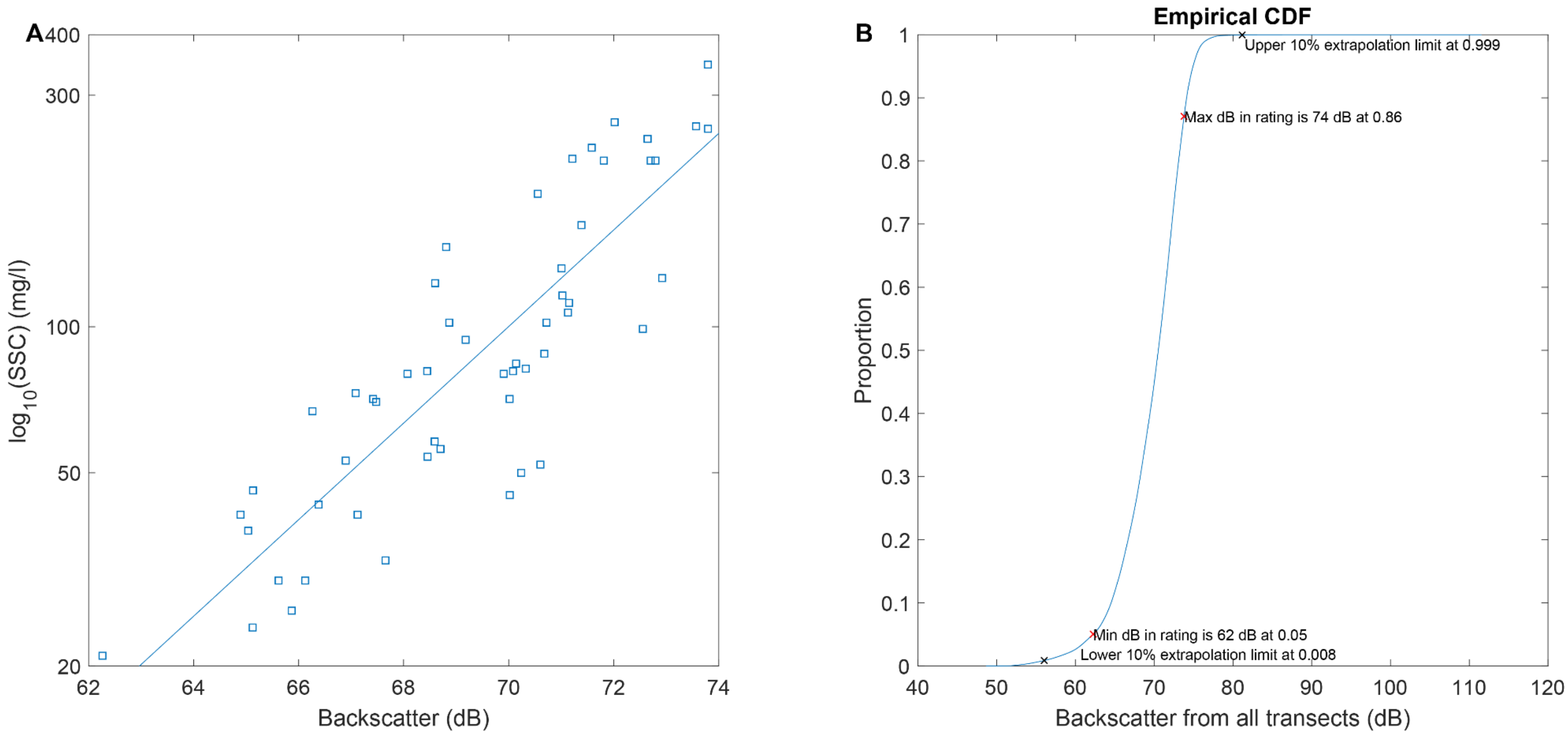

Figure 11. (A) Depth-averaged acoustic backscatter from boat-based ADCP data related to depth-averaged SSC samples used to compute SSC_{xs}. (B) Distribution of observed backscatter in boat-based ADCP data with range of acoustic backscatter data in panel A.

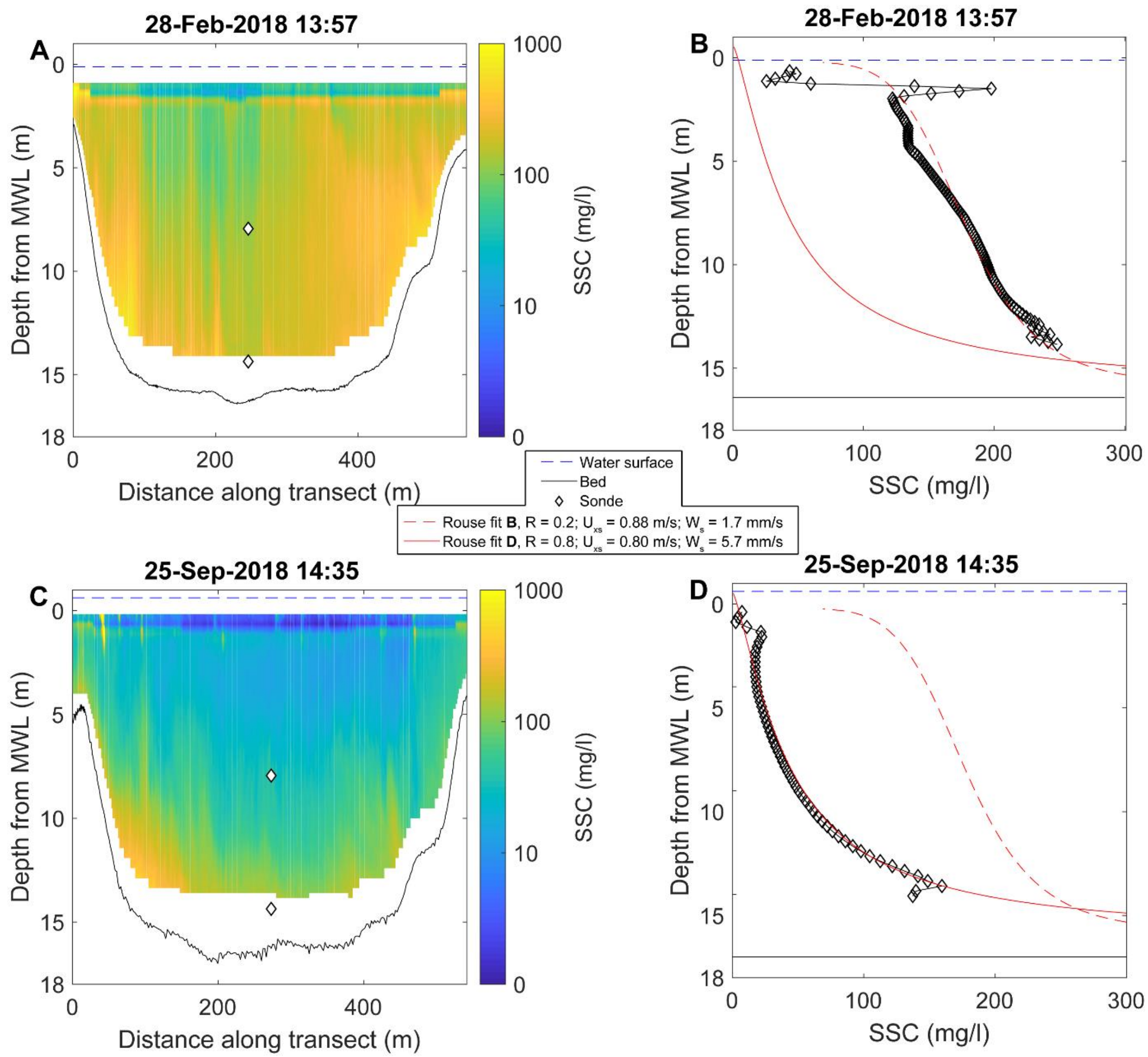

Figure 12. Channel SSC estimated from ADCP acoustic backscatter in the wet season (A) and dry season (C). SSC and Rouse-predicted SSC profiles in panels (B) and (D) computed from data in panel (A) and (C), respectively.

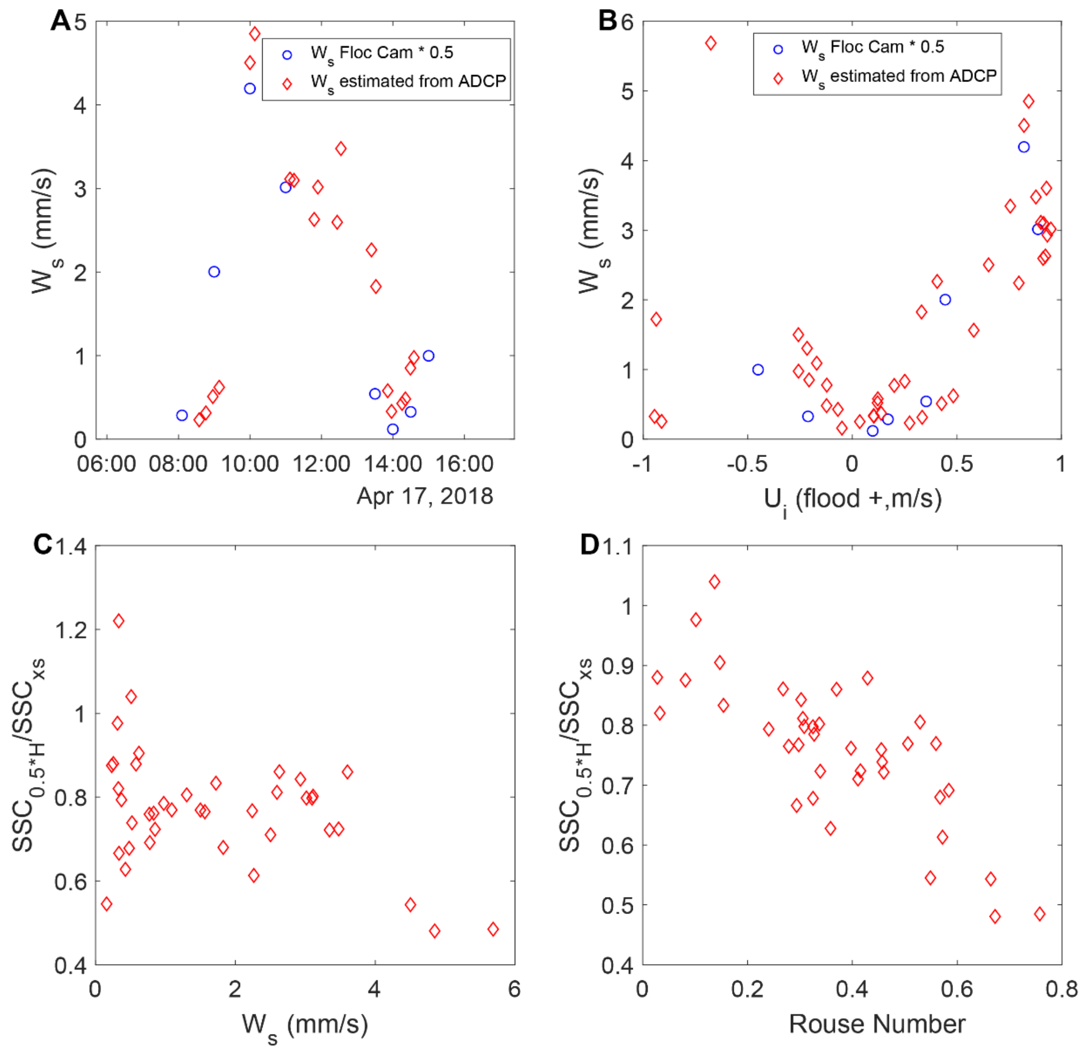

Figure 13. $\overline{W_s}$ computed from SSC profiles estimated from boat-based ADCP acoustic backscatter (A) compared to average cross section water velocity (B). (C,D) SSC at 0.5*H normalized to SSC_{xs} compared to cross-section $\overline{W_s}$ and the Rouse number, respectively.

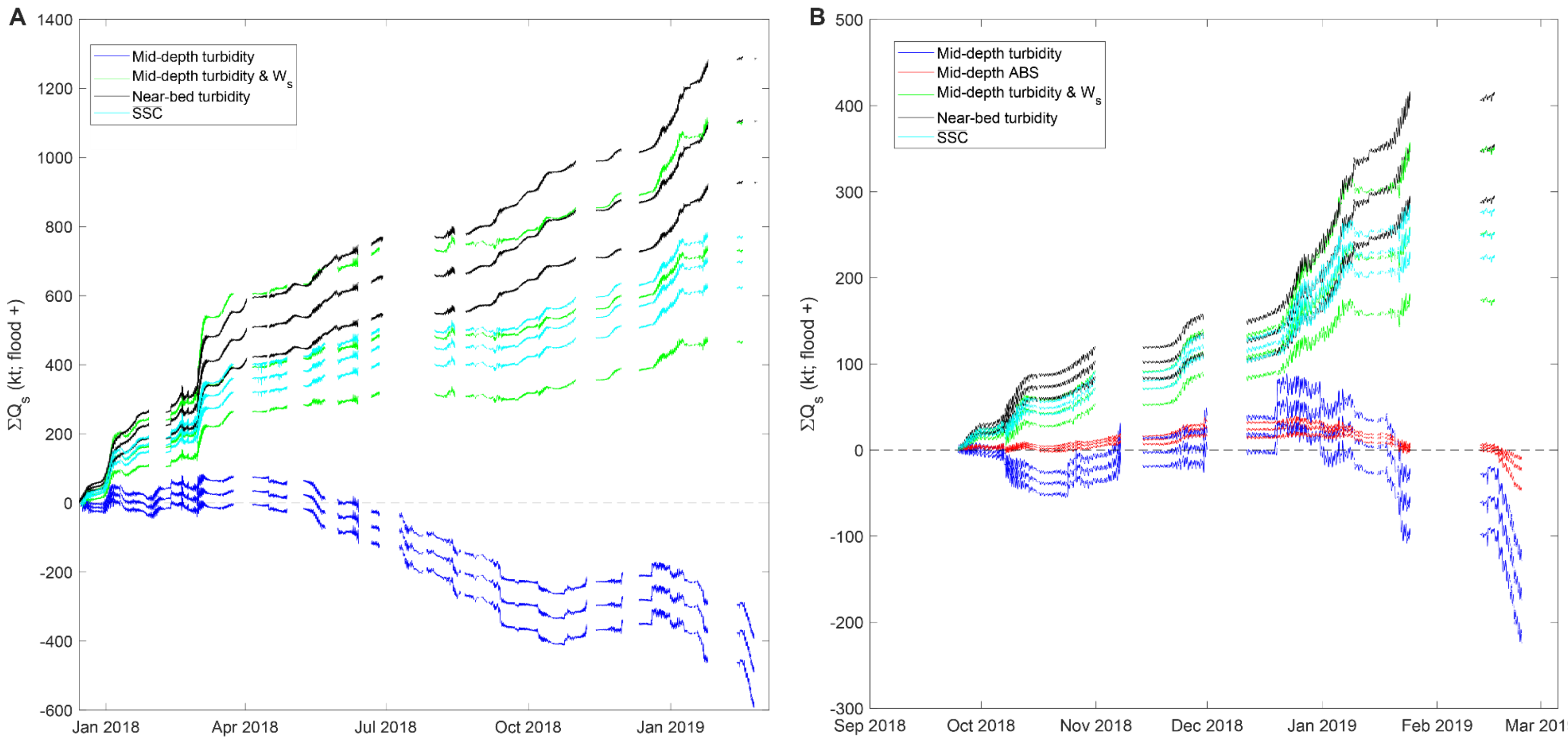

Figure 14. (A) Cumulative suspended-sediment flux ($\sum Q_s$) timeseries using different predictor variables indicated in the legend. $\sum Q_s$ timeseries in panel (B) span the time since the LISST ABS instrument was installed (September 2018 – March 2019). The center lines of each timeseries indicate the median confidence interval and outer lines indicate the 95% confidence intervals.

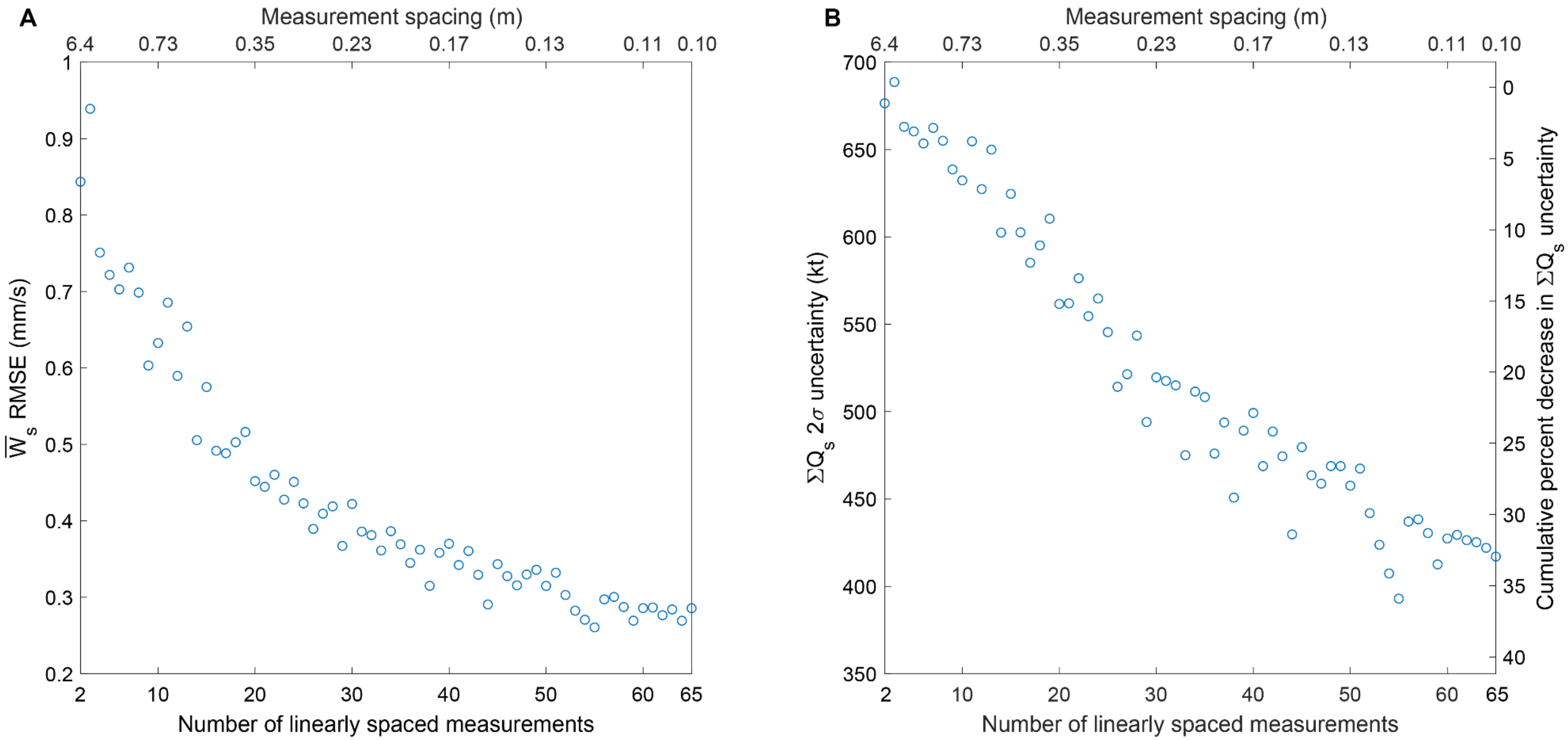

Figure 15. (A) Root mean squared error (RMSE) of Rouse-estimated, depth-averaged, settling velocity ($\overline{W_s}$) computed using a synthetic dataset of Rouse profiles and *n* linearly spaced measurements between the near-bed and mid-depth sensors. (B) $\sum Q_s$ computed using $\overline{W_s}$ with increasing RMSE from panel A.

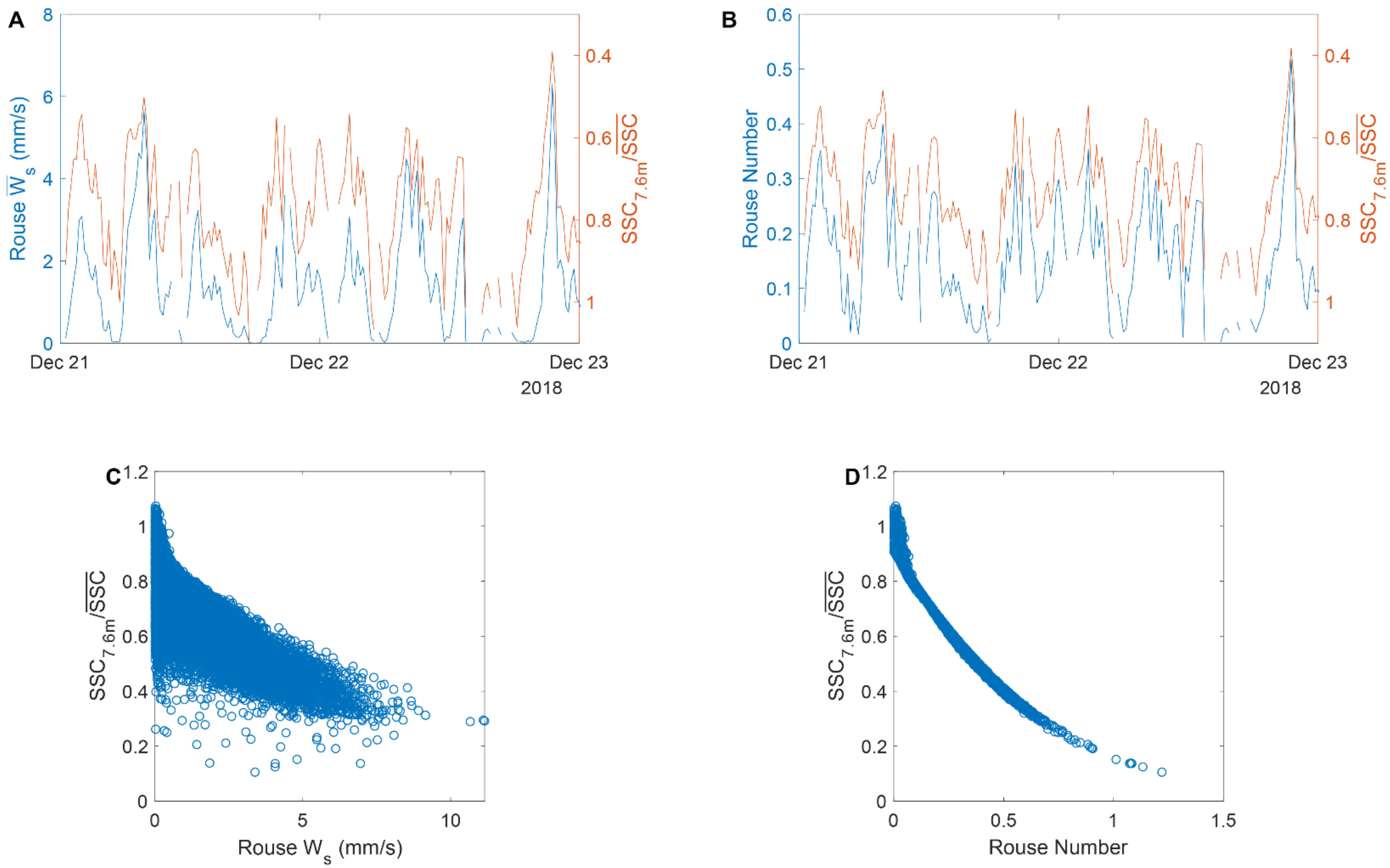

Figure 16. Time series and scatter plot comparisons of Rouse-estimated $\overline{W_s}$ (A,C) and Rouse number (B,D) compared to the ratio of SSC observed at mid-depth ($SSC_{7.6m}$) over depth-averaged SSC computed from Rouse-estimated SSC profiles at Dumbarton Bridge. Note increased $\overline{W_s}$ and Rouse number results in a change in the relationship between SSC at the mid-depth sensor and depth-averaged SSC.

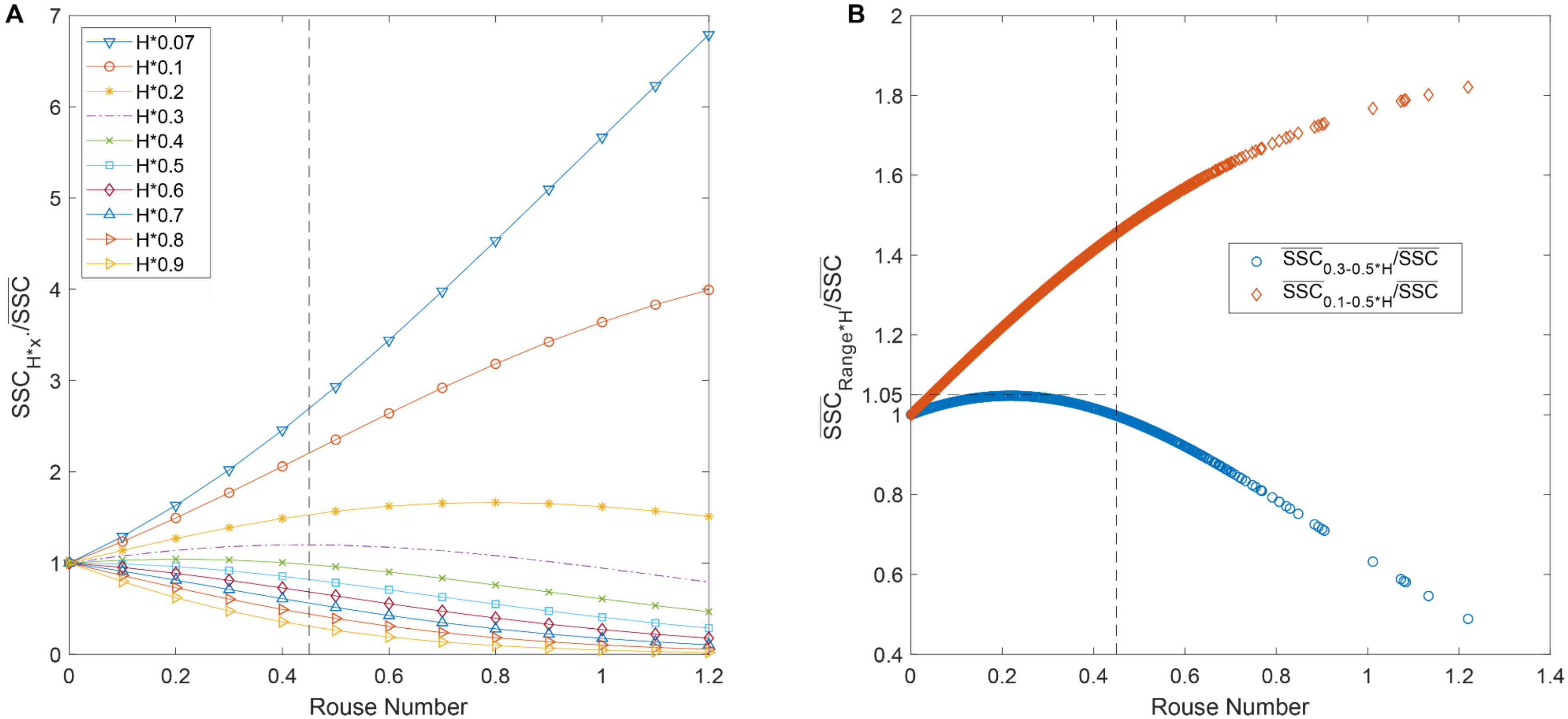

Figure 17. (A) Change in the ratio of SSC at variable depths in the water column relative to depth-averaged SSC computed with respect to range of observed Rouse numbers. The vertical dashed line indicates the 95th percentile of observed Rouse numbers in 2018. (B) The effect of increasing Rouse number on depth-averaged SSC computed from integration of Rouse profiles from 0.1 – 0.5*H and 0.3*H to 0.5*H.

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Evaluation of PCB Concentrations, Masses, and Movement from Dredged Areas in San Francisco Bay

Prepared by:

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San Francisco Estuary Institute

CONTRIBUTION #938 / March 2019

Evaluation of PCB Concentrations, Masses, and Movement from Dredged Areas in San Francisco Bay

Final Report
March 28 2019

Don Yee and Adam Wong
San Francisco Estuary Institute

SFEI Contribution #938

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EXECUTIVE SUMMARY

Dredged materials from San Francisco Bay undergo chemical analysis to determine appropriate disposal options, but the data were previously accessible primarily as standalone reports to the Dredged Materials Management Office (DMMO). The DMMO has undertaken an ongoing effort in recent years to compile dredging project testing data since approximately 2000 into a DMMO database to allow data to be more readily searched and downloaded. The database is available to the public (https://www.dmmosfbay.org "Data Search" page) and the data content as of April 2017 was downloaded for this study and a recent RMP dioxin synthesis report (Yee et al., 2019).

This report is a product of a Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) project funded to analyze sediment PCB data in the DMMO database to address priority management questions for PCBs. The first goal was to characterize the PCB concentrations in sediment from dredged areas. Data reported for the DMMO include individual congener results, but none were reported by the highest sensitivity methods used in the RMP (EPA 1668 variants), so there were extensive non-detects (NDs) in the DMMO data that resulted in substantial uncertainty about the distribution of concentrations found. The lower and upper bounds of estimates (using substitution by zero or method detection limits (MDL)) for the DMMO results bracket the RMP-measured ambient concentrations for the habitats most comparable (i.e., RMP margins versus dredged nearshore areas; and RMP open-Bay ambient concentrations versus dredging in open-Bay areas). The upper and lower limit estimates were often significantly different from the RMP results, but some variants of their central tendencies (e.g., NDs substitute at half of the MDL) were not significantly different from the corresponding ambient data.

Estimates of PCB masses in dredged nearshore areas derived from the DMMO data suggested these areas added relatively modest masses to the overall mass of PCBs in the Bay (about 1% to 2.5% or less of the Bay-wide inventory, depending on the convention used for estimating non-detects). Maximum concentrations in dredged nearshore sites are higher than those in the ambient open-Bay and often similar to ambient RMP margin sites, but are still one to two orders of magnitude less than the most contaminated sites found to date in the Bay. Thus although they are likely to have a small influence on contaminant exposure for wide-foraging sport fish, birds, and other wildlife, some areas may have presented or still present elevated risk to localized biota.

Estimates of PCB masses transferred from dredged areas in various Bay segments to disposal sites were also highly sensitive to the assumptions for handling NDs, but ND handling did not greatly alter the relative proportions allocated to in-Bay versus ocean or upland disposal. Overall, sediment volumes sent to ocean or upland/reuse disposal sites represent a net loss of PCBs from the Bay, as described in the San Francisco Bay PCB TMDL. For dredging projects with reported PCB data, this report estimates that just over 50% of the PCB mass encountered is removed from the Bay, independent of the method for handling NDs. However, these net transfers via dredging were relatively small (but not negligible) compared to PCB external loads and other internal cycling processes in the Bay; annual PCB export from the Bay and transfers within the Bay were equal to about 30% to 80% of present day local watershed loadings to the Bay.

This effort has provided a good initial assessment of PCB distributions, masses, and transfers from dredged areas. Efforts to more consistently populate some database fields (e.g. to exactly match project names with those in DMMO annual reports), and inclusion of some project metadata such as dredged volumes provided in the DMMO reports would improve the usability of the DMMO database for other purposes and help future efforts to more precisely estimate the contribution of dredging to overall PCB fate and transport in the Bay.

SECTION 1: BACKGROUND

PCB contamination in the San Francisco Bay region is spread widely across the land surface and mixed deep into the sediment, resulting in contamination of the Bay food web and health risks to humans and wildlife, a legacy of poor management practices of this group of contaminants. In 2008, the San Francisco Bay Regional Water Quality Control Board (Water Board) adopted a Total Maximum Daily Load (TMDL) for PCBs in San Francisco Bay (SFBRWQCB 2008), establishing a plan for reducing impairment from elevated PCB concentrations. The TMDL Implementation Plan calls for reductions in external loadings of PCBs to the Bay (mainly from the stormwater pathway), control of internal sources of PCBs within the Bay (including dredging), and management of risks to consumers of fish from the Bay.

Every year, millions of cubic yards of sediment are dredged in and around San Francisco Bay to maintain safe navigation in open-Bay channels and operations in ports and harbors. The Dredged Materials Management Office (DMMO) is an interagency group responsible for approving economically and environmentally sound dredging projects. The group is comprised of the US Army Corps of Engineers (USACE), US Environmental Protection Agency Region 9 (USEPA), San Francisco Bay Conservation and Development Commission, Water Board, State Water Resources Control Board, and the California State Lands Commission. Dredged sediment are analyzed for PCBs and other contaminants on either an ongoing or periodic basis, and compared to ambient sediment concentrations in the Bay measured by the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP). Remaining residual sediment (post-dredge surface sediment) are analyzed for PCBs and other contaminants on an as-needed basis if the results of overlying material warrants such analysis. Testing is required at sites where there are no recent data or past testing has shown highly contaminated sediment. At sites where past data suggest low risk of contamination (“Tier 1” sites), sample testing is required at a lower frequencies (e.g., every 3 to 5 years). The analysis of dredged material is used to determine the suitability for disposal at specific sites within the Bay, for reuse at upland sites around San Francisco Bay, or for open-ocean disposal.

The physical, chemical, and biological testing data for dredging projects were previously reported annually in standalone documents for each project. These data were recently compiled into a database on the DMMO website, providing the first opportunity to analyze and synthesize the results of dredged materials testing throughout the Bay. These analyses may provide valuable insights into the mass of contaminants from or moved around the Bay by dredging projects. This information can help us verify and refine our conceptual understanding of contamination in the Bay, contribute to answering management questions, and identify ways in which DMMO data can be more closely integrated with management strategies.

This effort focused on PCB testing results from dredged sediment. Sediment PCB data from the DMMO database were downloaded in April 2017. In addition to these data, each annual report published by DMMO specifies the total volume of dredged sediment from each project in the Bay and the destination of the dredged sediment (e.g., San Francisco Deep Ocean Disposal Site, in-Bay disposal sites, or upland for disposal or reuse). The DMMO database downloaded in early 2017 included complete physical, chemical, and biological testing data from sediment dredging projects from 2000 to 2016. Combining the relevant PCB sediment concentration testing data (i.e., for the dredged volumes, excluding data on the residual “z-layers” left post-dredging) with the project-specific dredged volumes and disposal sites as reported in the DMMO annual reports, we estimated the amount of PCBs in dredging projects moved out of the Bay or to other areas within the Bay.

The data from the DMMO database were also used to evaluate the spatial distribution of PCB concentrations in dredged sediment around the Bay. Dredging generally occurs at sites where sediment is accreting in depositional zones, so it was expected that these sediment pollutant concentrations would be similar to ambient concentrations in surrounding subtidal sites or nearby shallow water or intertidal margin sites. Comparisons among these groups of sites were used to help confirm our conceptual models of sediment and pollutant processes in the Bay (Jones et al., 2012). Where our conceptual model expectations were contradicted, we can begin to identify the factors involved and modify our conceptual models and management approaches.

By addressing these topics, the statistical and spatial analysis of dredged sediment testing data will help better inform the overall management of PCBs in the Bay Area. The comparison of sediment dredging data and RMP ambient data on a regional and local basis can inform understanding of appropriate management options for the dredged sediment, and evaluate opportunities for beneficial reuse. Rising sea level and a current deficit of sediment for wetland restoration projects (Goals Project, 2015) suggest a desire for increased beneficial reuse of dredged material where possible. The distribution of sediment PCB concentrations from dredging sites relative to nearby ambient sites can also help us evaluate whether there are more PCBs than expected from simple redistribution of nearby ambient sediment, suggesting unaccounted or unexpected nearby legacy or current sources. Lastly the estimates of net PCB movement via dredging and disposal activities allow us to evaluate whether or not dredging activities can have substantial impacts on PCB mass balances and the long-term recovery of the Bay from PCB contamination. Although dredging can sometimes bring up PCBs that were already settled below a biologically active zone, PCBs in dredged sediment largely represent a mass already present in the Bay, so dredging and disposal within the Bay is considered to have no net effect on the PCB inventory in the TMDL Staff Report (SFBRWQCB 2008). Although a small proportion of sediment contaminants disposed of in the ocean or at upland/reuse sites potentially could find their way back into the Bay, ocean and upland disposal mostly results in net removal of PCBs from San Francisco Bay.

Although this report focuses on sediment concentrations of PCBs, the DMMO database also contains results for other matrices, such as sediment elutriate (water) PCBs and concentrations in tissue from bioaccumulation testing. These matrices and methods are not used in RMP monitoring, and thus we have no appropriate sample group to which we could compare these results. A separate RMP special study evaluating bioaccumulation results in the DMMO database was proposed and will be considered for future RMP or Supplemental Environmental Projects (SEP) funding.

SECTION 2: CURRENT STATUS AND INVENTORY OF SEDIMENT PCBs

PCB Spatial Distributions

The DMMO database at the time of download in April 2017 included PCB concentrations for 391 samples obtained from 293 sites in 111 project studies from the years 1998 to 2016. Samples from “z-layers,” located below the planned dredging depth, and meant to represent residual concentrations exposed as the surface after dredging, were excluded. These dredging data most directly address one of the RMP management questions for PCBs, namely: MQ2. What is the spatial pattern of impairment?

We focused our data analysis on the 40 congeners historically reported for the RMP, with their coeluters in cases where the congeners were not individually isolated and quantified. The RMP-reported congeners represent those commonly most abundant in PCB technical mixtures, such as Aroclors, with the intent to quantify PCBs most likely to be present at ambient concentrations. Therefore, the RMP dataset typically has relatively few non-detects (NDs); any non-detects that do occur in RMP data reported since 2002 are typically for only the least abundant of the historically reported congeners.

One challenge of interpreting the PCB data in the DMMO database was the frequent occurrence of non-detects for individual congeners (Table 1). The minimum and maximum MDLs for non-detects are shown as <MDL values (in units of ug/kg dw). The MDLs varied among studies, with minimum and maximum MDLs within about a factor of 100 for most congeners. The primary goal of chemical analysis for dredged materials is to determine appropriate disposal, so non-detects are acceptable, so long as the detection limits are below disposal thresholds. However, non-detects introduce uncertainties in efforts to more generally characterize chemical distributions, as concentrations below detection limits are not quantified. Although the RMP data also had occasional non-detects for individual congeners, there were no samples where all of the targeted 40 congeners were non-detects. In contrast, of the nearly 400 samples with PCB concentrations reported in the DMMO database, 89 had non-detects on all congeners. The disparity in the prevalence of non-detects reflects the different goals for the analyses; RMP data are collected to characterize the overall distribution of concentrations, including relatively clean ambient locations. However, given that more sensitive analytical methods typically cost more, quantification at low concentrations below disposal thresholds may be seen as an unnecessary additional expense for projects reporting to the DMMO.

The RMP reporting convention is to substitute zero for the concentration of congeners not detected because there are generally relatively few, and they are usually among the least abundant congeners even when detected. For the DMMO dataset, despite the much higher prevalence of non-detects, we primarily reported PCB concentrations using the RMP convention of substituting zero for non-detects. We also explored some alternative assumptions or substitutions and the possible impacts to inferences or conclusions that might be drawn from the data. Substituting the MDL or half the MDL as the estimated concentrations for congeners not detected could sometimes grossly overestimate their abundance relative to the detected congeners, particularly when the detected (usually more abundant) congeners are only slightly above MDL. For example, two congeners might typically have a 3:1 ratio in a high concentration samples (due to relative abundances in source Aroclors). If the first congener is reported just above its MDL in a low concentration sample, and the second is reported ND with approximately the same MDL, substitution of MDL for the latter concentration may create an artifact of a 1:1 relative abundance.

Table 1 Reported congeners in the downloaded DMMO data (391 samples) with their minimum and maximum MDLs (shown as <MDL, often differing by ~100x among studies) and maximum values (in ug/kg dw). The total count of results (Tcount) varies, as some congeners were not reported in all studies. The percent of reported results that were ND (%ND) was over half the samples for many congeners. The average percentage contribution to reported Sum of 40 PCBs in DMMO data (Avg%ofSum) indicates which congeners were detected consistently at higher concentrations. Only samples with at least 28 of the 40 congeners reported were included to derive the Avg%ofSum.

AnalyteName	<MDL Min	<MDL Max	Max Value	TCount	% ND	Avg%ofSum
PCB 008	<0.055	<4.3	2	335	88.7	0.4%
PCB 018	<0.044	<5	12.6	391	83.6	1.9%
PCB 028	<0.013	<5	12.7	391	74.2	1.1%
PCB 031	<0.0335	<5	5.4	340	78.5	1.0%
PCB 033	<0.039	<5	1.9	344	84.6	0.5%
PCB 044	<0.065	<5	18.8	391	71.6	1.8%
PCB 049	<0.058	<5	12.7	391	64.7	2.4%
PCB 052	<0.059	<5	30.5	391	57.5	4.1%
PCB 056	<0.03	<2.2	3.1	330	82.1	1.0%
PCB 060	<0.039	<2.2	2.4	319	94.7	0.1%
PCB 066	<0.035	<5	19.6	391	65.2	1.0%
PCB 070	<0.051	<5	30.8	391	52.2	2.7%
PCB 074	<0.044	<5	11.3	391	84.1	0.9%
PCB 087	<0.038	<5	8.7	389	76.9	2.7%
PCB 095	<0.049	<7.1	8.6	344	42.4	3.7%
PCB 097	<0.053	<5	5.5	344	63.4	2.0%
PCB 099	<0.045	<5	7.8	391	47.3	2.7%
PCB 101	<0.049	<5	34	390	33.3	7.5%
PCB 105	<0.033	<5	8	391	61.9	2.8%
PCB 110	<0.035	<5	16.2	391	34.3	6.1%
PCB 118	<0.031	<5	12.5	389	34.2	5.4%
PCB 128	<0.031	<5	3.5	391	75.2	1.6%
PCB 132	<0.075	<5	2	280	91.8	0.4%
PCB 138	<0.064	<8.45	16	389	33.7	9.1%
PCB 141	<0.035	<5	3.1	344	72.1	1.2%
PCB 149	<0.067	<5	18.4	390	33.1	6.2%
PCB 151	<0.043	<5	3.2	391	68	1.7%
PCB 153	<0.038	<5	29	388	30.2	8.4%
PCB 156	<0.042	<5	2.1	391	81.6	0.7%
PCB 158	<0.028	<5	7	195	75.4	0.7%
PCB 170	<0.026	<5	5	391	54.2	2.4%
PCB 174	<0.03	<2.1	3.8	326	50	2.1%
PCB 177	<0.052	<5	2.4	388	72.2	1.4%
PCB 180	<0.053	<5	24.6	391	37.9	5.0%
PCB 183	<0.062	<5	2.6	389	64.3	1.5%
PCB 187	<0.047	<5	13.5	391	39.4	3.3%
PCB 194	<0.043	<5	2.9	386	75.9	1.2%
PCB 195	<0.031	<3.8	1.3	335	89	0.3%
PCB 201	<0.041	<7.85	0.7	391	93.9	0.2%
PCB 203	<0.039	<1.8	3.2	330	79.4	0.7%

Although the ND=0 substitution is used by the RMP, the bias on sums of PCBs relative to other substitution conventions is generally relatively small because few individual congeners are reported as ND, and the congeners substituted account for a small percentage of the sum. In contrast, for cases where many or all of the individual reported congeners are ND, which occurred frequently in the DMMO data, estimated concentrations can differ greatly between substituting conventions, so care must be taken to not over-interpret apparent differences that may be artifacts of the substitutions selected.

Concentrations of the sum of the 40 RMP-reported congeners (“SumOf40PCBs”) reported from various dredging projects in the DMMO database are shown in Figure 1, including data from the Bay Protection and Toxic Cleanup Program (BPTCP), RMP sampling of deeper open-Bay subtidal areas (RMP Bay), and more recent sampling of intertidal and very shallow (above 1 ft below mean lower low water) subtidal areas (RMP Margins) plotted on the same scale. For all the plotted data, non-detects were substituted with zero, so any samples where the sum of PCBs was zero (i.e., all congeners were ND, which only occurred in the DMMO data) do not appear at all on the map. For any given area within the Bay, the BPTCP reported concentrations were among the highest, which was expected, as the intention of that program was to characterize and remediate the most contaminated areas within the Bay.

Conversely, RMP open-Bay sampling sites usually had the lowest PCB concentrations, with DMMO reported samples taken from similar deep-water areas (i.e., channel maintenance dredging activities) also similarly low in PCB concentrations. RMP Margins sampling and DMMO data from nearshore sites generally fell into a middle range of concentrations, with some very low concentrations similar to open-Bay sites, and others nearly as high as some of the BPTCP sites.

The DMMO data also display north to south patterns in concentrations comparable to those from other programs. DMMO sites in the RMP Central Bay segment (from the southern edge of San Pablo Bay, to the area roughly between San Francisco and Oakland International Airports) have higher maximum concentrations than in sites of more northern (Suisun and San Pablo) or southern (South and Lower South) Bay segments, which is similar for the BPTCP and RMP Margins sites.

These distributions are in line with the RMP’s current conceptual model of PCBs sources and fate processes (Jones et al., 2012). The majority of PCBs originate from use and disposal at terrestrial sites, with loading to the Bay occurring primarily through stormwater conveyances carrying contaminated water and sediment from upland areas in watersheds to the edges of the Bay, or leaching and runoff from poorly contained landfills and other sites located along the shoreline. The generally higher concentrations in sites from nearshore areas within the database are consistent with this expectation. The higher maximum concentrations found in Central Bay sites within the DMMO database also fit the current conceptual model. Many areas of Central Bay watersheds were more extensively developed and industrialized during the peak of PCBs usage in the 1960s and 1970s, so especially higher concentrations near the shorelines of Central Bay areas would be expected.

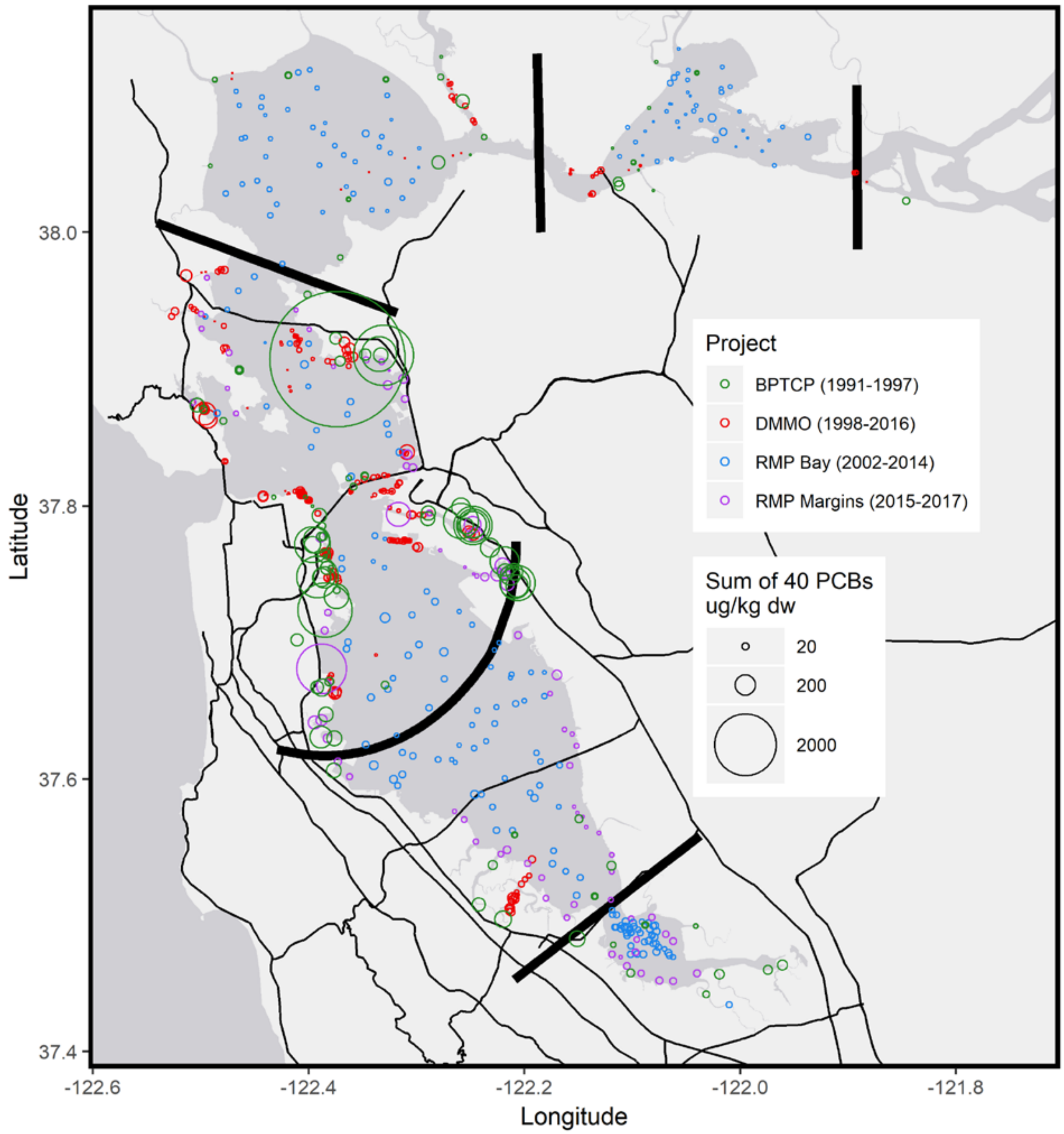

Figure 1 Sediment PCB concentrations reported by DMMO (dredging projects) and other San Francisco Bay projects. Concentrations are for the sum of 40 congeners reported routinely by the Bay RMP (Regional Monitoring Program), with non-detects substituted with zeros. Open-Bay RMP sites have generally lower PCB concentrations, with BPTCP (Bay Protection and Toxic Cleanup Program) sites usually the highest, and RMP Margins and DMMO data generally in a middle range. Bold black lines indicate boundaries of RMP Bay segments and fine black lines denote major (numbered) highways in the San Francisco region.

Although DMMO projects were not expected to be unbiased or spatially and temporally uniformly distributed, we generated empirical cumulative distribution functions (ECDFs) to explore the general distribution of PCB concentrations in the dataset, and considered whether they were significantly different from RMP open-Bay or Margins ambient concentrations. Our expectation was that dredged areas are likely to sediments similar to nearby ambient habitats, and the distributions of concentrations would therefore be not significantly different.

In generating the ECDFs, we assumed each of the DMMO reported values had equal weight, as the surface area that each individual reported sample was meant to represent was not pre-defined or constant; some projects may have more or fewer samples taken for a given surface area. Conceivably, a scheme for defining the areas of individual dredging projects, and adjusting for the sample counts and surface areas for sub-sections of each of the projects could be devised in a future analysis effort to assign an area weight to each sample individually. However, given the large number of studies in the DMMO database, compiling that level of detailed information is beyond the scope of this report.

Given the large percentage of samples that had non-detects for all congeners (i.e., with zero for sum of PCBs when non-detects are substituted with zero), we explored alternative substitution methods for non-detects, both for plotting the data in ECDFs and for PCB mass estimates of sediment inventories and transfer between or within areas of the Bay due to dredging activities. In addition to using the RMP convention of substituting zero for congener results not detected, we also generated estimates for sums of PCBs substituting values at the MDL for non-detects (ND=MDL) of each congener individually, or substituting the lowest detected value (ND=MinStudy) for the same congener within the study, or the lowest value detected in any DMMO study when a congener was never detected within its own study. These alternative substitutions represent upper bound worst case estimates for non-detects; the actual concentration in any given sample likely falls below these upper limits but above zero.

Because the sediment dredged in nearshore areas appeared to differ greatly from channel maintenance and other open-Bay areas, we plotted them separately against their comparable RMP margins and open-Bay samples, respectively. In designing the RMP open-Bay and margins sampling frames, port and marina areas were intentionally excluded. Any DMMO samples taken from subtidal areas excluded from both RMP sampling areas were designated as “nearshore” areas for this study, with the remaining DMMO samples characterized as “open-Bay” locations.

RMP margin data spanned much of the same range as reported for sampled nearshore sites in the DMMO sampling (Figure *2*). The handling of non-detects biased the estimated distribution of DMMO data high or low depending on the substitution used, with the ND = 0 substitution resulting in a majority of samples being far below RMP-reported ambient margin concentrations. However, for the top quartile of DMMO sites, results were still sometimes about the same or higher than the same quartile within the margins data. This is likely because those samples have relatively few or no non-detects, so the ND = 0 substitution only biases low a small portion of their sums.

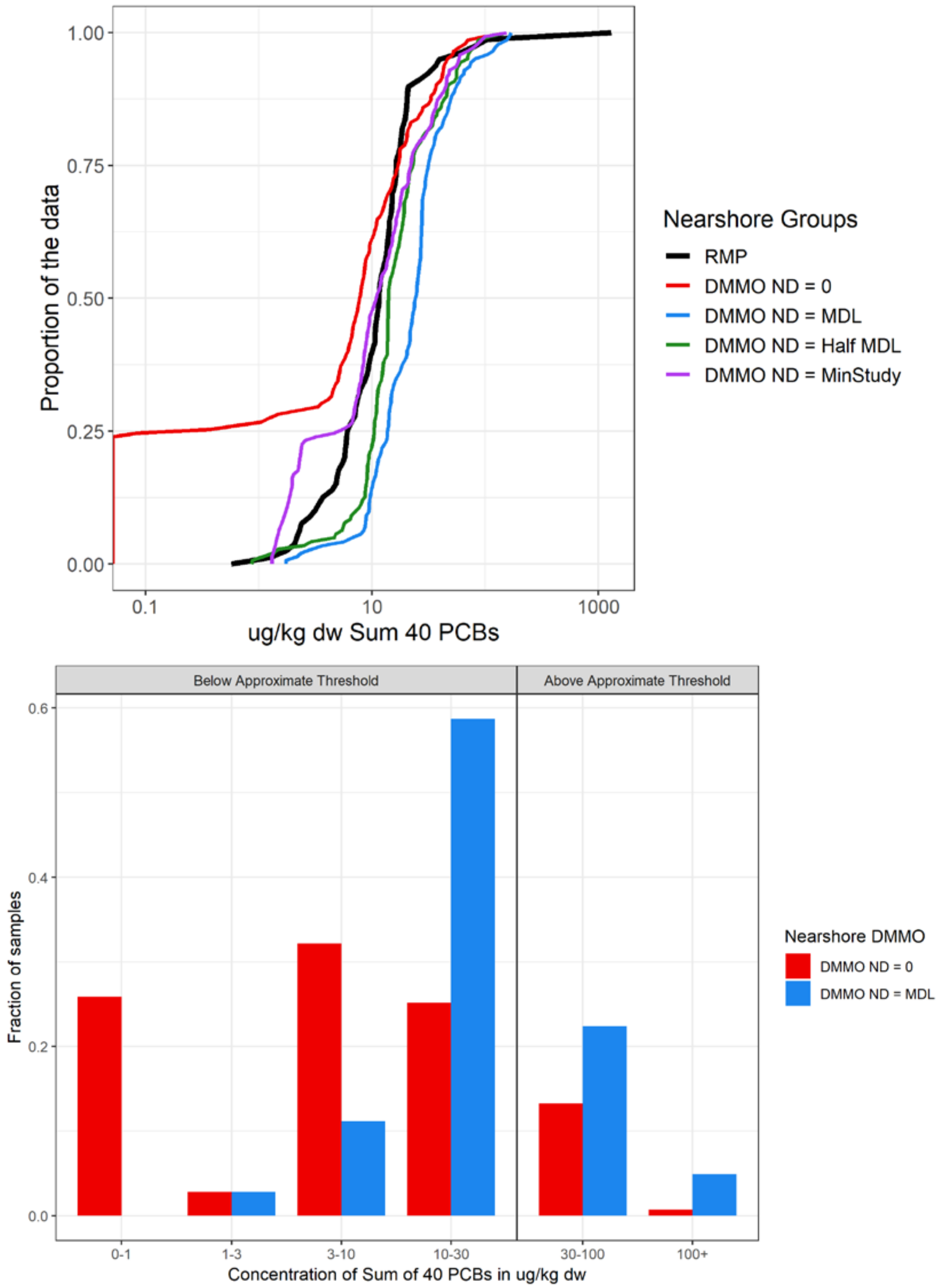

Figure 2 Distributions of RMP Margins Data Compared to DMMO Nearshore Data Using Different Handling for Non-Detects. Upper graph shows distributions as empirical CDFs, lower graph as histograms with fraction of samples in size bins grouped above and below the approximate in-Bay disposal threshold. Substituting zero for non-detects (ND = 0) yields the lowest estimates for DMMO-reported data due to extensive non-detects, with most results below ambient concentrations reported by the RMP. Substituting the MDL (ND = MDL) yields much higher estimates, mostly above RMP ambient values. Actual concentrations in DMMO data likely fall between these lower and upper limits. Substituting at the lowest concentration reported in the same study (ND = MinStudy) or at half the MDL (ND = Half MDL) yields distributions similar to the RMP samples.

Conversely, substituting ND = MDL for non-detects resulted in the highest distribution of PCBs in DMMO data compared to RMP ambient open-Bay and margins samples over most of the range. Similar to the case for ND = 0 substitution, the introduced bias of the ND = MDL substitution method decreases in importance as more of the individual congeners are detected. For the median DMMO concentrations and higher, the difference between the ND = 0 and ND = MDL substitutions diminishes.

Substituting ND = MinStudy or ND = Half MDL yielded distributions between the lower and upper limits that were similar to RMP margins concentrations. Although the RMP open-Bay and margins data are both reported using only the ND = 0 substitution method, the impact of the substitution is very small, as MDLs reported are typically less than those for most of the DMMO data, and very few congeners are reported as ND within each sample. For example, within the South Bay RMP Margins report (Yee et al., 2019 draft) PCB data, of the 40 historically reported RMP congeners, only one congener (PCB 151) was ever reported ND, in only 4% of samples.

Similarly, distributions for open-Bay sites in the DMMO data (Figure *3*) fell mostly below RMP open-Bay results for ND = 0 substitution, above for ND = MDL, and overlapping RMP ambient distributions for ND = MinStudy and ND = Half MDL substitutions. Care should therefore be exercised in interpreting plots of data with extensive non-detects, as estimates often differed by more than two-fold between the substitution methods. Again, although RMP open-Bay data are reported using the ND = 0 substitution, for the 40 historically reported RMP congeners, NDs are rare. For example, in 2014 RMP Status & Trends sediment sampling, no samples had any NDs for those 40 PCB congeners.

Methods for conducting statistical tests with left-censored data—such as non-detects—without using substitution have been developed, and we used such a method for comparing the DMMO data to ambient concentrations reported by the RMP. We used the cendiff function from the NADA R-statistical package (Lee 2016) to compare the ECDFs between the DMMO and RMP data from open-Bay areas, and between the DMMO and RMP data from margins (nearshore) areas. The package inverts approaches used for comparisons of survival studies with right censored data (e.g., with indeterminate survival times for some individuals past the end of a study), to apply to datasets that are typically left-censored, such as environmental concentrations with non-detects below one or more thresholds. The null hypothesis tested is that the compared groups (with either or both groups left-censored) originate from a single distribution. Despite the design of this statistical package explicitly to handle left-censored datasets, the substitutions for NDs still had an effect, because the functions are primarily designed for individual measured parameters rather than aggregated results, such as sums of PCBs, where with a single detected component, the sum is no longer censored. We explored treating samples where more than 12 congeners were NDs as also being censored (as unknown values below their reported sums) but the results suggested extremely low p-values (e.g., probabilities of $1x10^{-30}$ and lower that the RMP and DMMO sets originated from the same distribution), likely an artifact of the distribution of the very few values remaining uncensored in the DMMO sets (typically about 10% to 20% of the samples when using that handling).

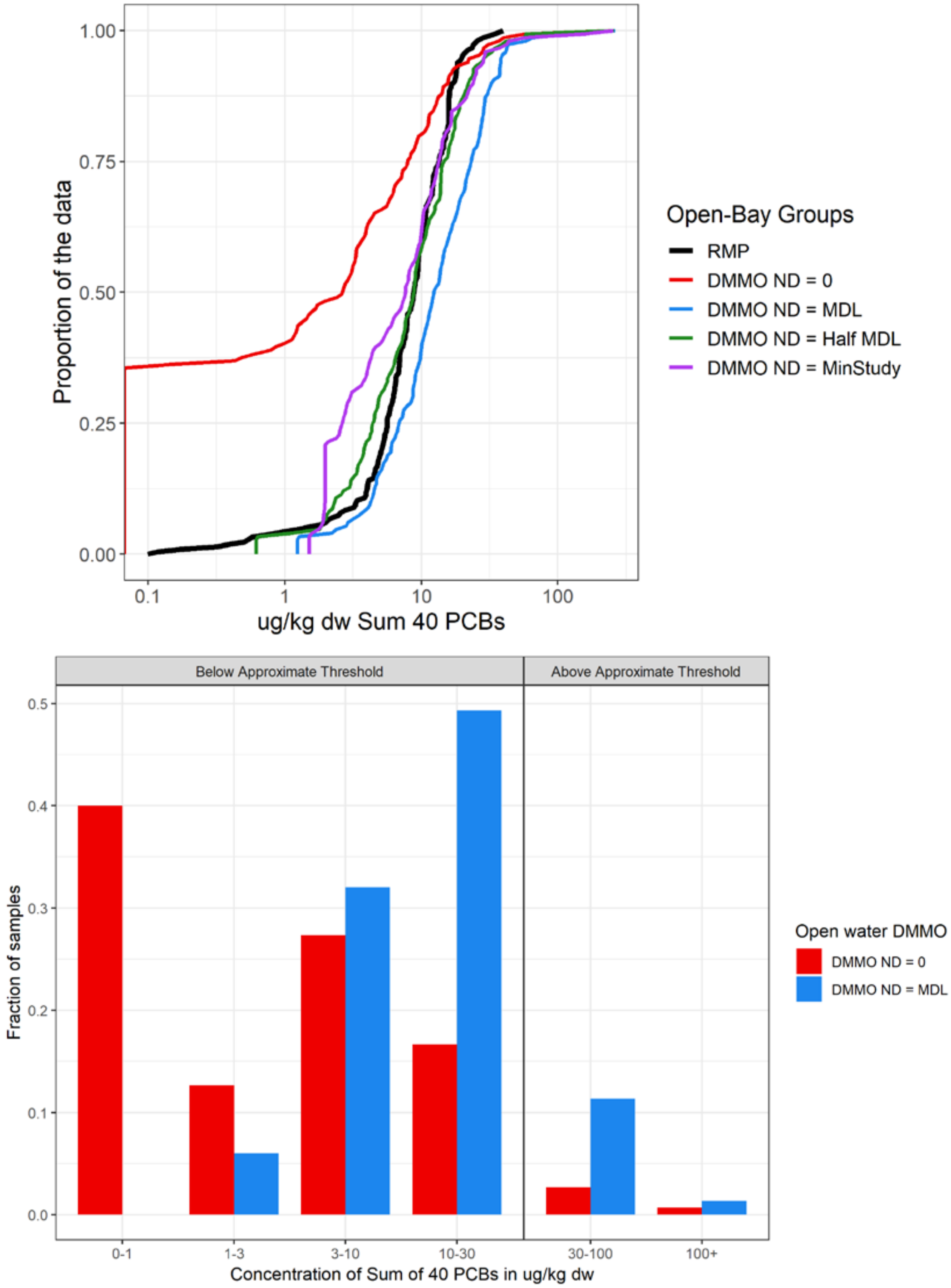

Figure 3 Distributions of RMP Open-Bay Data, and DMMO Open-Bay Data Using Different Handling for Non-Detects. Upper graph shows distributions as empirical CDFs, lower graph as histograms with fraction of samples in size bins grouped above and below the approximate in-Bay disposal threshold. Substituting zero for non-detects (ND = 0) yields the lowest estimates for DMMO-reported data due to extensive non-detects, with most results below ambient concentrations reported by the RMP. Substituting the MDL (ND = MDL) yields much higher estimates, mostly above RMP ambient values. Actual concentrations in DMMO data likely fall between these lower and upper limits. Substituting at the lowest concentration reported in the same study (ND = MinStudy) or at half the MDL (ND = Half MDL) yields distributions similar to the RMP samples.

Where some of the individual congeners were detected, a sum of PCBs can be reported, but the sum may be highly biased depending on the handling of the remaining NDs. With the ND = 0 substitution, the subset of samples with a zero sum of PCBs (the proportion where the ECDFs intersect the vertical axis in Figure 2 and Figure 3) were handled as unknown values less than their sum of MDLs. However, values above that threshold (with detections of one or more congeners, and thus an uncensored sum) were handled by the function as though they were fully quantitative values.

The distributions for the ND substituted DMMO nearshore data were statistically significantly different ($p < 0.05$), lower throughout nearly the whole range for ND = 0 substitution, when compared to the RMP margins group (Figure *2*). For the ND = MinStudy and ND = Half MDL substitutions for DMMO nearshore sites, the sums of PCBs largely overlapped with values reported for the RMP margins, and the groups were not significantly different ($p > 0.05$). Both these substitutions for DMMO nearshore sets yield wide variances, and the ECDFs cross the RMP nearshore distribution at multiple points across the range, increasing the probability that they appear to originate from the same distribution. Although we would expect the results to be entirely biased high, we also compared the DMMO data with NDs substituted by the MDLs for each congener (ND = MDL) for the sake of exploring the upper bound of possibilities. Sums for all samples with any non-detects were biased to their highest possible values, and the distribution was significantly higher for DMMO nearshore areas compared to RMP margins ($p < 0.05$). Because the ND = 0 and ND = MDL substitutions bias the DMMO set lower and higher than the RMP margins respectively, the apparent significant differences are likely just an artifact of the substitutions.

For the open-Bay areas, the ND = 0 substituted DMMO data (Figure *3*) were also lower and significantly different from the RMP open-Bay PCB results. For both the ND = MinStudy and ND = Half MDL substitutions (Table 2, Figure 3) for the DMMO open-Bay set, these substituted distributions were also significantly different from the RMP open-Bay data. It should be noted that cendiff and other comparative methods for ECDFs compare not only the central tendencies, but also the spread and tails of distributions. Thus although visually the open-Bay RMP data appears to cross the DMMO results for the ND = MinStudy and ND = Half MDL distributions around their medians, they significantly differ. The RMP Bay data is nearly always higher than the DMMO MinStudy and Half MDL substitutions below the median and lower than those DMMO cases above the median (indicating a smaller variance), thus appearing significantly different. Only the open-Bay DMMO results compared to open-Bay RMP samples were not significantly different ($p > 0.05$). Again, ECDF comparisons are not always as visually intuitive as means or median tests, but multiple intersections of the ECDFs between the RMP and ND = MDL substituted values for DMMO data suggest relatively little differentiation. Again, these outer bound distributions can be largely artifacts of their elected substitutions, so we should not dwell on their significant differences (or lack thereof) for each of the substitutions too much. Inferences derived are only robust if both substitution methods yield the same conclusion (e.g., that upper and lower bound substitutions are either both higher or both lower than the corresponding RMP distribution, i.e., significantly different in the same ways independent of the substitution method).

Table 2 Statistical comparison between DMMO and RMP PCBs Sample sets using different substitutions assumptions– ND = 0, ND = MinStudy, ND = Half MDL, and ND = MDL indicate different substitutions for non-detect results. For the nearshore data, the significant differences between RMP and DMMO sets for the lowest (ND=0) and highest (ND=MDL) substitutions appear to be an artifact of the substitution method, as the intermediate substitutions are not significantly different. However, for the open-Bay comparisons, there are stronger indications of a real difference, as three of the substitution methods for the DMMO data are significantly different from the RMP set, and in similar ways based on the ECDFs (higher concentrations than the RMP data for their top ~10% of samples, regardless of the substitution, and median and bottom quartile concentrations below corresponding values for the RMP data.

Comparison	DMMOSumGroup	p
RMP vs DMMO, Nearshore	DMMO ND = 0	0.0095
	DMMO ND = MinStudy	0.81
	DMMO ND = Half MDL	0.069
	DMMO ND = MDL	9.8E-06
RMP vs DMMO, Open-Bay	DMMO ND = 0	2.60E-16
	DMMO ND = MinStudy	0.00020
	DMMO ND = Half MDL	0.010
	DMMO ND = MDL	0.175

PCB Inventories

Another PCB management question of interest to the RMP concerns the existing inventory within the Bay: MQ3. What is the mass of PCBs in Bay sediment from DMMO reported areas compared to the mass in the rest of the open-Bay?

PCBs already in the Bay present a risk to resident biota and represent a persistent exposure that extends the time for recovery of the ecosystem. PCB inventories in open-Bay and margins sediment can be estimated using the concentration data obtained from RMP sampling in those areas. Similarly, PCBs in dredged nearshore areas may also cause exposure to biota, or be exported to other areas in the Bay and be mixed with cleaner sediment. An estimate of total PCBs in dredged nearshore areas relative to other inventories is of interest to evaluate the risk presented relative to other Bay inventories. Although PCB concentrations for open-Bay areas are also available in the DMMO database, such locations largely occur within areas already monitored in the RMP Status & Trends program, and thus are not an inventory separate from that already estimated for the RMP open-Bay areas.

In contrast, dredged nearshore areas are not sampled by the RMP in either the Status & Trends or Margins characterization efforts. Using the concentrations reported in DMMO samples, PCB inventories in dredged nearshore areas were estimated. The total surface area of nearshore areas in each of the RMP defined Bay segments was calculated and multiplied by the active layer depth (15 cm) used for the PCB mass budget inventory (Davis 2004). The same concentration of solids in sediment value of 0.5 kg/L as used by Davis (2004) was then applied to calculate a mass of sediment in dredged nearshore areas, and multiplied by the PCB concentration in DMMO port sites averaged by Bay segment to obtain an inventory estimate.

Based on the large differences in distributions depending on the handling of non-detects, the expected PCB inventories in DMMO dredged nearshore areas could also potentially vary by a large amount depending on the assumptions applied for the expected concentrations of congeners not detected, especially for samples where all or most congeners were NDs. Substitution of NDs by zero (ND = 0) or MDL (ND = MDL) provided lower and upper bounds of port inventories that differed by about a factor of two (Table 3). The ND = half MDL and ND = MinStudy substitution alternatives yield estimates between those lower and upper limits.

The mass of PCBs present in the active layer in DMMO nearshore areas was small relative to the estimated Baywide inventory of around 2500 kg, assuming a mixed layer depth of 15 cm (Davis 2004). Even in the upper limit case (ND = MDL), only about 2.5% of the Bay inventory is estimated to be present in DMMO nearshore areas. This is not surprising given the relatively small area of that stratum.

Table 3 Estimated Mass of PCBs (kg) Present in Port Areas by Segment, Using Different ND Substitution Methods

Region	ND = 0	ND = MDL	ND = Half MDL	ND = MinStudy
Central Bay	34.06	58.73	46.39	38.90
San Pablo Bay	0.73	2.63	1.68	1.14
South Bay	1.52	6.44	3.98	2.27
Suisun Bay	0.06	0.45	0.26	0.12

SECTION 3: PCB MOVEMENT VIA DREDGING

The dredged volumes and disposal sites for various projects listed in the DMMO annual report can be used with the reported sediment concentration data to estimate movement of PCBs within the Bay and exported outside of the Bay. These estimates are useful for partially addressing the following RMP management questions:

- MQ5. What is the relative contribution of each loading pathway as a source of PCBs impairment in the Bay?
- MQ6. What future impairment is predicted for PCBs in the Bay?

Dredging is not tracked as a “loading” pathway to the Bay because the dredged sediment is considered to already be in the Bay. However, this study presents an opportunity to assess the movement of PCBs via dredging, relative to loading pathways, and loss processes in PCB fate.

Tables 5 and 6 show the expected mass of PCBs moved in the period 2006 to 2017 for all projects reported in the DMMO database. Sediment PCB masses moved were calculated by taking the reported dredge volumes for each project, multiplying by the concentration of solids in sediment of 0.5 kg/L used in a PCB mass budget for San Francisco Bay (Davis 2004) to get a mass of sediment moved, and multiplying that mass by average PCB concentration for that project period. This value is likely to vary between dredge locations depending on the composition and degree of consolidation in the dredged sediment, but represents a reasonable starting point that makes estimates based on assumptions on a similar basis as those used in the Bay PCB TMDL and other RMP reports estimating PCB inventories and loads.

Table 4 Mass of PCBs (kg) Redistributed by Dredging from Bay Regions to Disposal Areas 2006-2017 (assuming ND=0)

Region	SF-10 San Pablo	SF-11 Alcatraz	SF-16 Suisun	SF-9 Carquinez	Total In-Bay	SFDODS Ocean	Upland/ Reuse	Total Out of Bay
Central Bay	2.72	16.57		0	**19.3**	9.64	10.05	**19.7**
San Pablo Bay	0	0		0.04	**0.04**		0.63	**0.6**
South Bay	0.62	16.57			**17.2**	2.65	14.22	**16.9**
Suisun Bay		0.15	0	0.39	**0.5**	0.08	1.07	**1.2**
Total Received	**3.34**	**33.29**	**0**	**0.43**	**37.1**	**12.37**	**25.96**	**38.3**

Table 5 Mass of PCBs (kg) Redistributed by Dredging from Bay Regions to Disposal Areas 2006-2017 (assuming ND=MDL)

Region	SF-10 San Pablo	SF-11 Alcatraz	SF-16 Suisun	SF-9 Carquinez	Total In-Bay	SFDODS Ocean	Upland/ Reuse	Total Out of Bay
Central Bay	7.89	57.62		0.01	**65.5**	30.91	47.89	**78.8**
San Pablo Bay	3.64	0.23		3.13	**7.0**		2.83	**2.8**
South Bay	0.85	26.11			**27.0**	3.39	22.55	**25.9**
Suisun Bay		0.45	1.25	2.01	**3.7**	0.15	4.06	**4.2**
Total Received	**12.38**	**84.41**	**1.25**	**5.15**	**103.2**	**34.45**	**77.33**	**111.8**

The mean DMMO reported concentration for each study location was determined for each year in which testing occurred and applied to the entire dredged volume in that year. Some projects were granted “Tier 1” status, for concentrations not above thresholds of concern in previous rounds of testing, so they did not have reported concentrations associated with dredged volumes reported in some years. For those projects, average results from the last previously tested year were applied to dredged sediment volumes. The database was downloaded in early 2017, so the testing data included in the DMMO database would be from 2016 and prior at the time of download. However, similar to the method we applied to sites with “Tier 1” status and only periodic chemistry data, we still calculated masses moved in 2017 projects, assuming that PCBs in sediment dredged in 2017 would equal their average concentrations from the last previous year tested (i.e., 2016 or prior) for that project. About half of the total reported dredged volumes in the DMMO Annual Reports did not have associated PCBs data.

The total PCB masses dredged for all Bay segments combined differ by nearly a factor of three between the ND = 0 and ND = MDL substitutions (Table 5, Table 6). Most dredging activity occurred in Central Bay, with about half the disposed PCB masses remaining in the Bay for both substitution methods. About 50-60% of the remaining PCBs were sent for upland disposal or reuse, with the remaining portion (about one-fourth of the total) sent to ocean disposal. South Bay, with the next greatest masses of PCBs moved, also had disposal about equally split between disposal inside the Bay and outside the Bay (upland/reuse or ocean). For in-Bay disposal, the vast majority from South Bay went to the Alcatraz disposal site in Central Bay. The majority of PCBs in South Bay sediment sent for disposal outside of the Bay went to upland and reuse sites. For dredging in the Suisun and San Pablo Bay regions, the PCB masses estimated for in-Bay versus upland/reuse differed greatly between the ND substitution methods, so the true net movement is highly uncertain.

This net movement of sediment PCBs, between about 80 to 200 kg (depending on the assumptions for NDs) over the course of 12 years, with about half of that mass disposed outside of the Bay, represents a moderate to large loss pathway for PCBs. An average removal rate of about 7 to 17kg per year is about 30% to 80% of the estimated yearly local stormwater input (approximately 20 kg annually), and higher than the net PCB movement via dredging for 2001 to 2005 (4.6 kg disposed in-Bay, 6.1 kg sent out (upland/ocean), approximately 1 kg per year for each), previously estimated in the San Francisco Bay PCB TMDL Final Staff Report

(SFBRWQCB 2008). Although the movement of sediment PCBs via dredging is moderate to small relative to loading from the largest loading pathways at a Bay-wide scale, it may be important to account for this pathway, especially in considering contaminant fate at a localized scale, e.g. for margin areas adjoining dredged nearshore sites or channels. In Bay disposal may also transfer some of the nearshore exposure risk to biota in open-Bay habitats, spreading and diluting somewhat more contaminated sediment over a wider area. However, the most contaminated sediment cannot be disposed of in-Bay, so the potential increase in exposure is not likely to be large.

SECTION 4: CONCLUSIONS AND FUTURE NEEDS

Qualitatively, PCB concentrations in dredged sediment reported by the DMMO follow general patterns seen in other data sets reported for the Bay. PCB concentrations were highest in Central Bay, particularly in nearshore and port areas. One of the greatest challenges in working with this dataset was the high frequency of non-detects, with around one-quarter of all the samples non-detect for all congeners. Data distributions were highly sensitive to handling of non-detects, with substitution by zero or MDL greatly skewing results, yielding distributions significantly different from RMP margins and open-Bay samples for the most part. Other substitutions such as half the MDL resulted in distributions often more similar to results from prior margins or open-Bay sampling, and may provide more realistic concentration estimates.

The uncertainties arising from extensive NDs extended to estimates of PCB inventories in port areas and the transfers of PCBs between regions. Minimum (ND = 0) and maximum estimates (ND = MDL) differ by about a factor of two. Due to the relatively small areas and volumes of sediment compared to overall Bay inventories, even the maximum estimate is only about 30 to 80% of Bay-wide PCB loading via watersheds. However, in some locations, the dredged areas may represent a larger proportion of the local habitat, and thus potentially a large fraction of local PCB loads and transport. However, regardless of the method used for handling non-detects, when evaluated at a Bay-wide scale, about half of the PCBs present in dredged sediment are removed from the Bay, via net export to ocean or upland/reuse disposal sites.

Although the existing methods used for analyzing dredged sediment may suffice for determining disposal options and evaluating needs for bioaccumulation testing and other regulatory needs, their usability for other applications will be limited or highly uncertain due to the high frequency of NDs. Use of more sensitive analytical methods for samples from areas that have demonstrated low concentrations in past analyses (especially those with NDs for all congeners) would make data more useful for applications beyond compliance testing for disposal. Approaches such as providing supplemental funding to composite archived material and reanalyze them with more sensitive analytical methods (e.g., batched with RMP samples in later analysis or reanalysis) to address more critical data gaps may help provide more useful information while incurring minimal additional costs.

Other challenges of working with the database included the lack of standardization in site or project naming conventions between database entries and published documents, such as the annual reports. Even slight mismatches prevented linking fields in database tables, requiring manual investigation of the reasons for seemingly missing data. Although many of these discrepancies were eventually resolved by consulting various sources (e.g., hardcopy reports, staff for involved agencies), the usability of the data would be improved by ensuring consistent naming and reporting conventions between reporting products, especially within a project. Other projects included ND data with reported MDLs of 0, impossible as an MDL of 0 would suggest never needing to report something as not-detected (for continuous data such as chemical concentrations). Although for our reporting here we substituted the MDLs of zero with the lowest non-zero MDL for the given congener reported from the same project (or the lowest non-zero MDL for any project in the DMMO data where there were no valid MDLs for the congener within the project)

Although an ultimate goal may be to make the data comparable to California Environmental Data Exchange Network (CEDEN) datasets from other providers, some accommodations to make entries to the database easier and more hands-on assistance in data entry and upload may help DMMO stakeholders make more accurate and complete reporting entries going forward. SFEI will be taking over the maintenance and management of the DMMO database moving forward, so we hope to play a role in developing and implementing methods to resolve some of these challenges. Despite the challenges, this exploration of the DMMO data has provided insights on the characteristics of this component of Bay ecosystem which has not been examined in much depth previously. We recommend continuing efforts to continue to report data from dredging projects digitally (beyond just PDFs or other hardcopy equivalents), as it ensures that the data are provided with sufficient detail and backing metadata to make them useful beyond just their immediate needs for documenting permit compliance.

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RMP Special Study Proposal: Bay Sediment Modeling Strategy

Summary: In 2016, RMP Sediment Workgroup was created to oversee RMP-funded studies addressing sediment dynamics in San Francisco Bay. The Workgroup is in the process of developing a sediment monitoring strategy to guide efforts for collecting data to fill key knowledge gaps, but there also needs to be an accompanying sediment modeling strategy to help address knowledge gaps that cannot be addressed with monitoring. The modeling strategy should be coordinated with other RMP regional modeling strategies and other regional sediment monitoring/modeling effort, focusing on Bay sediment transport, deposition, and resuspension dynamics under current and future conditions. The sediment modeling strategy needs to identify the types of modeling output needed to address key knowledge gaps as well as the appropriate modeling tools, indicating the need to update existing tools or develop new tools as necessary. This funding request is for budget to develop the sediment modeling strategy.

Estimated Cost: $63,900

Oversight Group: RMP Sediment Workgroup

Proposed by: Scott Dusterhoff, Jeremy Lowe, and Lester McKee (SFEI)

Proposed Deliverables and Timeline

Deliverable	Due Date
Workshop with experts to discuss elements of a sediment modeling strategy for San Francisco Bay	March 2020
Present the Initial Sediment Modeling Strategy at the WG Meeting	May 2020
Draft Sediment Modeling Strategy	August 2020
Expert review of Draft Sediment Modeling Strategy	September 2020
Final Sediment Modeling Strategy	November 2020

Background

In 2016, the RMP Sediment Workgroup was created to provide technical oversight and stakeholder guidance on RMP studies addressing questions about sediment delivery, sediment transport, dredging, and beneficial reuse of sediment within San Francisco Bay. The Workgroup includes representatives from federal and state agencies focused on understanding Bay sediment dynamics, including USEPA, USACE, USGS, San Francisco Bay RWQCB, and BCDC, as well as representatives from ports, the in-Bay dredging community, and private consulting firms. Since 2017, the Workgroup has funded several monitoring, modeling, and data compilation studies aimed at understanding sediment dynamics within the Bay, totaling approximately $520,000.

Currently, the Workgroup is developing a regional sediment monitoring strategy to guide future sediment data collection efforts that address key knowledge gaps. However, the Workgroup also needs a regional sediment modeling strategy to guide future modeling efforts that address key knowledge gaps in sediment transport, deposition, and resuspension dynamics that can not be addressed through monitoring alone. The sediment modeling strategy needs to identify the types of modeling output needed to address key knowledge gaps as well as the appropriate modeling tools, indicating the need to update existing tools or develop new tools. For example, sediment flux monitoring at the Golden Gate is logistically challenging and very costly, therefore modeling is needed to understand temporal dynamics of sediment flux through the Golden Gate. In addition, modeling is needed to forecast future sediment dynamics within the Bay as sediment delivery and sea level changes due to a changing climate.

The modeling strategy should be a companion to the in-progress monitoring strategy and be informed by the conceptual understanding of Bay sediment dynamics that is being developed as part of the monitoring strategy effort. The modeling strategy should also be coordinated with other RMP regional modeling strategies (e.g., San Francisco Bay Nutrient Management Strategy modeling workplan, Small Tributaries Loading Strategy trends strategy) and other regional sediment monitoring/modeling efforts (e.g., Wetlands Regional Monitoring Program), focusing on Bay sediment dynamics under current and predicted future conditions.

This request is for funds to develop a sediment modeling strategy for the Sediment Workgroup. The requested funds will support:

- the compilation of information regarding relevant existing Bay sediment modeling tools
- a workshop with regional experts to discuss the key elements of a sediment modeling strategy
- a sediment modeling strategy report that can be used to guide future Sediment Workgroup efforts

Study Objectives and Applicable RMP Management Questions

The study will provide essential information for setting long-term priorities for modeling sediment delivery to and transport, deposition, and resuspension within San Francisco Bay. Table 1 shows the objectives of the project and how the information will be used relative to the management questions of the RMP Sediment Workgroup.

Table 1. Study objectives and questions relevant to Sediment Workgroup management questions.

<table>
<tr><th>Management Question</th><th>Study Objective</th><th>Example Information Application</th></tr>
<tr><td>1) What are acceptable levels of chemicals in sediment for placement in the Bay, baylands, or restoration projects?</td><td></td><td></td></tr>
<tr><td>2) Are there effects on fish, benthic species, and submerged habitats from dredging or placement of sediment?</td><td></td><td></td></tr>
<tr><td>3) What are the sources, sinks, pathways, and loadings of sediment and sediment-bound contaminants to and within the Bay and subembayments?</td><td rowspan="3">Develop a sediment modeling strategy that: 1) fills data gaps related to the spatial and temporal variability of the current sources, concentration, and flux of sediment delivered to and transported within the Bay; and 2) enhances our understanding of climate change impacts on sediment dynamics within the Bay</td><td rowspan="3">The Sediment Workgroup can use the sediment modeling strategy to prioritize investments in sediment modeling development, analysis and visualization, and to prioritize model scenarios to answer management questions</td></tr>
<tr><td>4) How much sediment is passively reaching tidal marshes and restoration projects and how could the amounts be increased by management actions?</td></tr>
<tr><td>5) What are the concentrations of suspended sediment in the Estuary and its segments?</td></tr>
</table>

Approach

The RMP needs a regional sediment modeling strategy to identify key knowledge gaps regarding sediment dynamics within the Bay that can be filled using model outputs. This modeling strategy needs to be coordinated with a number of in-progress RMP efforts, including the regional sediment monitoring strategy, San Francisco Bay nutrient modeling, Small Tributaries Loading Strategy modeling strategy, and other regional efforts addressing sediment dynamics in the Bay (e.g., Wetlands Regional Monitoring

Program). Developing the strategy will involve the following tasks:

- Compiling information regarding existing numerical models that simulate sediment dynamics in the Bay
- Holding a workshop to discuss known knowledge gaps that can be addressed by modeling, guiding modeling questions that the sediment modeling strategy should address, and other key strategy elements
- Developing a sediment modeling strategy in coordination with other regional sediment monitoring and modeling efforts that the RMP Sediment Workgroup can use to guide future efforts

The tasks are described in more detail below.

A. **Compiling information on existing numerical models**
There is a wide variety of existing numerical modeling tools that are capable of simulating sediment transport and deposition dynamics in the Bay at various spatial and temporal scales. This task will focus on developing a list of these tools and associated key information such as model developer, model platform, model domain, temporal and spatial scale, model grid type, model applications to date, model ownership (open source vs. proprietary), calibration data needs, ability to link to other models, and any known model strengths and/or limitations. This task will also include gathering information on relevant numerical models that are currently in development and their capabilities.

B. **Workshop to discuss sediment modeling strategy elements**
SFEI will coordinate a half-day workshop with key RMP Sediment Workgroup members and sediment modeling experts to discuss key elements of the sediment modeling strategy. The workshop will focus on: 1) identifying key knowledge gaps with respect to sediment movement within the Bay (which will be informed by the sediment monitoring strategy development effort); 2) developing focused modeling questions to address key knowledge gaps; 3) assessing the technical capability of existing modeling tools (compiled in Task A) to address the modeling questions; 4) discussing the need to develop new or update existing numerical models; and 5) discussing the use of hybrid modeling/monitoring combinations. This workshop will be an important opportunity to receive input from the regional sediment modeling experts.

C. **Developing the sediment modeling strategy**
Based on the findings from Task A and the output from Task B, an initial sediment modeling strategy will be developed. The initial strategy will be an annotated report outline that provides the titles for the sections that will be included in the strategy, along with general details about the information that will be covered in each section. SFEI will lead the development of the initial strategy and will call upon selected Sediment Workgroup members to help develop the

content. As appropriate, external partners working on similar efforts focused on regional Bay sediment dynamics (e.g., Wetlands Regional Monitoring Program) will be asked to review the initial strategy. A working draft version of the initial strategy will be presented at the 2020 Annual Workgroup Meeting and will be used during that meeting to help guide funding priorities for 2021 and beyond.

Following input from the Sediment Workgroup, the initial sediment modeling strategy will be amended and expanded into a brief report (< 20 pages), focusing on the key information needed by the Sediment Workgroup to guide future sediment modeling efforts. SFEI will lead the expansion of the strategy and will call up selected Workgroup members to review the initial draft version of the report. Following incorporation of Workgroup member feedback, the updated draft will be circulated to a larger group within the RMP for review. The final report will be completed and available for use by the RMP by the end of November 2020.

Budget

The following budget represents estimated costs for this proposed special study (Table 2).

Table 2. Proposed Budget.

Expense	Estimated SFEI Hours	Estimated Cost
Task A: Information Compilation	58	$9,000
Task B: Workshop	60	$9,700
Task C: Modeling Strategy Development	224	$34,700
Subcontracts	--	$10,000
Direct Costs	--	$500
Grand Total	**342**	**$63,900**

<u>Budget Justification</u>
The majority of the time will be for Scott Dusterhoff, Zhenlin Zhang, Jeremy Lowe, and Jing Wu to have meetings with key partners, coordinate the workshop, and compile the sediment modeling strategy initial framework and draft and final report. There is also subcontract budget for workgroup members to help develop the the strategy through internal meetings, workshop participation, and report development.

Reporting

The final report will be reviewed by the RMP Sediment Workgroup and Technical Review Committee. It will be published by SFEI as a RMP technical report.

Special Study Proposal: Support for Sediment Bioaccumulation Evaluations Part 2

Summary: The Dredged Material Management Office (DMMO) is responsible for approving millions of cubic yards of routine dredging projects in San Francisco Bay to maintain safe navigation. Dredged sediment as well as the remaining residual sediment are evaluated to ensure projects do not cause adverse environmental impacts. We propose to support sediment bioaccumulation testing evaluations through two targeted studies. The first is to review all the PCB bioaccumulation test results from San Francisco Bay to assess the performance of current bioaccumulation testing trigger thresholds. The results of this review may be used to support reassessing these thresholds. The second is to review and recommend a standard set of values for bioaccumulation modeling. This information would ensure that bioaccumulation modeling evaluations use the best available science and are consistent within the region. The recommendations from this study will save dredgers and regulators time and money by improving the efficiency and consistency of dredging project evaluations.

Estimated Cost: $48,000

Oversight Group: Sediment Workgroup, PCB Workgroup

Proposed by: Ila Shimabuku and Diana Lin (SFEI)

PROPOSED DELIVERABLES AND TIMELINE

Deliverable	Due Date
Task 1: Kickoff Meeting with DMMO Stakeholders	January 2019
Task 2: Compilation of Preliminary Results (PCB bioaccumulation test results and bioaccumulation model parameters)	March 2019
Task 3: Mid-Project Meeting with DMMO Stakeholders	June 2020
Task 4: Draft Report	July 2020
Task 5: Final Report	October 2020

Background

Every year, millions of cubic yards of sediment are dredged in and around San Francisco Bay to maintain safe navigation. The Dredged Material Management Office (DMMO) is an interagency group, led by the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency Region 9 (USEPA), San Francisco Bay Conservation and Development Commission, the San Francisco Bay Regional Water Quality Control Board, and the State Water Resources Control Board. It is responsible for approving routine dredging projects in an economically- and environmentally-sound manner. Both the dredged sediment and the remaining residual sediment (post-dredge surface sediment) are systematically evaluated for negative impacts to aquatic organisms or human health due to potentially bioaccumulative compounds. The evaluation process requires sequential assessment of bioaccumulation in sediment, benthic organisms, and fish. The potential for bioaccumulation in fish is evaluated using a model if sediment and benthic organism screening criteria are exceeded.

For bioaccumulative compounds, the regulatory evaluation process for routine dredging projects in the Bay is determined by the sediment concentration.

1. If sediment concentrations are below the bioaccumulation trigger (BT): in-Bay sediment disposal of dredged sediment is acceptable.[1]
2. If sediment concentrations are above BTs but below TMDL in-Bay disposal limits: detected compounds are evaluated using a risk assessment approach (Step 2) that requires sediment bioaccumulation tests and analyses to determine whether in-Bay disposal is acceptable.[2]
3. If sediment concentrations exceed TMDL in-Bay disposal limits: in-Bay disposal is not allowed. (However, additional evaluation may still be required to consider acceptability for ocean disposal.)[3]

In 2012, the DMMO eliminated Step 2 for evaluating exposures to mercury for navigational dredging that will be discharged back into the Bay at designated unconfined aquatic disposal sites. The decision was due to findings from an analysis (EFH Consultation, 2011) that found that the number of mercury bioaccumulation tests conducted for sediment concentrations between the BT and TMDL was negligible and that none of the tested sediment would have "failed" in-Bay placement tests (Ross, 2012). Post-2012, dredged sediment with mercury concentrations below the TMDL has been cleared for possible disposal at in-Bay locations and dredgers and the DMMO have not spent time and money on mercury bioaccumulation tests. To date, the DMMO Database includes approximately 30 studies that have conducted PCB bioaccumulation tests between 2011 to present. Similar to the process for mercury, analysis of these data is likely to provide the information needed to evaluate the efficacy of the PCB bioaccumulation testing threshold.

In Step 2, potential negative impacts on benthic organisms due to exposure to Bay sediment are first evaluated by comparing bioaccumulation test (using benthic organisms) results with toxicity reference values (TRVs) that are chosen based on published studies showing

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[1] For all target bioaccumulating compounds: Mercury, Total PCBs, Total PAHs, Total DDTs, Total Chlordane, Dieldrin, Dioxins/Furans (https://www.sfei.org/projects/dmmo-ambient-sediment-conditions)

[2] For all target bioaccumulating compounds, except mercury

[3] For Mercury and Total PCBs

"effects" at particular concentrations. When bioaccumulation tests show TRVs may be exceeded in exposed invertebrates, biomagnification in the food chain is further evaluated using the Bioaccumulation Risk Assessment Modeling System (BRAMS) model, which contains two separate modules: the Trophic Trace model (TT) and the Bioaccumulation Evaluation Screening Tool (BEST). For organic compounds, the sediment-based food-web Trophic Trace model predicts fish concentrations using either user-specified sediment concentrations or tissue concentrations from bioaccumulation tests. For sediment dredging evaluations, the food web is typically modeled with the TT tool by specifying parameters for modeled fish, e.g., lipid content and weight, and their benthic diet.

The TMDL for PCBs includes a target tissue concentration for sport fish of 10 ppb (wet weight). However, ambient fish tissue concentrations in the Bay frequently exceed this target, so comparison to the TMDL target alone would "fail" much of the dredged sediment in the Bay even if they are cleaner than existing sediments. Instead, because PCB tissue concentrations in Bay-dwelling shiner surfperch and white croaker are the highest of all sport fish monitored in the Bay, dredging evaluations typically involve modeling biomagnification in these two species and comparing predicted tissue concentrations to reported ambient tissue concentrations. If conservative modeling indicates that exposure to a project's sediment would result in sport fish tissue concentrations that do not exceed current ambient levels, further evaluation is not needed. However, currently, certain steps in the modeling method and evaluation process are not standardized and need to be coordinated between dredgers and the DMMO on a case-by-case basis. Standardized Trophic Trace model inputs would make this evaluation process more efficient and consistent across the region.

This two-part study would be in support of the DMMO evaluation framework. First, this study will synthesize available PCB bioaccumulation test results in the DMMO database to evaluate the performance of the existing PCB bioaccumulation trigger as a tool for assessing the impact of dredged sediment. Second, this study would develop a recommended, standardized list of input data for Trophic Trace bioaccumulation modeling based on a literature review. These studies are related in that evaluating the PCB bioaccumulation trigger will necessarily involve conducting example modeling runs using parameters calculated herein, which will in turn help inform standardization of model inputs.

Evaluating the existing bioaccumulation trigger for PCBs and developing regionally standardized BRAMS model inputs should result in savings of time and money for dredgers and LTMS managers alike. These two studies would significantly streamline DMMO's evaluations, improving the consistency of decision-making across dredging projects.

Study Objectives and Applicable RMP Management Questions

This study will provide information and methods essential for evaluating bioaccumulation test results for dredging projects. This information is directly relevant to the following management questions for the RMP and the Sediment Workgroup (Table 1).

Overarching RMP Management Questions:

- 1: Are chemical concentrations in the Estuary potentially at levels of concern and are associated impacts likely?
  - 1.1: Which chemicals have the potential for impacts?
  - 1.2: What is the potential for impacts due to contamination?
  - 1.3: What are appropriate guidelines?

Table 1: Study objectives relevant to RMP Sediment Workgroup management questions

Management Question	Study Objective	Example Information Application
1) What are acceptable levels of chemicals in sediment for placement in the Bay, baylands, or restoration projects?	Develop targeted studies that: 1) assess the performance of current bioaccumulation testing trigger thresholds and the need for reassessment; and 2) recommend a standard set of values for bioaccumulation modeling that will ensure bioaccumulation modeling evaluations use the best available science and are consistent within the region	Provide key information that will result in cost savings for dredgers and permitting agencies by improving the efficiency and consistency of dredging project evaluations
2) Are there effects on fish, benthic species, and submerged habitats from dredging or placement of sediment?		
3) What are the sources, sinks, pathways, and loadings of sediment and sediment-bound contaminants to and within the Bay and subembayments?		
4) How much sediment is passively reaching tidal marshes and restoration projects and how could the amounts be increased by management actions?		
5) What are the concentrations of suspended sediment in the Estuary and its segments?		

Approach

We propose to support sediment bioaccumulation testing through two targeted studies. The first is to evaluate all the PCB bioaccumulation test results to assess the performance of current bioaccumulation trigger thresholds. The second is to recommend a standard set of values used for bioaccumulation modeling. The goal of this study is to make the evaluation process more efficient and consistent for dredgers and regulators.

1. Sediment Bioaccumulation Evaluation

The first part of this study is to evaluate the PCB bioaccumulation trigger by collecting, synthesizing, and analyzing results from PCB bioaccumulation testing reported to the DMMO for projects from 2011-present. With guidance from the DMMO, we will identify all bioaccumulation testing projects and extract all relevant PCB data. Data will be extracted from the DMMO database, as well as from reports not currently included in the database. Results from these reports will be added to the DMMO database as part of this study's data compilation task. Initial data analysis will include calculating total PCB concentrations from congener data as well as evaluating quality of tissue data analyses (e.g., detection of PCBs in control samples, evaluate detection limits, and evaluating frequencies of detection of different congeners). Similar to Figure 1, we will compare these bioaccumulation testing results to the Regional Monitoring Program's ambient fish tissue concentrations for shiner surfperch and white croaker and relevant PCB thresholds. These thresholds include TRVs for benthic organisms and TMDL targets for aquatic resources and wildlife as well as TMDL targets for human health. We will input the bioaccumulation results to the BRAMS model (using standard model inputs recommended from the second part of this study described below) in order to estimate bioaccumulation of PCBs in fish. We will compare the resulting fish tissue concentration model outputs with the same list of thresholds, i.e., TMDL targets, and RMP ambient fish concentrations. This study will also summarize the most recent RMP data on ambient fish tissue concentration data for the Bay (Sun et al., 2017) to clarify the values to which modeled fish concentrations should be compared. Additionally, we will estimate the total mass of dredged material with PCB concentrations below the BT, between the BT and TMDL, and above the TMDL, in order to place the testing results in context.

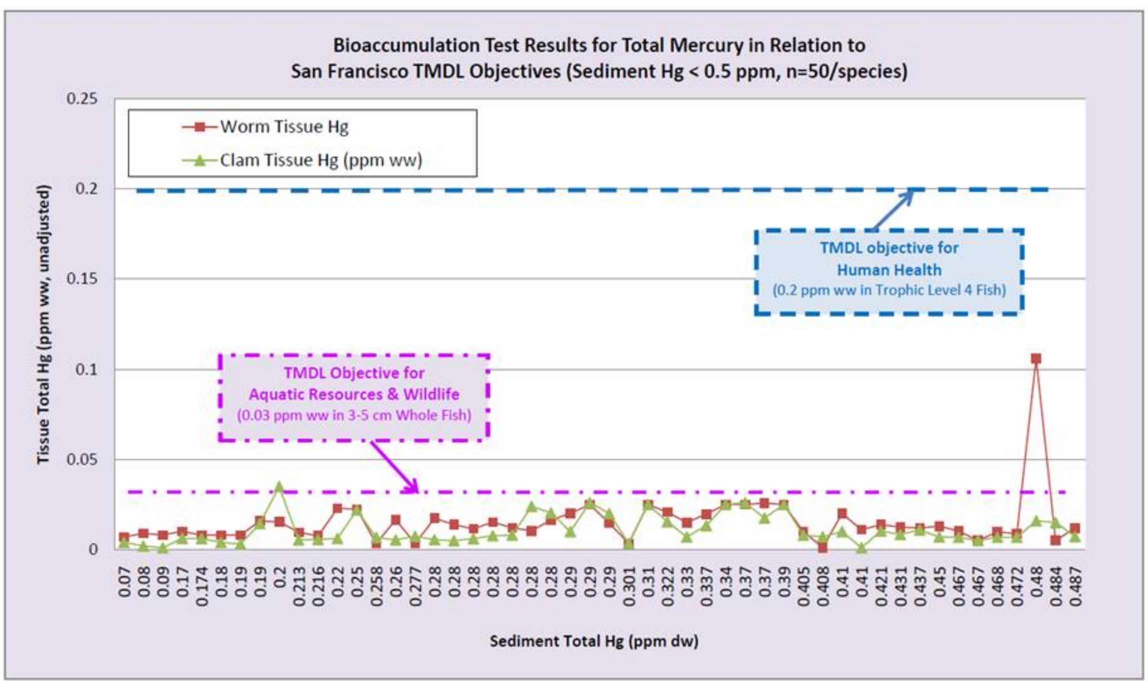

Figure 1 Findings from the mercury bioaccumulation-testing-analysis study mentioned in the background of this proposal (Ross, 2012).

2. Bioaccumulation Model Inputs

The second part of this study is to provide direct support for evaluations of food web transfer associated with contaminants in dredged sediment. We will review the latest literature, DMMO testing data, and RMP data and evaluations to develop a recommended list of standard bioaccumulation model inputs for food web modeling in BRAMS. This list will include parameters for modeled fish, composition of diet (lipid content of benthic organisms), and the physical and chemical parameters listed in Table 2. We will evaluate the sensitivity of predicted fish tissue concentrations to uncertainties or potential ranges in model input parameters as a basis for recommending standard values that are appropriate for screening level evaluations of Bay sediment. The list of partition coefficients will include recommended values to represent total PCBs, total PAHs, total DDTs, total chlordanes, dieldrin, and dioxins/furans. Recommendations will be developed based on discussions with DMMO.

Table 2: Model input parameters

Modeled fish lipid content
Modeled fish weight
Modeled fish diet lipid content
Composition of diet (sums to 100%)
Sediment TOC concentration
Overlying water particulate organic carbon
Overlying water dissolved organic carbon
Overlying water temperature
Contaminant organic carbon-water partitioning coefficient
Contaminant octanol-water partition coefficient

Budget

The following budget represents estimated costs for this proposed special study (Table 3). Efforts and costs can be scaled back by reducing the number of compounds evaluated.

Table 3. Proposed Budget.

	Costs	Estimated Hours	Estimated Budget
Sediment Bioaccumulation Evaluation	Project Staff (SFEI)	215	$22,500
Bioaccumulation Model Inputs	Project Staff (SFEI)	185	$25,500
		Total	**$48,000**

Budget Justification:

Project staff costs are based on estimated time required to:

1. **Sediment Bioaccumulation Evaluation**
    - Compile complete DMMO PCB bioaccumulation testing results from DMMO database and add any missing studies from reports. (80 hrs)
    - Analyze and evaluate data: compare sediment, benthic tissue, and predicted fish tissue PCB concentrations with relevant thresholds and ambient fish concentrations; discuss with DMMO. (50 hrs)
    - Calculate mass of dredged material. (15 hrs)
2. **Bioaccumulation Model Inputs**
    - Review literature on bioaccumulation model parameters. (55 hrs)
    - Implement model to test sensitivity to uncertainties in model inputs. (30 hrs)
    - Recommend standard values for model inputs and summarize ambient fish concentrations. (30 hrs)
3. **Reporting and Meetings** (split between the two tasks in Table 3. Reporting costs will be a higher if the tasks are funded independently)
    - Kickoff and mid-project meetings with DMMO stakeholders (25 hrs)
    - Draft Report (75 hrs)
    - Finalize Report (40 hrs)

Reporting

The primary deliverable will be a final technical report due in October 2020. A draft report will be prepared by July 2020.

References

Kendall, T. and Brush, J. EFH Consultation Letter to NOAA's National Marine Fisheries Service. San Francisco, CA. 12 March 2012.

Ross, B. 2012. Summary and Evaluation of Bioaccumulation Tests for Total Mercury Conducted by San Francisco Bay Dredging Projects Prepared in Support of Modifying the June 9, 2011 Programmatic Essential Fish Habitat (EFH) Consultation Agreement for San Francisco Bay Maintenance Dredging Projects. Long-Term Management Strategy. (http://www.sfei.org/sites/default/files/project/EFH%20Hg%20modification%20agreement%20%26%20report%2003-06-2012.PDF)

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RMP Special Study Proposal: Update of Erosion and Deposition in San Francisco Bay

Summary: In 2014 and 2015 the Ocean Protection Council (OPC) contracted for bathymetric surveys of large portions of San Francisco Bay. This data along with recent NOAA, USGS, and California State University Monterey Bay surveys can now be combined to create a revised bathymetric bathymetric Digital Elevation Model (DEM) of the whole of San Francisco Bay (South Bay, Central Bay, San Pablo Bay, and Suisun Bay). Analysis of these surveys and comparison with the USGS DEMs of earlier surveys will provide an update on the quantities and patterns of erosion and accretion in the Bay over the past 25 to 35 years. Such information can be used to assess how the Bay has responded to changes in sediment supply from the Delta and tributaries and provide managers with data for making decisions on a variety of issues including exposure of legacy contaminated sediment and strategies for beneficial dredge disposal.

Estimated Cost: $77,000 for Year 1 (2019)
Another $77,000 will be requested for Year 2 (2020)
Total project cost: $154,000

Oversight Group: RMP Sediment Workgroup

Proposed by: Bruce Jaffe, USGS

Proposed Deliverables and Timeline

Deliverable	Due Date
Composite DEM of San Francisco Bay based on 2014-2015 OPC bathymetric surveys and other recent bathymetric data.	July 2020
Update on the quantities and patterns of erosion and accretion in the Bay over the past 25 to 35 years.	July 2020
Final report	July 2020 (draft) October 2020 (final)

Background

The USGS has spent just over a decade developing the historic bathymetric DEMs of San Francisco Bay from surveys conducted by NOAA's office of coast surveys beginning in the 1850s and ending in the 1990s. These DEMs have provided valuable insight to historic patterns of sediment deposition and erosion, pathways of sediment and sediment-bound contaminants within the Bay and subembayments, and sediment budgets.

We expect that erosion and deposition has changed recently in response to a decrease in sediment supply from the Delta (Wright et al., 2004) and the corresponding increase in the relative importance of sediment supply from local tributaries (McKee et al., 2013). There is no comprehensive, bay-wide, documentation of the recent (25 to 35 years) erosion and deposition.

The record of historical erosion and deposition has proven to be valuable for interpreting the spatial distribution and concentrations of contaminants in the Bay (Hornberger et al., 1999; Yee et al., 2011; Nilsen et al., 2014). This update can further aid in the interpretation of contaminants in the Bay and subembayments. Another application of this type of research was shown by Higgins et al. (2007), who produced a map of the age of near-surface sediments in San Pablo Bay that may be useful for understanding the distribution of legacy contaminants. The proposed updated DEM would allow construction of a bay-wide version of that map. The proposed work will also have a strong influence on helping to understand sediment processes at the more local scale of operational landscape units (OLUs), recently defined in the Bay to assist adaptation planning (SFEI 2018) . The new DEMs created from this project will help us to better understand the morphology of mudflats adjacent to key margin areas, and to better define risk in relation to water depth, fetch, and wave energy.

Study Objectives and Applicable RMP Management Questions

The study will provide information essential to understanding sediment and sediment-bound contaminant pathways within San Francisco Bay and its subembayments. The objectives of the study and how the information will be used are shown in Table 1 relative to the management questions of the RMP Sediment Workgroup.

Table 1. Study objectives and questions relevant to RMP management questions.

Management Question	Study Objective	Example Information Application
MQ1: What are acceptable levels of chemicals in sediment for placement in the Bay, baylands, or restoration projects?		
MQ2: Are there effects on fish, benthic species, and submerged habitats from dredging or placement of dredged material sediment?		
MQ3: What are the sources, sinks, pathways, and loadings of sediment and sediment-bound contaminants to and within the Bay and subembayments?	Update the distribution and quantities of erosion and deposition in the Bay and subembayments. Update mass balances for sediment in the Bay and subembayments. *Potential scope expansion: Assess the age of near-surface sediment.*	1) What are the present areas of erosion and accretion in San Francisco Bay? 2) How have human activities affected the erosion and accretion in the Bay? *What regions are erosional and may have older sediment with legacy contaminants near the sediment-water interface?*
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 segments?		

Approach

This research uses approaches developed by the USGS that documented erosion and accretion in San Francisco Bay from the mid-1800s to 1990s (Jaffe et al., 1998; Cappiella et al., 1999; Foxgrover et al., 2004; Jaffe and Foxgrover, 2006; Jaffe et al., 2007; Fregoso et al., 2008). Details of the development of data, phasing of research, and dissemination of study results are below.

1. Data Development

A. The 2014-15 OPC survey will be gridded using GIS surface modeling software to create a continuous bathymetric DEM. Gridding of the OPC surveys is time intensive because there are 93 surveys comprising a patchwork of surveys collected using either multibeam or interferometric sidescan sonar systems with varying spatial coverage. Some regions have continuous bathymetric coverage while others consist of striped trackline patterns with various spacing (Figure 1). Of the 93 surveys, 75 consist of swaths of bathymetry ranging from 18 to just over 100 meters wide. These swaths are collected along tracklines with spacings of 10 to just over 300 meters that will have to be interpolated across to create a continuous bathymetric surface DEM. The OPC data will support 1 m grid cells in regions with continuous coverage; larger grid cells may be necessary to accurately represent the bathymetry in regions where the bathymetry is only narrow swaths with larger gaps between adjacent tracklines.
B. Gaps in the OPC survey will be filled with the most recent bathymetric data from other sources, NOAA, USGS, CSUMB, and others, to allow a more complete comparison with earlier surveys (Figure 2). There are approximately 40 non-OPC surveys that will be used for gap filling.
C. All surveys will be resampled to a common resolution and mosaicked, with careful attention paid to edges, and possible discontinuities, between surveys.
D. After correcting to common vertical and horizontal datums, the bathymetric DEM of recent bathymetry will be differenced from existing 25 and 50 m resolution bathymetric DEMs of the 1970s-1990s to create a change DEM. This change DEM will be analyzed using GIS tools to document the quantities and patterns of erosion and accretion with South, Central, and San Pablo Bays during the past 25 to 35 years. These analyses will be conducted on both Bay segments and OLUs.

2. Phasing of Research

In the first year of the study we will refine methodology for creating an accurate modern DEM from bathymetric surveys with differing sounding densities and produce a DEM for Central Bay north of Tiburon, San Pablo Bay, and Suisun Bay. A DEM will be produced for the remainder of Central Bay and for South Bay in the second year of the study. The data release and final report will be prepared in the second year of the study as well.

3. Presentation of Results at Local Scientific Meeting
Results of this study will be presented at either the State of the Estuary or Bay-Delta Science Conference.

4. Report and Data Release
The final report will be published as a USGS Open-File Report. Contents will include the methodology for creation of the modern bathymetric DEM and analyses of the updated erosion and deposition. Analyses of erosion and accretion will be conducted on both Bay segments and OLUs. The modern bathymetric and change DEMs will be distributed as a USGS data release. Timeline for products is 18-24 months from start of the work. A draft of the report will be reviewed by the RMP Sediment Workgroup and Technical Review Committee.

Budget

The following budget represents estimated costs for this proposed study (Table 2).

Table 2. Proposed Budget.

Expense	Estimated Cost
Year 1 Labor	$49,500
Year 1 Overhead	$27,500
Year 1 Total	**$77,000**
Year 2 Labor	$49,500
Year 2 Overhead	$27,500
Year 2 Total	**$77,000**
Grand Total	**$154,000**

<u>Budget Justification</u>

Labor Costs
Theresa Fregoso (11 months labor) will create a whole bay modern DEM from the 2014-2015 OPC surveys and other recent bathymetric data, conduct analyses of change DEM to quantify update erosion and accretion in the Bay and subembayments, compile data releases for modern and change DEMS, prepare final report. Amy Foxgrover (1/2 month labor) will assist Fregoso in the analyses.

$10,000 of funding for Bruce Jaffe's involvement with the project is being contributed by the USGS. Jaffe's primary contribution is to the final report.

Note: At the request of the Sediment Workgroup, USGS contacted the California Ocean Protection Council (OPC) to inquire whether they were already funding related work or if they would co-fund this proposal. OPC stated that related work was not underway and matching funds were not available.

Reporting

The final report will be published as an USGS Open-File Report. A draft of the report will be reviewed by the RMP Sediment Workgroup and Technical Review Committee.

References

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Yee, D., B. Bemis, D. Hammond, W. Heim, B. Jaffe, A. Rattonetti, S. van Bergen. 2011. Age Estimates and Pollutant Concentrations of Sediment Cores from San Francisco Bay and wetlands. A Technical Report of the Regional Monitoring Program: SFEI Contribution 652. San Francisco Estuary Institute, Oakland, CA. 45pp + Appendices A, B and C.

Figure 1- Coverage of the Ocean Protection Council 2014-2015 bathymetric surveys. Inset shows regions with continuous (solid colors) and striped (colored lines with no data between lines) coverage.

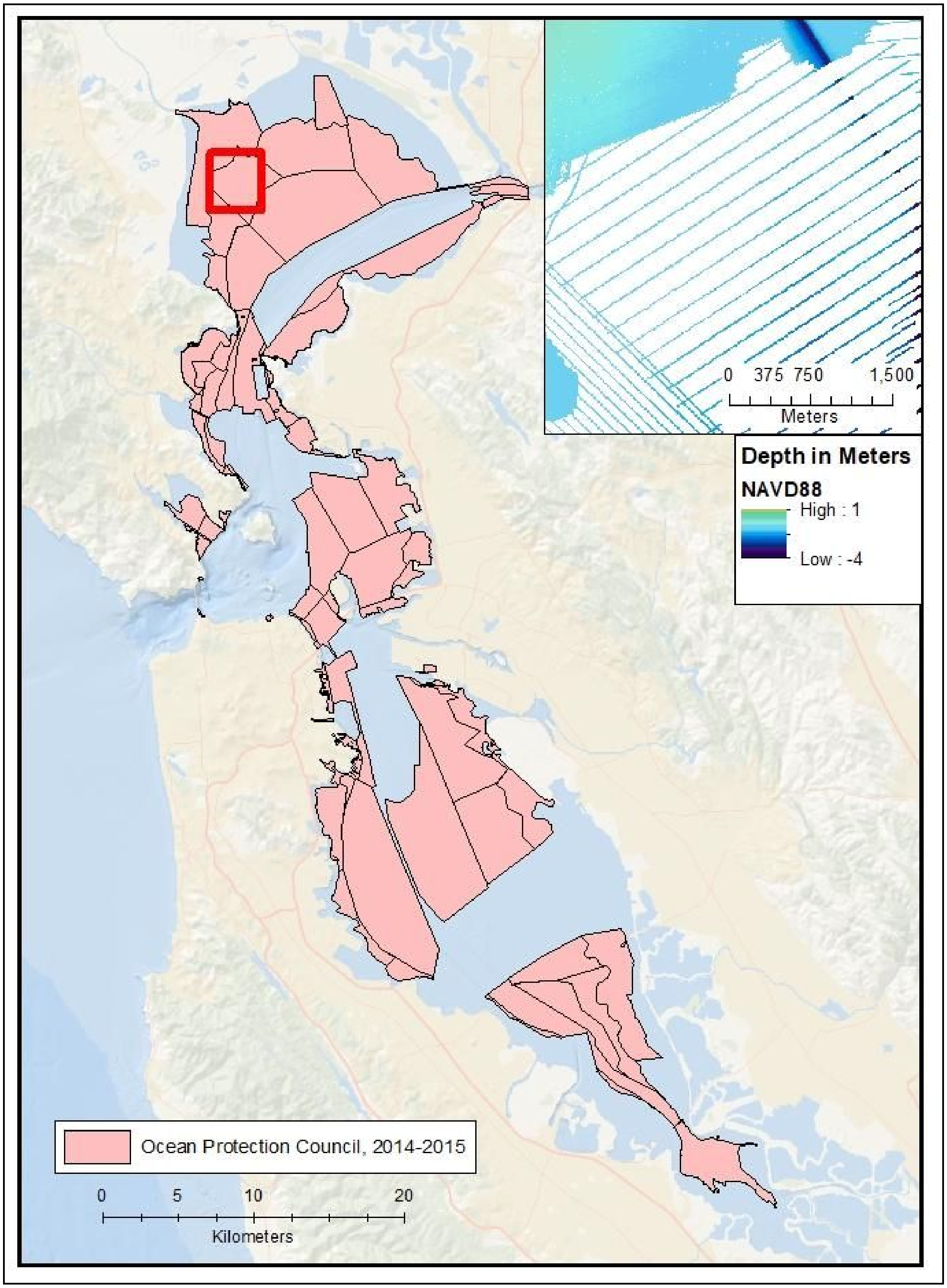
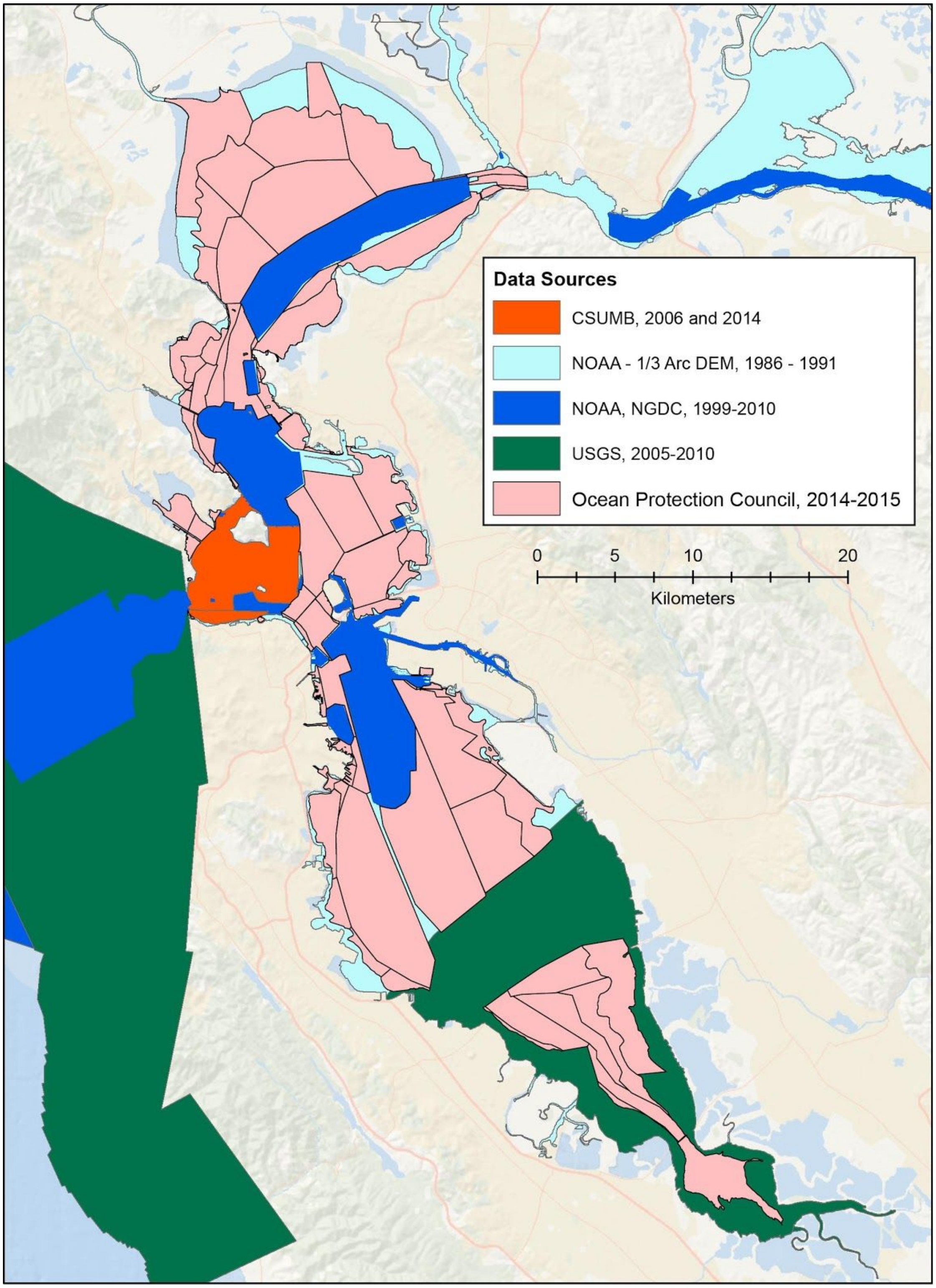


Figure 2- Coverage of Ocean Protection Council 2014-2015 and other recent surveys. The combination of surveys allows updated estimates of erosion and accretion in the majority of South, Central and San Pablo Bays and the main channel of Suisun Bay.



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ANCHOR QEA

Regional Monitoring Program Special Study Proposal
Golden Gate Sediment Flux Modeling

May 9, 2018

To: Philip Trowbridge, PE, Program Manager, Regional Monitoring Program for Water Quality in San Francisco Bay

From: Michael L. MacWilliams, PhD, PE, Anchor QEA, LLC

Re: Golden Gate Sediment Flux Modeling

Proposal Summary	The U.S. Geological Survey (USGS) measured sediment fluxes through the Golden Gate during complete tidal cycles in March and June 2016 and February 2017. The sediment flux measurements in February 2017 showed a greater sediment flux into San Francisco Bay on flood tide than the flux out on the preceding ebb tide. USGS hypothesized that this result occurred because the measurements were made on the falling limb of the hydrograph and that during peak outflows the sediment flux out was greater than the flux in. This study proposes to simulate the sediment flux across the February 2017 high flow period, validate the model-predicted sediment flux using the one tidal cycle of flux observations collected by USGS, and then compute the total predicted sediment flux through the Golden Gate over a 3-month period. The primary motivation is to understand why the measured sediment flux back into the Bay during the observation period was greater than the flux out, and whether this is related to being on the tail end of the sediment pulse. The model simulations can also be used to assist in developing surrogate measurements of sediment flux at the Golden Gate that are critical for understanding the overall sediment mass balance in San Francisco Bay. The predicted sediment flux at the Golden Gate will be compared to observed parameters such as suspended sediment concentration (SSC) at Alcatraz or Sacramento-San Joaquin Delta (Delta) outflow to develop these relationships. Predicted sediment fluxes between each subembayment will also be calculated from this simulation to inform calculation of sediment fluxes within the Bay.
Relevant Management Questions	**MQ3:** What are the sources, sinks, pathways, and loadings of sediment and sediment-bound contaminants to and within the Bay and subembayments? **MQ5:** What are the concentrations of suspended sediment in the Estuary and its segments? One of the single greatest uncertainties related to developing a sediment budget for San Francisco Bay is the uncertainty related to the sediment flux at the Golden Gate. The application of an existing hydrodynamic and sediment transport model to simulate the period of data collection will add value to the existing data set from February 2017 by helping to understand sediment fluxes immediately prior to the sampling event during peak flows and allow for an assessment of why the measured flux back into the Bay during the observation period was greater than flux out (MQ3). The model predictions will also be compared to observed SSC throughout the Bay (MQ5).
Estimated Cost	$45,000
Proposed by	Michael L. MacWilliams, PhD, PE, and Aaron Bever, PhD, Anchor QEA, LLC

1. Background

This project will apply an existing 3-D hydrodynamic, salinity, and sediment transport model of San Francisco Bay to predict sediment fluxes at the Golden Gate and between each subembayment of the Estuary. This project leverages an existing model that has already been extensively calibrated and validated for SSC throughout the Estuary and the Delta and will build on existing work currently being conducted to simulate sediment concentrations in Suisun Bay and the Delta during 2017. As a result, this project provides a cost-efficient way to add significant value to the data set collected by USGS in February 2017, provides a way to investigate the hypothesis that the net sediment flux into the Bay through the Golden Gate was positive because the measurements were made on the falling limb of the hydrograph and that during peak flows the flux out was greater than the flux in, and provides additional information that can be used to develop surrogate flux estimates.

While simulating the two periods in March and June 2016 when flux measurements were made would also provide additional information that would be useful in understanding sediment fluxes at the Golden Gate, this proposal only includes simulations of the first three months of 2017 to keep the cost down. Based on what we learn from the modeling of 2017 period, an additional simulation spanning March and June 2016 could be simulated using the same approach at a later date if additional funding is available.

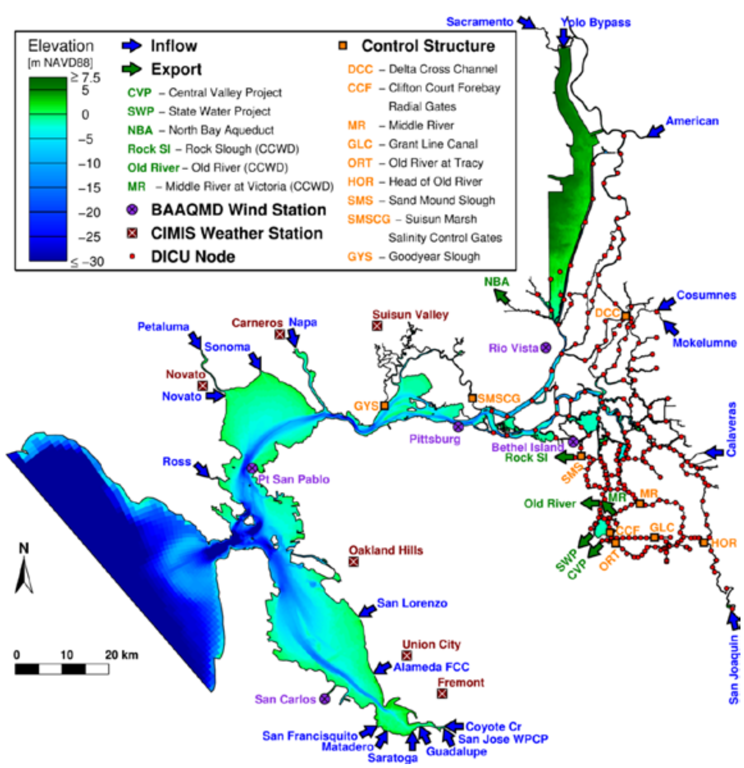
1.1 Sediment Modeling Background

The UnTRIM Bay-Delta model (MacWilliams et al. 2007, 2008, 2009, 2015) will be applied together with the SWAN (SWAN Team 2009a) wave model and the SediMorph sediment transport and seabed morphology model (BAW 2005), as a fully-coupled hydrodynamic-wave-sediment transport model. This coupled modeling system has been used previously to predict sediment transport throughout the Bay-Delta system, as part of two projects for the U.S. Army Corps of Engineers (USACE) to investigate how sea level rise and a reduced sediment supply to the Delta impacted the sediment routing through the Bay-Delta system and the sediment deposition within Suisun and San Pablo Bays (MacWilliams et al. 2012; Bever and MacWilliams 2014). The coupled models were also used to investigate the effects of breaching Prospect Island on regional turbidity and sediment dynamics in the north Delta and Cache Slough region (Delta Modeling Associates 2014). Other applications of the sediment transport model include simulations of dredged material dispersal in Northern San Francisco Bay (MacWilliams et al. 2012) and South San Francisco Bay (Bever and MacWilliams 2014; Bever et al. 2014) to determine the fate of dredged material and investigate whether open water placements can potentially be used to augment mudflat and marsh sedimentation. Bever and MacWilliams (2013) applied the coupled modeling system to investigate wave shoaling and sediment fluxes between the channel and shoals in San Pablo Bay. The model has also been used to investigate sediment fluxes at Dumbarton Bridge (Delta Modeling Associates 2013), following a similar approach to that proposed in this study.

The UnTRIM San Francisco Bay-Delta model (UnTRIM Bay-Delta model) is a 3-D hydrodynamic model of San Francisco Bay and the Delta developed using the UnTRIM hydrodynamic model (MacWilliams et al. 2007, 2008, 2009, 2015). The UnTRIM Bay-Delta model extends from the Pacific Ocean through the entire Sacramento-San Joaquin Delta (Figure 1), and takes advantage of the grid flexibility allowed in an unstructured mesh by gradually varying grid cell sizes, beginning with large grid cells in the Pacific Ocean and gradually transitioning to finer grid resolution in the smaller channels of the Delta. This approach offers significant advantages both in terms of numerical efficiency and accuracy and allows for local grid refinement for detailed analysis of local hydrodynamics, while still incorporating the overall hydrodynamics of the larger estuary in a single model.

The SWAN model (SWAN Team 2009a) is a widely used model for predicting wind wave properties in coastal areas (e.g., Funakoshi et al. 2008). SWAN "represents the effects of spatial propagation, refraction, shoaling, generation, dissipation and nonlinear wave-wave interactions" (SWAN Team 2009b) on wind waves. Therefore, SWAN can estimate the wind waves in coastal regions with variable bathymetry and ambient currents. SWAN can also accommodate spatial variability in bottom friction parameters and wind velocity. In the coupled modeling system, the SWAN model runs on the same unstructured grid as UnTRIM, providing high resolution in areas where it is needed.

Figure 1
Model domain and boundary conditions for the UnTRIM Bay-Delta model

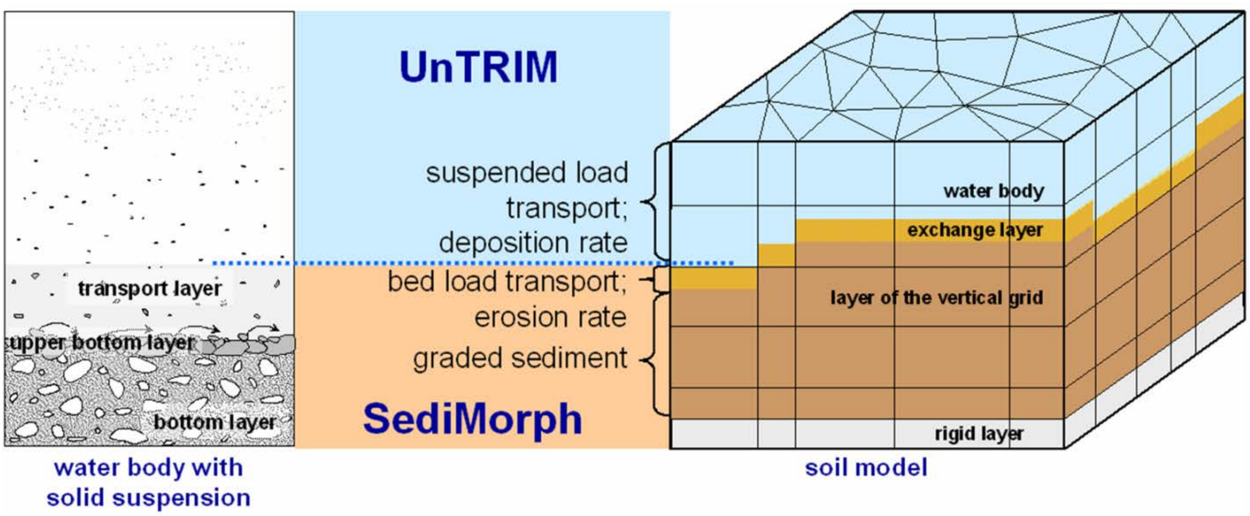


The primary purpose of the SediMorph module is to compute the sedimentological processes at the alluvial bed of a free-surface flow, including the following (Weilbeer 2005):

- The roughness of the bed resulting from grain and form roughness (ripples and/or dunes)
- The bottom shear stress as a result of roughness, flow, and waves
- Bed load transport rates (fractioned)
- Erosion and deposition rates (fractioned)
- Bed evolution
- Sediment distribution within the bed exchange layer

SediMorph is designed to use the same horizontal computational mesh as the UnTRIM hydrodynamic model. In the vertical, the SediMorph module allows for evolution of the bed elevation above a pre-defined rigid layer in each cell. Above the rigid layer, SediMorph includes at least one exchange layer in which sediments are mixed and exchange processes such as erosion and deposition occur. Figure 2 shows the horizontal and vertical grid structure of the UnTRIM and SediMorph models and provides a schematic representation of the location of the sediment transport processes within the model grid structures.

Figure 2
Horizontal and vertical grid structure of the UnTRIM and SediMorph models (right); schematic (left) and process list (middle) show the location of the sediment transport processes within the model grid structures (Source: BAW)



Sediment transport simulations using the UnTRIM San Francisco Bay-Delta Model include multiple sediment classes, an initial sediment bed based on over 1,300 observed seabed grain size distributions within the Bay and the Delta, sediment input from 10 Bay-Delta tributaries, and wave- and current-driven sediment resuspension and transport.

In this coupled modeling system, UnTRIM calculates the flow, water level, salinity, sediment advection, sediment settling, and sediment mixing. SWAN calculates the temporally and spatially varying waves needed for accurate predictions of sediment resuspension in the presence of wind waves. SediMorph calculates the erosion and deposition of sediment and the seabed morphologic change, and keeps track of the sedimentological properties within the seabed. The model bathymetry in each grid cell is adjusted each time step to account for erosion and deposition.

The calibration and validation of salinity, flow, and water level in the UnTRIM Bay-Delta model has been well-documented (e.g., MacWilliams et al. 2007, 2008, 2009, 2015). The model accurately predicts the salinity, flow, and water level throughout the San Francisco Bay and the Delta under a wide range of conditions. The SWAN wave results have been calibrated and validated to observed wave properties in San Pablo and Suisun Bays and at four locations south of Dumbarton Bridge. The sediment transport within the coupled modeling system has been calibrated using SSC time series at five stations within San Francisco Bay (red squares on Figure 3), eight stations within the Sacramento-San Joaquin Delta (orange triangles on Figure 3), and using vertical SSC profiles along a transect along the axis of San Francisco Bay from the far South Bay to Rio Vista (yellow circles on Figure 3). Figure 4 shows an example of the observed and predicted SSC at Rio Vista spanning a 7-month period during water year 2011. This shows that the model accurately predicts both the magnitude and seasonal patterns of SSC in the Sacramento River indicating the model is accurately predicting the outflow of sediment from the Delta during high flows. Figure 5 shows a comparison of observed and predicted SSC along the axis of San Francisco Bay on June 14, 2011, and demonstrates that the model is capturing the primary features in the vertical and longitudinal SSC. The model has also been validated through comparison of observed and predicted deposition within a breached salt pond during the period following the initial breach (Bever and MacWilliams 2014). The sediment validations demonstrate that the coupled hydrodynamic-wind wave-sediment model is accurately capturing the processes that resuspend, deposit, and advect sediment throughout the Bay-Delta system, and would therefore be suitable for evaluating sediment fluxes both at the Golden Gate and between each subembayment of the Bay. By simulating suspended sediment processes directly, the physical feedbacks between changing forcing and their influence on local and regional sediment dynamics can all be explicitly evaluated.

Figure 3
The locations of SSC data within the San Francisco Bay (red squares), within the Delta (orange triangles), and for the transect vertical profiles (yellow circles)

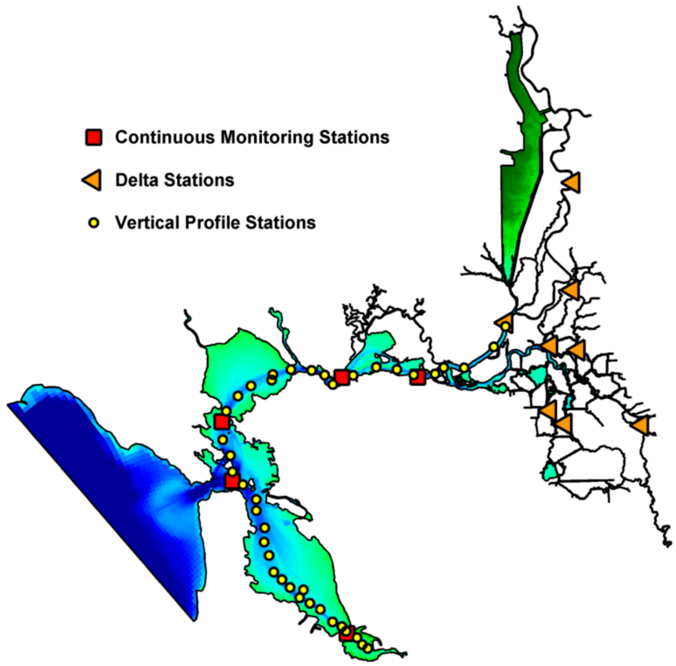


Figure 4
Observed and predicted cross-section average SSC at the Sacramento River at Rio Vista (RIO)

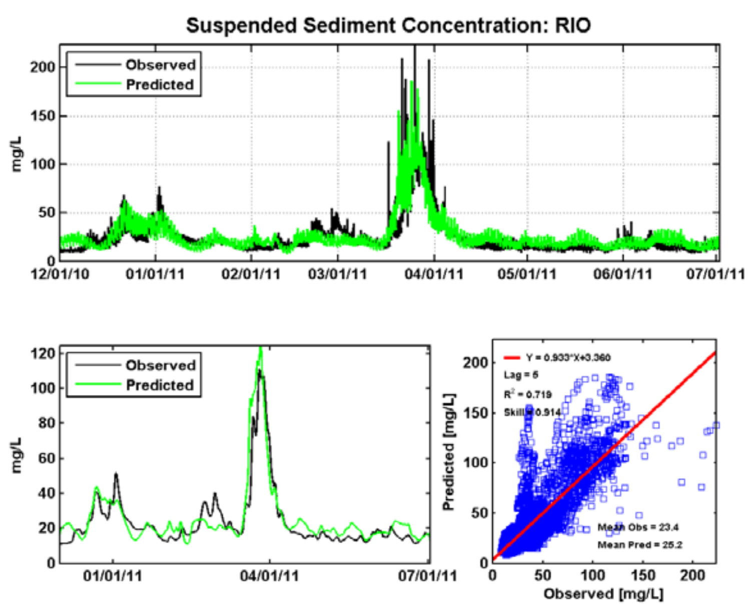
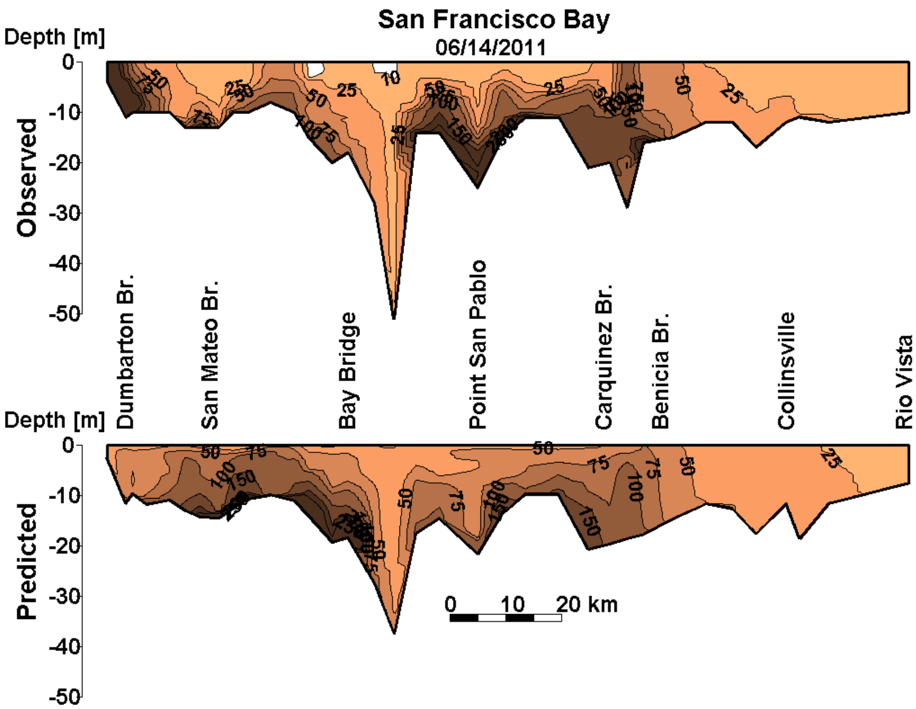


Figure 5
Observed and predicted SSC along a transect from the far South Bay to Rio Vista on June 14, 2011



1.2 Sediment Flux at Dumbarton Bridge

The UnTRIM Bay-Delta model was previously used to provide a detailed evaluation of sediment flux at Dumbarton Bridge based on data estimates and model predictions (Delta Modeling Associates 2013). Model results of water flow and sediment flux at Dumbarton Bridge were compared to USGS estimates. While the modeled and observed water flow agreed well on a tidal time scale, the directions of net observed and predicted water flow were different (Figure 6). The model predicted a net water flow toward the north out of the far South Bay (8.99 cubic meters per second [m^3/s]), while the USGS estimates have a southward net water flow (-46.9 m^3/s). When the model-predicted net flows in the channel (red line) are compared to the observed flows (black line), they match closely and indicate a net flow into the far South Bay (Figure 7). The boat-based sampling spanned only the channel and did not include the shoals (Figure 8). This analysis suggests that the discrepancy in the water net flow direction occurred because the observed flow does not include the northward net flow which occurs on the relatively shallow shoals, and that when the flows on the shoals are included, the net water flow is north (Figure 7, green line).

Figure 6
USGS estimated (Observed) and model predicted (Predicted) water discharge past Dumbarton Bridge from December 2010 through July 2011. The upper panel shows the instantaneous values while the lower left panel shows the tidal average. Negative discharge is southward into the far South Bay.

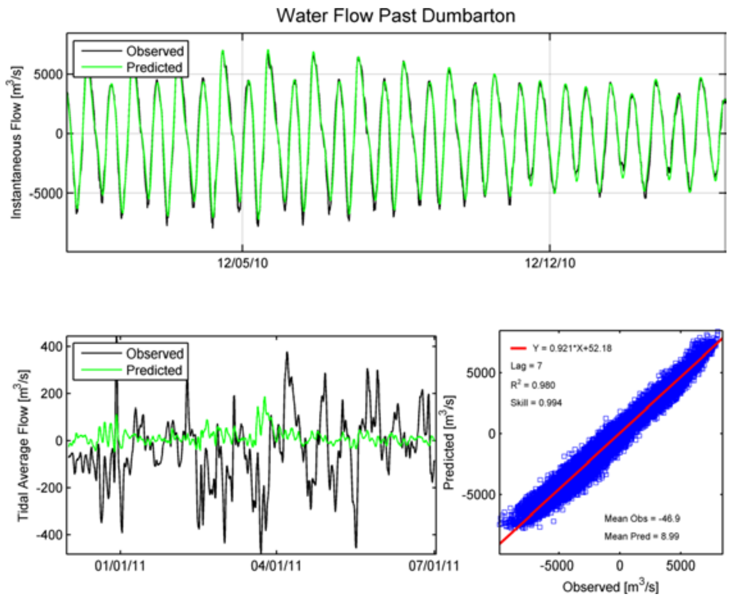


Figure 7
USGS estimated (Observed) and model predicted cumulative water discharge within the entire cross section (green) and in just the channel (red) past Dumbarton Bridge for December 2010 through July 2011. Negative flow is southward into the far South Bay.

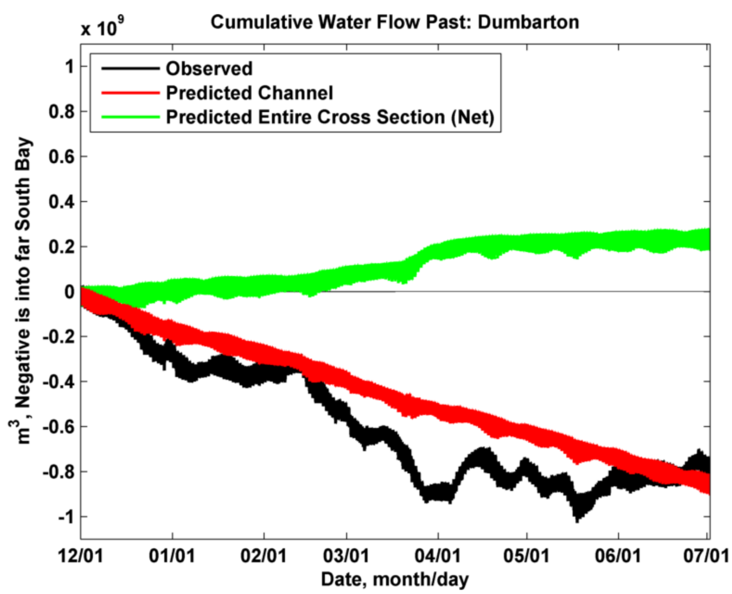
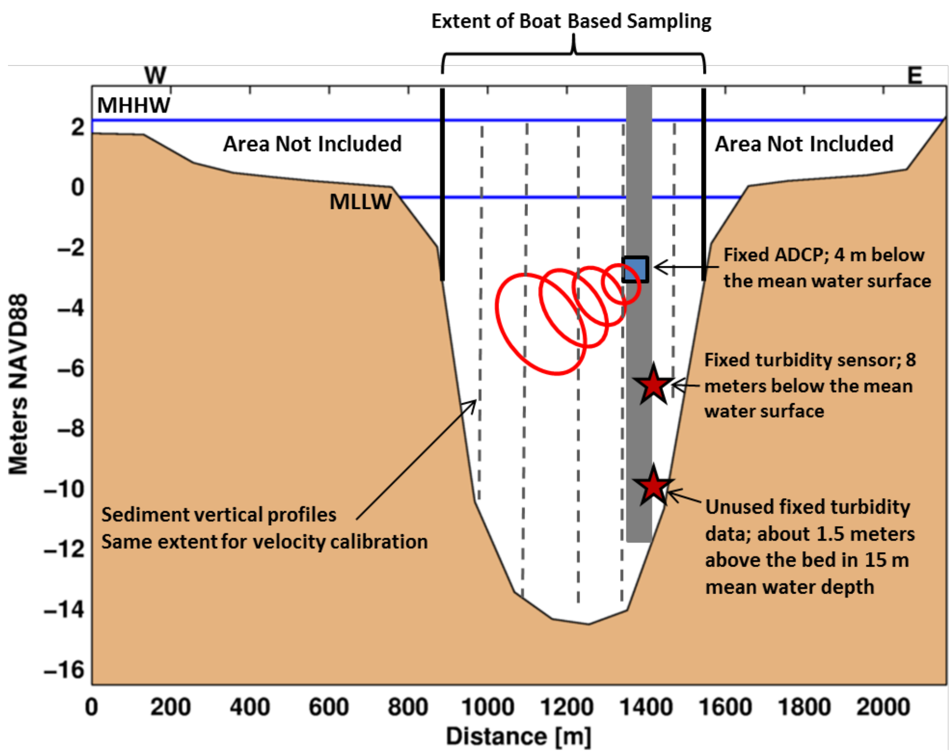
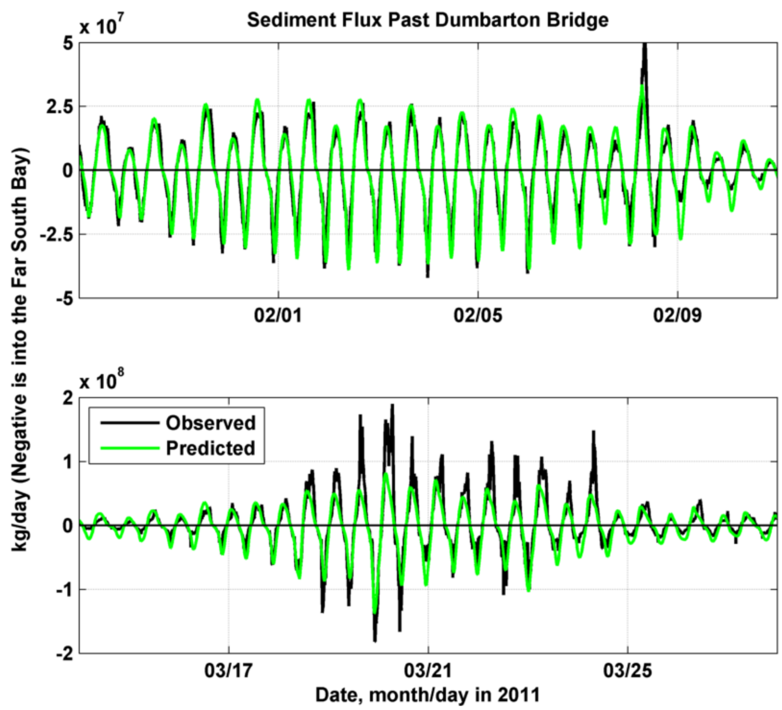


Figure 8
The cross section underneath Dumbarton Bridge highlighting the deeper main channel and shallower shoals. The water surface shows the mean higher high water (MHHW) and mean lower low water (MLLW) levels at Dumbarton Bridge. The thick grey line represents the bridge piling with the ADCP (blue square) and turbidity (red stars) sensors (vertical and horizontal locations are approximate). The dashed grey lines show the approximate locations of the vertical profiles used to correlate the point SSC to cross-section averaged concentration. The approximate extent of the boat-based sampling for determining the cross-section quantities is also shown.



The modeled and observed sediment fluxes also agreed well on a tidal time scale (Figure 9), yet had different net flux directions, with the net flux from the model toward the south and from the USGS estimates toward the north. A detailed comparison of multiple sediment flux estimates calculated using the available SSC data suggested that the USGS estimated sediment flux may overestimate the northward sediment flux (Delta Modeling Associates 2013). The analysis suggested that this northward overestimate may occur because only the SSC from the upper turbidity sensor on Dumbarton Bridge was used to determine the cross-sectional SSC. Sediment flux estimates calculated using the upper sensor result in a much more northward sediment flux compared to calculating the flux using the lower sensor or the average of the two sensors. The model results demonstrated that the sediment concentration near the bed was not in phase with the sediment concentration higher in the water column (which was also confirmed using the data), and thus the observed sediment flux direction was highly sensitive to which sensor was used to calculate the flux. Because of this analysis, USGS conducted additional data collection to improve the estimate of sediment flux at Dumbarton Bridge. This demonstrates the utility of applying a 3-D hydrodynamic and sediment transport model to understand and investigate the data used to estimate observed sediment fluxes.

Figure 9
Observed and predicted instantaneous sediment flux past Dumbarton Bridge for two time periods. These time periods are shaded in Figure 6 for reference.



1.3 Sediment Flux at the Golden Gate

USGS measured sediment fluxes through the Golden Gate during complete tidal cycles in March and June 2016 and February 2017. Observed sediment fluxes are calculated by multiplying the measured discharge across the cross-section by the sediment concentration across the section (Figure 10). Discrete measurements of sediment concentrations were estimated from backscatter and velocity transects were measured using a boat-mounted ADCP for approximately 32 transects on February 27, 2017 (Figure 11). However, the sediment flux measurements in February 2017 showed a greater sediment flux into San Francisco Bay on flood tide than the flux out on the preceding ebb tide (Figure 12). USGS hypothesized that this result occurred because the measurements were made on the falling limb of the hydrograph and that during peak flows the flux out was greater than the flux in. The model will be used to investigate this hypothesis. Previous comparisons of model simulations of sediment flux at Dumbarton Bridge (Delta Modeling Associates 2013) have demonstrated the utility of this approach, and ultimately resulted in improved sediment flux estimates from the observations.

Figure 10
Calculation of observed sediment flux from measurements (Source: USGS)

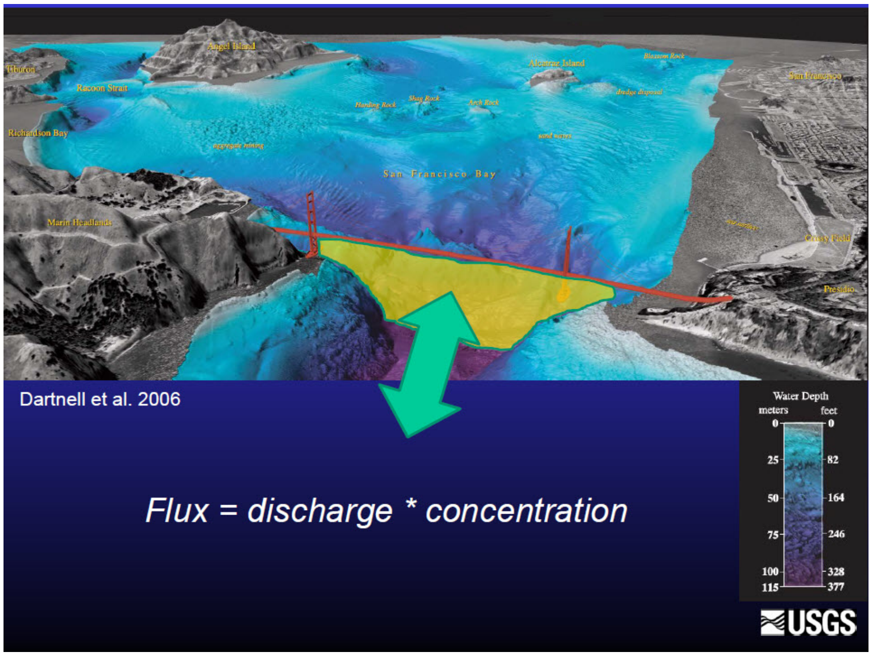


Figure 11
Example of measured acoustic backscatter (top) and velocity magnitude used to calculate observed sediment flux from measurements (Source: USGS)

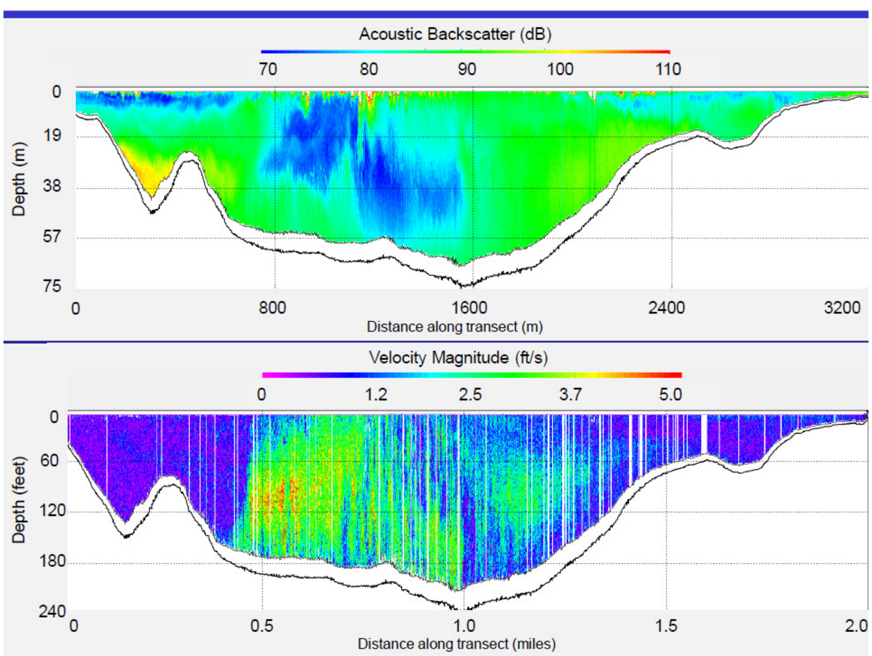
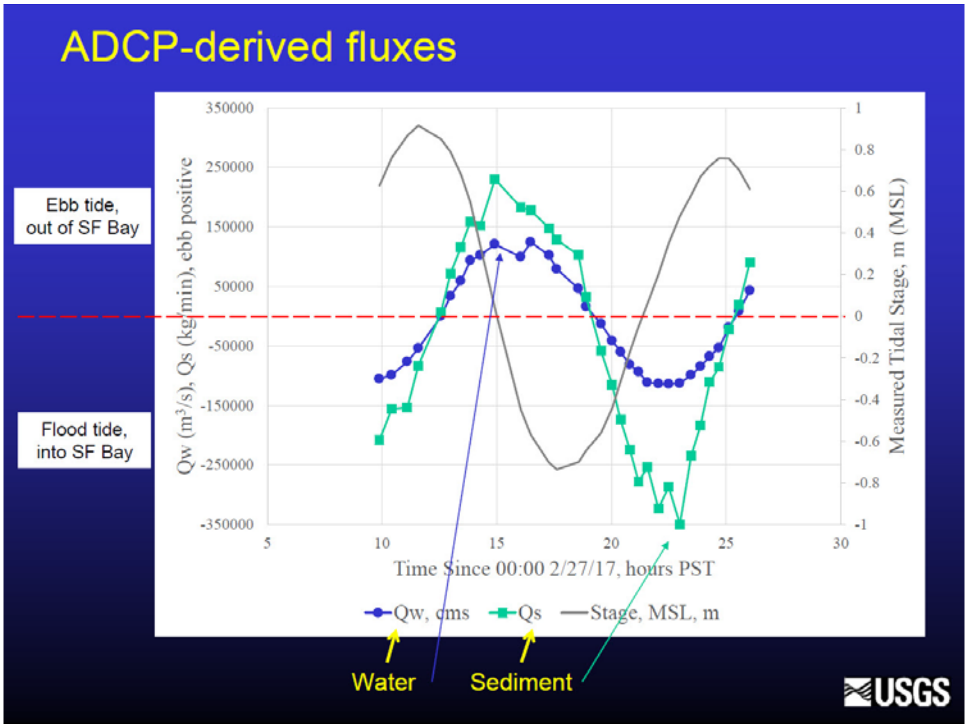


Figure 12
ADCP derived fluxes (water and sediment) at the Golden Gate on February 27, 2017 (Source: USGS)



II. Study Approach

The following section provides a detailed description of the work to be completed. Revisions or refinements to the scope of work can be made if requested.

Task 1: Simulation of Sediment Flux during January through March 2017

The UnTRIM Bay-Delta model will be used to simulate hydrodynamics, salinity, and sediment transport for the period from January 1, 2017, through March 31, 2017. This period spans the USGS sediment flux measurements at the Golden Gate made on February 27, 2017. This period is also particularly interesting because it spans two large outflow periods (Figure 13, top) and a period when the observed SSC at the Richmond San Rafael Bridge is higher than at Benicia (Figure 13, bottom).

The predicted sediment concentrations will be compared to observed SSC throughout the Estuary to validate model predictions of SSC. The sediment flux at the Golden Gate and between each of the subembayments of the Estuary will be calculated over the 3-month period. While the USGS sediment flux measurements span only a single day, the prediction of sediment fluxes during the 3-month high flow period in 2017 will allow for an increased understanding of how sediment fluxes vary on the rising and falling limbs of large outflow events.

During the data collection period on February 27, 2017, the model predictions of velocity and sediment concentration will be compared to the observed measurements of velocity and estimates of sediment concentration from backscatter (Figure 11). Previous comparisons between observed and predicted velocity transects have demonstrated that the model can accurately predict the complex velocity patterns near the Golden Gate (Figure 14). The model-predicted net flow, SSC, and net flux will be compared to the observations at each of the approximately 32 transects collected on February 27. This will allow for a detailed assessment of how differences between the predictions and observations affect the flux estimates for each discrete measurement transect.

Following the approach used at Dumbarton Bridge (Figure 9), the model-predicted sediment flux on each flood and ebb tide will be calculated for each day during the simulation period. These predictions will be used to investigate the hypothesis that the net sediment flux into the Bay through the Golden Gate during the sampling period was positive because the measurements were made on the falling limb of the hydrograph and that during peak flows the sediment flux out was greater than the flux in.

Because the model predictions of sediment flux at the Golden Gate will span a much longer period that the single day of data collection, the model predictions of sediment flux also be used to assist in developing surrogate measurements of sediment flux at the Golden that are critical for understanding the overall sediment mass balance in San Francisco Bay. The predicted sediment flux at the Golden Gate will be compared to observed parameters such as SSC at Alcatraz or Delta outflow to help develop these relationships.

The results of these analyses will be included in a draft technical memorandum which will be provided to the Regional Monitoring Program sediment workgroup for review. Based on the comments received, the document will be revised, and a final memorandum will be submitted.

Task 1 Deliverables

- Draft technical memorandum describing sediment simulation period, model validation to continuous monitoring sensors, model comparisons to observed sediment flux on February 27, and model predictions of sediment fluxes between embayments during simulation period
- Final technical memorandum incorporating revisions based on comments from the Regional Monitoring Program sediment workgroup

Figure 13
Observed flow, salinity, and SSC during 2017 (Source: USGS)

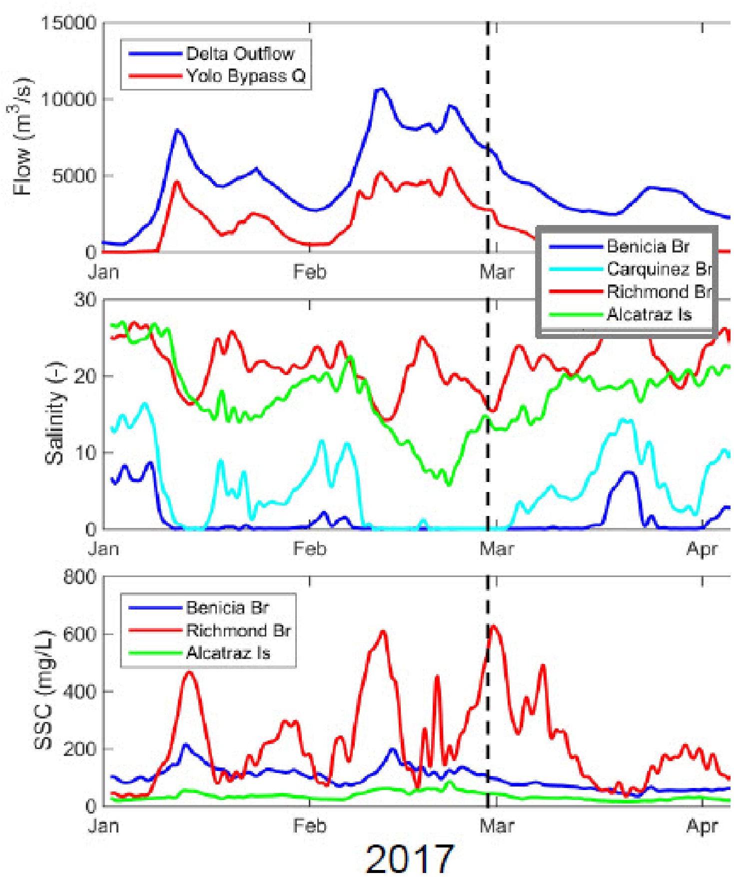
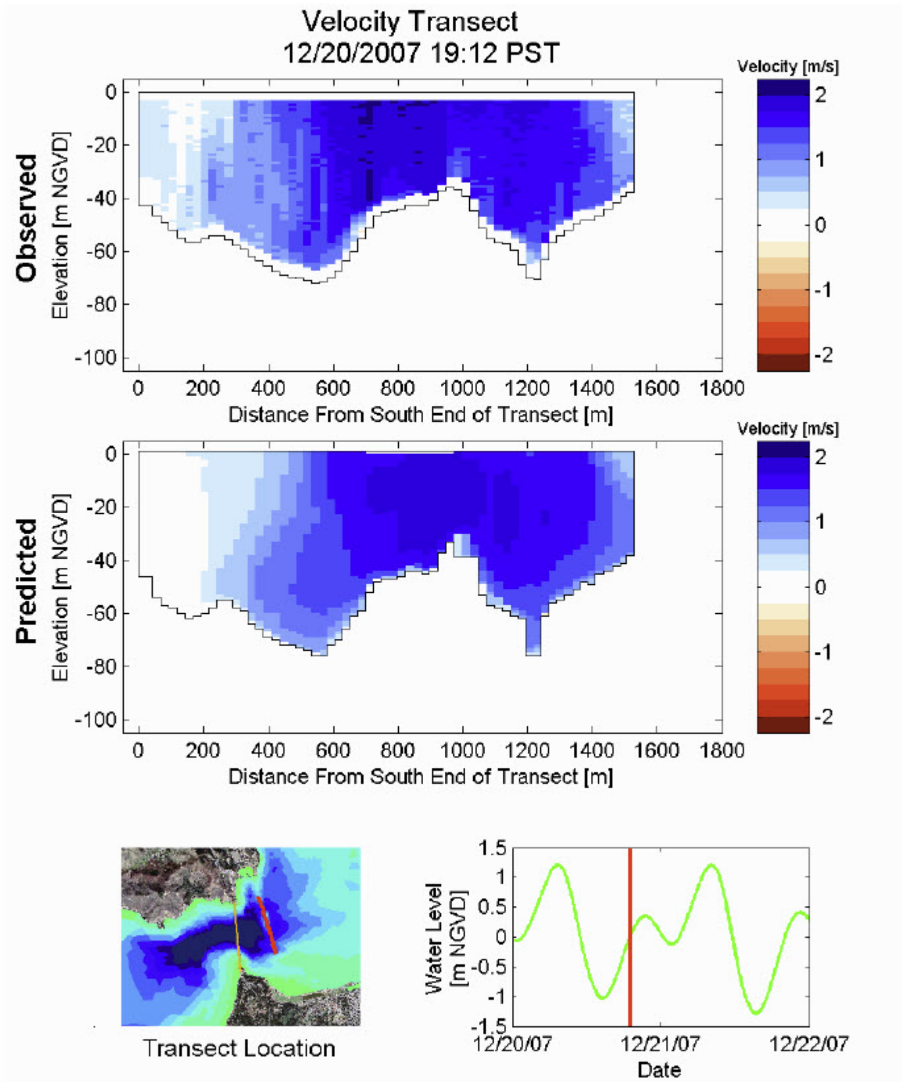


Figure 14
Observed (top) and predicted (middle) velocity transect on December 20, 2007, at 19:12 PST. The location of the transect (red line) is shown (lower left) relative to the position of the Golden Gate Bridge (orange line). Observed water level at Fort Point is shown with the red line indicating the start time of the transect (lower right).



4. Cost Estimate

A detailed project budget will be added after this scope of work is finalized. Based on the scope of work as described in the preceding sections, the estimated cost of this work is summarized in Table 1.

Table 1
Cost Estimate

Task Number	Description	Estimated Budget
1	Simulation of Sediment Flux from January through March 2017	$45,000
	Total	**$45,000**

5. Schedule

We anticipate that the draft technical memorandum will be completed within 4 months of notice to proceed. The final technical memorandum will be submitted within 1 month of receiving comments on the draft technical memorandum.

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RMP
REGIONAL MONITORING PROGRAM FOR WATER QUALITY IN SAN FRANCISCO BAY

sfei.org/rmp

MULTI-YEAR PLAN

2019 ANNUAL UPDATE

FINAL
January 2019

2018 Sediment Cruise. Photograph by Shira Bezalel

RMP ORIGIN AND PURPOSE

In 1992 the San Francisco Bay Regional Water Board passed Resolution No. 92-043 directing the Executive Officer to send a letter to regulated dischargers requiring them to implement a regional multi-media pollutant monitoring program for water quality (RMP) in San Francisco Bay. The Water Board's regulatory authority to require such a program comes from California Water Code Sections 13267, 13383, 13268 and 13385. The Water Board offered to suspend some effluent and local receiving water monitoring requirements for individual discharges to provide cost savings to implement baseline portions of the RMP, although they recognized that additional resources would be necessary. The Resolution also included a provision that the requirement for a RMP be included in discharger permits. The RMP began in 1993, and over ensuing years has been a successful and effective partnership of regulatory agencies and the regulated community.

The goal of the RMP is to collect data and communicate information about water quality in San Francisco Bay in support of management decisions.

This goal is achieved through a cooperative effort from a wide range of regulators, dischargers, scientists, and environmental advocates. This collaboration has fostered the development of a multifaceted, sophisticated, and efficient program that has demonstrated the capacity for considerable adaptation in response to changing management priorities and advances in scientific understanding.

RMP PLANNING

This collaboration and adaptation is achieved through the participation of stakeholders and scientists in frequent committee and workgroup meetings (Figure 1).

The annual planning cycle begins with a workshop in October in which the Steering Committee articulates general priorities among the information needs on water quality topics of concern. In the second quarter of the following year the workgroups and strategy teams forward recommendations for study plans to the Technical Review Committee (TRC). At their June meeting, the TRC combines all of this input into a study plan for the following year that is submitted to the Steering Committee. The Steering Committee then considers this recommendation and makes the final decision on the annual workplan.

In order to fulfill the overarching goal of the RMP, the Program has to be forward-thinking and anticipate what decisions are on the horizon, so that when their time comes, the scientific knowledge needed to inform the decisions is at hand. Consequently, each of the workgroups and teams develops five-year plans for studies to address the highest priority management questions for their subject area. Collectively, the efforts of all these groups represent a substantial body of deliberation and planning.

PURPOSE AND ORGANIZATION OF THIS DOCUMENT

The purpose of this document is to guide efforts and summarize plans developed within the RMP. The intended audience includes representatives of the many organizations who directly participate in the Program. This document will also be useful for individuals who are not directly involved with the RMP but are interested in an overview of the Program and where it is heading.

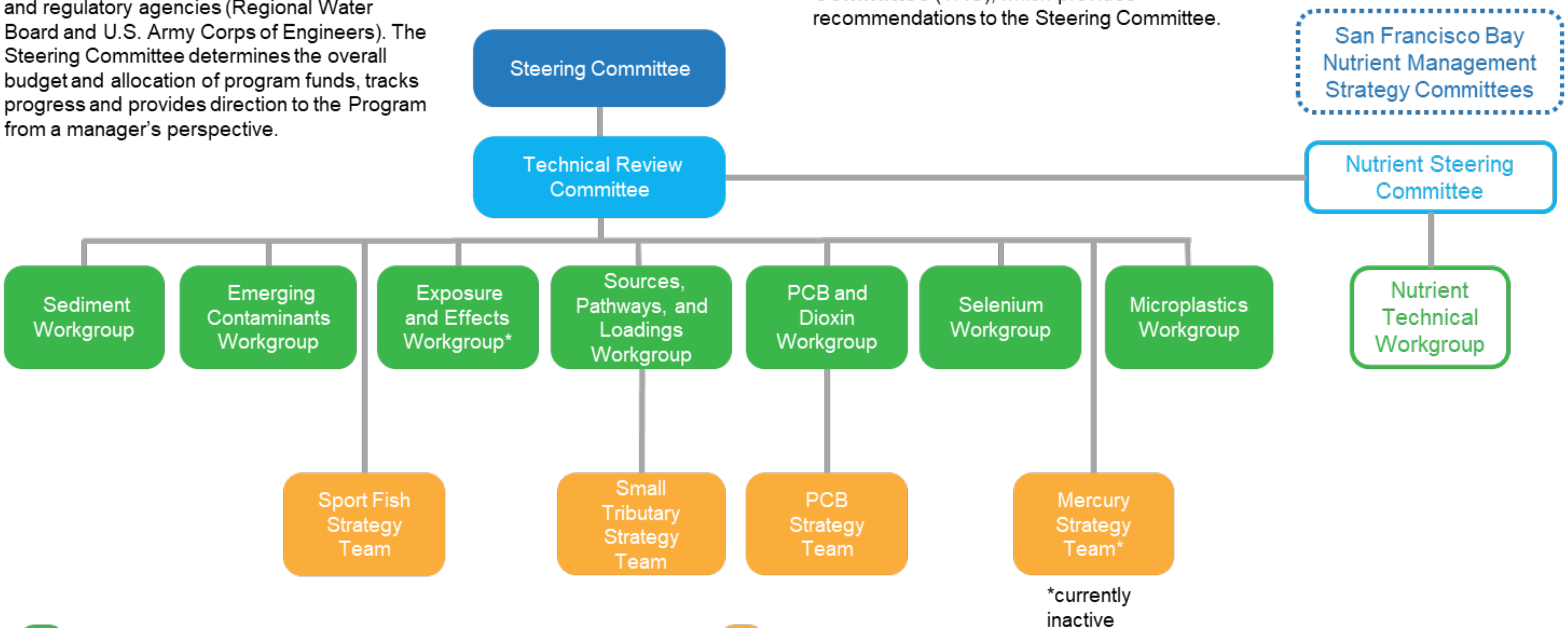
The organization of this Multi-Year Plan parallels the RMP planning process (Figure 2). Section 1 presents the long-term management plans of the agencies responsible for managing water quality in the Bay and the overarching management questions that guide the Program. The agencies' long-term management plans provide the foundation for RMP planning (page 5). The first step the RMP takes to support these plans, is to distill prioritized lists of management questions that need to be answered in order to turn the plans into effective actions (page 6). The prioritized management questions then serve as a roadmap for scientists on the Technical Review Committee, the workgroups, and the strategy teams to plan and implement scientific studies to address the most urgent information needs. This information sharpens the focus on management actions that will most effectively and efficiently improve water quality in the Bay.

Figure 1. Collaboration and adaptation in the RMP is achieved through the engagement of stakeholders and scientists in frequent committee and workgroup meetings.

PROGRAM OVERSIGHT

The Steering Committee consists of representatives from discharger groups (wastewater, stormwater, dredging, industrial) and regulatory agencies (Regional Water Board and U.S. Army Corps of Engineers). The Steering Committee determines the overall budget and allocation of program funds, tracks progress and provides direction to the Program from a manager's perspective.

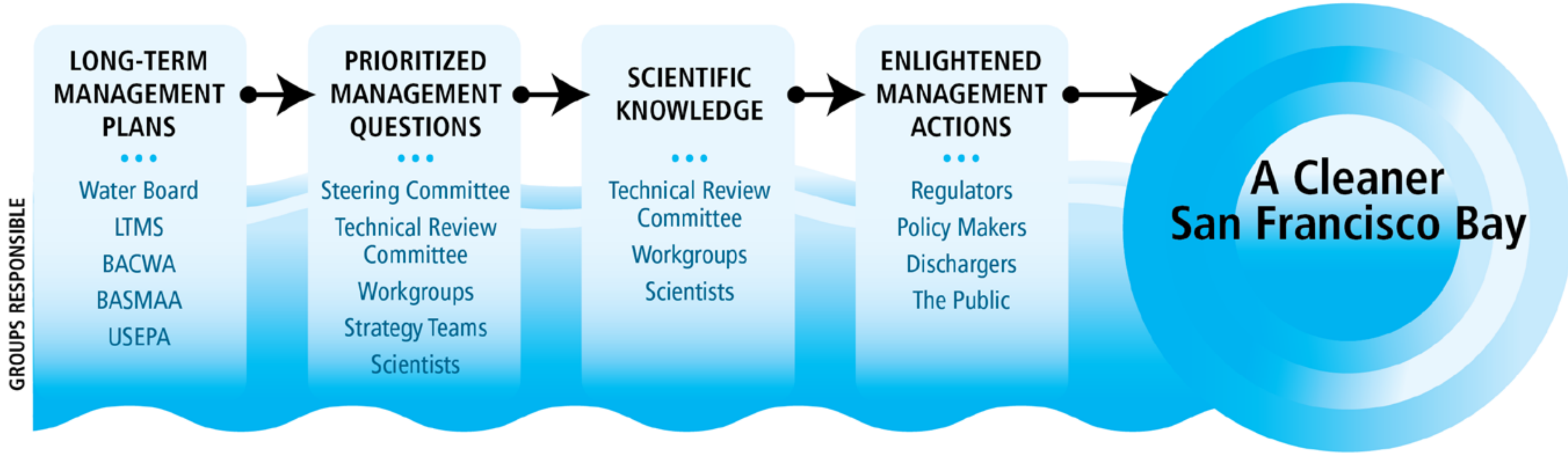
Oversight of the technical content and quality of the RMP is provided by the **Technical Review Committee** (TRC), which provides recommendations to the Steering Committee.



Workgroups report to the TRC and address the main technical subject areas covered by the RMP. The Nutrient Technical Workgroup was established as part of the committee structure of a separate effort – the Nutrient Management Strategy – but makes recommendations to the RMP committees on the use of the RMP funds that support nutrient studies. The workgroups consist of regional scientists and regulators and invited scientists recognized as authorities in the field. The workgroups directly guide planning and implementation of special studies.

RMP strategy teams constitute one more layer of planning activity. These stakeholder groups meet as needed to develop long-term RMP study plans for addressing high priority topics.

Figure 2. Science in support of water quality management.



Section 2 provides an overview of the budget of the RMP, including where the funding comes from and how it is allocated among different elements of the Program. This section provides a summary of the priority topics to be addressed by the Program over the next five years.

Section 3 presents the five-year plans developed by the workgroups and strategy teams for the current focus areas: PCBs, selenium, emerging contaminants, small tributary loads, exposure and effects, nutrients, sediment, and microplastics. Led by the stakeholder representatives that participate in these groups, each workgroup and strategy team has developed a specific list of management questions for each topic that the RMP will strive to answer over the next five years. With guidance from the science advisors on the workgroups, plans have been developed to address these questions. These plans include proposed projects and tasks and projected annual budgets. Information synthesis efforts are often conducted to yield recommendations for a next phase of studies. For now, study plans and budget allocations for these strategies are largely labelled as “to be determined”. Other pieces of information are also included to provide context for the multi-year plans. First, for each high priority topic, specific management policies or decisions that are anticipated to occur in the next few years are listed. Second, the latest advances in understanding achieved through the RMP and other programs on Bay water quality topics of greatest concern are summarized. Lastly, additional context is provided by listing studies performed within the last two years and studies that are currently underway.

Section 4 describes five-year plans for other elements that are essential to the mission of the RMP: Status and Trends Monitoring, Program Management, Communications, Data Management, and Quality Assurance.

Section 5 contains lists of RMP studies that are relevant to specific permit conditions for dredging, wastewater discharges, and stormwater discharges.

A Living Document

The RMP Multi-Year Plan is updated annually to provide an up-to-date description of the priorities and directions of the Program. An annual Planning Workshop is held in conjunction with the October Steering Committee meeting. A draft Multi-Year Plan is prepared before the workshop, and approved by the Steering Committee at the January meeting.

More detailed descriptions of the elements of the RMP are provided in the annual Detailed Workplan (available at www.sfei.org/rmp).

Figure 3. Annual planning calendar for the Regional Monitoring Program.

Annual Steering Committee Calendar

- January
  - Approve Multi-Year Plan
  - Review of incomplete projects from the previous year
  - Approve annual report outline
  - Pick date for Annual Meeting
- April
  - Plan for Annual Meeting
  - Provide additional planning guidance to workgroups
- July
  - Multi-year Plan: mid-year check-in, workshop planning
  - Approve special studies recommended by the TRC for the next year and update projects list for SEP funding
  - Plan for Annual Meeting
  - Report on SFEI financial audit
  - Briefly discuss fees for year after next
  - Select annual report theme for next year
- October
  - Confirm chair(s) and Charter
  - Planning Workshop
  - Decision on fees for the year after next
  - Approve workplan and budget for next year
  - Approve general Pulse outline for next year
  - Decision on workshops to be held next year

Each meeting (except October) includes a Science Program Update from a workgroup or strategy team focus area.

Annual Technical Review Committee Calendar

- March
  - Confirm chair(s)
  - Provide additional planning guidance to workgroups
- June
  - Recommend special studies for funding
  - Review S&T target analyte list, CEC tiers
  - Review plans for Annual Meeting and annual report
- September
  - Prepare for Annual Meeting
  - Review Status and Trends Monitoring Design
- December
  - Review Pulse outline for next year
  - Informatics update
  - Present workplan for next year and outcome of Multi-Year Planning Workshop
  - Review magnitude of Workgroup planning budgets relative to actual funds available

Each meeting includes and feedback on proposed and current studies.

Annual Workgroup Calendar

Workgroups meet annually in April-June to discuss results from prior studies and select proposals to recommend to the TRC and SC for the next year.

Multi-Year Calendar: RMP fees are approved in 3-year increments. The most recent approval was for 2019-2021. The dredger fee schedule is reviewed every 3 years. The most recent approval was for 2018-2020. The MOU between SFEI and the Water Board for administering the RMP is amended every two years. The most recent amendment was for 2019-2020.

CURRENT AND ANTICIPATED MANAGEMENT DECISIONS, POLICIES, AND ACTIONS BY THE REGULATORY AGENCIES THAT MANAGE BAY WATER QUALITY

Decisions, Policies, and Actions	**Timing**
BAY WATERSHED PERMITS (CURRENT & NEXT RENEWAL)	
Municipal Regional Stormwater Permit	2015, 2020*
Mercury and PCBs Watershed Permit for Municipal and Industrial Wastewater	2017, 2022
Nutrient Watershed Permit for Municipal Wastewater	2019, 2024
CURRENT DRIVERS BY TOPIC	
Determination of Wastewater Permit Limits	Ongoing
303(d) List and 305(b) Report Current listings and next cycle	2017, 2022
Dredging Permits Bioaccumulation testing triggers and in-Bay disposal thresholds+	2019
Copper Site specific objectives triggers+	2018
Cyanide Site specific objectives triggers+	2018
PCBs Review existing TMDL and establish plan to revise*	2020
Mercury Review existing TMDL and establish plan to revise*	2020
Selenium North Bay Selenium TMDL EPA Water Quality Criteria South Bay Selenium TMDL	2016 ~2018 ~2020?
Nutrients Nutrient Management Strategy Nutrient Monitoring Program Nutrient Water Quality Objective	Ongoing 2019 2024
Chemicals of Emerging Concern Updates to CEC Tiered Risk Framework Opportunities to inform regional actions and state and federal regulations	Annual Ongoing

Decisions, Policies, and Actions	**Timing**
Current Use Pesticides EPA Registration Review of fipronil and imidacloprid DPR fipronil mitigation measures	Ongoing
Legacy Pesticides (DDT, Dieldrin, Chlordane) Monitoring recovery	Ongoing
Dioxins Review 303(d) listings and establish TMDL development plan or alternative	2018
Toxicity New state plan on effluent and receiving water toxicity (schedule depends on State Water Board)	2019
Sediment Hot Spots Review 303(d) listings and establish TMDL development plan or alternative Phase 2 Sediment Quality Objectives (Human Health)	2018, 2022 2018
Long-Term Management Strategy for Placement of Dredged Material Regional Sediment Management Strategy	Ongoing
Pathogens Bay Beaches Bacteria TMDL Amend TMDL to add 2017 listings State Board Bacteria Objectives	2016 2019 2018
Suisun Marsh Establish TMDL for DO, mercury, nutrients, salinity	2018
POTENTIAL FUTURE DRIVERS	
Wetland Restoration Permits Regional wetland monitoring (under development)	2020
Trash and Microplastic	2021
Effects of reduced wastewater and stormwater inputs to the Bay	TBD

+ Comparisons to triggers will be updated on the RMP sampling frequency (every 4 years for sediment, every 2 years for water)
* The dates for reviewing the Mercury and PCB TMDLs coincide with the schedule for reissuing the Municipal Regional Stormwater Permit.

RMP Outcomes

Legislation
- CA Flame Retardants in Consumer Products (2018)
- CA Pharmaceutical Stewardship (2018)
- SF Flame Retardant Ordinance (2017)
- Palo Alto & San Francisco expanded polystyrene ordinances (2015, 2016)
- CA Microbead Ban (2015)
- US Microbead Ban (2015)
- CA Copper in Brake Pads (2010)
- CA PBDE Ban (2003)

NPDES Regional Permits
- *Municipal and industrial wastewater*
  - Mercury and PCBs (2017)
- *Municipal stormwater*
  - MRP 2.0 (2015)
  - MRP 1.0 (2010)

Regulations
- CA Safer Consumer Products Regulations (ongoing)
- CA Fipronil Application (2017)
- CA Flame Retardants in Furniture (2013)
- CA Pyrethroid Application (2012)

TMDLs
- Selenium (2016)
- PCBs (2009)
- Mercury (2008)
- Urban Creeks Diazinon and Pesticide-Related Toxicity (2007)

Water Quality Objectives
- Copper and Nickel (North of Dumbarton) (2010)
- Copper and Nickel (North of Dumbarton) (2002)

San Francisco Bay 303(d) List Updates
- 2018
- 2010
- 2006
- 2002
- 1998
- 1996

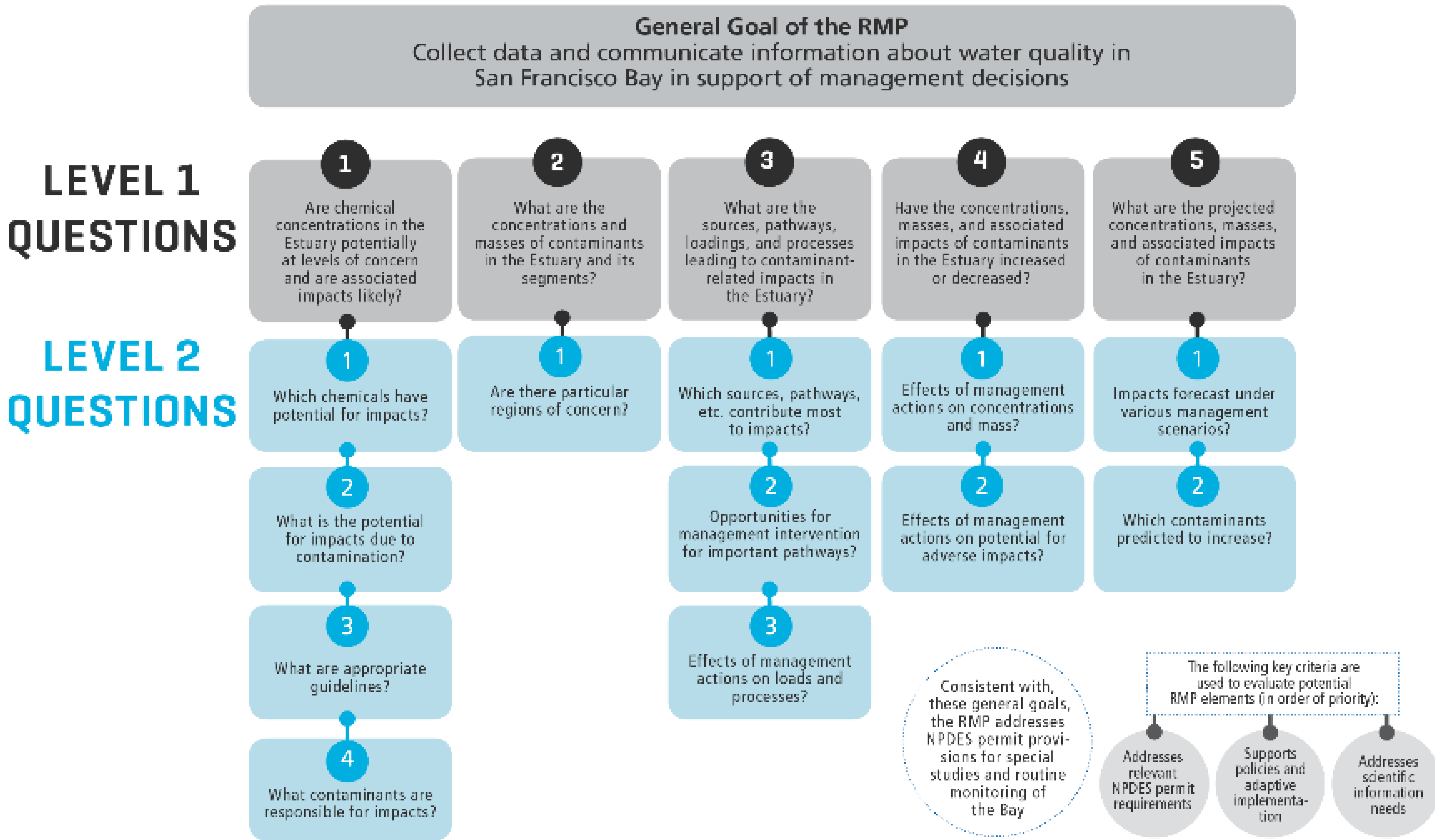
Phase-outs
- US PFOA (2015)
- US Deca-BDE (2013)
- US PFOS (2002)

Fish Advisory
- SF Bay (2011)

*Outcomes as of February 2019

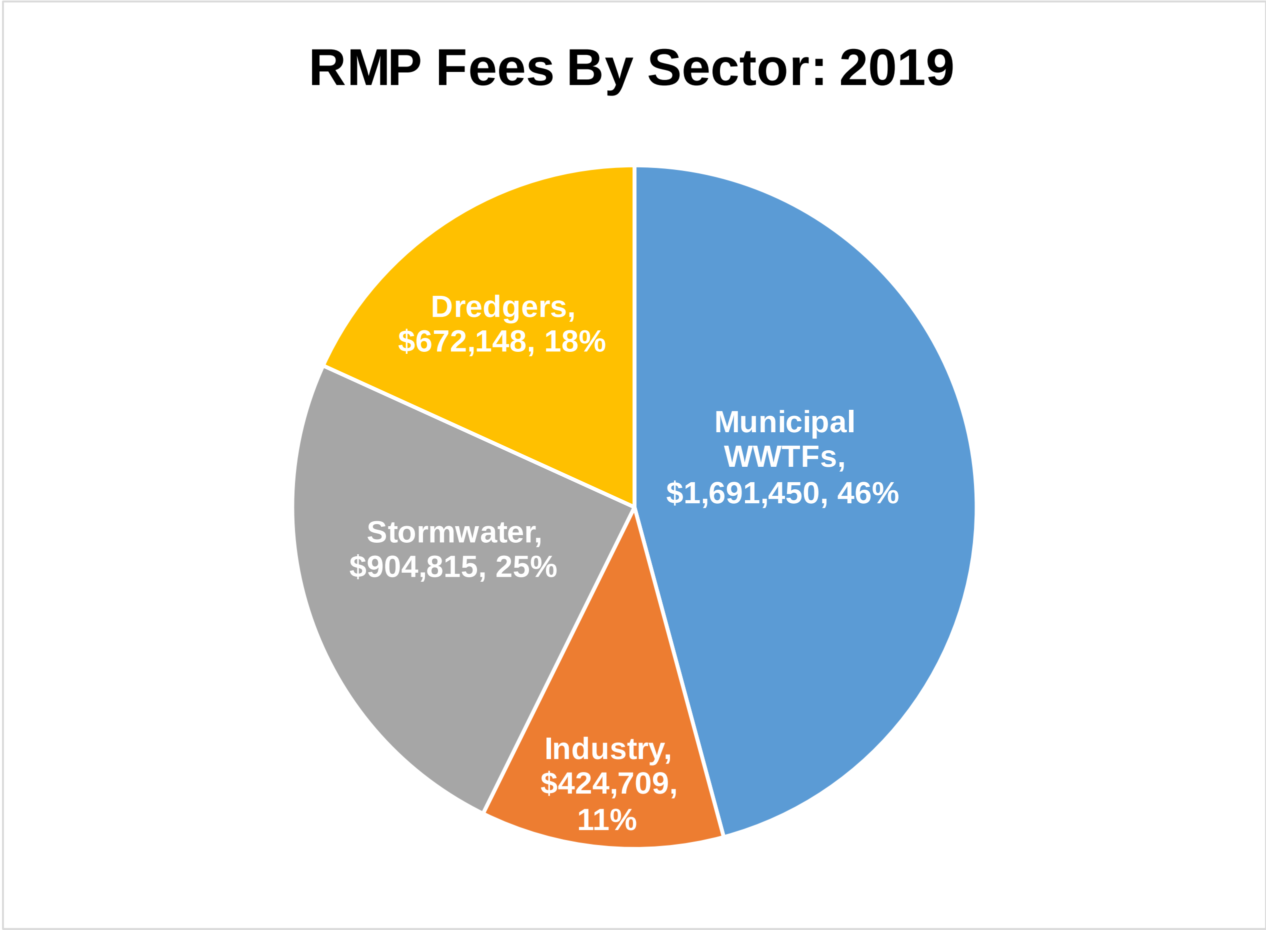
RMP GOAL AND MANAGEMENT QUESTIONS

RMP stakeholders have articulated an overarching goal and a tiered framework of management questions that organize and guide RMP studies. The management questions are closely linked to existing and planned regulations.



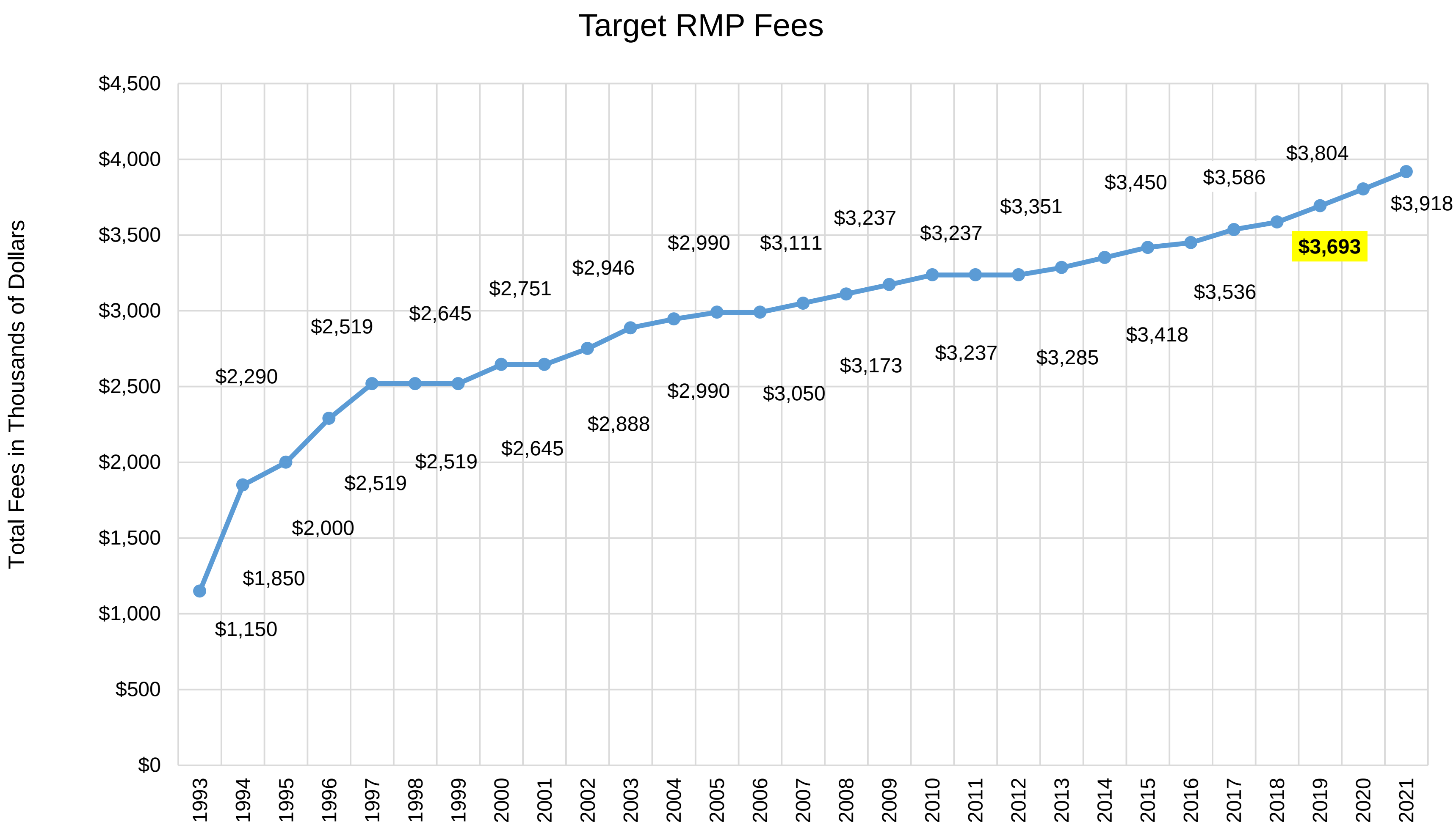
BUDGET: Revenue by Sector

RMP fees are divided among four major discharger groups. Total fees in 2019 will be $3.693 million. Municipal wastewater treatment agencies are the largest contributor, and stormwater agencies are the second largest contributor. The contribution from dredgers includes $250,000 from the U.S. Army Corps of Engineers. Refineries constitute the majority of the industrial sector, and also contribute to the Program due to dredging activities at their facilities. The last cooling water discharge phased out of operation in 2017. The fees formerly paid for cooling water discharges will not be passed on to the other participants. In addition to fees, the RMP also receives penalty funds for Supplemental Environmental Projects and Alternative Monitoring Requirement funds from municipal wastewater agencies.



BUDGET: Revenue by Year

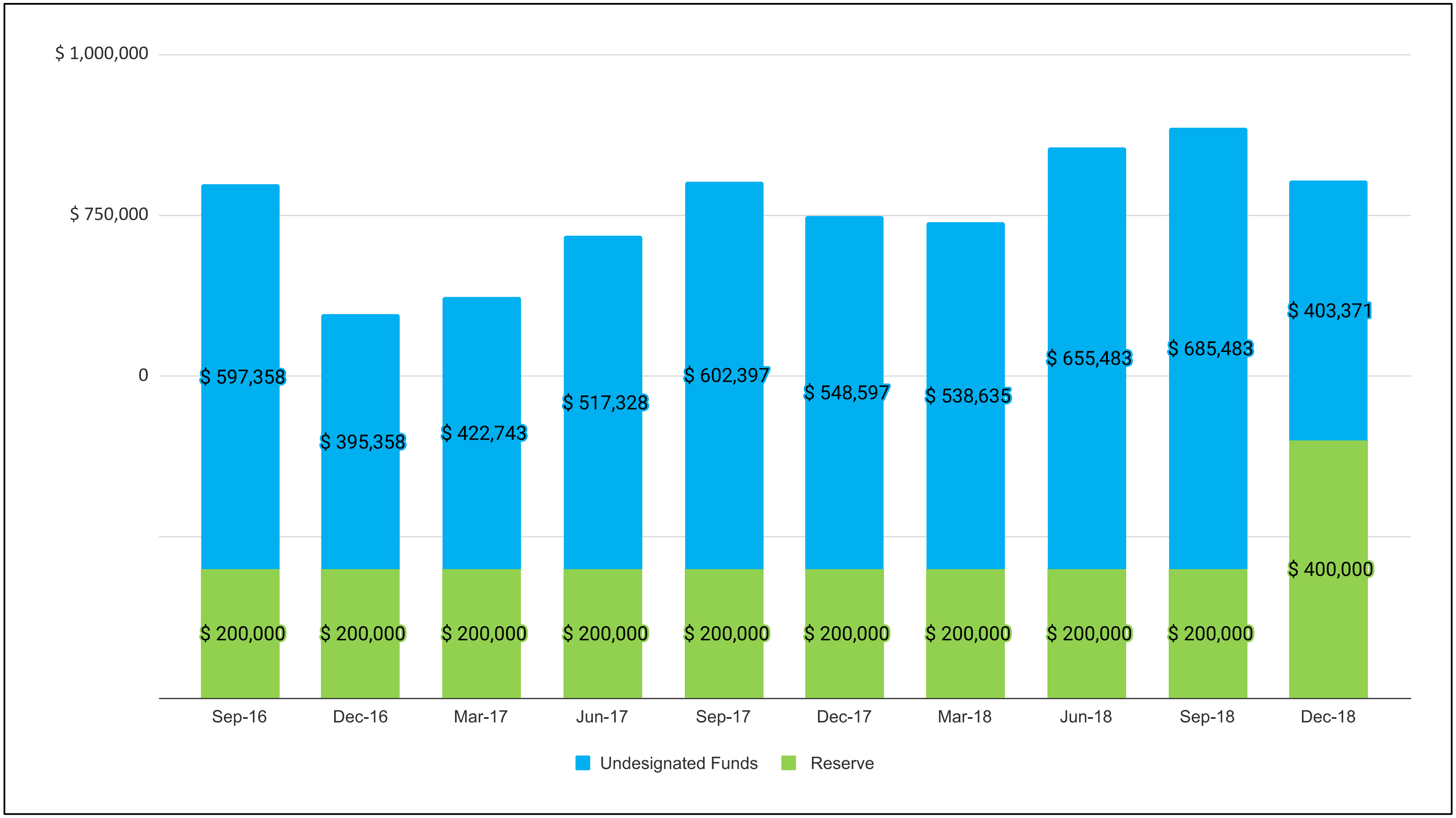
Target RMP fees in 2019 are $3.693 million. For 2019-2021, the Steering Committee has approved 3% per year increases in fees. Over the past 20 years, RMP fee growth has not kept up with inflation.



BUDGET: Reserve Funds

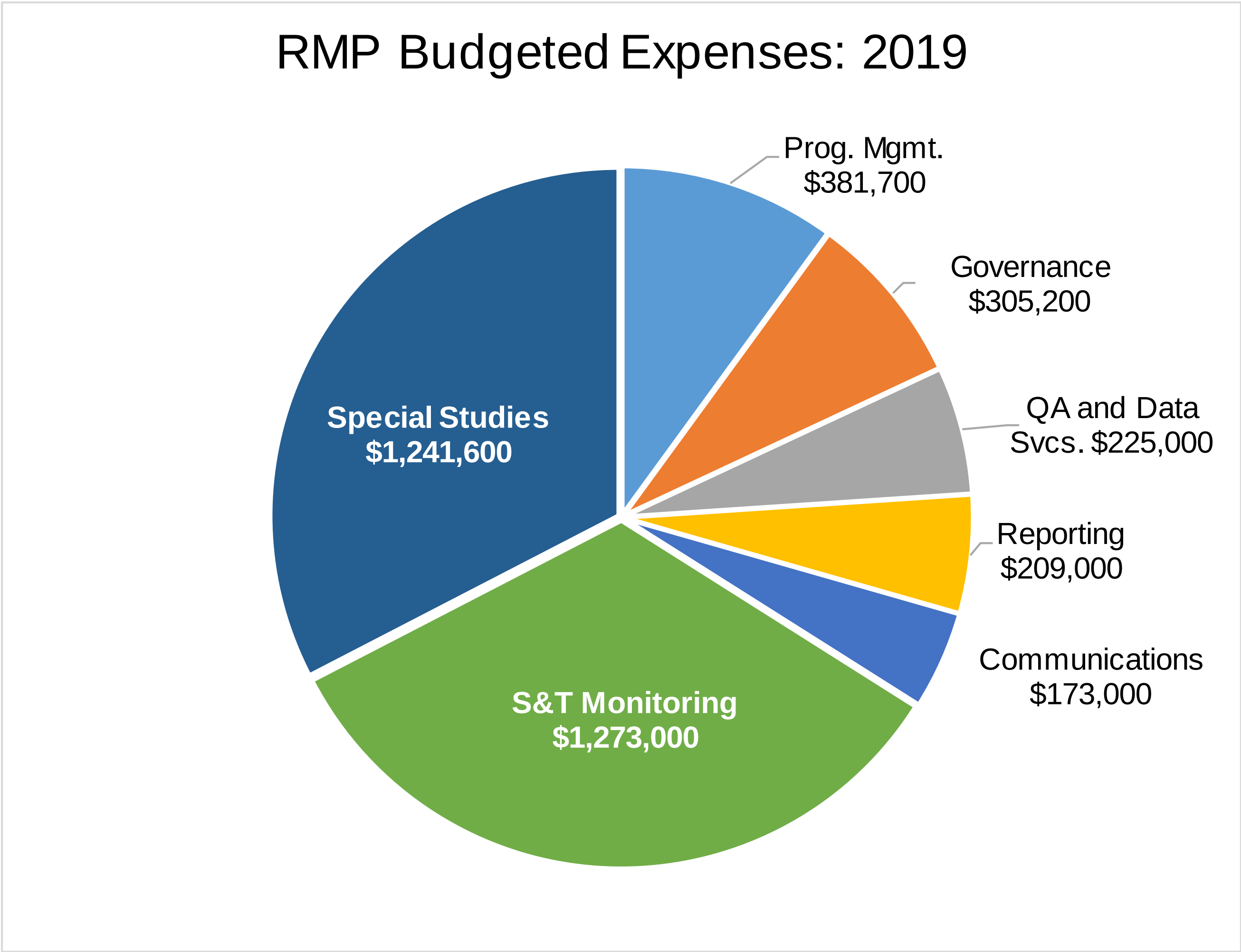
The RMP maintains a balance of Undesignated Funds for contingencies. Higher than anticipated revenues and elimination or reduction of lower priority elements sometimes leads to accumulation of funds that can be used for high priority topics at the discretion of the Steering Committee.

The Bay RMP Undesignated Funds balance over the past two budget years is shown below. The height of the bar shows the total balance of the Undesignated Funds. The bars are color coded to indicate the RMP policy that $400,000 of the Undesignated Funds should be held as a Reserve. The Steering Committee increased the Reserve amount from $200,000 to $400,000 in 2018 so that it is now approximately 10% of the annual Program budget.



BUDGET: Expenses

Each year, approximately 70% of the budget is spent on monitoring and special studies. Quality assurance and data systems, reporting, and communications are each approximately 5% of the budget. Governance meetings (8%) are critical to ensure that RMP is addressing stakeholder needs and conducting studies that include peer-review from project planning through report preparation. Finally, 12% of the budget is needed for program management, including fiduciary oversight of contracts and expenditures.



BUDGET: Special Studies 2016-2022

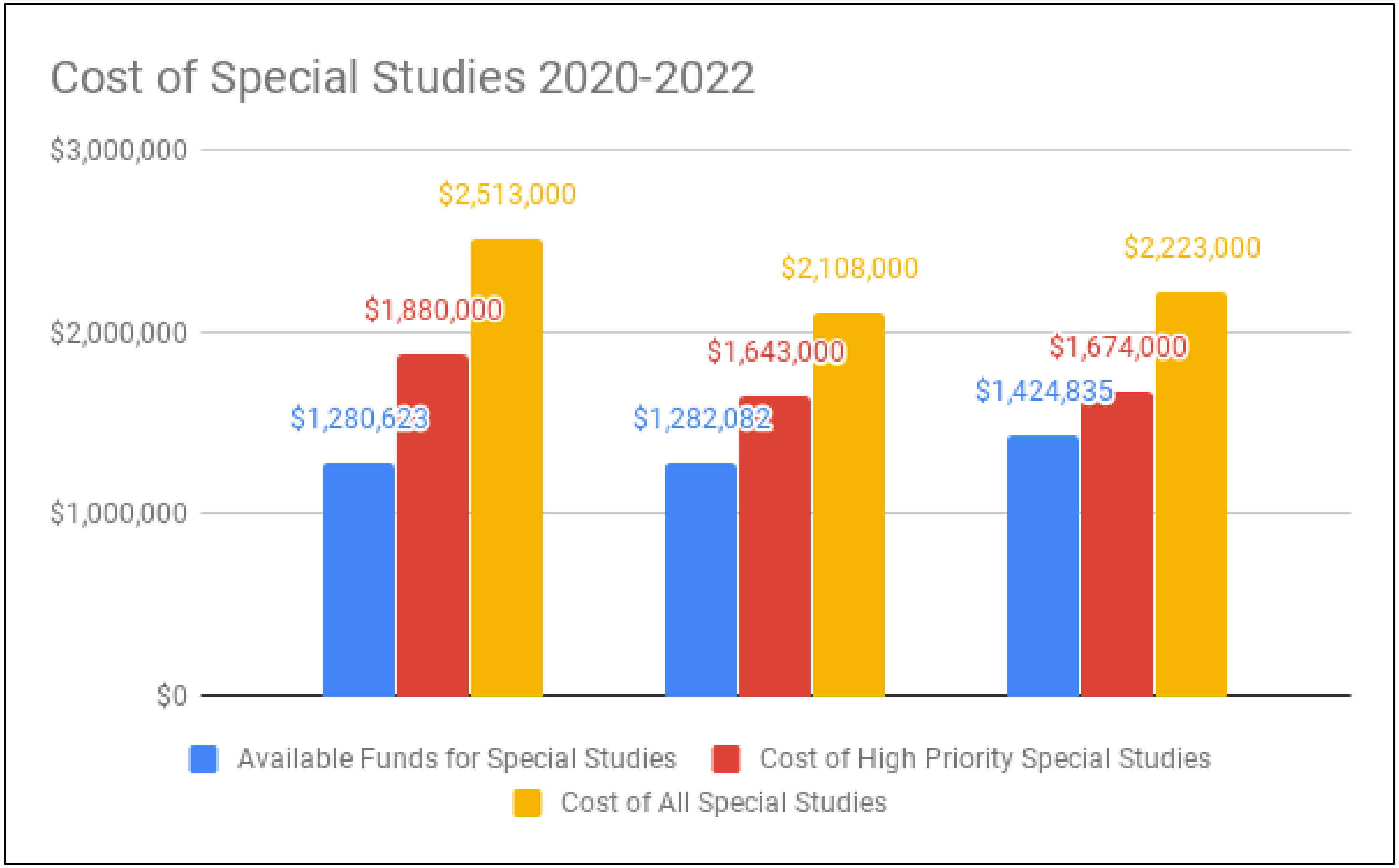
RMP actual and planned expenditures on special study topics. Costs for 2016-2019 are the approved budgets. Costs for 2020 and beyond are estimates for planning based on the most recent input from the Workgroups and Strategy Teams. The funds available for 2020-2022 were estimated by assuming RMP revenue will increase by 3% per year, subtracting estimated programmatic expenses (pages 13-30), and subtracting estimated Status and Trends monitoring costs (page 32).

FOCUS AREA	2016	2017	2018	2019	2020	2021	2022
	Budget	*Budget*	*Budget*	*Budget*	*Planning*	*Forecast*	*Forecast*
PCBs	$40,000	$70,000	$31,000	$40,000	$120,000	$110,000	$110,000
Emerging Contaminants	$130,000	$284,835	$366,000	$325,000	$465,000	$571,000	$669,000
Small Tributaries	$311,000	$410,000	$302,000	$275,000	$400,000	$400,000	$400,000
Exposure and Effects	$35,000	$55,000	$61,000	$0	$0	$0	$00
Selenium	$47,000	$106,000	$10,000	$107,000	$120,000	$107,000	$144,000
Nutrients	$300,000	$373,000	$350,000	$250,000	$400,000	$400,000	$400,000
Microplastic	$25,000	$75,000	$46,000	$30,000	$115,000	$235,000	$215,000
Sediment	$33,000	$90,000	$215,000	$215,000	$260,000	$345,000	$345,000
SPECIAL STUDIES TOTAL	**$921,000**	**$1,515,835**	**$1,381,000**	**$1,242,000**	**$1,880,000**	**$2,268,000**	**$2,383,000**
PREDICTED SPECIAL STUDIES BUDGET TOTAL					**$1,280,623**	**$1,282,082**	**$1,424,835**
Predicted RMP Core Budget for Special Studies					$1,010,623	$1,012,082	$1,154,835
Predicted AMR Funds					$270,000	$270,000	$270,000

*The estimated RMP budgets on this table do not cover all of the funding needs for the Nutrients Management Strategy and Small Tributary Loading Strategy. Funding for these strategies is partially provided from other sources.

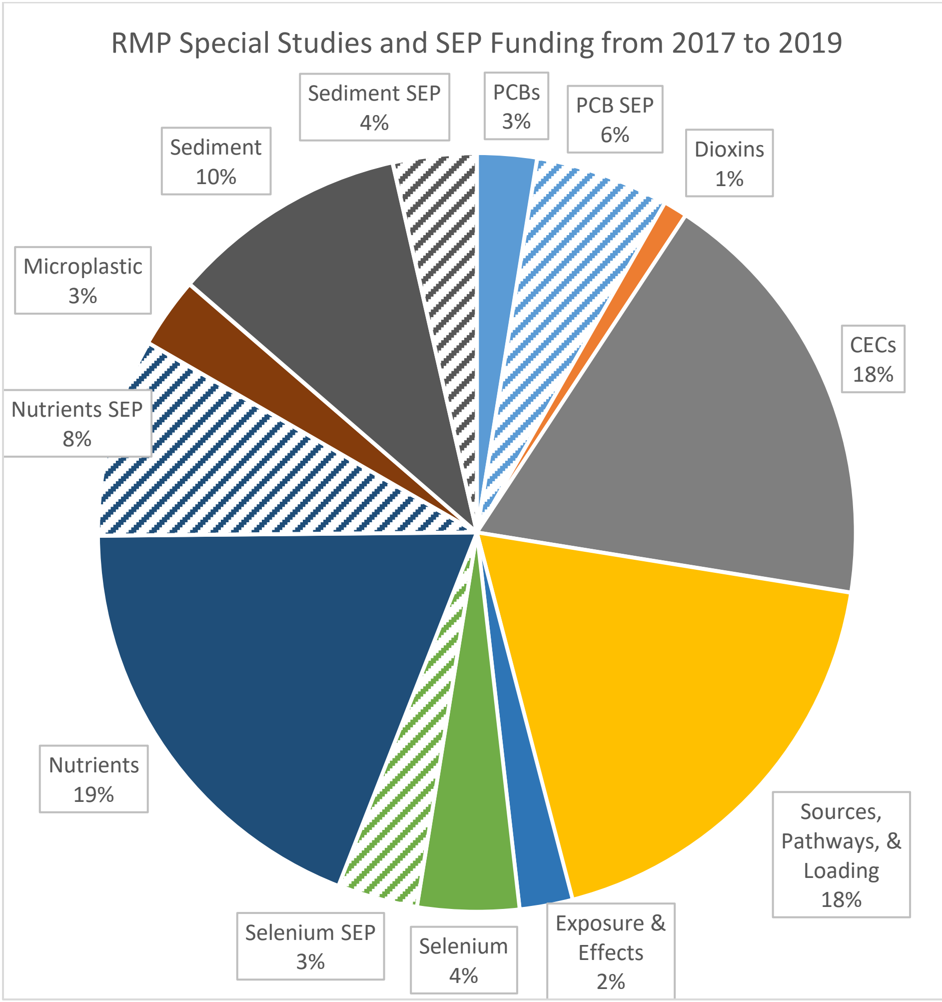
In 2016, the RMP became eligible to receive penalty funds for Supplemental Environmental Projects. Wastewater agencies also began to provide the RMP with Alternative Monitoring Requirement (AMR) funds for additional emerging contaminants studies. These new funding streams will augment the core RMP budget for special studies. The AMR funds are tied to a permit condition so the amount is predictable. The SEP funds are not predictable. Therefore, only AMR funds have been included in the predicted special studies budget total in the table above.

Projected funds available for special studies for 2020-2022 (blue), the cost of high priority studies identified for 2020 (red), and the cost of all special studies in the preliminary plans for each workgroup (yellow). High priority studies for 2021 and 2022 have not yet been selected by the workgroups.

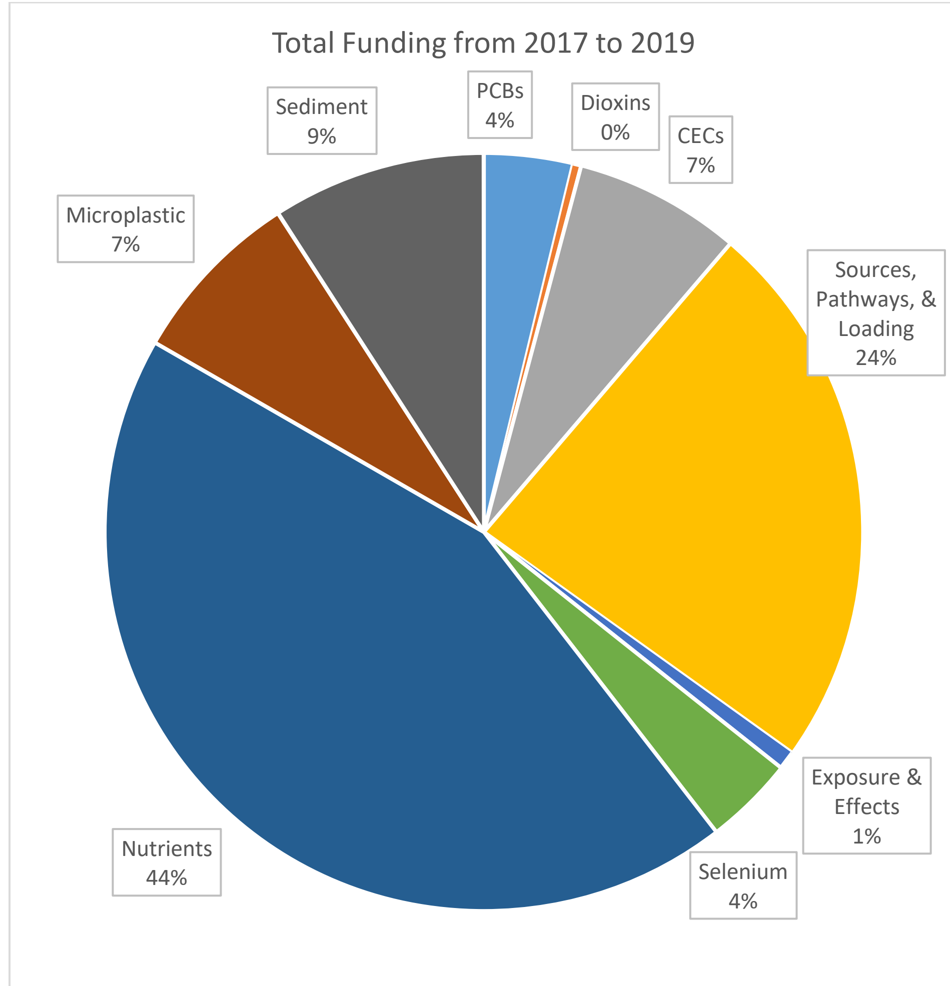


BUDGET: Special Studies 2017-2019

Actual allocation of special studies and Supplemental Environmental Projects funds over the past three years.



Total funding for special studies over the past three years, including Supplemental Environmental Projects, Alternative Monitoring Requirements, RMA partner funding, and external funding.



Fishing on the Bay. Photograph by Shira Bezalel.

EMERGING CONTAMINANTS

Relevant Management Policies and Decisions

Regional Action Plans for emerging contaminants

Early management intervention, including green chemistry and pollution prevention

State and federal pesticide regulatory programs

Recent Noteworthy Findings

The RMP updated its CEC Strategy, adding a strategy specific to monitoring emerging contaminants in pathways like wastewater and stormwater. The pathways monitoring strategy prioritizes special studies based on available Bay monitoring data, chemical properties, and understanding of CEC uses in the urban landscapes surrounding the Bay. Informed by this strategy, the RMP elected to fund the first year of a multi-year study to screen a broad array of CECs in stormwater. Analytes of interest include newly identified compounds derived from vehicle tires, poly- and perfluoroalkyl substances (PFASs), phosphate flame retardants, and ethoxylated surfactants.

The RMP reviewed wastewater pharmaceuticals data generated voluntarily by seven treatment facilities located throughout the Bay Area. This analysis for 104 pharmaceutical compounds represents the most comprehensive dataset to date in the region. The concentrations of pharmaceuticals in Bay Area influent and effluent were consistent with other studies in the US. Effluent concentrations were generally significantly lower than influent concentrations, though estimated removal efficiency varied by pharmaceutical, and in some cases, by treatment type. Pharmaceuticals detected at the highest concentrations and with the highest frequencies in effluent were commonly used drugs, including treatments for diabetes and high blood pressure, antibiotics, diuretics, and anticonvulsants. Based on available ecotoxicity data, it may be appropriate to conduct future monitoring for 17 of these drugs in the Bay.

RMP scientists and emerging contaminants experts have authored a book chapter on the occurrence and sources of pesticides to wastewater and the environment. The chapter describes a conceptual model of all pesticide uses with the potential for down-the-drain transport. In the US, 42 current use pesticides and related compounds have been identified in wastewater. Conventional treatment technologies have limited ability to remove pesticides, and seven compounds, including three pyrethroids, carbaryl, fipronil and its sulfone degradate, and imidacloprid, have been detected in treated wastewater effluent at levels exceeding USEPA aquatic life toxicity benchmarks. This state-of-the-science review indicates this pathway is significant and should be examined to identify sources and develop effective pollution prevention strategies. RMP findings were highlighted in the chapter, which will be part of an American Chemical Society online book, “Pesticides in Surface Water: Monitoring, Modeling, Risk Assessment, and Management.”

Priority Question for the Next Five Years

1. Which CECs have the potential to adversely impact beneficial uses in San Francisco Bay?
2. What are the sources, pathways and loadings leading to the presence of individual CECs or groups of CECs in the Bay?
3. What are the physical, chemical, and biological processes that may affect the transport and fate of individual CECs or groups of CECs in the Bay?
4. Have the concentrations of individual CECs or groups of CECs increased or decreased in the Bay?
5. Are the concentrations of individual CECs or groups of CECs predicted to increase or decrease in the future?
6. What are the effects of management actions?

MULTI-YEAR PLAN FOR EMERGING CONTAMINANTS

Emerging contaminant studies and monitoring in the RMP from 2014 to 2022. Numbers indicate budget allocations in $1000s. Budgets in parentheses represent funding or in-kind services from external partners. Items included in planning budget are shaded in yellow. Bold boxes indicate multi-year studies.

Element	Study	Funder	Questions addressed	2014	2015	2016	2017	2018	2019	2020	2021	2022
CEC Strategy				20	20	48	50	65	70	65	65	80
MODERATE CONCERN CECs												
PFOS/PFASs	Perfluorinated Compounds in Harbor Seals	RMP	1,4,6	26								
	Sediment, Effluent Precursor Monitoring	AXYS	1,2	(30)								
	CECs in Municipal Wastewater[1]	RMP	1,2,4		27.5							
	Effluent TOP Analysis	DTSC	1,2,4,6		(50)							
	Perfluorinated and Polyfluorinated Compounds in San Francisco Bay: Synthesis and Strategy	RMP	1-6				56					
	Margin Sediment Archiving	RMP	1					2.5				
	PFOS/PFOA Bay Model Development	Interwaste	1,2,3,5					(7)				
	Stormwater PFASs[2]	RMP	1,2						33	40	39	
	Sediment and Seal PFASs	RMP	1,2,4,6								80	
	PFASs in Ambient Bay Water	RMP	1,4,6								65	
	Air Deposition PFASs	RMP	1,2									100
	RMP Status and Trends[3]	RMP S&T	1,4	F		E		E	F		E	
NP/NPEs	Margin Sediment Archiving, Analysis	RMP	1,4					2.5				
	Stormwater Ethoxylated Surfactants[2]	RMP	1,2						33	40	39	
	Ethoxylated Surfactants in Ambient Water, Margin Sediment, and Wastewater	RMP	1,2,4						123			
	Archived Tissue	RMP	1,4									100
Fipronil	CECs in Municipal Wastewater[1]	RMP	1,2,3		27.5							
	Fipronil, Fipronil Degradates, and Imidacloprid in Municipal Wastewater	RMP	1,2,3			30						
	Fipronil, Fipronil Degradates, and Imidacloprid in Biosolids	ASU	1,2,3			(8)						
	RMP Status and Trends[3,4]	RMP	1,3,4	S				S	F			S

Element	Study	Funder	Questions addressed	2014	2015	2016	2017	2018	2019	2020	2021	2022
LOW or POSSIBLE CONCERN CECs												
PBDEs	RMP Status and Trends[3]	RMP S&T	1,3,4	S, B, F		B, E		S, E	F		E	S
Alt. Flame Retardants	Monitoring Alternative Flame Retardants in SF Bay Water, Effluent, Stormwater, Sediment and Biota	RMP	1,2,4	104								
	Phosphate Flame Retardants in Ambient Bay Water	RMP / ECCC	1,4	(2)			47				60	
	Stormwater Phosphate Flame Retardants[2]	RMP	1,2						33	40	39	
	Conceptual and Steady-State Model	RMP	1,2,3,6									94
Pharmaceut-icals	Pharmaceuticals in Wastewater	RMP / POTWs	1,2,4			(68)		30				
	Antibiotics and QACs in Surface Sediment and Cores	U Minn	1,3,4					(8)				
	Pharmaceuticals in Water & (Archived) Sediment – coordinated with EEWG glucocorticoid bioanalytical tools	RMP	1,2,4							180		
Plastic Additives	Bisphenol Compounds in Ambient Bay Water	RMP / SIU	1		(25)		50					
	Bisphenol Compounds in Archived Sediment	RMP	1							50		
	Phthalates in Bay Matrices	RMP	1,4								70	
Personal Care/Cleaning	Siloxanes in Bivalves	ECCC	1	(5)								
	Triclosan in Small Fish	RMP	1				41					
	Musks in Water & Sediment[5]	RMP	1					64.5				
	Siloxanes in Sediment and Effluent	SWEAM / DTSC	1,2					(15)				
	Sunscreen Chemicals in Wastewater	RMP	1,2							50		
Pesticides	Imidacloprid, Imidacloprid Degradates and other Neonicotinoids in Ambient Bay Water	RMP	1				40					
	DPR Priorities in Water & Sediment[5]	RMP / USGS	1,2,3					64.5 (6.8)				
	Agricultural Pesticides in Water & Sediment – coordinated with North Bay Margins	RMP	1,2							100		
SDPAs/BZTs	Water, Sediment	ECCC	1	(3)								
OH-BDEs / Triclosan	Water, Sediment Cores	U Minn	1,3,4	(125)								

Element	Study	Funder	Questions addressed	2014	2015	2016	2017	2018	2019	2020	2021	2022
PHCZs	Sediment, Tissue	SIU	1		(15)	(20)	(40)					
Brominated Azo Dyes	Archived Sediment, Tissue	RMP	1							60		
NON-TARGETED & OTHER STUDIES												
Non-targeted	Non-targeted Analysis of Water-soluble CECs	RMP / Duke / AXYS	1,2			52 (10) (6)						
	Non-targeted Analysis of Sediment	RMP	1,2					101				
	Follow-up Targeted Study, Stormwater[2]	RMP	1,2						33	40	39	
	Tissue (Polar and Nonpolar Compounds)	RMP	1								75	75
	Follow-up Targeted Study (2018 results)	RMP	1									100
	Non-targeted Analysis of Runoff from North Bay Wildfires	RMP / DTSC / Water Board / Duke	1,2					36 (20) (27) (3)				
Other	Trash Hot Spots Study	RMP	1									120
	Toxicology	RMP	1							60	60	60
RELEVANT STUDIES IN OTHER WORKGROUPS												
Bioassay (EEWG)	Linkage of In Vitro Estrogenic Assays with In Vivo End Points	RMP / SCCWRP / UF	1,2	56 (125)			45					
RMP-funded Special Studies Subtotal - ECWG				**150**	**75**	**130**	**284**	**366**	**325**	**725**	**631**	**729**
RMP-funded Special Studies Subtotal – Other Workgroups				**56**	**0**	**0**	**45**	**0**				
RMP Supplemental Environmental Project Subtotal				**0**	**0**	**0**	**0**	**0**				
Pro-Bono & Externally Funded Studies Subtotal				**165**	**90**	**112**	**90**	**37**				
OVERALL TOTAL				**371**	**165**	**242**	**419**	**403**	**325**	**725**	**631**	**729**

1 – The 2015 CECs in Municipal Wastewater study was a $55k study that included analyses of PFOS/PFAS and fipronil; in this table the budget for this study has been split between these two contaminant groups.
2 – The proposed multi-year (2019-2021) stormwater study includes four sets of analytes: PFASs, ethoxylated surfactants, phosphate flame retardants, and followup target stormwater analytes identified via non-targeted analysis. The total cost ($448k) is spread across the four analyte groups and three years of study.
3 – When a CEC is proposed for inclusion in the the RMP Status and Trends monitoring, there is a letter in the cell denoting the matrix for which monitoring is proposed: W = water; S = sediment; B = bivalve; E = eggs; F = fish.
4 – Analysis of fipronil and fipronil degradates in sediment has been added to the RMP Status and Trends monitoring effort for 2018. In addition, an initial investigation of these analytes in sport fish was recommended for 2019 via Status and Trends monitoring.
5 – The 2018 CECs in Municipal Wastewater study was a $129k study that included analyses of pesticides and fragrance ingredients; in this table the budget for this study has been split between these two contaminant groups.

SMALL TRIBUTARY LOADING

Relevant Management Policies and Decisions

Refining pollutant loading estimates for future TMDL updates.

Informing provisions of the current and future versions of the Municipal Regional Stormwater Permit (MRP).

Identifying small tributaries to prioritize for management actions.

Informing decisions on the best management practices for reducing concentrations and loads.

Stormwater sampling. Photograph by Jennifer Sun.

Recent Noteworthy Findings

Based on particle ratio information collected by the RMP in stormwater to-date, the samples with the highest concentrations for PCBs have been collected from watersheds draining to Pulgas Creek Pump Station, a ditch on Industrial Rd. in San Carlos, Santa Fe Channel, a storm drain on Gull Dr. in South San Francisco, and an outfall at Gilman Street. The outfall at Gilman Street, and the Santa Fe Channel sites also appear to be relatively polluted for mercury.

Remote sediment samplers were pilot tested at 14 sites, and show promise as a lower-cost stormwater characterization tool, especially for PCBs. These samplers will be used for characterizing new sites in 2019.

Using a statistical model developed for PCB loads in the Guadalupe River, 80% of the variability in loads is accounted for by rainfall characteristics and seasonality, providing insight into monitoring design to detect trends in PCB loads for this watershed.

A rare five-year storm event was sampled in Guadalupe River in January 2017. The load measured during the five-day storm event was 70 kg, far more than the total wet season loads for every year since 2003.

Note: "Small tributary" refers to the rivers, creeks, and storm drains that enter the Bay from the nine counties that surround the Bay.

Special studies for this focus area assess contaminant loading to the Bay from these small tributaries.

Priority Questions for the Next Five Years

1. What are the loads or concentrations of pollutants of concern from small tributaries to the Bay?
2. Which are the "high-leverage" small tributaries that contribute or potentially contribute most to Bay impairment by pollutants of concern?
3. How are loads or concentrations of pollutants of concern from small tributaries changing on a decadal scale?
4. Which sources or watershed source areas provide the greatest opportunities for reductions of pollutants of concern in urban stormwater runoff?
5. What are the measured and projected impacts of management action(s) on loads or concentrations of pollutants of concern from the small tributaries, and what management action(s) should be implemented in the region to have the greatest impact?

MULTI-YEAR PLAN FOR SMALL TRIBUTARY LOADING STRATEGY

Small tributaries loading studies in the RMP from 2015 to 2022. Numbers indicate budget allocations in $1000s. Budgets in parentheses represent funding or in-kind services from external partners. Items included in the planning budget are shaded in yellow. Bold boxes indicate multi-year studies.

Element	Funder	Questions addressed	2015	2016	2017	2018	2019	2020	2021	2022
Coordination and management	RMP		26	26	30	32	40	50	50	50
Source Area Monitoring/EMC development	RMP	1,2,3,4								
Source Area Monitoring/EMC development and RAA	BASMAA	1,2,3,4	(450)	(350)	(450)	(950)	(1000)	(750)	(500)	(500)
Regional Watershed Spreadsheet Model: Water, Sediment, PCBs and Mercury	RMP	1,2,4	35	35	40	7				
POC Reconnaissance Monitoring	RMP	1,2,3,4	374	150	200	125	125	100	100	100
POC Reconnaissance Monitoring	BASMAA	1,2,3,4	(200)	(200)	(200)					
Advanced Data Analysis	RMP	1,2,3,4				100	50	50	50	25
Trends Strategy - Modeling	RMP	3,5	35	100	100		60	125	150	175
Trends Strategy - Monitoring	RMP							150	150	150
AFR conceptual model development	RMP	1,4				13				
Emerging Contaminants coordination	RMP	1,4								
Guadalupe River Hg loads	RMP				40					
Innovative monitoring methods	RMP	1,2,3,4								
Unallocated	RMP					25				
RMP-funded Special Studies Subtotal – STLS			**470**	**311**	**410**	**302**	**275**	**475**	**500**	**500**
RMP-funded Special Studies Subtotal – Other Workgroups			**0**	**0**	**0**	**0**				
RMP Supplemental Environmental Projects			**0**	**0**	**0**	**0**				
Pro-Bono & Externally Funded Studies Subtotal			**650**	**550**	**650**	**950**	**1000**	**750**	**500**	**500**
Overall Total			**1120**	**861**	**1060**	**1252**	**1275**	**1150**	**1000**	**1000**

Screening and characterization to identify high-leverage watersheds will be the major emphasis for the next several years, along with an increasing focus on data analysis and detecting trends in loads or concentrations of pollutants of concern from small tributaries.

NUTRIENTS

The Nutrient Management Strategy (NMS) is a major collaborative regional science program that receives funding from the RMP for nutrient monitoring and special studies.

Relevant Management Policies and Decisions

Developing nutrient numeric endpoints and assessment framework

Evaluating need for revised objectives for dissolved oxygen and other parameters

Assessing water quality impairment status

Implementing NPDES permits for wastewater and stormwater

Recent Noteworthy Findings

In 2016, the NMS finished a 10-year Science Plan for addressing monitoring and research needs.

Major progress on numerical models has been made in the first two years of the program. A major validation report was produced in 2017 that showed the hydrodynamic model in its current state sufficiently represents transport in South Bay to support water quality studies with a South Bay focus.

Data from high-frequency sensors and fish trawls in Lower South Bay are being synthesized to explore the issue of where and when there is adequate dissolved oxygen to support resident fish species. The report, which was completed in 2018, was a collaboration between SFEI and the University of California Davis.

Funding for a Supplemental Environmental Project is being used for a major study on harmful algae and toxins. The study will investigate whether toxins are accumulating in small fish and mussels. The use of new molecular techniques to identify harmful algae will also be tested. A report on this study will be prepared in 2019.

Priority Questions for the Next Five Years

1. What conditions in different Bay habitats would indicate that beneficial uses are being protected versus experiencing nutrient-related impairment?

2. In which subembayments or habitats are beneficial uses being supported? Which subembayments or habitats are experiencing nutrient-related impairment?

3A. To what extent is nutrient over-enrichment, versus other factors, responsible for current impairments?

3B. What management actions would be required to mitigate such impairments & protect beneficial uses?

4A. Under what future scenarios could nutrient-related impairments occur and which of these scenarios warrant pre-emptive management actions?

4B. What management actions would be required to protect beneficial uses under those scenarios?

5. What nutrient sources contribute to elevated nutrient concentrations in subembayments or habitats that are currently impaired, or would be impaired in the future by nutrients?

6. When nutrients exit the Bay through the Golden Gate, where are they transported and how do they influence water quality in the Gulf of Farallones or other coastal areas?

7. What specific management actions, including load reductions, are needed to mitigate or prevent current or future impairment?

MULTI-YEAR PLAN FOR NUTRIENTS

Special studies and monitoring in the RMP from 2013 to 2022. Numbers indicate budget allocations in $1000s. Budgets in parentheses represent funding or in-kind services from external sources. The projects funded by non-RMP sources are not specified; only general allocations are indicated. This table does not show nutrient monitoring done for Status & Trends. Items included in planning budget are shaded in yellow. Bold boxes indicate multi-year studies.

Element	Study	Funder	Questions Addressed	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	RMP funding												
Strategy	Program coordination	RMP	1-5	20	20								
Monitoring	Moored sensors	RMP	1	200	215	190	39.3	220	230	250	400	400	400
	Ship-based channel monitoring	RMP	1					153	120				
	Algal biotoxins	RMP SEP	1	65					(195)				
	Stormwater loads	RMP	3	40	35								
	Monitoring program development	RMP	1,3		50		20						
	Dissolved oxygen						200						
	HF mapping					115							
	Chl-a analysis						15.7						
	Data management						25						
Modeling	Modeling[1]	RMP SEP	4,5	100	200	165		(240)					
Synthesis	Conceptual model report	RMP	1-5	50									
	Synthesis: nutrient loads and data gaps	RMP	3	30									
RMP-funded Special Studies Subtotal				**505**	**520**	**470**	**300**	**373**	**350**	**250**	**400**	**400**	**400**
RMP Supplemental Environmental Projects Subtotal								**240**	**195**				
Pro-Bono & Externally-funded Special Studies Subtotal[1]				**845**	**725**	**1010**	**880**	**1437**	**1952**	**1480**	**2200**	**2200**	**2200**
OVERALL TOTAL				**1460**	**1417**	**1652**	**1372**	**2022**	**2537**	**1572**	**2849**	**2857**	**2864**

[1] Funding provided by BACWA, CCCSD, DSP, Regional San, City of Palo Alto, City of Sunnyvale, State Water Resources Control Board, and DWR-EMP for a range of studies that support the Nutrient Management Strategy. The descriptions of these projects are not included here for simplicity.

MICROPLASTIC

Relevant Management Policies and Decisions

Regional bans on plastic bags, foam packaging materials, and plastic straws

Proposed bans on single use plastic

State and Federal bans on microbeads

Trash TMDL

Potential for public outreach and education regarding pollution prevention for microplastic and macroplastic that can disintegrate to microplastic

> **Microplastic**
>
> Commonly defined as plastic particles smaller than 5 mm, come in a broad range of shapes and sizes. Commonly observed particles include fragments, fibers or lines, pellets, films, or foam bits. Differences in size and shape can affect the way particles move through the environment, and may modify their potential for toxicity.

Recent Noteworthy Findings

In 2015, a preliminary screening study visually identified microparticles, which include but are not limited to microplastic, in San Francisco Bay surface water, and in effluent discharged to the Bay. In response to this finding, RMP convened a Microplastic Workgroup and developed a Microplastic Strategy to prioritize microplastic monitoring and science in the Bay, and to develop a list of management questions to guide this work.

In 2017, with a generous grant from the Gordon and Betty Moore Foundation ($968,000) and the financial and in-kind support of the RMP, EBMUD, City of Palo Alto, and Patagonia, SFEI and the 5 Gyres Institute embarked on a two-year project to conduct a comprehensive study of the San Francisco Bay and the adjacent National Marine Sanctuaries to provide scientific information to answer many of the questions outlined in the Microplastic Strategy.

The sampling and analysis plan (SAP) explains the rationale and methods for the two-year study to sample and analyze Bay and sanctuary waters, sediment, prey fish, stormwater runoff and wastewater effluent.

All of the field sampling activities outlined in the SAP have been successfully completed. Several hundred samples have been shipped to the laboratory where they are currently being extracted, enumerated by size, color, and morphology, and, for a subset of samples, analyzed using chemical spectroscopy to determine plastic composition. Significant progress has been made on laboratory method development and CEDEN data reporting formats.

Preliminary results suggest that microplastic is detected in most matrices, in some cases at relatively high concentrations (e.g., Bay water).

In addition to the Moore project, with external funding, SFEI staff have conducted small pilot study of the efficacy of rain gardens to remove microplastic. This demonstration project suggests that rain gardens can significantly reduce concentrations of microplastic by greater than 90%.

A report summarizing the two-year study will be available in Fall of 2019.

Priority Questions for the Next Five Years

1. How much microplastic pollution is in the Bay?
2. What are the health risks?
3. What are the sources, pathways, loadings, and processes leading to microplastic pollution in the Bay?
4. Have the concentrations of microplastic in the Bay increased or decreased?
5. What management actions could be effective in reducing microplastic pollution?

MULTI-YEAR PLAN FOR MICROPLASTIC

Microplastic studies and monitoring in the RMP from 2016 to 2022. Numbers indicate budget allocations in $1000s. The asterisk indicates RMP match funding for the Moore Foundation grant. Budgets in parentheses represent funding or in-kind services from external partners. Budgets with “x” values indicate unknown total funding from externally-funded projects that will be used to inform work conducted as part of this strategy. Items included in planning budget are shaded in yellow. Bold boxes indicate multi-year studies.

Element	Study	Funder	Questions Addressed	2016	2017	2018	2019	2020	2021	2022
Strategy	Microplastic Strategy	RMP	1,2,3,4,5	25			15	15	15	15
	Private Foundation Grant Match	RMP	1,2,3,4,5		75*					
Method Development	New methods for collection, extraction, analysis, & intercomparison	EPA / NOAA	1,3			(x)	(x)			
	Follow up on new method development	RMP							50	
Monitoring biota	Bivalves	RMP	1,2,4			46				
	Sport fish	RMP					15[1]	100		
	Benthic organisms	RMP							50	
	Prey fish	Moore Foundation			(130)					
	Assessing ecological impacts	RMP							120	
Monitoring water and sediment	Ambient & margins sediment	Moore Foundation	1,3,4		(100)					
	Sediment cores	RMP								
	Surface water: Bay /Ocean	Moore Foundation			(238)					
	Monitoring abiotic matrices	RMP								100
	Monitoring surface water	Bay Keeper				(x)				
Characterizing sources, pathways, loadings, processes	Stormwater and wastewater effluent	Moore Foundation	1,3			(90)				
	Evaluating efficacy of rain gardens	SFEP			(10)					
	Model transport in Bay & ocean	Moore Foundation				(80)				
	Monitoring in pathways	RMP						120		
Evaluating control options	Options for source control/ efficacy of microbead ban, foam bans	Moore Foundation	5			(40)				
	Characterize microplastic additives to assess exposure	RMP								100
Synthesis	Synthesize findings (e.g. report, factsheet, video), hold symposium	Moore Foundation	1,3				(290)			
RMP-funded Special Studies Subtotal – MPWG				**25**	**75**	**46**	**30**	**235**	**235**	**215**
RMP-funded Special Studies Subtotal – Other Workgroups				**0**	**0**	**0**				
RMP Supplemental Environmental Projects Subtotal				**0**	**0**	**0**				
Pro-Bono & Externally-funded Special Studies Subtotal				**0**	**478**	**210**	**290**			
OVERALL TOTAL				**25**	**553**	**256**	**320**	**235**	**235**	**215**

1 – Collection at two sites and archiving.

PCBs

Relevant Management Policies and Decisions

PCBs TMDL and potential update

Implementation of NPDES permits

Selecting management actions for reducing PCB impairment

Municipal Regional Permit

Recent Noteworthy Findings

Shiner surfperch have a Bay-wide average concentration nine times higher than the TMDL target, and these concentrations have resulted in an advisory from the Office of Environmental Health Hazard Assessment (OEHHA) recommending no consumption for all surfperch in the Bay. Concentrations in shiner surfperch and white croaker show no clear sign of decline. Average concentrations in Suisun Bay sediments are lower than in the other Bay segments, indicating a lower degree of impairment in this region.

Urban stormwater is the pathway carrying the greatest PCB loads to the Bay and with the greatest load reduction goals. Concentrations of PCBs and mercury on suspended sediment particles from a wide range of watersheds are being measured as an index of the degree of watershed contamination and potential for effective management action. Stormwater samples from Pulgas Creek Pump Station North and South, Industrial Road Ditch, an outfall to Colma Creek, and Gull Drive Storm Drain in San Mateo County; Santa Fe Channel in Contra Costa County; Line 12H at Coliseum Way, and Outfall at Gilman Street in Alameda County; and Outfall to Lower Silver Creek in Santa Clara County had the highest concentrations of PCBs on suspended sediment particles measured to date.

An assessment of the Emeryville Crescent established a conceptual model as a foundation for monitoring response to load reductions and for planning management actions. The key finding was that PCB concentrations in sediment and the food web could potentially decline fairly quickly (within 10 years) in response to load reductions from the watershed.

A conceptual model and extensive field studies in San Leandro Bay have documented persistent sediment contamination that is likely due to continuing inputs from the watershed.

Priority Questions for the Next Five Years

1. What are the rates of recovery of the Bay, its segments, and in-Bay contaminated sites from PCB contamination?
2. What are the present loads and long-term trends in loading from each of the major pathways?
3. What role do in-Bay contaminated sites play in segment-scale recovery rates?
4. Which small tributaries and contaminated margin sites are the highest priorities for cleanup?
5. What management actions have the greatest potential for accelerating recovery or reducing exposure?
6. What are the near-term effects of management actions on the potential for adverse impacts on humans and aquatic life due to Bay contamination?

MULTI-YEAR PLAN FOR PCBs

Special studies and monitoring in the RMP from 2015 to 2022. Numbers indicate budget allocations in $1000s. Budgets in parentheses represent funding or in-kind services from external sources. Items included in planning budget are shaded in yellow. Bold boxes indicate multi-year studies.

Element	Study	Funder	Questions addressed	2015	2016	2017	2018	2019	2020	2021	2022
General	Develop and update multi-year workplan and continued support of PCB Workgroup meetings	RMP		10	10	10	10	10	10	10	10
PMU	Prioritize Margin Units	RMP	1, 4, 5, 6	30							
	Develop Conceptual Site Models and Mass Balances for PMUs (4 PMUs)	RMP SEP	1, 4, 5, 6	45	30 (30)	60					
	PMU Field Studies to Support the Development of Conceptual Site Models and Monitoring Plans	RMP SEP	1, 4, 5, 6		(202)		21[1]	30[2] (37)[2]	110	100	100
	PMU Trend Monitoring (4 PMUs)	SEP	1, 4, 5, 6					(60)[3]			
DMMO	Synthesis of DMMO data for PCB hot spots and mass removed	SEP	1				(45)				
RMP-funded Special Studies Subtotal – PCBs				**85**	**40**	**70**	**31**	**40**	**120**	**110**	**110**
RMP-funded Special Studies Subtotal – Other Workgroups				**0**	**0**	**0**	**0**				
RMP Supplemental Environmental Projects Subtotal				**0**	**232**	**0**	**45**	**97**			
Pro-Bono & Externally Funded Studies Subtotal				**0**	**0**	**0**	**0**				
OVERALL TOTAL				**85**	**272**	**70**	**76**	**137**	**120**	**110**	**110**

[1] San Leandro Bay gut contents
[2] PMU stormwater sampling
[3] Shiner Surfperch PMU Survey

SELENIUM

Relevant Management Policies and Decisions

North Bay Selenium TMDL

USEPA Selenium Criteria for the Bay-Delta

South Bay Selenium TMDL (under consideration)

Recent Noteworthy Findings

White sturgeon, a benthic species, is recognized as a key indicator of selenium impairment in the North Bay due to its susceptibility to selenium bioaccumulation. In general, white sturgeon muscle selenium concentrations measured over the past 30 years have exceeded the North Bay TMDL target in some individual sturgeon, but annual average concentrations have remained below the target and no long-term trend has been apparent since 1987. The highest tissue selenium concentrations were measured in in Suisun Bay; the lowest were in Central Bay. Sturgeon muscle plug sampling provides a non-lethal means of obtaining a larger sample size of concentrations in the North Bay. Selenium concentrations measured in sturgeon muscle plugs and muscle fillets are well-correlated. Concentrations in muscle plugs were relatively high in 2015 and 2016, with medians near the TMDL target. Concentrations were much lower, however, in 2017, apparently in response to high flows in the winter of water year 2017.

The Lower South Bay has much higher average selenium concentrations in water than the other Bay segments, but white sturgeon collected in South Bay have had lower concentrations than North Bay sturgeon. This difference from the North Bay may be due to the low abundance of *Potamocorbula* (overbite clam) in the South Bay.

The RMP Selenium Workgroup has developed a monitoring plan for sturgeon, water, and clams to track trends, with a special emphasis on early detection of change. It is an integrated, long-term design for all three indicators based on a solid statistical framework that is explicitly linked to management decision-making.

Priority Questions for the Next Five Years: General

1. What are appropriate thresholds?
2. Are the beneficial uses of San Francisco Bay impaired by selenium?
3. What is the spatial pattern of selenium impairment?
4. How do selenium concentrations and loadings change over time?
5. What is the relative importance of each pathway of selenium loading in the Bay?

Priority Questions for the Next Five Years: North Bay

6. Are the beneficial uses of north San Francisco Bay impaired by selenium?
7. Are changes occurring in selenium concentrations that warrant changes in management actions?
8. Will proposed changes in water flows and/or selenium loads in the Bay or upstream cause impairment in the North Bay?

Selenium Multi-Year Plan

Selenium studies and monitoring in the RMP from 2014 to 2023. Numbers indicate budget allocations in $1000s. Budgets in parentheses represent funding or in-kind services from external sources. Items included in planning budget are shaded in yellow. Bold boxes indicate multi-year studies.

Element	Funder	Questions addressed	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Selenium Strategy Coordination	RMP SEP	1,2,3,4,5, 6,7,8	10	10	10	25 (10)	10	10	10	10	10	10
Selenium Information Synthesis	SEP	1,2,3,4,5, 6,7,8		10		(50)						
Selenium Sturgeon Plugs	SEP	1,2,3,4, 6,7,8	23	35		(57)		22	24	22	24	22
Selenium Sturgeon Derby		1,2,3,4,6		29	37	42						
Selenium Monitoring in North Bay Clams and Water		1,2,3,4,5, 6,7,8				39		75	110	75	110	75
Selenium in North Bay Water: Synthesis	SEP	1,2,3,4,5, 6,7,8				(50)						
Selenium South Bay Synthesis		1,2,3,4,5										
Selenium South Bay Food Web Sampling		1,2,3,4										
Selenium South Bay Model		5										
RMP-funded Special Studies Subtotal - Se			**33**	**84**	**47**	**106**	**10**	**107**	**144**	**107**	**144**	**107**
RMP-funded Special Studies Subtotal – Other Workgroups			**0**	**0**	**0**	**0**	**0**					
RMP Supplemental Environmental Projects Subtotal			**0**	**0**	**0**	**167**	**0**					
Pro-Bono & Externally Funded Studies Subtotal			**0**	**0**	**0**	**0**	**0**					
OVERALL TOTAL			**33**	**84**	**47**	**273**	**10**	**107**	**144**	**107**	**144**	**107**

SEDIMENT

The mission of the Sediment Workgroup is to provide technical oversight and stakeholder guidance on RMP studies addressing questions about sediment delivery, sediment transport, dredging, and beneficial reuse of sediment.

Relevant Management Policies and Decisions

Long-Term Management Strategy for Dredged Material in SF Bay (LTMS) to comply with the Basin Plan

NOAA 2011 Programmatic Essential Fish Habitat Agreement & 2015 LTMS Amended Programmatic Biological Opinion

PCB TMDL

Mercury TMDL

Regional Restoration Plans[1]

Recent Noteworthy Findings

In water years (WY) 2016 and 2017, the USGS monitored the sediment flux through the Golden Gate. This flux is the largest unknown in the sediment budget for the Bay. Results indicate that sediment loads from the Delta during winter storms were mostly retained in San Pablo Bay, even during the historically high floods of WY2017. One recommendation from the report[2] was to use modeling to evaluate cumulative fluxes over longer periods than can be monitored.

USGS monitoring of suspended sediments at the Dumbarton Bridge in WY2016 indicated that particle flocculation is an important factor for accurately calculating the sediment flux into Lower South Bay. The RMP has allocated funds for a special study in 2018-2019 to follow-up on this finding.

A synthesis report estimated that net average annual sediment supply to San Francisco Bay from terrestrial sources during the most recent 22-year period (WY1995-2016) was 1.95 million metric tons. Approximately 63% of the sediment supply was estimated to be from small tributaries that drain directly to the Bay. Net supply from the Central Valley (measured at Mallard Island) was approximately 37% of the total supply. Bedload supply, after accounting for dredging, removals, and storage in flood control channels, was essentially zero. Recent data do not indicate any trends other than the step decrease in supply from the Delta in 1999. The report contains initial recommendations for improvements in sediment supply monitoring.

Priority Questions for the Next Five Years

1. What are acceptable levels of chemicals in sediment for placement in the Bay, baylands, or restoration projects?

2. Are there effects on fish, benthic species, and submerged habitats from dredging or placement of sediment?

3. What are the sources, sinks, pathways and loadings of sediment and sediment-bound contaminants to and within the Bay and subembayments?

4. How much sediment is passively reaching tidal marshes and restoration projects and how could the amounts be increased by management actions?

5. What are the concentrations of suspended sediment in the Estuary and its segments?

[1] San Francisco Bay Restoration Authority Goals, Baylands Goals Update for Climate Change, Subtidal Habitat Goals Project, and Action 13 “Manage sediment on a regional scale and advance beneficial reuse” from the Comprehensive Conservation and Management Plan.

[2] https://www.sfei.org/documents/water-and-suspended-sediment-flux-measurements-golden-gate-2016-2017.

MULTI-YEAR PLAN FOR SEDIMENT

Special studies and monitoring in the RMP from 2014 to 2022. Numbers indicate budget allocations in $1000s. Budgets in parentheses represent funding or in-kind services from external sources. Budgets that are starred represent funding that has been allocated for the given study within other workgroups. This table does not show suspended sediment monitoring done for Status & Trends. Items included in planning budget are shaded in yellow. Bold boxes indicate multi-year studies.

Element	Study	Funder	Questions addressed	2015	2016	2017	2018	2019	2020	2021	2022
Strategy	Sediment Monitoring Strategy	RMP WQIF	1,3,4			50 (238)		78			
	Strategy/Workgroup Support	RMP	1,2,3,4				10		10	10	10
	Sediment Modeling Strategy		1,2,3,4						40		
Screening Values	Sediment Bioaccumulation Guidance	RMP	1				30*		48		
	Benthic Index Development	RMP	1				21*		29		
Impact Studies	Participate in Essential Fish Habitat Studies	RMP LTMS	2						TBD	TBD	TBD
	Synthesis of Light Attenuation Near Dredging		1,2							40	
Data Mining	DMMO Database and Online Tools	RMP	1				55	Database maintenance costs covered by core program			
	Synthesis of DMMO Data	RMP	1,2			12*		(45)	40	40	40
Beneficial Reuse	Beneficial Reuse and Strategic Placement Projects or Planning	RMP	1,2					30	40	50	50
	Bulk Density of Sediment Types	RMP	4					30			
Sediment Budgets	Sediment Supply Synthesis	RMP USGS	3,4			40 (40)					
	Golden Gate Sediment Flux Study	RMP SEP	3,4		33 (98)	(69)			45		
	Lower South Bay Sediment Flux Study	RMP SEP	3,4		(98)		120	(158)			
	Mallard Island Sediment Flux Monitoring	RMP	3,4				30				
	Bathymetric Change Studies	RMP	3,4					77	77		
	Maintain Stream Gages and Add New Ones	RMP SEP	3				(115)		60	60	60
General	General Allocation to Fill High Priority Data gaps									125	125
RMP-funded Special Studies Subtotal – Sediment				**0**	**33**	**90**	**215**	**215**	**389**	**325**	**285**
RMP-funded Special Studies Subtotal – Other Workgroups				**0**	**0**	**12**	**51**				

RMP Supplemental Environmental Projects Subtotal	**0**	**196**	**69**	**115**	**158**			
Pro-Bono & Externally Funded Studies Subtotal	**0**	**0**	**278**	**0**	**45**			
OVERALL TOTAL	**0**	**229**	**49**	**381**	**418**	**389**	**325**	**285**

STATUS AND TRENDS MONITORING

Relevant Management Policies and Decisions

Define ambient conditions in the Bay

Water Quality Assessment – 303(d) impairment listings or de-listings

Determination if there is a reasonable potential that a NPDES-permitted discharge may cause violation of a water quality standard

Evaluation of water and sediment quality objectives

Dredged material management

Development and implementation of TMDLs for mercury, PCBs, and selenium

Site-specific objectives and anti-degradation policies for copper and cyanide

Development and evaluation of a Nutrient Assessment Framework

Recent Noteworthy Findings

In 2015, the RMP monitored sediments in the margin areas of Central Bay. The study determined the ambient concentrations of PCBs, mercury, and other contaminants in these areas. On average, PCB concentrations were 4-5 times higher in the margins than in the open Bay. The study also detected a number of “warm spots” where the concentrations of contaminants were significantly elevated and one previously unknown “hot spot”. This assessment was repeated in 2017 in South Bay and Lower South Bay.

In 2017, the RMP published the latest information on contaminant concentrations in sport fish tissue. The most recent data show that there was no long-term trend for mercury and little evidence of PCB declines in important sport fish species.

Copper concentrations in water, last monitored in 2017, remain below trigger levels.

Over a decade of monitoring shows that PBDE levels have declined in bivalves, bird eggs, sport fish, and sediment following nationwide phase-outs and state bans of these toxic and persistent flame retardant chemicals. The RMP now considers PBDEs to be in the “low concern” category and will reduce, but not eliminate, monitoring for them. Conversely, fipronil, a current use pesticide was added to the list of target analytes for sport fish and sediment because of increased concern about this chemical.

Priority Questions for the Next Five Years

1. Are contaminants at levels of concern?

2. What are concentrations and masses of priority contaminants in the Bay, its compartments, and its segments?

3. Are there particular regions of concern?

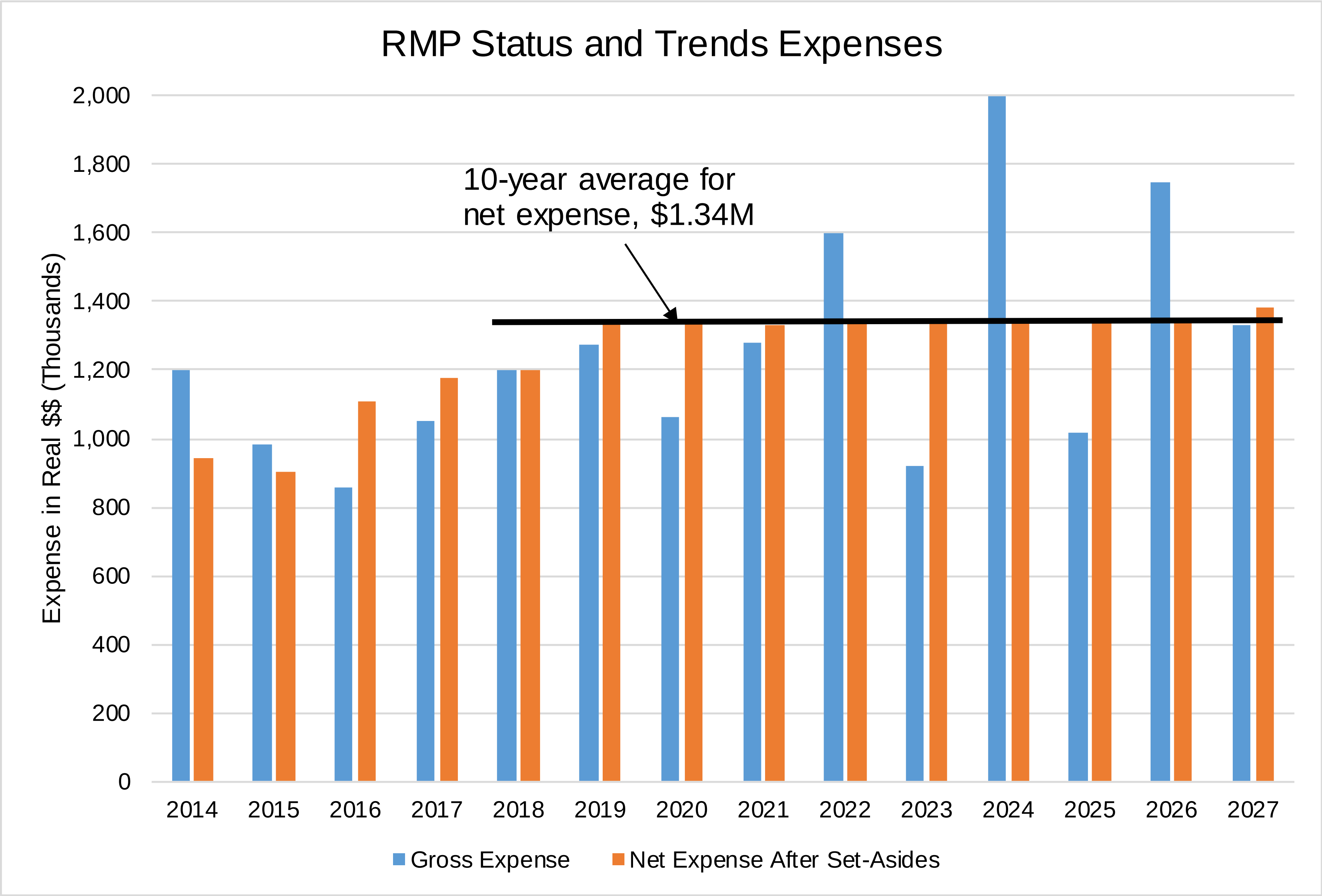
4. Have concentrations and masses increased or decreased?

> When recommending addition of any analyte to S&T, the following details need to be specified: relevance of the analyte to a management question, the matrix to be monitored, the frequency of monitoring, the minimum duration of the monitoring, and the spatial extent (e.g., all sites or a subset).

MULTI-YEAR PLAN FOR STATUS AND TRENDS MONITORING

Status and Trends Monitoring in the RMP from 2014 to 2027. Numbers indicate budget allocations in $1000s.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Monitoring Type	*Actl*	*Actl*	*Actl*	*Actl*	*Bdgt*	*Est*	*Fcst*	*Fcst*	*Fcst*	*Fcst*	*Fcst*	*Fcst*	*Fcst*	*Fcst*
USGS Moored Sensor Network for Suspended Sediment	250	250	250	250	250	250	250	250	250	250	250	250	250	250
USGS Monthly Cruises for Nutrients and Phytoplankton	173	173	223	229	235	242	249	257	264	272	281	289	298	307
S&T Water		179		221		216		243		257		273		290
Water-Organics								124						
Water-CTR		40										53		
S&T Bivalves	136		144		118		138		147		156		165	
Bivalves-PCBs									20					
S&T Bird Eggs			198		222			254			277			303
Bird Egg Report											54			
S&T Margins Sediment		233		231			252		267		284		301	
Margins Report		42		50			55							
S&T Sediment	251				291				356				400	
Tox/Benthos									135				152	
S&T Sport Fish	311					355					448			
Sport Fish Report	41					50					60			
Archives	20	48	22	51	47	62	58	60	62	64	66	68	70	72
NIST Contract						22		24		26		27		29
Reporting	19	18	19	8	10	22	23	24	25	26	26	27	28	29
Lab Intercomp Studies				10	30	55	37	43	73	29	100	30	82	52
Grand Total	**1,202**	**983**	**856**	**1,050**	**1,203**	**1,273**	**1,063**	**1,278**	**1,599**	**923**	**2,001**	**1,017**	**1,746**	**1,330**
Set-Aside Funds Used	**417**	**79**	**0**	**0**	**0**	**0**	**0**	**0**	**250**	**0**	**650**	**0**	**400**	**0**
Set-Aside Funds Saved	**161**	**0**	**250**	**125**	**0**	**66.5**	**275**	**50**	**0**	**425**	**0**	**325**	**0**	**50**
Set-Aside Funds Balance	**297**	**218**	**468**	**593**	**593**	**659.5**	**934.5**	**984.5**	**734.5**	**1159.5**	**509.5**	**834.5**	**434.5**	**484.5**
Net S&T Funding Needed	**946**	**904**	**1,106**	**1,175**	**1,203**	**1,340**	**1,338**	**1,328**	**1,349**	**1,348**	**1,351**	**1,342**	**1,346**	**1,380**


RMP Status and Trends Expenses
10-year average for
net expense, $1.34M
Expense in Real $$ (Thousands)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
Gross Expense
Net Expense After Set-Asides

Regional Monitoring Program for Water Quality in San Francisco Bay

Monitoring Design for the Status and Trends Monitoring Program (2014-2027)

Program	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
USGS Moored Sensor Network for Suspended Sediment (5 targeted sites) [a]														
Parameters: SSC, Water temperature, Salinity	X	X	X	X	X	X	X	X	X	X	X	X	X	X
USGS Monthly Cruises for Nutrients and Phytoplankton in Deep Channel (38 targeted sites)														
Parameters: CTD profiles, light attenuation, SSC, DO, Chl-a, Phytoplankton speciation, Nutrients (NO_2, NO_3, NH_4, PO_4, Si) [b]	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Every 2 Years: Toxic Contaminants in Water (5 targeted sites and 17 random sites)														
MeHg, Cu, Se (dissolved & particulate fractions in 2017 and onwards, dissolved & total fractions measured in 2015)		X		X		X		X		X		X		X
CN, Hardness, SSC, DOC, POC		X		X		X		X		X		X		X
Aquatic Toxicity (9 stations) [c]		X		X		X		X		X		X		X
Chl-a and Nutrients (NH4, NO3, NO2, TN, PO4, TP, Si) (at GG site only).				X										
PCBs, PAHs, Pesticides								X						
CTR parameters (10 samples at 3 targeted stations) [d]		X										X		
Every 2 years: Toxic Contaminants in Bivalve Tissue (7 targeted sites) [e]														
Se, PAHs	X		X		X		X		X		X		X	
PBDEs	X		X											
PCBs	X								X					
Every 3 Years: Toxic Contaminants in														

Program	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Bird Egg Tissue														
Cormorant Eggs: Hg, Se, PCBs, PBDEs, PFCs (3 targeted sites) [f]			X		X			X			X			X
Tern Eggs: Hg, Se, PBDEs (variable fixed sites) [g]			X		X			X			X			X
Every 2 Years: Toxic Contaminants in Bay Margin Sediments (~40 random sites)														
Ag, Al, As, Cd, Cu, Fe, Hg, MeHg, Mn, Ni, Pb, Se, Zn, PCBs, TOC, N, % Solids, Grain Size		X		X			X		?		?		?	
Every 4 Years: Toxic Contaminants in Sediment (7 targeted sites and 20 random sites) [h]														
Ag, Al, As, Cd, Cu, Fe, Hg, MeHg, Mn, Ni, Pb, Se, Zn, PAHs, PCBs, TOC, N, % Solids, Grain Size	X				X				X				X	
PBDEs	X				X				X					
Fipronil	X				X				X				X	
Legacy Pesticides	X								?				?	
Sediment Toxicity [i]									?				?	
Benthic Macroinvertebrates [j]									?				?	
Every 5 Years: Toxic Contaminants in Sport Fish Tissue (7 targeted sites)														
Hg, Se, PCBs, PBDEs, PFCs, Dioxins	X					X					X			
Fipronil						X					?			

Notes:

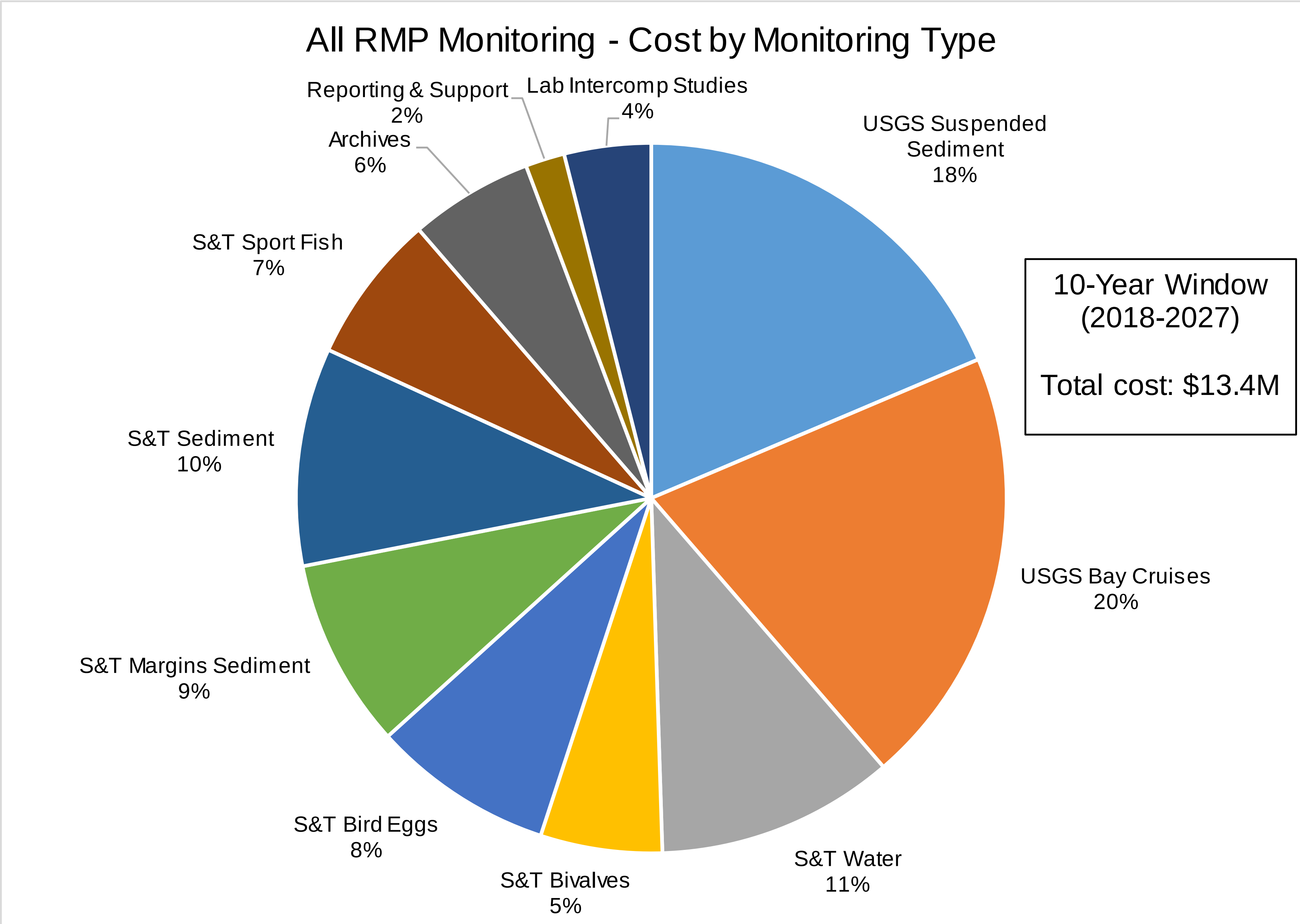
"X" = Planned sampling event. “?” = Event that is planned but must be approved by the RMP Steering Committee before implementation. Additional parameters can be added to sampling events to support RMP Special Studies.

a. The RMP Status and Trend Program provides direct support to the U.S. Geological Survey (PI: Dave Schoellhamer) for 5 SSC stations. However, this contribution leverages SSC data at 2 more stations and salinity at 8 stations funded by other partners. In addition, since 2012, the RMP has used Special Studies funds to add DO sensors at 6 stations and nutrient-related sensors to 3 stations.

b. Monthly cruises are completed by the U.S. Geological Survey (PI: Jim Cloern). Phytoplankton speciation and nutrient sampling only occurs at 14 of stations.
c. Aquatic Toxicity is measured following EPA Method 1007.0 (*Americamysis bahia*).
d. CTR sampling occurs at the Sacramento River, Yerba Buena Island, and Dumbarton Bridge sites.
e. Mussels (*Mytilus californianus*) are collected from Bodega Head State Marine Reserve, an uncontaminated "background" site of known chemistry, and are transplanted to 7 targeted locations in the Bay. After ~100 days, mussels from the transplanted sites and a sample from Bodega Head are collected for analysis. Three of the 7 transplant sites serve as back-ups in case something goes wrong with the transplants at the 4 primary sites. At the same time, resident clams (*Corbicula fluminea*) are collected from 2 sites in the Sacramento River and San Joaquin River.
f. Double-crested Cormorants (*Phalacrocorax auritus*). Cormorant eggs are collected at three sites: Don Edwards National Wildlife Refuge, the Richmond-San Rafael Bridge, and Wheeler Island.
g. Forster's Tern (*Sterna forsteri*). Tern eggs are typically collected from multiple sites in the Don Edwards National Wildlife Refuge and the Hayward Shoreline Regional Park.
h. Sediment samples are collected in the dry season (summer).
i. Sediment toxicity is measured using the following methods: EPA 600/R-94-025 (*Eohaustorius estuaries*), EPA 821/R-02-012M (*Ceriodaphnia dubia*), EPA 600/R-99-064 (*Hyalella azteca*), and EPA 600/R-95-136M (*Mytilus galloprovincialis*)
j. Benthic macroinvertebrates are measured during dry-season sediment sampling events (2014, 2022). Sediment samples are sieved through nested 1.0 and 0.5 mm sieves Organisms are sorted into major taxonomic categories and taxonomy and abundance are determined to the lowest practical taxonomic level.

Acronyms:

SSC: Suspended Sediment Concentration
Chl-a: Chlorophyll-a
CTD: Conductivity, Temperature, and Depth
CTR: California Toxics Rule, see http://water.epa.gov/lawsregs/rulesregs/ctr/
DO: Dissolved Oxygen
DOC: Dissolved Organic Carbon
MeHg: Methylmercury
NH_4: Ammonia (dissolved)
NO_2: Nitrite (dissolved)
NO_3: Nitrate (dissolved)
PAHs: Polynuclear Aromatic Hydrocarbons
PCBs: Polychlorinated Biphenyls
PBDEs: Polybrominated Diphenyl Ethers
"Pesticides": The suite of legacy pesticides that has been routinely measured by the RMP: Chlordanes (Chlordane, cis-; Chlordane, trans-; Heptachlor; Heptachlor Epoxide; Nonachlor, cis-; Nonachlor, trans-; Oxychlordane); Cyclopentadienes (Aldrin; Dieldrin; Endrin); DDTs (DDD(o,p'); DDD(p,p'); DDE(o,p'); DDE(p,p'); DDT(o,p'); DDT(p,p')); HCHs (HCH, alpha-; HCH, beta-; HCH, delta-; HCH, gamma-); Organochlorines (Hexachlorobenzene; Mirex).
PFCs: Perfluorinated Compounds
PO_4: Phosphate (dissolved)
POC: Particulate Organic Carbon
Si: Silica (dissolved)
TN: Total Nitrogen
TOC: Total Organic Carbon
TP: Total Phosphorus


All RMP Monitoring - Cost by Monitoring Type
Reporting & Support
2%
Lab Intercomp Studies
4%
USGS Suspended
Sediment
18%
Archives
6%
S&T Sport Fish
7%
10-Year Window
(2018-2027)
Total cost: $13.4M
S&T Sediment
10%
USGS Bay Cruises
20%
S&T Margins Sediment
9%
S&T Bird Eggs
8%
S&T Water
11%
S&T Bivalves
5%

PROGRAM MANAGEMENT

Approximately 11% of the total budget

Program management includes the following activities:

Program planning

- Preparing the Detailed Workplan and Multi-Year Plan

Contract and financial management

- Tracking expenditures versus budgets
- Developing and overseeing contracts and invoicing
- Providing financial updates to the RMP Steering Committee

Technical oversight

- Internal review by senior staff of reports, presentations, posters, workplans, memos, and other communications

Internal coordination

- Workflow planning
- Tracking deliverables and preparing RMP Deliverables Stoplight and Action items reports
- Staff meetings

External coordination

- Twenty meetings with external partners (SCCWRP, Delta RMP, SWAMP, and others) to coordinate programs and leverage RMP funds

Administration

- Office management assistance

Program Review

Periodically, the RMP conducts an overall peer review of the Program as a whole. Two external Program Reviews have been conducted to date, in 1997 and in 2003. The RMP has evolved considerably since the 2003 Review, with greatly enhanced planning processes that have made the Program much more forward-looking and thoroughly peer-reviewed.

A review of RMP governance was conducted in 2014 and a charter for the Program was adopted in 2015. An internal program review was conducted in 2016, focused on identifying new high priority technical areas and issues for the program to address. New science advisors, program partners, and technical focus areas were identified and will be further developed with the Technical Review Committee and Steering Committee.

The timing and scope of Program Reviews are determined by the Steering Committee. The Steering Committee does not consider a further External Program Review necessary at this time, as ongoing review of critical elements is well established.

Peer Review

Extensive peer review is a key to the cost-effective production of reliable information in the RMP. This peer review is accomplished through the following mechanisms.

- **Workgroups** include leading external scientists that work with stakeholders to develop workplans and provide feedback on project planning, implementation, and reporting
- The **Technical Review Committee** provides general technical oversight of the Program
- **Peer-reviewed publications** provide another layer of peer review for most significant RMP studies

GOVERNANCE

Approximately 8% of the total budget

RMP meetings provide a collaborative forum for communication among regulators, regulated entities, and scientists. This forum is provided by regular meetings of organizational and technical committees to track progress and guide future work. Additional information about the function and activities of each governance group can be found in Figures 1 and 3 in this booklet.

- **Steering Committee** – quarterly meetings to track progress, provide management direction, and track financials.
- **Technical Review Committee** – quarterly meetings to provide technical oversight.
- **Workgroups** – annual meetings to develop multi-year work plans, guide planning and implementation of special studies and Status and Trends monitoring, and provide peer-review of study plans and reports.
- **Strategy Teams** - stakeholder groups that meet as needed to provide frequent feedback on areas of emerging importance, and develop long-term RMP study plans for addressing these high priority topics. The RMP currently has active strategy teams for sport fish monitoring, small tributary loadings, and PCBs.

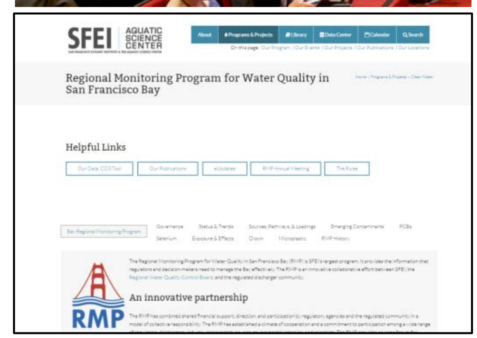
ANNUAL REPORTING & COMMUNICATIONS

Approximately 8% of the total budget (+$85,000 in years when a full Pulse report is produced)

Includes the Pulse of the Bay, Annual Meeting, RMP Update, Multi-Year Plan, State of the Estuary report card, RMP website, Annual Monitoring Report, technical reports, journal publications, Estuary News, oral presentations, posters, & media outreach.

These platforms are used to make information from the RMP available to the following target audiences:

- Primary Audience
  - **RMP Participants**. Need information to encourage support for the RMP and water quality programs in the Bay. The Pulse, Annual Meeting, Multi-Year Plan, State of the Estuary report card, RMP website, newsletter, fact sheets, oral presentations, media outreach.
- Secondary Audiences
  - **Other regional managers**. Need information to inform their decisions and evaluate effectiveness of their actions. A target audience for all communication products.
  - **Regional law and policy makers**. Need information to encourage support for water quality programs in the Bay. The Pulse, State of the Estuary report card, media outreach.
  - **Regional Scientists**. Need to share information to increase understanding of water quality and maintain technical quality of the science. A target audience for all communication products.
  - **Media, public outreach specialists, educators**. Need information to encourage support for the RMP and water quality programs in the Bay, and to protect their health. A target audience for the Pulse, Multi-Year Plan, State of the Estuary report card, RMP web site, newsletter, fact sheets, media outreach.
  - **Managers and scientists from other regions**.



www.sfei.org/rmp

Highlights for the Next Five Years

- Pulse of the Bay (2019)
- RMP Update (2020)
- Continued partnership with SFEP's "Estuary News" to reach broader audience
- Continued website improvement

QUALITY ASSURANCE AND DATA SERVICES

Approximately 6% of the total budget for general support, plus funding in Status and Trends for handling S&T datasets

Data Services
Data management includes formatting, uploading, and reporting each year's Status and Trends data; managing, maintaining, and improving the RMP dataset to enable easy access to RMP data through CD3; coordinating with statewide data management initiatives (e.g., SWAMP and CEDEN); supporting quality assurance evaluation, data analysis, and RMP report production.

Quality Assurance
Quality assurance includes the review of data submitted by the analytical laboratories; development and application of the QAPP; review of data in comparison to data quality objectives and prior results; review of congener ratios; and troubleshooting problems with the chemical analyses. Occasional special studies to assess sampling methods, analytical methods, or lab performance are conducted.

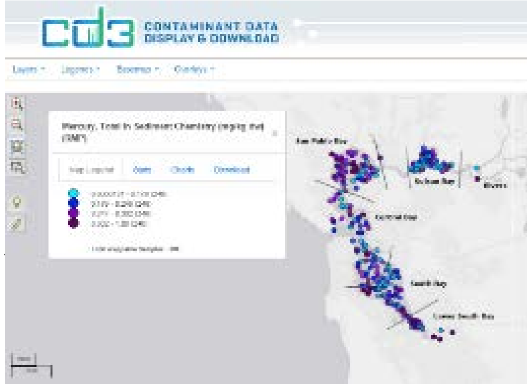
Online Data Access
CD3 (cd3.sfei.org) is an online tool that makes the RMP data available to water quality managers, stakeholders, scientists, and the public.

Recent Noteworthy Findings

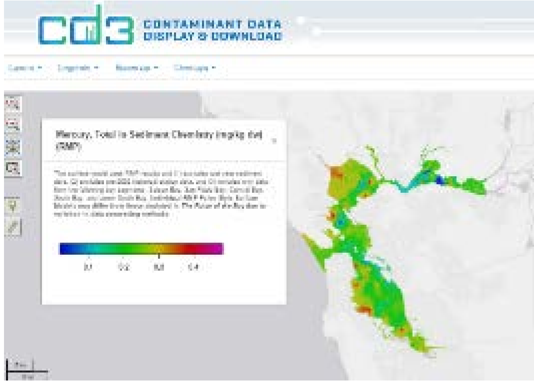
The RMP's 25-year dataset contains approximately 1.4 million records. All data are stored in SFEI's Regional Data Center database and are comparable to CEDEN's statewide standards.

CD3 provides public access and visualizes RMP data along with other relevant datasets. A new data download tool allows users to customize their queries and easily download large quantities of data.

In 2018, the DMMO database and website were transferred to SFEI's Regional Data Center. The costs for the first few years will include upgrading outdated technology, integrating DMMO data into CD3, and uploading a backlog of data to the database. After completing these security and backlog tasks, annual costs can be reduced to hosting and maintaining the system.



- Efficiencies in Data Uploading and Formatting
- Enhancement of Data Access and Visualization Tools
- Coordination with the Estuary Portal
- Coordination with SFEI's Environmental Informatics Program
- Hosting, managing and providing access to DMMO data



RMP STUDIES ASSISTING PERMITTEES WITH ADDRESSING SPECIFIC PERMIT CONDITIONS

Dredgers

Policy	Provision	Study
2011 Programmatic Essential Fish Habitat Agreement, Measure 1	Conduct benthic recovery study in dredged areas	Benthos Recovery After Dredging, Benthic Assessment Tools
2011 Programmatic Essential Fish Habitat Agreement, Measure 7	Conduct bioaccumulation testing evaluations for in-Bay sediment disposal. Clearly define bioaccumulation triggers for testing and subsequent permitting decisions.	S&T Sediment Monitoring– determine ambient bay sediment concentrations for bioaccumulation testing thresholds
PCBs TMDL	Monitor PCB loads in dredged materials disposed in-Bay relative to TMDL allocation	S&T Sediment Monitoring – determine ambient bay sediment concentrations for in-Bay disposal limits
Mercury TMDL	Monitor mercury loads in dredged materials disposed in-Bay relative to TMDL allocation	S&T Sediment Monitoring– determine ambient bay sediment concentrations for in-Bay disposal limits
Long-Term Management Strategy	Establish how much dredged material can be disposed of in-Bay, and where	USGS Suspended Sediment Monitoring, Bay sediment budgets

RMP STUDIES ASSISTING PERMITTEES WITH ADDRESSING SPECIFIC PERMIT CONDITIONS

Industrial Wastewater Treatment Plants

Policy	Provision	Study
Mercury Watershed Permit	Better understand mercury fate, transport, the conditions under which methylation occurs, and biological uptake	Mercury Strategy Studies: Food Web Uptake (small fish), DGTs, Isotopes
Copper Action Plan	Investigate possible copper sediment toxicity	S&T Sediment Toxicity
Copper Action Plan	Investigate sublethal effects on salmonids	Effects of Copper on Salmon (NOAA)

RMP STUDIES ASSISTING PERMITTEES WITH ADDRESSING SPECIFIC PERMIT CONDITIONS

Municipal Wastewater Treatment Plants

Policy	Provision	Study
Mercury Watershed Permit	Better understand mercury fate, transport, the conditions under which methylation occurs, and biological uptake	Mercury Strategy Studies: Food Web Uptake (small fish), DGTs, Isotopes
Copper Action Plan	Investigate possible copper sediment toxicity	S&T Sediment Toxicity
Copper Action Plan	Investigate sublethal effects on salmonids	Effects of Copper on Salmon (NOAA)
Nutrient Watershed Permit	Characterize nutrients and nutrient-related parameters in the Bay	Contributions to Nutrient Management Strategy studies

RMP STUDIES RELATED TO SPECIFIC PERMIT CONDITIONS

Urban Stormwater

MRP link: http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/Municipal/R2-2015-0049.pdf

Policy	Provision	Study or linkage
Municipal Regional Stormwater Permit (MRP)	C.8.f Pollutants of Concern Monitoring	Sources, Pathways, and Loadings Workgroup (SPLWG) / Small Tributary Loading Strategy (STLS) studies on PCBs and Hg and other POCs can fulfill a portion of requirement in conjunction with BASMAA efforts.
		ECWG in collaboration with SPLWG to conduct the required special study for emerging contaminants in stormwater to include at least PFOS, PFOA and alternative flame retardants.
MRP	C.8.g. iii Wet Weather Pesticides and Toxicity Monitoring	Possible linkage to STLS/ SPLWG studies but the details are still to be determined.
MRP	C.11/12.a Implement Control Measures to Achieve Mercury/ PCB Load Reductions	STLS/ SPLWG monitoring efforts will help identify priority watersheds / management areas where coordinated with stormwater program planning.
MRP	C.11/12.b. Assess Mercury/ PCB Load Reductions from Stormwater	STLS/ SPLWG information could be used by stormwater programs to help with refinements and documentation for methodology assessing load reductions
MRP	C.11/12.c. Plan and Implement Green Infrastructure to reduce mercury / PCB loads	STLS/ SPLWG information and the RWSM outputs can help stormwater permittees with quantifying relationships between areal extent of green infrastructure and load reductions.
MRP	C.11/12.d. Prepare Implementation Plan and Schedule to Achieve TMDL Allocations	STLS/ SPLWG information and the RWSM outputs can help stormwater permittees with the development of a reasonable assurance analysis.
MRP	C.12.g. Fate and Transport Study of PCBs: Urban Runoff Impact on San Francisco Bay Margins	PCB Strategy Team will implement required study via the multi-year Bay Margins project to develop Conceptual Models of Priority Margin Units
		STLS/ SPLWG concentrations and loads information is helping to complete the Bay margins mass balance pilot projects that aims to provide information on the fate of PCBs in Urban Runoff and impact on San Francisco Bay margins.

2018 Bivale Cruise. Photograph by Paul Salop

RMP Sediment Workgroup
2020 SEP Ideas

Study Name	Approximate budget	Lead Principal Investigator(s)	Description	Submitted by
Filling Bathymetry Data Gaps	$25,000+ (there is an economy of scale and diminishing returns for surveying of small areas because of the costs of mobilization and demobilization)	TBD, dependent on data gaps identified	In 2014 and 2015 the Ocean Protection Council surveyed the bathymetry of large portions of San Francisco Bay. However, because of funding constraints, there were data gaps. Data from other sources exist for some of these gaps but not for others. The concept of this SEP study idea is to fill these data gaps as funding becomes available, starting with the ones that are most critical for understanding of the bay system. A possible way to identify the most critical gaps is use the current update of bathymetry and erosion to identify all gaps and then widely circulate this information to stakeholders and researchers for input.	Bruce Jaffe (USGS) at the request of the Sediment Workgroup
Implementation of Recommendations for Updated Beneficial Reuse Thresholds	$30,000	San Francisco Bay Regional Water Quality Control Board SFEI	Acquiring suitable material for use in restoration projects around the San Francisco Bay area is difficult and very costly for local project sponsors. Funding that is currently spent on material acquisition efforts could be spent on additional project restoration components if the supply of suitable material was expanded. In the fall of 2019, there will be an RMP-funded workshop to discuss the protectiveness of the current approach to screening contaminants in dredged sediments (i.e. too protective, not protective enough, or just right). The deliverable will be a workshop summary that will distill the findings relative to the charge questions and recommendations to the Water Board regarding revisions to the Sediment Screening and Testing Guidelines. Unfortunately, this beneficial reuse workshop is unlikely to generate consensus on revised numeric thresholds that can inform regulatory decisions. The proposed funding would be used to implement as many of the workshop recommendations as possible to begin the process of updating the beneficial reuse thresholds appropriately.	Roxanne Grillo (Valley Water)
Toxicity Reference Value Refinement	$30,000	Diana Lin (SFEI)	Toxicity Reference Values are used as a conservative screening tool to efficiently evaluate whether observed invertebrate test organism body burdens could indicate adverse ecological effects on benthic organisms in situ. SFEI published a report in December 2018 (contribution number 916) in an attempt to promote consistent application of TRVs to evaluate bioaccumulation testing results submitted by individual dredgers in San Francisco Bay for the six different contaminants with bioaccumulation trigger values (PCBs, PAHs, DDTs, chlordanes, dieldrin, dioxins/furans, and	Josh Gravenmeier (Arcadis)

			mercury). The assessment provided low confidence level TRV recommendations for PCBs, DDTs, total chlordane, and dieldrin and was not able to provide a recommendation for dioxins/furans or total PAHs due to insufficient quality data in the Environmental Residue Effects Database (ERED). The report recommended including data from outside the ERED for additional relevant, published, peer-reviewed sediment toxicity studies. This study would determine what additional studies could be included to increase the confidence level of the SFEI report, update the report, and determine what (if any) additional data gaps exist to providing higher confidence TRV screening values for San Francisco Bay.	
DMMO Data Review & Summary Tools	$40,000	Don Yee and Adam Wong (SFEI)	The Dredged Material Management Office (DMMO) maintains a database that compiles sediment chemistry testing data available from dredging projects in San Francisco Bay. This database has used in recent projects to evaluate dioxin and PCB distributions in dredged areas, and an assessment of net PCB movement via dredging activities. This study would build upon those prior efforts the available information from the DMMO database to evaluate concentrations of other priority pollutants from dredging projects, compare their concentrations ranges to other areas (e.g., open water and margin ambient sites), and estimate their masses moved or removed from the Bay by dredging. Some of the major challenges identified in the prior efforts were gaps or inconsistencies in the reported data, which greatly changed estimated masses depending on the substitutions used to fill those gaps. Products from this effort would include a set of tools for querying the DMMO database, and user adjustable settings to explore the impacts of different assumptions and substitution methods for filling various data gaps.	Don Yee (SFEI)
Combining Remotely Sensed Turbidity and Sediment Transport Modeling to Investigate the Conditions Responsible for Observed Complex Turbidity Patterns	$95,000	Aaron Bever (Anchor QEA) Christine Lee (NASA Jet Propulsion Laboratory) Nick Tufillaro (Oregon State University)	Remote sensing provides a tool for estimating surface turbidity throughout the entire San Francisco Bay (Bay). However, work remains to understand how to interpret the periodic remote sensing data with regard to the time-varying waves, currents, and sediment supply that drive the observed complex patterns and magnitudes. The NASA Jet Propulsion Laboratory and Oregon State University are leading a project to estimate turbidity using satellite remote sensing throughout the Bay at a 30-m horizontal resolution and have previously collaborated with Anchor QEA to use remote sensing to validate a calibrated Bay-wide sediment transport model (see Bever et al. 2018). The proposed study leverages this previous work by comparing 1 year of remotely sensed turbidity snapshots to hydrodynamic, wave, and sediment transport model results to examine the patterns in surface turbidity (and by correlation suspended sediment concentration [SSC]) throughout the Bay. This study seeks to investigate the processes responsible for the observed turbidity patterns, such as wave and current conditions, to provide a better understanding of how periodic remotely sensed turbidity fields relate to underlying processes and sediment transport. This proposed work will also establish a workflow to directly test remote sensing products within a	Aaron Bever (Anchor QEA)

			regional monitoring context and strategy, with case studies including supporting estimates of sediment transport throughout the Bay or changes to turbidity on mudflats or shallows due to resuspension. Advancing understanding of sediment plume presence and extent associated with dredging activity could be enhanced through remote sensing. The study would also have the benefit of further cross-validating turbidity and SSC patterns estimated from both the sediment transport model and the remote sensing data.	
Developing a protocol for assessing sediment storage dynamics within flood control channels at the fluvial-tidal interface around San Francisco Bay.	\$100,000 - 200,000 over two calendar years	Sarah Pearce, Cristina Grosso, Lester McKee (SFEI)	Currently, very few flood control channels at the fluvial-tidal interface have ongoing regular channel cross-section or longitudinal profile surveys to document the change in channel elevation, and the associated change in stored sediment volume, over the long-term and directly following major storms or dredging events. In addition, there is currently a lack of data for the flood control channels that are regularly dredged around the fluvial-tidal interface pertaining to the location, volume, grain size, and fate of dredged sediment. These data are needed to determine long-term sediment deposition and storage trends for individual channels (i.e., whether channels are actively aggrading, incising, or in equilibrium) and can be used with watershed sediment supply data to determine the portion of watershed sediment that gets trapped in flood control channels. This information is essential for developing appropriate redesign options aimed at improving sediment transport capacity and routing of sediment to adjacent tidal habitats, and identifying local dredged sediment sources for a range of tidal habitat restoration projects (e.g., fine sediment appropriate for building marsh plains, coarse sediment appropriate for building beaches). This project will focus on developing a protocol for collecting flood control channel topographic and sediment data, and a data entry tool and database for the collected data. The specific tasks are: ● Working with the regional flood control agencies and technical advisors, design or adopt a practical protocol for regionally consistent use for: 1) collecting repeat high resolution channel topographic data (cross-sections and longitudinal profiles or topographic survey data using unmanned aerial vehicles) and bed grain size data at the fluvial-tidal interface for the larger flood control channels around the Bay; and 2) compiling pertinent information for individual dredging events (e.g., location, volume, grain size, and sediment fate) for flood control channels that are dredged regularly or periodically. ● Working with regional flood control agencies and regulatory agencies, design and trial an online data entry and reporting tool for collecting and reporting standardized data on channel cross-sections, longitudinal profiles, and grain size of stored sediment to estimate volume stored, location, texture, volume removed, and ultimate fate of sediment removed from flood control channels. The data will be	Lester McKee (SFEI)

			publically-accessible online and available for a variety of planning, management, maintenance, and restoration applications. Opportunities to leverage and integrate these data with the existing SediMatch tool for tracking the beneficial reuse of sediment in the Bay will be explored.	
Developing tools to track sediment sources, sinks, and pathways the San Francisco Estuary	$220,000 over two calendar years	Daniel Livsey and Maureen Downing-Kunz (USGS)	Tools to quantify the sources, sinks and pathways of sediment in the San Francisco Estuary (Estuary) are needed to inform an array of management actions identified by the RMP regarding: the beneficial reuse of dredged sediment, the quantification of passive sediment accretion in tidal marshes, and identifying sources and trajectories of sediment-bound contaminants from watersheds and Bay margins into the Estuary (SFEI, 2017, 2018). Quantitative measures of sediment provenance (i.e., origin of sediment) are needed to track sediment sources, sinks, and pathways and to address two of the four priority questions identified by the RMP sediment working group (SFEI, 2018). Scientists routinely measure sediment loadings throughout the Estuary; however, scientists have not developed tools to quantitatively track sediment provenance of silt and clay that is needed to quantify sediment sources, sinks, and pathways. The primary objective of this research is to develop tools to track the sources, sinks, and pathways of clay, silt and sand between the Estuary's watersheds, flood-control and navigation channels, Bayland tidal marshes, shoals, and channels. Specifically, the results of this work will quantify the primary sources of sand, silt, and clay depositing in the Port of Redwood City, Alameda Flood Control Channel, and South Bay Salt Pond Restoration Project using two conservative tracers of sediment provenance: trace-element analysis of clay and silt and grain-shape analysis of silt and sand.	Daniel Livsey (USGS)