Annotated Bibliography

Supporting the Sediment for Wetland Adaptation Project and the San Francisco Bay Sediment and Soil Beneficial Reuse Action Plan for Wetland Restoration and Adaptation

Overview

This document summarizes the main documents, reports, and scientific literature referenced in and/or used to support the background and actions in the Sediment for Wetland Adaptation Project's (SWAP) "San Francisco Bay Sediment and Soil Beneficial Reuse Action Plan for Wetland Restoration and Adaptation" (Action Plan). Section 1 includes documents and reports created by SWAP partner agencies and organizations, and Section 2 includes scientific literature referenced throughout the Action Plan.

Documents and Reports by Partner Agencies and Organizations

1. Sediment for Survival (2021)

Citation and Link: Dusterhoff, S., McKnight, K., Grenier, L., and Kauffman, N. 2021. Sediment for Survival: A Strategy for the Resilience of Bay Wetlands in the Lower San Francisco Estuary. A SFEI Resilient Landscape Program. A product of the Healthy Watersheds, Resilient Baylands project, funded by the San Francisco Bay Water Quality Improvement Fund, EPA Region IX. Publication #1015, San Francisco Estuary Institute, Richmond, CA.

The Sediment for Survival (2021) report by Dusterhoff et al. highlights the importance of tidal marshes to the San Francisco Bay region (Bay Area) and its communities. The authors use the best available science, focused on environmental parameters such as physical processes influencing sediment transport, to estimate the existing volume of sediment available to tidal marshes. Under various scenarios, the authors modeled how much sediment will be required by the end of the century to preserve, conserve, and restore tidal marshes and mudflats as sea levels continue to rise. It is predicted that by the end of the century, there will not be enough sediment available within the estuary to help both existing and restored tidal marshes, as well as existing mudflats, keep pace with sea level rise. The report brings to light alternative sediment sources (e.g., construction projects and flood control channels) throughout the Bay Area that can be used to supply tidal marshes with the necessary sediment for their survival. Furthermore, the authors stress that current management and regulations must evolve to become streamlined and efficient in accessing different sources of sediment, while also offering potential strategies, to protect and enhance these critical habitats.

As one of the pillars guiding the Action Plan, this report provides critical information on how much sediment is available in the estuary and the amount needed to help tidal wetland habitats survive before the end of the century. The report also gives the Action Plan a handful of recommendations for further research and analysis instead of starting from scratch. Although this report is valuable, it does have some limitations. These include the uncertainty in the analysis, the lack of a clear direction on how to allocate the finite supply of sediment towards sustaining and restoring tidal marshes, the absence of a system that determines whether restoring or sustaining is more important, and the lack of information on the governance structure for transporting sediment onto tidal marshes and mudflats where it is needed. Thus, the authors suggest considering their proposed findings and recommendations when developing a regional action plan. The report does not entirely influence the Action Plan but is one of the pillars that will guide development of efficient decision-making regarding sediment management.

2. Baylands Ecosystem Habitat Goals (1999)

Citation and Link: Goals Project. 1999. Baylands Ecosystem Habitat Goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U.S. Environmental Protection Agency, San Francisco, Calif./S.F. Bay Regional Water Quality Control Board, Oakland, Calif.

The Baylands Ecosystem Habitat Goals (1999) prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project (with authors from USEPA, SFBRWQCB, CDFW, PWA, and SFEI) offers the San Francisco Bay area various recommendations for the type and distribution of tidal wetland habitat type required to sustain biodiversity within San Francisco Bay. The document details recommendations at three levels: Region, Subregion, and Segment. Some of these recommendations focus on habitat modifications to support key species, restoring tidal marshes and salt ponds, and protecting other natural habitats along the Bay's edge. The regional goal is to increase tidal marsh habitat extent from ~50,000 acres to ~100,000 acres. The authors also highlight potential roadblocks for reaching this restoration goal, such as sea-level rise, sediment availability, site designs, and management that may occur when implementing a recommendation. Though the report offers guidance, the authors mention there is still a need for further research to fully understand the impacts of these recommendations at an environmental and public level, even though there is readily available literature. Lastly, the document offers guidance on moving forward, which involves improved coordination among different agencies and organizations, determining research and monitoring opportunities, and working to amend, if needed, policies and practices within agencies.

The 1999 Habitat Goals report is another pillar of the Action Plan as it provides a foundation that can be built upon for the preservation and restoration of natural resources throughout the region. Furthermore, the report established the goal of restoring 100,000 acres of tidal marsh within the region. However, it also indicated the potential shortage of sediment may hinder the realization of this goal. It is important to note that the recommendations were developed based on data that was available during this time. This report is being used as a stepping stone to guide modern decision-making supported by new science regarding sea-level rise, sediment transport and availability, wetland strategy design, and economic costs.

3. Dredged Material Management Office (DMMO) Annual Report (2022)

Citation and Link: Dredge Material Management Office. (2022 in prep.). Annual Report 2022. https://www.spn.usace.army.mil/Missions/Dredging-Work-Permits/Dredged-Material-Management-Office-DMMO/Annual-Reports/

This annual report summarizes all the dredging activity, sediment disposal and placement, and best management practices that occurred in 2022 within the region. In 2022, approximately 2.79 million cubic yards of sediment was dredged from federal and non-federal projects with estimates of 7%, 15%, 32%, and 46% being taken to upland, deep ocean, beneficial reuse, and in-Bay sites, respectively. The report further details, at a project level, the amount of sediment that was dredged for the year.

This annual report is relevant to the Action Plan as a tool that is used to monitor the volume and movement of sediment during each dredging season.

4. LTMS Management Plan (2001)

Citation and Link: LTMS (Long-Term Management Strategy). 1998. Long-Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region. Final Policy Environmental Impact Statement, Programmatic Environmental Impact Report. Volume III. Prepared by the US Army Corps of Engineers, US Environmental Protection Agency, Bay Conservation and Development Commission, San Francisco Bay Regional Water Quality Control Board, and State Water Resources Control Board.

The "Long-Term Management Strategy for Placement of Dredged Material in the San Francisco Bay Region (LTMS) Management Plan" was developed by several agencies – San Francisco Bay Conservation and Development Commission (BCDC), State Water Resources Control Board (SWRCB), San Francisco Bay Regional Water Quality Control Board (SFBRWQCB), U.S. Army Corps of Engineers San Francisco District (USACE), U.S. Environmental Protection Agency (USEPA), and State Lands Commission (SLC) – and implemented in 2001. The overarching goal of the LTMS plan is to protect, enhance, and minimize effects of dredged sediment placement to water quality, wildlife, coastal communities, and other Bay resources by using environmental practices to (i) manage the impacts of navigational dredging and disposal, (ii) maximize the beneficial reuse of dredged sediment, (iii) reduce in-bay disposal, and (iv) offer a streamlined permitting process for navigational dredging projects.

The LTMS Management Plan acts as another pillar to the Action Plan because it focuses on effective coordination between federal and state agencies to achieve a significant goal (i.e, reducing in-Bay disposal while increasing beneficial reuse). While the LTMS Management Plan continues to be successful in reducing in-Bay disposal, the authors have acknowledged that agencies need more flexible programs to increase beneficial reuse of dredged sediment. The LTMS Management Plan does not have a direct influence on the Action Plan, but it provides a blueprint for how to create an effective plan among varying levels of governance.

5. Beneficial Use of Dredged Material Command Philosophy Notice (2023)

Citation and Link: Spellmon, Scott A., "Beneficial Use of Dredged Material Command Philosophy Notice." Letter to the U.S. Army Corps of Engineers, 25 January 2023. (Letter)

This is a letter written by Lieutenant General Scott A. Spellmon of the U.S. Army Corps of Engineers (USACE) that sets a path for expanding the beneficial reuse of dredged sediment program. The General states that dredged sediment is a resource that should be used to benefit the ecosystem, economy, and to efficiently implement the USACE's mission. Furthermore, the General states that dredged material (i.e., sediment, sand, gravel and rock) should be beneficially reused and considered in the USACE's placement plans. The letter ends with the USACE looking to increase beneficial reuse to 70% by 2030.

This letter is relevant to the Action Plan because it shows that the USACE, the largest dredger in the nation and in the Bay Area, aims to adjust their dredging program to increase the beneficial reuse of sediment within the region. Additionally, its focus on the ongoing regional changes of increasing beneficial reuse will further support the implementation of the Action Plan.

6. SFEI, 2017 – Changing Channels: Regional Information for Developing Multi-Benefit Flood Control Channels at the Bay Interface

Citation and Link: San Francisco Estuary Institute-Aquatic Science Center. 2017. Changing Channels: Regional Information for Developing Multi-Benefit Flood Control Channels at the Bay Interface. A SFEI-ASC Resilient Landscape Program report developed in cooperation with the Flood Control 2.0 Regional Science Advisors, Publication #801, San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA.

Abstract: Over the past 200 years, many of the channels that drain to San Francisco Bay have been modified for land reclamation and flood management. The local agencies that oversee these channels are seeking new management approaches that provide multiple benefits and promote landscape resilience. This includes channel redesign to improve natural sediment transport to downstream bayland habitats and beneficial re-use of dredged sediment for building and sustaining baylands as sea level continues to rise under a changing climate. Flood Control 2.0 is a regional project that was created to help develop innovative approaches for integrating habitat improvement and resilience into flood risk management at the Bay interface. Through a series of technical, economic, and regulatory analyses, the project addresses some of the major elements associated with multi-benefit channel design and management at the Bay interface and provides critical information that can be used by the management and restoration communities to develop long-term solutions that benefit people and wildlife. This report provides a regional analysis of morphologic change and sediment dynamics in flood control channels at the Bay interface, and multi-benefit management concepts aimed at bringing habitat restoration into

flood risk management. The findings presented here are built on a synthesis of historical and contemporary data that included input from Flood Control 2.0 project scientists, project partners, and science advisors. The results and recommendations, summarized below, will help operationalize many of the recommendations put forth in the Baylands Ecosystem Habitat Goals Science Update (Goals Project 2015) and support better alignment of management and restoration communities on multi-benefit bayland management approaches.

This report is relevant to the Action Plan because it focuses on flood control channel modifications over time and their influence on sediment transport. Additionally, it provides information regarding how much sediment is collected and removed from major flood control channels around the Bay Area, as well as the cost for removal and how the fate of the removed sediment. One of the limitations with this report is the “quality and quantity” or characterization of sediment that moves downstream and is removed from the different channels. Overall, this document supports the Action Plan as flood control channels provide an additional sediment source, which can be used for beneficial reuse in restoration sites that are located further inland.

7. McKnight Et al., 2023 – Conceptual Understanding of Fine Sediment Transport in San Francisco Bay

Citation and Link: McKnight, K; Braud, A; Dusterhoff, SD; Grenier, L; Shaw, S; Lowe, J; Foley, MM; McKee, LJ. 2023. Conceptual Understanding of Fine Sediment Transport in San Francisco Bay. SFEI Contribution No. 1114. San Francisco Estuary Institute: Richmond, CA.

Abstract: Sediment is a lifeblood of San Francisco Bay (Bay). It serves three key functions: (1) create and maintain tidal marshes and mudflats, (2) transport nutrients and contaminants, and (3) reduce impacts from excessive human-derived nutrients in the Bay. Because of these important roles, authors need a detailed understanding of sediment processes in the Bay. This report offers a conceptual understanding of how fine-grained sediment (i.e. silt and finer, henceforth called fine sediment) moves around at different scales within the Bay, now and into the future, to synthesize current knowledge and identify critical knowledge gaps. This information can be used to support Bay sediment management efforts and help prioritize funding for research and monitoring. In particular, this conceptual understanding is designed to inform future San Francisco Bay Regional Monitoring Program (RMP) work under the guidance of the Sediment Workgroup of the RMP for Water Quality in San Francisco Bay, which brings together experts who have worked on many different components of the landscape, including watersheds and tributaries, marshes and mudflats, beaches, and the open Bay. This report describes sediment at two scales: a conceptual understanding of open-Bay sediment processes at the Bay and subembayment scale (Chapter 2); and a conceptual understanding of sediment processes at the baylands scale (Chapter 3). Chapter 4 summarizes the key knowledge gaps and provides recommendations for future studies.

This report is essential to the Action Plan as it provides information with the best available science regarding the transport of fine sediment across the San Francisco Bay under different perspectives. The report also highlights pathways towards future research topics, so that there is a continued understanding of the estuary's sediment transport and budget. This report, like the others, serves as a guide to the Action Plan by providing us with tools to better manage sediment placement and monitoring the amount available for restoration.

8. BCDC, 2016 - Central San Francisco Bay Regional Sediment Management Plan

Citation and Link: San Francisco Bay Conservation and Development Commission (BCDC). 2016. Central San Francisco Bay Regional Sediment Management Plan. A report prepared by the San Francisco Bay Conservation and Development Commission. [accessed 2025 Jan 10]. 168p

This sediment management plan for Central Bay created by BCDC shows the various actions that were taken to understand, as well as inform others, about the sediment dynamic processes in this embayment, and how to best manage sediment sources (mud and sand) for the benefits of wildlife, habitat, and shoreline communities. The plan further highlights what type of research is needed to address various topics, such as modeling sediment movement, sediment budgets, and improving existing tools to support regional management.

Though this plan is detailed, it does have limitations in that it focuses on the Central Bay and not the entire Bay. This report is relevant to the Action Plan as it provides a communication strategy between various stakeholders, organizations and communities regarding sediment processes and management practices.

9. McKee et al., 2020 – Sediment Monitoring and Modeling Strategy

Citation and Link: McKee, L., Lowe, J., Dusterhoff, S., Foley, M., and Shaw, S. (2020). Sediment Monitoring and Modeling Strategy. A technical report prepared for the Regional Monitoring Program for Water Quality in San Francisco Bay (RMP) Sediment Workgroup. SFEI Contribution No. 1016. San Francisco Estuary Institute, Richmond, CA.

The Sediment Monitoring and Modeling Strategy (2020) report by McKee and colleagues was developed as a "foundation document" for the Bay RMP Sediment Workgroup that lays out high priority sediment monitoring and modeling recommendations for addressing the management questions of the Sediment Workgroup and other regional entities. The existing management questions presented in the report focus on prospective studies on sediment transport process, and upland and tidal wetland restoration practices. Additionally, this strategy document highlights critical knowledge gaps that necessitate research and development, to support existing and future policy and management plans. Most importantly, the authors provided recommendations on how to move forward when reviewing the management questions. The limitation of this report is that while it offers critical questions and recommendations on how to move forward, there is no governance structure in which organizations have the capacity or finances to take on these tasks.

This report is relevant to the Action Plan as it offers an insight into what science is known to the region and it encourages the sediment and dredging community to continue addressing key knowledge gaps. This strategy report will be used as a guide by connecting the management questions with proposed actions to support the Action Plan overall goals.

10. McKee et al., 2023 – Sand budget and sand transport in San Francisco Bay

Citation and Link: McKee, L.J., Zi, T., Pearce, S.A., Grosso, C., Wong, A., Weaver, M., Dusterhoff, S., Lowe, J., Elias, E., Roelvink, F., 2023. Sand budget and sand transport in San Francisco Bay. A report prepared by SFEI-ASC for the State Coastal Conservancy (SCC), and the San Francisco Bay Conservation and Development Commission (BCDC). SFEI Contribution #1125. Richmond, CA.

This technical document on the San Francisco Bay's Sand Budget by McKee and colleagues was to address concerns about the relationship between dredging and mining on habitat and infrastructure loss, coastal erosion, and flooding. The authors concluded that the estuary has experienced net sediment loss of both mud and sand between 2001-2020, with sand mining being the single largest outflow of sand from the system. Thus, because of human actions, the estuary has been designated as a sediment source. The report also details that sand is not delivered to the Bay from the Delta anymore but coming into the Bay from local watershed erosion. A limitation of this document is that the authors acknowledge there is some uncertainty in the data, particularly with the budget findings. It is also important to note that the authors do offer recommendations on actions that can be done to reduce this uncertainty in the data.

This document is relevant to the Action Plan as it helps managers and other entities better understand how dredging and/or mining impact the sediment (mud and sand) budget. In doing so, sediment source management can be improved and prioritized when designing enhancement and restoration projects. This technical report won't significantly influence the basis of the Action Plan, but it will serve as a guide to prioritizing sediment for restoration projects to achieve the overall objective.

11. The Baylands and Climate Change (2015)

Citation and Link: Goals Project. 2015. The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015 prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. California State Coastal Conservancy, Oakland, CA.

This report is recognized as an update to the Bayland Ecosystem Habitat Goals (1999) document and incorporates the latest science to best understand climate and sediment supply. Furthermore, the update report includes revised recommendations towards the conservation and restoration of Baylands across the region. The authors of the report emphasize the importance of tidal wetlands and how they can help mitigate the impacts of sea-level rise, sediment significance to the region, and point to additional sources of sediment (e.g., flood-control channels).

Like the original report, this revised document is a critical pillar that can be used to support the Action Plan objectives and give guidance in areas that are not well established. A limitation of this report is that it offers recommendations on how to address certain issues but does not dive into the technicality on how to complete them with respect to sea-level rise. Overall, this report will serve as a guide towards informed decision making, wetland design, and the development of regional management plans.

12. Pearce et al., 2021 – Towards a Coarse Sediment Strategy for the Bay Area

Citation and Link: Pearce, S., McKee, L., Whipple, A., and Church, T., 2021. Towards a Coarse Sediment Strategy for the Bay Area. SFEI Publication # 1032. San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA.

Abstract: Historic and current regional management of watersheds and channels for water supply and flood control across the San Francisco Bay Area have cut off much of the coarse sediment that was historically delivered to the Bay. Here authors define coarse sediment as having grain sizes larger than 0.0625 mm, which includes sand, gravel and even cobble, as opposed to fine sediment that includes clay, mud and silt. Future projections indicate that sediment supply will not meet the demand from extant and restored tidal marshes to keep pace with sea-level rise. The U.S. EPA Water Quality Improvement Fund "Preparing for the Storm" grant has funded the Zone 7 Water Agency, the San Francisco Estuary Institute and the San Francisco Bay Joint Venture to support the future development of a successful regional coarse sediment reuse strategy. Development of such a strategy requires an understanding of logistical and regulatory hurdles and identification of key strategies for breaking down barriers. One potential solution for meeting the sediment demand along the Bay margin is to utilize coarse sediment that is removed from flood control channels by public agencies. To date, very little of this sediment that is removed is beneficially reused for restoration along the Bay shoreline. The current economic and regulatory framework around sediment removal presents many challenges, barriers and lack of incentives for agencies to reuse their sediment.

This document supports the Action Plan because it represents a step forward toward beneficially reusing coarse flood control channel sediment by outlining reuse challenges and identifying incentives for participation and potential solutions. The Action Plan includes actions regarding assessing coarse sediment from flood control channels for potential beneficial reuse at restoration sites throughout the region.

Scientific Literature

1. Milligan and Holmes, 2017 - Sediment is critical infrastructure for the future of California's Bay-Delta

Citation and Link: Milligan, B., & Holmes, R. (2017). Sediment is critical infrastructure for the future of California's Bay-Delta. Shore & Beach, 85(2), 2.

Abstract: In coastal and estuarine regions, sediment is a crucial resource that should be recognized as such and managed for its infrastructural role as substrate for a myriad of important human and environmental processes. This paper uses California's Bay-Delta as a case study to both show this significance and to develop recommendations for the management of sediment as infrastructure. The paper presents selections from and distillations of a longer report that describes the background, methods, and findings from Dredge Fest California. This event, held in the Bay Area in June 2016, brought together designers, scientists, engineers, regulators, and policymakers to examine the future of sediment design in the Bay-Delta.

2. Schoellhamer et al., 2013 – Adjustment of the San Francisco estuary and watershed to decreasing sediment supply in the 20th century

Citation and Link: Schoellhamer, D. H., Wright, S. A., & Drexler, J. Z. (2013). Adjustment of the San Francisco estuary and watershed to decreasing sediment supply in the 20th century. Marine Geology, 345, 63-71.

Abstract: The general progression of human land use is an initial disturbance (e.g., deforestation, mining, agricultural expansion, overgrazing, and urbanization) that creates a sediment pulse to an estuary followed by dams that reduce sediment supply. Authors present a conceptual model of the effects of increasing followed by decreasing sediment supply that includes four sequential regimes, which propagate downstream: a stationary natural regime, transient increasing sediment supply, transient decreasing sediment supply, and a stationary altered regime. The model features characteristic lines that separate the four regimes. Previous studies of the San Francisco Estuary and watershed are synthesized in the context of this conceptual model. Hydraulic mining for gold in the watershed increased sediment supply to the estuary in the late 1800s. Adjustment to decreasing sediment supply began in the watershed and upper estuary around 1900 and in the lower estuary in the 1950s. Large freshwater flow in the late 1990s caused a step adjustment throughout the estuary and watershed. It is likely that the estuary and watershed are still capable of adjusting but further adjustment will be as steps that occur only during greater floods than previously experienced during the adjustment period. Humans are actively managing the system to try to prevent greater floods. If this hypothesis of step changes occurring for larger flows is true, then the return interval of step changes will increase or, if humans successfully control floods in perpetuity, there will be no more step changes.

3. Barnard et al., 2013 - Sediment transport in the San Francisco Bay coastal system: an overview

Citation and Link: Barnard, P. L., Schoellhamer, D. H., Jaffe, B. E., & McKee, L. J. (2013). Sediment transport in the San Francisco Bay coastal system: an overview. Marine Geology, 345, 3-17.

Abstract: The papers in this special issue feature state-of-the-art approaches to understanding the physical processes related to sediment transport and geomorphology of complex coastal–estuarine systems. Here authors focus on the San Francisco Bay Coastal System, extending from the lower San Joaquin–Sacramento Delta, through the Bay, and along the adjacent outer Pacific Coast. San Francisco Bay is an urbanized estuary that is impacted by numerous anthropogenic activities common to many large estuaries, including a mining legacy, channel dredging, aggregate mining, reservoirs, freshwater diversion, watershed modifications, urban run-off, ship traffic, exotic species introductions, land reclamation, and wetland restoration. The Golden Gate strait is the sole inlet connecting the Bay to the Pacific Ocean, and serves as the conduit for a tidal flow of ~8 × 109 m3 / day, in addition to the transport of mud, sand, biogenic material, nutrients, and pollutants. Despite this physical, biological and chemical connection, resource management and prior research have often treated the Delta, Bay and adjacent ocean as separate entities, compartmentalized by artificial geographic or political boundaries. The body of work herein presents a comprehensive analysis of system-wide behavior, extending a rich heritage of sediment transport research that dates back to the groundbreaking hydraulic mining-impact research of G.K. Gilbert in the early 20th century."

4. McKee et al., 2013 - Comparison of sediment supply to San Francisco Bay from watersheds draining the Bay Area and the Central Valley of California

Citation and Link: McKee, L. J., Lewicki, M., Schoellhamer, D. H., & Ganju, N. K. (2013). Comparison of sediment supply to San Francisco Bay from watersheds draining the Bay Area and the Central Valley of California. Marine Geology, 345, 47-62.

Abstract: Quantifying suspended sediment loads is important for managing the world's estuaries in the context of navigation, pollutant transport, wetland restoration, and coastal erosion. To address these needs, a comprehensive analysis was completed on sediment supply to San Francisco Bay from fluvial sources. Suspended sediment, optical backscatter, velocity data near the head of the estuary, and discharge data obtained from the output of a water balance model were used to generate continuous suspended sediment concentration records and compute loads to the Bay from the large Central Valley watershed. Sediment loads from small tributary watersheds around the Bay were determined using 235 station-years of suspended sediment data from 38 watershed locations, regression analysis, and simple modeling. Over 16 years, net annual suspended sediment load to the head of the estuary from its 154,000 km2 Central Valley watershed varied from 0.13 to 2.58 (mean = 0.89) million metric t of suspended sediment, or an average yield of 11 metric t/km2 /yr. Small tributaries, totaling 8145 km2 , in the nine-county Bay Area discharged between 0.081 and 4.27 (mean = 1.39) million metric t with a mean yield of 212 metric t/km2 /yr. The results indicate that the hundreds of urbanized and tectonically active tributaries adjacent to the Bay, which together account for just 5% of the total watershed area draining to the Bay and provide just 7% of the annual average fluvial flow, supply 61% of the suspended sediment. The small tributary loads are more variable (53-fold between years compared to 21-fold for the inland Central Valley rivers) and dominated fluvial sediment supply to the Bay during 10 out of 16 yr. If San Francisco Bay is typical of other estuaries in active tectonic or climatically variable coastal regimes, managers responsible for water quality, dredging and reusing sediment accumulating in shipping channels, or restoring wetlands in the world's estuaries may need to more carefully account for proximal small-urbanized watersheds that may dominate sediment supply.

5. Fregoso et al., 2023 - Sediment Deposition, Erosion, and Bathymetric Change in San Francisco Bay, California, 1971–1990 and 1999–2020

Citation and Link: Fregoso, T.A., Foxgrover, A.C., and Jaffe, B.E., 2023, Sediment deposition, erosion, and bathymetric change in San Francisco Bay, California, 1971–1990 and 1999–2020 (ver. 1.1, June 2024): U.S. Geological Survey Open-File Report 2023–1031, 19 p., https://doi.org/10.5066/P1332UUW

Abstract: Bathymetric change analyses document historical patterns of sediment deposition and erosion, providing valuable insight into the sediment dynamics of coastal systems, including pathways of sediment and sediment-bound contaminants. In 2014 and 2015, the California Ocean Protection Council, in partnership with the National Oceanic and Atmospheric Administration (NOAA) Office of Coastal Management, provided funding for new bathymetric surveys of large portions of San Francisco Bay. A total of 93 bathymetric surveys were conducted during this 2-year period, using a combination of interferometric side scan and multibeam sonar systems. These data, along with recent NOAA, U.S. Geological Survey (USGS), U.S. Army Corps of Engineers, and private contractor surveys collected from 1999 to 2020 (hereinafter referred to as 2010s), were used to create the most comprehensive bathymetric digital elevation models (DEMs) of San Francisco Bay since the 1980s. Comparing DEMs created from these 2010s surveys with USGS DEMs created from NOAA's 1971–1990 (hereinafter referred to as 1980s) surveys provides information on the quantities and patterns of erosion and deposition in San Francisco Bay during the 9 to 47 years between surveys. This analysis reveals that in the areas surveyed in both the 1980s and 2010s, the bay floor lost about 20 million cubic meters of sediment since the 1980s. Results from this study can be used to assess how San Francisco Bay has responded to changes in the system, such as sea-level rise and variation in sediment supply from the Sacramento-San Joaquin Delta and local tributaries, and supports the creation of a new, system-wide sediment budget. This report provides data on the quantities and patterns of sediment volume change in San Francisco Bay for ecosystem managers that are pertinent to various sediment-related issues, including restoration of tidal marshes, exposure of legacy contaminated sediment, and strategies for the beneficial use of dredged sediment.

6. Parker et al., 2019 - Sea-Level Rise and Climate Change Impacts on an Urbanized Pacific Coast Estuary

Citation and Link: Parker, V. T., & Boyer, K. E. (2019. Sea-level rise and climate change impacts on an urbanized Pacific Coast estuary. Wetlands, 39, 1219-1232.

Abstract: The San Francisco Bay-Delta estuary, the largest estuary on the west coast of North America, has lost over 90% of its tidal wetlands through conversion to agriculture, grazing or urban development. Accelerated sea-level rise poses an additional threat to the remaining wetlands, and keeping pace requires that they increase in relative elevation through trapping of suspended sediment or increasing organic productivity in the root zone. Suspended sediment concentrations (SSC have been declining in rivers and deep channels, and although little is known about sediment dynamics in shallow areas, sediment supply to tidal wetlands may not be sufficient to maintain their elevations in the future. Wetlands will be constrained by existing development and mountainous terrain. Increases in tidal wetland salinity have been occurring in saline, brackish and the western edges of freshwater tidal wetlands. To mitigate for sea-level rise, considerable acreages currently are being restored, with and without active management practices. Restoration techniques are being piloted to increase shoreline protection, resiliency, and high tide refuge in adaptation to current and projected sea-level rise. Authors recommend additional research into plant physiological responses to combinations of climate change impacts, as well as suggest potential practical policy positions.

7. Buffington et al., 2021 - Incorporation of uncertainty to improve projections of tidal wetland elevation and carbon accumulation with sea-level rise

Citation and Link: Buffington, K. J., Janousek, C. N., Dugger, B. D., Callaway, J. C., Schile-Beers, L. M., Borgnis Sloane, E., & Thorne, K. M. (2021. Incorporation of uncertainty to improve projections of tidal wetland elevation and carbon accumulation with sea-level rise. PLoS One, 16(10, e0256707.

Abstract: Understanding the rates and patterns of tidal wetland elevation changes relative to sea-level is essential for understanding the extent of potential wetland loss over the coming years. Using an enhanced and more flexible modeling framework of an ecosystem model (WARMER-2, authors explored sea-level rise (SLR impacts on wetland elevations and carbon sequestration rates through 2100 by considering plant community transitions, salinity effects on productivity, and changes in sediment availability. Authors incorporated local experimental results for plant productivity relative to inundation and salinity into a species transition model, as well as site-level estimates of organic matter decomposition. The revised modeling framework includes an improved calibration scheme that more

accurately reconstructs soil profiles and incorporates parameter uncertainty through Monte Carlo simulations. Using WARMER-2, authors evaluated elevation change in three tidal wetlands in the San Francisco Bay Estuary, CA, USA along an estuarine tidal and salinity gradient with varying scenarios of SLR, salinization, and changes in sediment availability. Authors also tested the sensitivity of marsh elevation and carbon accumulation rates to different plant productivity functions. Wetland elevation at all three sites was sensitive to changes in sediment availability, but sites with greater initial elevations or space for upland transgression persisted longer under higher SLR rates than sites at lower elevations. Using a multi-species wetland vegetation transition model for organic matter contribution to accretion, WARMER-2 projected increased elevations relative to sea levels (resilience) and higher rates of carbon accumulation when compared with projections assuming no future change in vegetation with SLR. A threshold analysis revealed that all three wetland sites were likely to eventually transition to an unvegetated state with SLR rates above 7 mm/yr. Our results show the utility in incorporating additional estuary-specific parameters to bolster confidence in model projections. The new WARMER-2 modeling framework is widely applicable to other tidal wetland ecosystems and can assist in teasing apart important drivers of wetland elevation change under SLR.

8. Lacy et al., 2020 – Seasonal Variation in Sediment Delivery Across the Bay-Marsh Interface of an Estuarine Salt Marsh

Citation and Link: Lacy, J. R., Foster-Martinez, M. R., Allen, R. M., Ferner, M. C., & Callaway, J. C. (2020). Seasonal variation in sediment delivery across the bay-marsh interface of an estuarine salt marsh. Journal of Geophysical Research: Oceans, 125(1), e2019JC015268.

Abstract: Sediment transport across bay-marsh interfaces depends on wave energy, vegetation, and marsh-edge morphology and varies over a range of timescales. Authors investigated these dynamics in a tidal salt marsh with a gently sloped, vegetated edge adjacent to northern San Francisco Bay. Spartina foliosa (cordgrass) inhabits the lower marsh and Salicornia pacifica (pickleweed) predominates on the marsh plain. Authors measured suspended-sediment concentration (SSC) and hydrodynamics in bay shallows and along a 100-m cross-shore transect in the marsh, during winter and summer. Four-year averaged accretion measured with marker-horizon plots was twice as great along the marsh transect as adjacent to a tidal creek, 50 m from the bay. Authors estimated deposition and trapping efficiency from the time series data to assess its variation with season and wave energy. At high tide the transition zone (between cordgrass and pickleweed) was usually erosional, the pickleweed zone was depositional, and both erosion and deposition increased with wave energy, as did the landward position of maximum deposition. Erosion from the transition zone accounted for approximately one third of the sediment flux into the pickleweed. In the pickleweed zone, SSC, the difference between flood- and ebb-tide SSC, and trapping efficiency were greater in summer than winter for comparable wave conditions, which authors attribute to increased sediment trapping by dense summer cordgrass. Moderate waves in summer (46%) accounted for more annual accretion in the pickleweed zone than larger waves in winter (28%), although the contribution of winter storms was diminished by the dry winter during the study.

9. Milligan et al., 2015 – The Pulse, the Sink, and the Shortfall

Citation and Link: Milligan, B., Maly, T., Holmes, R. (2015). "The Pulse, the Sink, and the Shortfall." Ground Up 04: Out West.

This article summarizes the events that caused there to be a large sediment plume that entered the San Francisco Bay, its transport and distribution, and how the anthropogenic activity influenced a sediment shortfall across the region. The document is relevant to the project as it provides foundational information regarding sediment supply to the San Francisco Bay.

10. Brand et al., 2010 – Wind-enhanced resuspension in the shallow waters of South San Francisco Bay: Mechanisms and potential implications for cohesive sediment transport

Citation and Link: Brand, A., Lacy, J. R., Hsu, K., Hoover, D., Gladding, S., & Stacey, M. T. (2010). Wind-enhanced resuspension in the shallow waters of South San Francisco Bay: Mechanisms and potential implications for cohesive sediment transport. Journal of Geophysical Research: Oceans, 115(C11).

Abstract: Brand et al. investigated the driving forces of sediment dynamics at the shoals in South San Francisco Bay. Two stations were deployed along a line perpendicular to a 14 m deep channel, 1000 and 2000 m from the middle of the channel. Station depths were 2.59 and 2.19 m below mean lower low water, respectively. Acoustic Doppler velocimeters were used for the simultaneous determination of current velocities, turbulence, sediment concentration and fluxes. Maximum current shear velocities were 0.015 m s−1 at the station further from the channel (closer to the shore) and 0.02 m s−1 at the station closer to the channel. Peak wave-induced shear velocities exceeded 0.015 m s−1 at both stations. Maximum sediment concentrations were around 30 g m−3 during calm periods (root mean square wave height <0.15 m). During wavy periods, sediment concentrations increased to 100 g m−3 and sediment fluxes were 5 times higher than in calm conditions (0.02 g m−2 s−1 versus >0.10 g m−2 s−1) at the station further from the channel 0.36 m above the bed. Closer to the channel, sediment concentrations and vertical fluxes due to wind wave resuspension were persistently lower (maximum concentrations around 50 g m−3 and maximum fluxes around 0.04 g m−2 s−1). Most resuspension events occurred during flood tides that followed wave events during low water. Although wave motions are able to resuspend sediment into the wave boundary layer at low tide, the observed large increases in sediment fluxes are due to the nonlinear interaction of wind waves and the tidal currents.

11. Lacy et al., 1996 – Suspended-solids flux at a shallow-water site in South San Francisco Bay, California

Citation and Link: Lacy, J. R., Schoellhamer, D. H., & Burau, J. R. (1996). Suspended-solids flux at a shallow-water site in South San Francisco Bay. In Proceedings of the North American water and environment congress.

Abstract: This study addresses time series measurements of current velocity and suspended solids concentration (SSC) made during December 1993 and March 1994 at a shallow water site in South San Francisco Bay were used to estimate and compare suspended-solids flux during the two periods. In December, the average residual flux at the site was 2.88 g/m/s, to the northeast, whereas in March the average residual flux was four times greater, 12.2 g/m/s, and was directed to the southeast, the direction of flood tide. Residual flux was decomposed and the three components that accounted for most of the flux were analyzed: residual advective flux (ah'*), Stokes drift flux (u'h'*), and dispersive flux, which is the tidal cycle correlation between velocity and SSC (u'Fic'). During both periods, the Stokes drift flux was to the north, and the dispersive flux was to the southeast. In December, these two components, with nearly opposite directions, had the greatest magnitudes, resulting in a lower total residual flux. In March, the residual advective flux was greater than the Stokes drift flux and was in the same direction as the dispersive flux because of a southeasterly residual current. Wind data indicate that the residual current in March was induced by persistent northwest winds. The southeasterly dispersive flux in March and December was due to generally higher SSC on flood than ebb tides. Increases in SSC frequently occurred at low water (before flood tides). Comparison of calculated bottom orbital velocities to SSC identified wind waves as a mechanism of resuspension.

12. Lacy et al., 2015 – Mechanisms of sediment flux between shallows and marshes

Citation and Link: Lacy, J. R., SCHILE, L. M., CALLAWAY, J. C., & FERNER, M. C. (2015). Mechanisms of sediment flux between shallows and marshes. In The Proceedings of the Coastal Sediments 2015.

Abstract: A field study was conducted to investigate temporal variation and forcing mechanisms of sediment flux between a salt marsh and adjacent shallows in northern San Francisco Bay. Suspended-sediment concentration (SSC), tidal currents, and wave properties were measured over the marsh, in marsh creeks, and in bay shallows. Cumulative sediment flux in the marsh creeks was bayward during the study, and was dominated by large bayward flux during the largest tides of the year. This result was unexpected because extreme high tides with long inundation periods are commonly assumed to supply sediment to marshes, and long-term accretion estimates show that the marsh in the study site is depositional. A water mass-balance shows that some landward transport bypassed the creeks, most likely across the marsh-bay interface. An estimate of transport by this pathway based on observed SSC and inferred volume indicates that it was likely much less than the observed export.

13. Swanson et al., 2014 – Wetland Accretion Rate Model of Ecosystem Resilience (WARMER) and Its Application to Habitat Sustainability for Endangered Species in the San Francisco Estuary

Citation and Link: Swanson, K. M., Drexler, J. Z., Schoellhamer, D. H., Thorne, K. M., Casazza, M. L., Overton, C. T., ... & Takekawa, J. Y. (2014). Wetland accretion rate model of ecosystem resilience (WARMER) and its application to habitat sustainability for endangered species in the San Francisco estuary. Estuaries and Coasts, 37, 476-492.

Abstract: Salt marsh faunas are constrained by specific habitat requirements for marsh elevation relative to sea level and tidal range. As sea level rises, changes in relative elevation of the marsh plain will have differing impacts on the availability of habitat for marsh obligate species. The Wetland Accretion Rate Model for Ecosystem Resilience (WARMER) is a 1-D model of elevation that incorporates both biological and physical processes of vertical marsh accretion. WARMER was used to evaluate changes in marsh surface elevation and the impact of these elevation changes on marsh habitat for specific species of concern. Model results were compared to elevation-based habitat criteria developed for marsh vegetation, the endangered California clapper rail (Rallus longirostris obsoletus), and the endangered salt marsh harvest mouse (Reithrodontomys raviventris) to determine the response of marsh habitat for each species to predicted >1-m sea-level rise by 2100. Feedback between vertical accretion mechanisms and elevation reduced the effect of initial elevation in the modeled scenarios. Elevation decreased nonlinearly with larger changes in elevation during the latter half of the century when the rate of sea-level rise increased. Model scenarios indicated that changes in elevation will degrade habitat quality within salt marshes in the San Francisco Estuary, and degradation will accelerate in the latter half of the century as the rate of sea-level rise accelerates. A sensitivity analysis of the model results showed that inorganic sediment accumulation and the rate of sea-level rise had the greatest influence over salt marsh sustainability.

14. Callaway et al., 2012 – Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands

Citation and Link: Callaway, J. C., Borgnis, E. L., Turner, R. E., & Milan, C. S. (2012). Carbon sequestration and sediment accretion in San Francisco Bay tidal wetlands. Estuaries and Coasts, 35, 1163-1181.

Abstract: Tidal wetlands play an important role with respect to climate change because of both their sensitivity to sea-level rise and their ability to sequester carbon dioxide from the atmosphere. Policy-based interest in carbon sequestration has increased recently, and wetland restoration projects have potential for carbon credits through soil carbon sequestration. Sediment accretion was measured, along with mineral and organic matter accumulation, and carbon sequestration rates using 137Cs and 210Pb downcore distributions at six natural tidal wetlands in the San Francisco Bay Estuary. The accretion rates were, in general, 0.2–0.5 cm year−1, indicating that local wetlands are keeping pace with recent rates of sea-level rise. Mineral accumulation rates were higher in salt marshes and at low-marsh stations within individual sites. The average carbon sequestration rate based on 210Pb dating was 79 g C m−2 year−1, with slightly higher rates based on 137Cs dating. There was little difference in the sequestration rates among sites or across stations within sites, indicating that a single carbon sequestration rate could be used for crediting tidal wetland restoration projects within the Estuary.

15. Wright and Schoellhamer, 2004 – Trends in the Sediment Yield of the Sacramento River, California, 1957–2001

Citation and Link: Wright, S. A., & Schoellhamer, D. H. (2004). Trends in the sediment yield of the Sacramento River, California, 1957–2001. San Francisco estuary and watershed science, 2(2).

Human activities within a watershed, such as agriculture, urbanization, and dam building, may affect the sediment yield from the watershed. Because the equilibrium geomorphic form of an estuary is dependent in part on the sediment supply from the watershed, anthropogenic activities within the watershed have the potential to affect estuary geomorphology. The Sacramento River drains the northern half of California's Central Valley and is the primary source of sediment to San Francisco Bay. In this paper, it is shown that the delivery of suspended-sediment from the Sacramento River to San Francisco Bay has decreased by about one-half during the period 1957 to 2001. Many factors may be contributing to the trend in sediment yield, including the depletion of erodible sediment from hydraulic mining in the late 1800s, trapping of sediment in reservoirs, riverbank protection, altered land-uses (such as agriculture, grazing, urbanization, and logging), and levees. This finding has implications for planned tidal wetland restoration activities around San Francisco Bay, where an adequate sediment supply will be needed to build subsided areas to elevations typical of tidal wetlands as well as to keep pace with projected sea-level rise. In a broader context, the study underscores the need to address anthropogenic impacts on watershed sediment yield when considering actions such as restoration within downstream depositional areas.

16. Shoellhamer, 2011 – Sudden Clearing of Estuarine Waters Upon Crossing the Threshold from Transport to Supply Regulation of Sediment Transport as an Erodible Sediment Pool is Depleted: San Francisco Bay, 1999

Citation and Link: Schoellhamer, D. H. (2011). Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts, 34(5), 885-899.

Abstract: The quantity of suspended sediment in an estuary is regulated either by transport, where energy or time needed to suspend sediment is limiting, or by supply, where the quantity of erodible sediment is limiting. This paper presents a hypothesis that suspended-sediment concentration (SSC) in estuaries can suddenly decrease when the threshold from transport to supply regulation is crossed as an erodible sediment pool is depleted. This study was motivated by a statistically significant 36% step decrease in SSC in San Francisco Bay from water years 1991–1998 to 1999–2007. A quantitative conceptual model of an estuary with an erodible sediment pool and transport or supply regulation of sediment transport is developed. Model results confirm that, if the regulation threshold was crossed in 1999, SSC would decrease rapidly after water year 1999 as observed. Estuaries with a similar history of a depositional sediment pulse followed by erosion may experience sudden clearing.

17. Keller, 2009 – Literature review of Unconsolidated Sediment in San Francisco Bay and Nearby Pacific Ocean Coast

Citation and Link: Keller, B. R. (2009). Literature review of unconsolidated sediment in San Francisco Bay and nearby Pacific Ocean Coast. San Francisco Estuary and Watershed Science, 7(1).

Abstract: A review of the geologic literature regarding sedimentation in the San Francisco Bay estuarine system shows that the main part of the bay occupies a structural tectonic depression that developed in Pleistocene time. Eastern parts, including San Pablo Bay and Suisun Bay, have had sedimentation throughout late Mesozoic and Tertiary. Carquinez Strait and the Golden Gate may represent antecedent stream erosion. Sedimentation has included estuarine, alluvial, and eolian deposition. The ages of estuarine deposition includes the modern high sea level stand and earlier Pleistocene interglacial periods. Sediment sources can be generally divided into the Coast Ranges, particularly the Franciscan Complex, and "Sierran." Much of the estuarine system is floored by very fine sediment, with local areas of sand floor. Near the Golden Gate, sediment size decreases in both directions away from the deep channel. Bedforms include sand waves (submarine dunes), flat beds, and rock and boulders. These are interpreted in terms of dominant transport directions. Near the Golden Gate is an ebb-tidal delta on the outside (including San Francisco bar) and a flood-tidal delta on the inside (parts of Central Bay). The large tidal prism causes strong tidal currents, which in the upper part of the estuary are normally much stronger than river currents, except during large floods. Cultural influences have altered conditions, including hydraulic mining debris, blasting of rocks, dredging of navigation channels, filling of the bay, and commercial sand mining. Many of these have served to decrease the tidal prism, correspondingly decreasing the strength of tidal currents.

18. Holmes et al., 2023 – Silt Sand Slurry: Dredging, Sediment, and the Worlds We Are Making

Citation and Link: Holmes, R., Milligan, B., Wirth, G. (2023). Silt Sand Slurry: Dredging, Sediment, and the Worlds We Are Making. Applied Research & Design

The book prepared by Holmes and colleagues (2023) summarizes the world of dredging and the importance of sediment across the United States. The authors investigate four regions providing information about the landscape history of each area, dredging impacts, sediment removal equipment, and the importance it has to the coastal zone. Additionally, the authors provide a quick introduction to dredging and, most interestingly, offer an insight into what federal, state, and local agencies and other entities are currently doing within their regions.

The book is relevant to the Action Plan since it offers a “snapshot” of fundamental knowledge that may be applied to improve management techniques, broaden networks, and deepen one’s awareness of the dredging industry. Though the book provides stories based on current knowledge, it is not appropriate for other aspects of the Action Plan, such as policy changes and building a finance strategy. Overall, the authors provide excellent information and it will be used moving forward to help educate the public on this important topic.

19. Morris, 2020 – Classification of Management Alternatives to Combat Reservoir Sedimentation

Citation and Link: Morris, G. L. (2020). Classification of management alternatives to combat reservoir sedimentation. Water, 12(3), 861.

Abstract: Sedimentation is steadily depleting reservoir capacity worldwide, threatening the reliability of water supplies, flood control, hydropower energy and other benefits that form the basis of today’s water-intensive society. The strategies available to combat reservoir sedimentation may be classed into four broad categories. Three proactive categories seek to improve the sediment balance across reservoirs by: (a) reducing sediment yield from the watershed, (b) routing sediment-laden flows around or through the storage pool, and (c) removing deposited sediment following deposition. The fourth category (d) consists of strategies that adapt to capacity loss, without addressing the sediment balance. Successful management will typically combine multiple strategies. This paper presents a comprehensive classification of both proactive and adaptive strategies, consistent with current international practice. Functional descriptions and examples are given for each strategy, and criteria are provided to differentiate between them when there is potential for ambiguity. The classification categories can be used as a checklist of strategies to consider in evaluating sediment management alternatives for new designs as well as remedial work at existing sediment-challenged reservoirs. This will also help practitioners to more clearly describe and communicate the nature of their management activities. Widespread application of both active and adaptive strategies is required to bring sedimentation under control to sustain benefits of water storage for today’s and future generations.

20. Shoellhamer, 2002 – Variability of suspended-sediment concentration at tidal to annual time scales in San Francisco Bay, USA

Citation and Link: Schoellhamer, D. H. (2002). Variability of suspended-sediment concentration at tidal to annual time scales in San Francisco Bay, USA. Continental Shelf Research, 22(11-13), 1857-1866.

Abstract: Singular spectrum analysis for time series with missing data (SSAM) was used to reconstruct components of a 6-yr time series of suspended-sediment concentration (SSC) from San Francisco Bay. Data were collected every 15 min and the time series contained missing values that primarily were due to sensor fouling. SSAM was applied in a sequential manner to calculate reconstructed components with time scales of variability that ranged from tidal to annual. Physical processes that controlled SSC and their contribution to the total variance of SSC were (1) diurnal, semidiurnal, and other higher frequency tidal constituents (24%), (2) semimonthly tidal cycles (21%), (3) monthly tidal cycles (19%), (4) semiannual tidal cycles (12%), and (5) annual pulses of sediment caused by freshwater inflow, deposition, and subsequent wind-wave resuspension (13%). Of the total variance 89% was explained and subtidal variability (65%) was greater than tidal variability (24%). Processes at subtidal time scales accounted for more variance of SSC than processes at tidal time scales because sediment accumulated in the water column and the supply of easily erodible bed sediment increased during periods of increased subtidal energy. This large range of time scales that each contained significant variability of SSC and associated contaminants can confound design of sampling programs and interpretation of resulting data. Published by Elsevier Science Ltd.

21. Shoellhamer and Burau, 1998 – Summary of Findings About Circulation and the Estuarine Turbidity Maximum in Suisun Bay, California

Citation and Link: Schoellhamer, D. H., & Burau, J. R. (1998). Summary of findings about circulation and the estuarine turbidity maximum in Suisun Bay, California (No. 047-98). US Geological Survey.

Abstract: Suisun Bay, California, is the most landward subembayment of San Francisco Bay and is an important ecological habitat. During the 1960s and 1970s, data collected in Suisun Bay were analyzed to develop a conceptual model of how water, salt, and sediment move within and through the Bay. This conceptual model has been used to manage freshwater flows from the Sacramento-San Joaquin Delta to Suisun Bay to improve habitat for several threatened and endangered fish species. Instrumentation used to measure water velocity, salinity, and suspended solids concentration (SSC) greatly improved during the 1980s and 1990s. The U.S. Geological Survey (USGS) has utilized these new instruments to collect one of the largest, high-quality hydrodynamic and sediment data sets available for any estuary. Analysis of these new data has led to the revision of the conceptual model of circulation and sediment transport in Suisun Bay.

22. Barbier et al., 2023 – The value of estuarine and coastal ecosystem services

Citation and Link: Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecological monographs, 81(2), 169-193.

Abstract: The global decline in estuarine and coastal ecosystems (ECEs) is affecting a number of critical benefits, or ecosystem services. This study reviews the main ecological services across a variety of ECEs, including marshes, mangroves, nearshore coral reefs, seagrass beds, and sand beaches and dunes. Where possible, estimates of the key economic values arising from these services were indicated, and the natural variability of ECEs impacts their benefits, the synergistic relationships of ECEs across seascapes, and management implications were discussed. Although reliable valuation estimates are beginning to emerge for the key services of some ECEs, such as coral reefs, salt marshes, and mangroves, many of the important benefits of seagrass beds and sand dunes and beaches have not been assessed properly. Even for coral reefs, marshes, and mangroves, important ecological services have yet to be valued reliably, such as cross-ecosystem nutrient transfer (coral reefs), erosion control (marshes), and pollution control (mangroves). An important issue for valuing certain ECE services, such as coastal protection and habitat–fishery linkages, is that the ecological functions underlying these services vary spatially and temporally. Allowing for the connectivity between ECE habitats also may have important implications for assessing the ecological functions underlying key ecosystems services, such coastal protection, control of erosion, and habitat–fishery linkages. Finally, an action plan for protecting and/or enhancing the immediate and longer-term values of ECE services was recommended. Because the connectivity of ECEs across land–sea gradients also influences the provision of certain ecosystem services, management of the entire seascape will be necessary to preserve such synergistic effects. Other key elements of an action plan include further ecological and economic collaborative research on valuing ECE services, improving institutional and legal frameworks for management, controlling and regulating destructive economic activities, and developing ecological restoration options.

23. Callaway et al., 2011 – Tidal Wetland Restoration in San Francisco Bay: History and Current Issues

Citation and Link: Callaway, J. C., Parker, V. T., Vasey, M. C., Schile, L. M., & Herbert, E. R. (2011). Tidal wetland restoration in San Francisco Bay: history and current issues. San Francisco Estuary and Watershed Science, 9(3).

Abstract: Early restoration efforts in San Francisco Bay focused primarily on establishing appropriate elevations for plant recruitment, based on plant distributions in natural wetlands. Sites were graded and planted, and tidal connections were re-established with the expectation that restored wetlands would quickly resemble natural ecosystems. Over time, restoration efforts have evolved, with the realization that natural development of restoration sites is preferable, including a dense channel network and the accumulation of soil of appropriate texture. Bay restoration efforts also have grown substantially in size and scope. Whereas projects of 50 hectares were considered large in the 1980s, now many projects are 100s of hectares. Larger projects are on the scale of 1000s of hectares, with the largest approximately 6000 hectares (the South Bay Salt Pond Restoration Project). This massive increase in scale has brought enormous restoration opportunities, but it also has increased the complexity of restoration projects and highlighted the necessity of large-scale

public involvement. Awareness of non-native plants at restoration sites is just one example of factors that have increased restoration complexity. Potential impacts of climate change also have moved to the forefront of restoration design, as sea-level rise and potential shifts in salinity are critical factors for long-term restoration planning.

24. Baptist et al., 2019 – Beneficial use of dredged sediment to enhance salt marsh development by applying a 'Mud Motor'

Citation and Link: Baptist, M. J., Gerkema, T., Van Prooijen, B. C., Van Maren, D. S., Van Regteren, M., Schulz, K., ... & van Puijenbroek, M. E. B. (2019). Beneficial use of dredged sediment to enhance salt marsh development by applying a 'Mud Motor'. Ecological Engineering, 127, 312-323.

Abstract: Baptist et al. test an innovative approach to beneficially re-use dredged sediment to enhance salt marsh development. A Mud Motor is a dredged sediment disposal in the form of a semi-continuous source of mud in a shallow tidal channel allowing natural processes to disperse the sediment to nearby mudflats and salt marshes. They describe the various steps in the design of a Mud Motor pilot: numerical simulations with a sediment transport model to explore suitable disposal locations, a tracer experiment to measure the transport fate of disposed mud, assessment of the legal requirements, and detailing the planning and technical feasibility. An extensive monitoring and research program was designed to measure sediment transport rates and the response of intertidal mudflats and salt marshes to an increased sediment load. Measurements include the sediment transport in the tidal channel and on the shallow mudflats, the vertical accretion of intertidal mudflats and salt marsh, and the salt marsh vegetation cover and composition. In the Mud Motor pilot a total of 470,516 m3 of fine grained sediment (D50 of ~ 10 μm) was disposed over two winter seasons, with an average of 22 sediment disposals per week of operation. Ship-based measurements revealed a periodic vertical salinity stratification that is inverted compared to a classical estuary and that is working against the asymmetric flood-dominated transport direction. Field measurements on the intertidal mudflats showed that the functioning of the Mud Motor, i.e. the successful increased mud transport toward the salt marsh, is significantly dependent on wind and wave forcing. Accretion measurements showed relatively large changes in surface elevation due to deposition and erosion of layers of watery mud with a thickness of up to 10 cm on a time scale of days. The measurements indicate notably higher sediment dynamics during periods of Mud Motor disposal. The salt marsh demonstrated significant vertical accretion though this has not yet led to horizontal expansion because there was more hydrodynamic stress than foreseen. In carrying out the pilot, they found that the feasibility of a Mud Motor depends on an assessment of additional travel time for the dredger, the effectiveness on salt marsh growth, reduced dredging volumes in a port, and many other practical issues. Our improved understanding on the transport processes in the channel and on the mudflats and salt marsh yields design lessons and guiding principles for future applications of sediment management in salt marsh development that include a Mud Motor approach.

25. Thorne et al., 2019 – Thin-layer sediment addition to an existing salt marsh to combat sea-level rise and improve endangered species habitat in California, USA

Citation and Link: Thorne, K. M., Freeman, C. M., Rosencranz, J. A., Ganju, N. K., & Guntenspergen, G. R. (2019). Thin-layer sediment addition to an existing salt marsh to combat sea-level rise and improve endangered species habitat in California, USA. Ecological Engineering, 136, 197-208

Abstract: Current tidal marsh elevations and their accretion rates are important predictors of vulnerability to sea-level rise. When tidal marshes are at risk, adaptation measures, such as sediment addition to increase elevations, can be implemented to prevent degradation and loss. In 2016, wildlife managers prescribed a thin-layer sediment addition of locally sourced dredged material from Anaheim Bay to mitigate plausible future impacts of sea-level rise to Seal Beach National Wildlife Refuge, an urbanized, subsiding, sediment limited, and low elevation tidal marsh in southern California, USA. In this study, our objectives were to determine how suspended sediment concentrations (SSC) and fluxes associated with sediment application affected an adjacent eelgrass bed and a more distant deep tidal channel at different time periods throughout the project and how sediment application affected tidal marsh elevation. Due to the sediment addition the tidal marsh elevation increased by 25.4 cm across 3.06 ha. Mean SSC levels at the eelgrass site increased from 4 mg/L during pre-augmentation to 16 mg/L during sediment application. SSC levels also increased up to 40 mg/L with the installation of sediment barriers. Winter storms during construction also had an influence on SSC, with an extreme storm event increasing SSC from 9 mg/L pre-storm levels to 16 mg/L during the storm. However, SSC at the deep site remained constant during all time periods with a mean of 7 mg/L. Our results show that little to zero sediment was exported out of Anaheim Bay during the study period, illustrating that any impacts were localized to the application area. These findings suggest that although long-range export of applied dredge material is unlikely from future thin-layer sediment application at this site, adjacent habitats could experience impacts if erosion control measures are not implemented effectively. Future projects will benefit from similar pre- and post-addition monitoring to establish the long-term efficacy of sea-level rise adaptation measures.

26. Suedel et al., 2021 – Beneficial use of dredged sediment as a sustainable practice for restoring coastal marsh habitat

Citation and Link: Suedel, B. C., McQueen, A. D., Wilkens, J. L., Saltus, C. L., Bourne, S. G., Gailani, J. Z., … & Corbino, J. M. (2021). Beneficial use of dredged sediment as a sustainable practice for restoring coastal marsh habitat. Integrated Environmental Assessment and Management, 18(5), 1162-1173.

Coastal Louisiana (USA) continues to sustain immense land and habitat losses due to subsidence, sea-level rise, and storm events. Approximately 65 million m3 (85 million cubic yards) of sediment is dredged annually from Gulf Coast federal navigation channels to maintain safe waterway passage. The beneficial use of these sediments continues to increase, and now this sediment is recognized as a critical resource in large-scale (estimated multibillion dollar) ecosystem restoration efforts to mitigate land and habitat losses along the US Gulf Coast. However, the documentation of restoration benefits where dredged sediments are the primary resource is lacking, which limits the potential for future applications. Therefore, this study documents the progress to restore marsh habitat and the resultant benefits in West Bay, Louisiana, and investigates how the restoration practices align with principles of the US Army Corps of Engineers (USACE) Engineering with Nature® (EWN®) and UN Sustainable Development Goals (UN SDGs). West Bay, a 4964-ha subdelta adjacent to the Mississippi River, typifies risks of coastal land loss that also threatens the integrity of the adjacent federal navigation channel. To help restore coastal marsh habitat on a large spatial and temporal scale, the USACE constructed an uncontrolled diversionary channel from the Mississippi River and with subsequent direct and strategic placement of dredged sediment. Restoration performance was assessed through remotely sensed methods using data spanning approximately 70 years. To date, placement of dredged sediment in the bay has facilitated the creation of over 800 ha of new land in the formerly open waters of West Bay. The West Bay restoration project aligns with the principles of the EWN initiative, which supports more sustainable practices to deliver economic, environmental, and social benefits through collaborative processes and meaningfully integrates 10 of the UN SDGs designed to achieve a better and more sustainable future.

27. Gailani et al., 2019 - Strategic placement for beneficial use of dredged material

Citation and Link: Gailani, J., K. E. Brutsch, E. Godsey, P. Wang, and M. A. Hartman. (2019). Strategic placement for beneficial use of dredged material. Technical Rep. No. ERDC/CHL SR-19-3. Vicksburg, MS: USACE.

Abstract: The U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency are changing their perception of dredged material, from a byproduct of the dredging process to a valuable resource. The negative perception of navigation dredged material is codified under the 1972 Clean Water Act Section 502, which specifically defines “dredge spoils” as a pollutant, along with solid waste, sewage, and garbage. However, navigation dredged material is typically a mixture of sand, silt, clay, and possibly gravel. These sediments resources are critical to controlling flood risks and providing environmental benefits. This document provides details regarding the use of dredged material to support NNBF through strategic placement. Strategic placement is the process of placing sediment at one location with the expectation that hydrodynamic and possibly aerodynamic forces will transport specified classes of that sediment to desired locations. Strategic placement is a beneficial use option that may have less negative impact on the final receptor sites and often can be performed at a reduced cost when compared to direct placement (such as beach nourishment). Cost controls are critical to developing sustainable dredged sediment management plans that address the Federal Standard, which guides the disposal and placement of dredged material.

28. Myszewski and Alber, 2017 – Use of Thin Layer Placement of Dredged Material for Salt Marsh Restoration

Citation and Link: Myszewski, M., & Alber, M. (2017). Use of Thin Layer Placement of Dredged Material for Salt Marsh Restoration. Report prepared for the Coastal Resources Division. Georgia Department of Natural Resources by the Georgia Coastal Research Council, University of Georgia, Athens, GA, 45.

Summary: This report reviews the use of TLP of fine sediments (i.e. silt and clay) in salt marshes. Part I describes TLP and how it is being used for the nourishment and restoration of salt marshes. Part 2 examines how TLP projects are planned and designed. Part 3 discusses the importance of monitoring TLP projects before, during, and after construction. Physical, biological, and chemical parameters that are commonly part of successful monitoring plans are described and results from case studies are discussed with a focus on the parameters useful for Georgia projects. Part 4 provides a discussion of factors that make up a successful TLP project.

29. Randall et al., 2000 – Texas Gulf Intracoastal Waterway (GIWW Dredged Material: Beneficial Uses, Estimating Costs, Disposal Analysis Alternatives, and Separation Techniques

Citation and Link: Randall, R., Basilotto, J., Cobb, D., Graalum, S., He, Q., Miertschin, M., & Edge, B. (2000). Texas gulf intracoastal waterway (GIWW) dredged material: Beneficial uses, estimating costs, disposal analysis alternatives, and separation techniques (No. FHWA/TX-01/1733-S). Texas Transportation Institute.

Abstract: A two-year project, Alternative Dredging and Disposal Methods for the Texas Gulf Intracoastal Waterway, investigates the cost and engineering of long distance pumping, beneficial uses of GIWW-dredged material for the Texas coastal zone, separation techniques for GIWW-dredged material, optimum slurry flow, and alternatives for analyzing dredged material disposal. A cost-estimating program incorporates fuel costs, dredge crew labor costs, routine maintenance and repairs, major repairs, overhead costs, depreciation, profit, mobilization and demobilization, and capital investment cost for a cutter suction dredge. The Cutter Suction Dredge Cost Estimation Program (CSDCEP) estimates the production rate and cost of dredging projects. Comparisons with actual production rate and costs show CSDCEP is accurate. An attractive beneficial use of dredged material from the GIWW is manufactured soil, which can be manufactured using dredged material, recyclable organic waste materials (sewage sludge), and biomass (cellulose or saw dust). Researchers estimate the manufacturing and transportation costs at $13 to $20 per cubic yard depending on the blending method, mode of transportation, and ease of excavation.

Another beneficial use is thin-layer disposal, spraying dredged material on adjacent wetlands. A geotube filled with dredged material placed along the Texas GIWW could provide a beneficial use while preventing further inundation of wetlands due to erosion. Dewatering wheels and hydro cyclones have been identified as two potential separation techniques. Results from the CD-CORMIX software show that the reduced flow from smaller dredges can reduce turbidity during the dredging process.

30. Zapp and Mariotti, 2021 – Evaluating direct and strategic placement of dredged material for marsh restoration through model simulations

Citation and Link: Zapp, S. M., & Mariotti, G. (2021). Evaluating direct and strategic placement of dredged material for marsh restoration through model simulations. Shore & Beach, 89(4), 33.

Abstract: Dredged material can be used for marsh restoration by depositing it on the marsh surface (thin-layer placement), by releasing it at the mouth of channels and allowing tidal currents to transport it onto the marsh platform (channel seeding), or by creating new marshes over shallow areas of open water. Zapp and Mariotti investigate the efficacy of these different methods using a comprehensive 2D marsh evolution model that simulates tidal dynamics, vegetation processes, bank and wave erosion, and ponding. Total marsh area is assessed over 50 years in an idealized microtidal marsh under different relative sea level rise (RSLR) scenarios. For a given volume of total sediment added, the frequency of deposition is relatively unimportant in maximizing total marsh area, but the spatial allocation of the dredged material is crucial. For a given volume of sediment, thin-layer deposition is most effective at preserving total marsh area, especially at high rates of RSLR. Channel seeding is less efficient, but it could still provide benefits if larger amounts of sediment are deposited every 1-2 years. Marsh creation is also beneficial, because it not only increases the marsh area, but additionally slows the erosion of the existing marsh. The 2D model is highly computationally efficient and thus suited to explore many scenarios when evaluating a restoration project. Coupling the model with a cost assessment of the different restoration techniques would provide a tool to optimize marsh restoration.