FINES: RETHINKING OUR RELATIONSHIP

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Abstract: Delivery of sediment to the nearshore environment has been greatly altered from historical norms. Here, two novel projects and scientific results that are directly related to sediment with a high proportion of fines are summarized. Additionally, management challenges of fines in the coastal zone are presented. In Winter 2014, a focus group comprised of regulators and managers was convened to inform the development of a product to translate existing technical and scientific information into a useful and applied format for a coastal management audience. Emergent themes from the focus group are highlighted that represent persistent questions in the management and regulatory community including ecological considerations, the role of numerical modeling, and regional application of demonstration project results. Implications of this work for future use of fines in similar settings are discussed.

Introduction: Fine-Grained Sediment

Sediment is the natural product of weathering in the geologic cycle, and the finest fraction of this sediment, here described as simply "fines" "fine sediment", or "fine-grained sediment", is composed of silt and clay particles. While small in size, fines are typically described as being smaller than 0.063 mm in diameter and often represents the bulk of the sediment mass exported from the landscape to the ocean. For example, Farnsworth and Warrick (2008) calculate that 70 to 80% of the suspended-sediment load from California coastal rivers is fine-grained and that this export averages about 34 million tonnes of fines per year.

The massive rate of fine sediment export from the California landscape to the sea is consistent with the active tectonic geologic setting of this region.

Furthermore, these rates are consistent with sediment export to the sea from other active tectonic settings (Millimand and Syvitski, 1992). Thus, California coastal waters are understood to receive high loading of fines owing to natural weathering processes related to the geologic cycle.

This does not suggest that humans have had little impact on these fine sediment supplies. In contrast, humans have significantly altered the rates of erosion throughout the California landscape primarily through land use (e.g., Trimble, 1997; Warrick et al., 2013) while also reducing sediment delivery to the sea by trapping behind dams and debris basins (e.g., Willis and Griggs, 2003). These patterns in California are consistent with human impacts worldwide on sediment delivery to the sea (Syvitski et al., 2005). The net effect of these two effects – increased erosion and reduced delivery – are generally found to balance for broad geographical regions, although they might not balance for specific watersheds or intervals of time (Syvitski et al., 2005).

The net result of the flux of fines from California to the sea has been the building of coastal wetlands and rich supplies of fines on the continental shelf and in the deep sea (Farnsworth and Warrick, 2008). One important challenge will be whether coastal wetlands – not only in California, but also worldwide – will be sustainable in the near future when sea-level rise is expected to accelerate (e.g., Stralberg et al., 2011). Fine sediment supplies are expected to be a primary driver of wetland sustainability, and systems without adequate supplies of fines are expected to submerge (Stralberg et al., 2011). In contrast, other wetland systems have been overwhelmed by high rates of sedimentation resulting from poor land use and exceptional landscape erosion within their watersheds (e.g., Farnsworth and Warrick, 2008; Tijuana Estuary-Friendship Marsh Restoration Feasibility and Design Study, 2008). These excessive sediment supplies could potentially be used to make up sediment deficits in other coastal systems, including those along the beaches that line the outer shoreline.

Thus, it is imperative to adequately understand and properly manage fines along the California coast to best deal with threats to critical coastal habitats and infrastructure from both sea-level rise and altered rates of sediment delivery from watersheds. The goals of this paper are to present an overview of some novel projects and scientific results that are directly related to management challenges of fines in the coastal zone. Specifically, we summarize studies of the use of beach nourishment sediment with a high proportion of fines and discuss the implications of this work to future use of fines in similar settings.

Fine-Grained Sediment Management Along the California Coast

Sediment requires much management along the urbanized California coastline and within its watersheds. As such, coastal decision-makers (NOAA, 2008) must focus on innovative techniques and approaches for adaptive, cost-effective management. These coastal decision-makers include regulators who have a coastal mandate (e.g., U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, California Coastal Commission); coastal and natural resource managers and regulators (e.g., U.S. Fish and Wildlife Agency, California Department of Fish and Wildlife, California State Parks) and practitioners (e.g., non-governmental agencies who engage in habitat restoration often focused on wetlands). Each group approaches fine-grained sediment with different perspectives, and these perspectives can be summarized broadly as: regulators reduce impacts, resource managers protect resources, and practitioners often propose coastal projects that involve the movement and or placement of sediment. However, these groups must work together to achieve their distinct and common missions.

An Example of Coastal Management and Resource Protection: The "80/20 Rule"

The 80/20 Coarse-to-Fines "Rule-of-Thumb" Ratio (CSMW Task 5, 2005) is regularly referenced as the "80/20 Rule" in coastal manager discussions regarding regulatory considerations in placement of sediment in the coastal zone. The "80/20 Rule" is rather a "Rule-of-Thumb"—a consensus view among regional offices of the U.S. Environmental Protection Agency and the Interagency National Dredging Team—for the purpose of applying the testing exclusion criteria under the Marine Protection, Research, and Sanctuaries Act (MPRSA) (CSMW, 2005). Specifics of the exemption are codified in 40 CFR – Part 227, Section 227.13 (b)(1) (U.S. Code of Federal Regulations, 2003a) (CSMW, 2005) such that dredged material that is less than 20% fine-grained sediment (i.e., "composed predominantly of sand") is deemed environmentally acceptable for ocean dumping or beach replenishment without further chemical or toxicity testing. Thus, only a knowledge of the dredged material grain-size is needed to make this determination.

The logic behind the an upper limit of 20% fine-grained sediment content in the "80/20 Rule-of-Thumb" is based on the characteristics of silts and clays to adsorb chemical contaminants that may have adverse impacts on marine environments or human health (CSMW, 2005). The Coastal Sediment Management Workgroup (CSMW) Task 5 report describes a "widespread misperception" about the 80/20 rule, "… within both regulatory agencies and the regulated community, that an 80/20 Coarse-to-Fines "Rule-of-Thumb" Ratio is an inviolate rule prohibiting the use of dredged material containing more than 20% fines for beach nourishment purposes" (CSMW, 2005). That is to say that the "80/20 Rule-of-Thumb" in no way prohibits dumping or reuse of sediment with greater than 20% fines, it simply requires more thorough testing of the material.

Nevertheless, the "80/20 rule" arises regularly in discussions among coastal managers as a perceived obstacle to nearshore coastal placement of sediment with substantial proportion of fines, even if the material has been tested and is not contaminated. While this is technically incorrect, there are additional constrains in the current regulatory environment to utilizing sediment with a high portions of fines. For example, beach fill, or "nourishment", is the only activity identified as a beneficial use of dredged sediment. That is, the placed sediments must be found to provide adequate benefits to the active beach, which is generally defined to be from the upper beach berm to the "depth of closure" water depth, below which little sediment moves to-and-from the beach. To provide these benefits, the sediment must adequately match the grain-size distribution of the beach that it is "benefiting." Otherwise, the sediment placement will be considered waste disposal, and thus must be conducted at a deeper ocean disposal site.

Although these regulatory constructs generally provide adequate protection of resources, there are concerns that important and clean sediment supplies – both fine- and coarse-grained – are being lost to waste disposal. For example, if the grain-size distribution of dredged sediment does not match a receiving beach owing to an abundance (say 20-50%) of fine sediment, then any potential benefit that the sand fraction of the material could have provided to the beach will not be realized. If dredged material is greater than 50% fine-grained by weight, then it is commonly determined that it cannot provide any benefit to the beach, and the sediment must be deposed of as waste.

New Developments

Recent dynamic and inclusive partnerships across these groups have enabled developments in the asking of important (and perhaps difficult) questions about the nature and fate of various sediments in the ocean and the furthering of our scientific understanding of fine-grained sediment in coastal settings. These developments are initiating discussions about the future directions and advancements in coastal sediment policy and management. Two example projects have been important to these developments and are presented briefly: (1) Santa Cruz Harbor Demonstration Project and (2) the Tijuana River Demonstration Project.

Santa Cruz Harbor Demonstration Project

This demonstration project was conducted at the Santa Cruz Harbor, California, during 2009 to determine if sediment dominated by fines (71% by weight) could be dredged from the inner portion of the harbor and discharged to the coastal ocean without significant impacts to the beach and inner shelf. Over 7600 m^3 of sediment (i.e., 5400 m^3 of fine-grained sediment) was dredged during 17 days and discharged approximately 60 m offshore of the harbor at a water depth of 2 m. An integrated mapping and oceanographic monitoring and process study was conducted to investigate the fate of the fine sediment and to determine if these fines would deposit on the shoreline and/or inner shelf. Additionally, a three-dimensional numerical circulation and sediment transport model was developed to better understand the fate of the fine-grain sediment dredged from Santa Cruz Harbor and the potential consequences of disposing this type of material on the beach and on the northern Monterey Bay continental shelf. Results from this project generally revealed that the energetic conditions of the ocean rapidly transported the fine-grained fraction of the sediment to deeper portions of the shelf where fine sediments dominate. These results are presented in Storlazzi et al. (2011) and summarized in Warrick and Storlazzi (2013).

Tijuana River demonstration project

This demonstration project was conducted at the Tijuana River National Estuarine Research Reserve, which is part of the National Oceanic and Atmospheric Administration's National Estuarine Research Reserve System, to evaluate the fate and transport of sediment with a high portion of fines (40% by weight). The sediment was derived from sediment retention basins built to protect the estuary from excessive sedimentation caused by poor land uses in the watershed. In 2005, for example, 18 acres of salt marsh was buried due to the overtopping of sediment retention basins (TRNERR Comprehensive Management Plan, 2010), presenting a threat to protected habitat and future restoration projects (Zedler & West, 2008). The primary purpose of the Demonstration Project, commonly referred to as "fate and transport study", was to collect and provide information about the directions, rates, and processes of fine-sediment transport along and across a California beach and nearshore setting.

In 2008 and 2009, a combined 35,000 m^3 of sediment with 40% fines was placed on the beach between the Tijuana River mouth and the U.S.-Mexico International Border. Before, during, and after the project, seawater, beach sediment, and seafloor properties were monitored by physical sampling, instrumentation, and remote sensing. The initial transport of fine sediment from the beach was influenced strongly by longshore currents of the surf zone, and the mean residence time of fine sediment in the surf zone—once it was suspended—was approximately one hour. A mass balance of the fine sediment suggested that it largely moved far away (over 2 km) from the nourishment site or to water depths greater than 10 m, where fine sediment represents a substantial portion of the bed material. Additional work was conducted on the biological, bacteriological, and nutrient impacts of the project. Results and observations are presented in Warrick et al. (2012), Warrick (2013), Rippy et al. (2013) and summarized in Warrick and Storlazzi (2013).

Implications for Sediment Management

Results from the demonstration projects at Santa Cruz and Tijuana River have contributed to a better scientific understanding of the fate and transport of fine-grained materials in the coastal ocean. However, this research was conducted with other goals: (i) to disseminate and translate scientific information to the coastal management communities along the California coast; and (ii) to advance the dialogue among the coastal management community and regulators about sediment management and regulation.

After publication of a fact sheet by U.S. Geological Survey (Warrick and Storlazzi, 2013), it was decided to develop a report to synthesize current technical and scientific information into a useful and applied format for a coastal management audience. As such, it will need to effectively describe the various elements of managing for fine-grained sediment, synthesize the portfolio of considerations, relate these considerations to the scientific research and current regulatory landscape, and identify opportunities for informing state and federal policy. A focus group among the coastal management community was planned and held to understand the needs and utilities of this report and solicit input on the format and content. Bringing stakeholders together is one strategy in a movement towards a more integrated sediment management effort that supports research, evaluation, and policy implementation (Owens et al., 2005).

Focus Group Outcomes

In December 2014, a focus group was held at TRNERR and included 19 participants, including both project proponents of wetland restoration and regulatory and resource agencies. Organizational affiliations of participants included federal government, state government, regional government, non-governmental agencies, and consultants. The format of the focus group was an in-person four-hour meeting that included scientific and policy presentations and opportunity for discussion and dialogue between regulators and managers. Some attendees participated by phone.

Four major themes, representing persistent questions around fine-grained sediment management among managers for regulators arose in the focus group: (i) ecological impacts; (ii) bacteria and nutrients; (iii) the role of numerical modeling; and (iv) regional application of demonstration project results. These themes are addressed independently below. Initial discussion evolved around the concern around the "80/20 Rule", however, it was clarified that regulatory agencies rely more on site information, i.e., appropriate grain size, when making decisions, rather than considering this as an exclusionary rule of thumb. This reinforces the assertion contained within CSMW's Task 5 report regarding the "widespread misconception", which is highlighted above (CSMW, 2005). Various contributions to the focus group clarified an important perspective: that the fate and transport study, fundamentally, was not conducted to examine beach replenishment and its benefit(s), but rather to determine the transport and fate of fine-grained sediment when placed in the coastal nearshore.

Ecological Considerations

Referring to examples in the scientific literature, it was noted that three main variables help determine the potential biological responses to fine sediments: (i) the concentration of sediment loading; (ii) the duration of exposure; and (iii) the characteristics of the grain size distribution. Despite the fate and transport project's primary focus on examining physical processes, regulatory and management communities also recognized that fine sediment could have measurable effects on sensitive habitats and species. Thus, the demonstration project was also monitored for a small, yet ecologically significant, subset of biological effects using a few key indicator species. Beach invertebrates were the most comprehensively monitored biological community (Biological Resources Monitoring Report, 2013), and results demonstrated that the subtidal communities studied appeared to be resilient to the addition of fines. Species such as western snowy plover, and sand dollar and pismo clam populations did not appear to be negatively affected by the project. When fine-scale population differences were observed, project impacts were unlikely the source of such variation (Biological Resources Monitoring Report, 2013). Changes in beach fauna were attributable to forces such as: recovery/recolonization, high natural variability, and resilience of the sandy intertidal community (Biological Resources Monitoring Report, 2013).

The expectation to understand the response of every potential species in or near the study area, where these ecosystems comprised of hundred to thousands of species, can be a "management hamstring", as one participant raised during the focus group. Alternatively, with an empirical understanding of what the system does naturally, and what environment the species are exposed to and can tolerate, assumptions can be made or placement activities can be designed to be less than a natural perturbation. The Tijuana River mouth, for example, represents a site choice where the River delivers far more sediment than the proposed project. Focus group input included the desire to develop a programmatic approach to addressing these challenges by considering justifiable tradeoffs, and amplifying monitoring efforts of sensitive indicator species. Potentially this could include assessments—perhaps with numerical models or scaling—that assess whether sediment concentration-duration relationships will either extend above critical thresholds within sensitive habitats or whether these relationships are significantly above background levels for the study area. Additionally, the desire was articulated at the focus group to understand more not just about the tolerance of biological communities to fine-grained sediment, but the benefits that it could provide for some species. It was shared that the decisions about how to manage sediment at the Tijuana Estuary, for example, is central to the protection of critical habitat for endangered species and consequences of lack of sediment management must be weighed against the uncertainty.

Bacteria and nutrients

Although the placement sediments were tested clean before the projects, short-duration surf-zone increases in concentrations of the fecal indicator *Enterococcus* were observed during the Tijuana fate and transport project. Contamination was constrained to the nourishment site (Rippy et al., 2013) and nourishment fines were identified as a source of the *Enterococcus* (Rippy et al., 2013). Concerns raised at the focus group included the introduction of bacteria into the nearshore environment, especially along coastlines characterized by high seasonal public use. Timing of placement was discussed, and examples of ideal timeframes were provided, for example, a placement activity would not be considered by regulators during peak summer season when beach use is highest. Furthermore, public access could be removed for the coastal waters immediately around and for the duration of the project. Discussion also focused on the consideration of the ambient coastal system and its patterns and durations of contamination. For example, a placement activity during a high flow event in the adjacent Tijuana River, would likely produce limited contamination effects owing to the high bacteria loading of the river. In this manner, sediment management should consider the "signal-to-noise" of the water quality implications of the project. This, however, raised the need for additional research on techniques for testing and interpreting source materials.

Case-by-Case or a More Regional Approach?

The purpose of the demonstration projects was not only to develop better understanding for the study sites, but also to be used as examples for extrapolation to other coastal areas, including coastal wetlands, in southern California. One manner to extrapolate these results is through the use of numerical models, which were shown to adequately mimic the rates and processes of sediment dispersal from both demonstration projects. Discussion about the application of these kinds of tools for use in the regulatory and permitting stages of projects emphasized that the general sediment transport physics and model approaches can be extrapolated to other parts of California, and yet, the specific conditions of each new site (e.g., bathymetry, currents, and waves) must be considered carefully.

Thus, it was concluded that some additional field data would need to be collected at individual sites as the scale and timeframe of the project could produce different results. That is, if other sites were to be considered for future projects, there are unique aspects of these sites (e.g., waves) that need to be captured. That said, the physics of water and sediment movement are more universal and standardized in the models. It was also concluded that models may help to represent a range of project scenarios to optimize sediment placement, minimize potential impacts, and better address the concerns of resource managers and regulators.

Additional research conducted on these topics will contribute to the, as one participant termed an "economy of scale", and allow regulators to point to existing studies in making decisions. Future work may include much larger sediment placement projects, use of different placement rates, techniques or water depths of placement, substantially different sediment grain-size distributions, and/or geographical settings. It was noted that future research should be focused on making progress in understanding projects that are quite different than those already studied, owing that two relatively similar projects were conducted in somewhat different settings and produced similar results (Warrick and Storlazzi, 2013). Furthermore, additional work will be able to speak to whether the quick dissipation of fine-grained sediment in coastal waters is a function of project size. The focus group agreed that the work done to-date in establishing a methodology and approach for other areas is significant. It was articulated that additional work needs to show that results can be compared to modeling for other areas with substantially different nearshore profiles and/or source materials.

Information that could result in a more streamlined regulatory process on fine-grained placement projects includes: (i) more information about the source material and its potential to cause water quality effects; (ii) additional field work to groundtruth ocean conditions (bathymetry, currents and waves) so that numerical models can be shown to be adequately resolving the important processes and patterns of new study sites; (iii) and studies and subsequently designed projects that replicate the natural deposition of sediment. Specific to numerical modeling, it was suggested that further reliability of these tools would be gathered by: (i) modeling that adequately mimics natural conditions during river flood events; (ii) modeling to determine the ambient turbidity conditions during natural events such as wave resuspension of native sediments; and (iii) a model of a scaled-up project to assess much larger projects.

Conclusion and Next Steps

Project proponents agreed to the notion of collecting lessons learned from these demonstration projects would be helpful in supporting projects involving future fine-grained sediment projects at other sites, especially with the prospect of large-scale wetlands restoration projects on the horizon. This, among other objectives, could work towards streamlining permitting, the so-called the "holy grail" by a focus group participant. Additionally, recommendations were made for the forthcoming product to address concerns about sea level rise and resulting need for sediment and provide background and context for the modeling work. Regulators reinforced the utility for a report to distill the scientific findings to be applied to current decision-making and continued science communication to inform decision-making and on-the-ground management.

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