San Francisco Bay Conservation and Development Commission
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July 11, 2014

TO: Commissioners and Alternates

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SUBJECT: Sediment Transport and Sand Mining Background Report
(For Commission consideration on July 17, 2014)

Summary

This document has been prepared to provide the Commission with background information on the San Francisco Bay sediment system, with a focus on sand dynamics and sand mining activities, in preparation for upcoming sand mining permit applications. Relevant information on sand transport, human impacts to the sediment system, ecology of subtidal sandy habitats, sand mining methods, and economics have been summarized from a number of scientific papers, applicant submissions, and agency reports. Analysis of the proposed projects will be provided in the Staff Summary and Recommendations to follow in early fall of this year.

Staff Report

Context of this Report. Currently, three companies mine Bay sands for use in the construction industry: Jerico Products, Inc. (Jerico), Hanson Marine Operations (Hanson), and Suisun Associates, a joint venture of Jerico and Hanson. The existing permits expired in 2008 and authorized Jerico, Hanson, and Suisun Associates (the Applicants) to mine up to 2.24 million cubic yards of sand annually; maximum mined volume was 1.98 million cubic yards. Since then, time extensions have been issued annually on the remaining previously authorized volumes. The Applicants are now seeking new 10-year permits to mine a total of 2.04 million cubic yards annually; the areas proposed for mining include Central Bay (1.54 million cubic yards annually) and Suisun Bay (500,000 cubic yards annually). Applications were submitted in February 2013. Since that time, the Applicants have provided additional requested information to BCDC and other agencies; currently, approval from the resource agencies (National Marine Fisheries Service, US Fish and Wildlife Service, and the California Department of Fish and Wildlife) and the Regional Water Quality Control Board are outstanding. An Environmental Impact Report (EIR) was certified as part of the California Environmental Quality Act (CEQA) review completed by the California State Lands Commission (SLC) in 2012; this review was challenged for adequacy in 2013 and upheld in 2014. In addition, the Commission staff hosted a science panel on sand mining in 2014. To support the Commission in its review of the forthcoming applications, this report covers the following topics: an introduction to sediment, a description of the sediment system in San Francisco Bay, sand transport dynamics and sandy habitats in the Bay, sand mining history and methods, natural replenishment of mined sand, sand transport to beaches, and markets and economics of Bay sand.

Introduction to Sediment. Sediment is made up of loose particles of sand, silt, and clay carried by water and wind. Silt and clay are commonly referred to as mud, and are smaller than sand. Sand grains are between 63 micrometers and 2 millimeters (0.002 and 0.08 inches) in diameter, and can be further categorized by size (e.g., fine, medium, and coarse sand). In this report, "sediment" refers to sand and mud together; otherwise, the more specific term is used. Sediment is important for its role as the substrate that creates and protects tidal marshes and beaches, as habitat for subtidal and intertidal plants and animals, in recreation on beaches and wildlife viewing, and as a commercial resource (mined sand).

The San Francisco Bay Sediment System. Sediment enters San Francisco Bay from two major sources: (1) the Sacramento and San Joaquin Rivers, which drain the Sierra Nevada mountains and Central Valley; and (2) smaller Bay tributaries. Other sediment sources include tidal marshes and wetlands, shoreline bluff and cliff erosion, coastal sources from outside the Golden Gate, and the Bay floor. Sediment travels both in the water column as suspended load (mostly mud) or rolls, slides, and bounces along the Bay floor as bedload (mostly sand).

Once inside the Bay, sediment is incorporated into mudflats, tidal marshes, deepwater sandy habitats, the muddy Bay floor, and beaches (Figure 1a). Some sediment is redistributed within the Bay by wind waves and tidal circulation patterns, and some exits the Bay through the Golden Gate. From there, some sediment is carried by the tides to a 60 square mile underwater sand bar (the San Francisco Bar, or ebb-tidal delta, Figure 1b) and the outer coast region to the south. Some sediment returns into the Bay or enters from the open coast.

Sediment dynamics in the Bay are complex and change over time; the Bay sediment system has been erosional (more sediment leaving than entering) during some periods and accretional (more sediment entering than leaving) in others. In addition to this natural variability, humans have greatly modified sediment dynamics in the Bay and Delta. As a result of hydraulic mining during the Gold Rush, sediment input increased drastically: the annual sediment load between 1849 and 1919 was estimated to be 9 times higher than the pre-Gold Rush rate.[1] This amounted to approximately 1.1 billion cubic yards, which could fill a large football stadium nearly 500 times. By 1999, the pulse of sediments from the Gold Rush had largely worked through the Bay system; suspended sediment flows into the Bay have since decreased markedly and are not expected to increase or return to previous levels.[2] In the early 2000s, suspended sediment concentrations in the Sacramento River were just half of the amount entering over the previous half-century. In addition, water control structures, large dams, reservoirs, flood control projects, and other modifications to upstream hydrology have reduced sediment inflows from the Bay and Delta tributaries (Figure 2).

In addition to the decrease of sediment inflows into the Bay, both navigational dredging (of sand and mud) and mining (of sand) remove sediment from the Bay. At least 262 million cubic yards of sediment, including 71 million cubic yards of sand or coarser sized material, have been removed over the past century[3], which is enough to fill a large football stadium over 100 times. Overall, humans remove more sediment from the Bay each year than enters it.[4]

At present, suspended sediment from the Central Valley rivers and Bay tributary watersheds enter the Bay in approximately equal amounts, though supply varies both seasonally and annually, with a higher amount arriving during the rainy season and in higher runoff years.[5] Currently, Central Bay, Suisun Bay, and San Pablo Bay are erosional, and only the South Bay is accreting sediment.[6]

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[1] Grove, Karl, *Hydraulic-Mining Debris in the Sierra Nevada*, US Government Printing Office, 1917.
[2] David H. Schoellhamer, "Sudden Clearing of Estuarine Waters upon Crossing the Threshold from Transport Supply Regulation of Sediment Transport as an Erodible Sediment Pool Is Depleted: San Francisco Bay, 1999," *Estuaries and Coasts* 34, no. 5 (2011): 885–99.
[3] Kate L. Dallas and Patrick L. Barnard, "Anthropogenic Influences on Shoreline and Nearshore Evolution in the San Francisco Bay Coastal System," *Estuarine, Coastal and Shelf Science* 92, no. 1 (2011): 195–204.
[4] Dredged Material Management Office, *Annual Report*, 2012; McKee et al., "Comparison of Sediment Supply to San Francisco Bay from Watersheds Draining the Bay Area and the Central Valley of California."
[5] L. J. McKee et al., "Comparison of Sediment Supply to San Francisco Bay from Watersheds Draining the Bay Area and the Central Valley of California," *Marine Geology* 345 (2013): 47–62.
[6] Patrick L. Barnard et al., "Sediment Transport in the San Francisco Bay Coastal System: An Overview," *Marine Geology* 345 (2013): 3–17.

Historically, Bay sediment has been seen both as a hindrance to commerce by silting in channels (thus the rise of navigational dredging) and as a resource (e.g., for fill of the Bay and for use as material in the construction industry). However, with the onset of sea level rise, keeping sediment in the system is increasingly viewed as a benefit. BCDC, the LTMS agencies, and other stakeholders continue to focus on re-using dredged sediment in wetland restoration projects to bring subsided areas up to marsh plain elevation. Similarly, public works and flood control agencies are undertaking efforts to reconnect sediment flows to the Bay to maintain shorelines and provide habitat benefits.

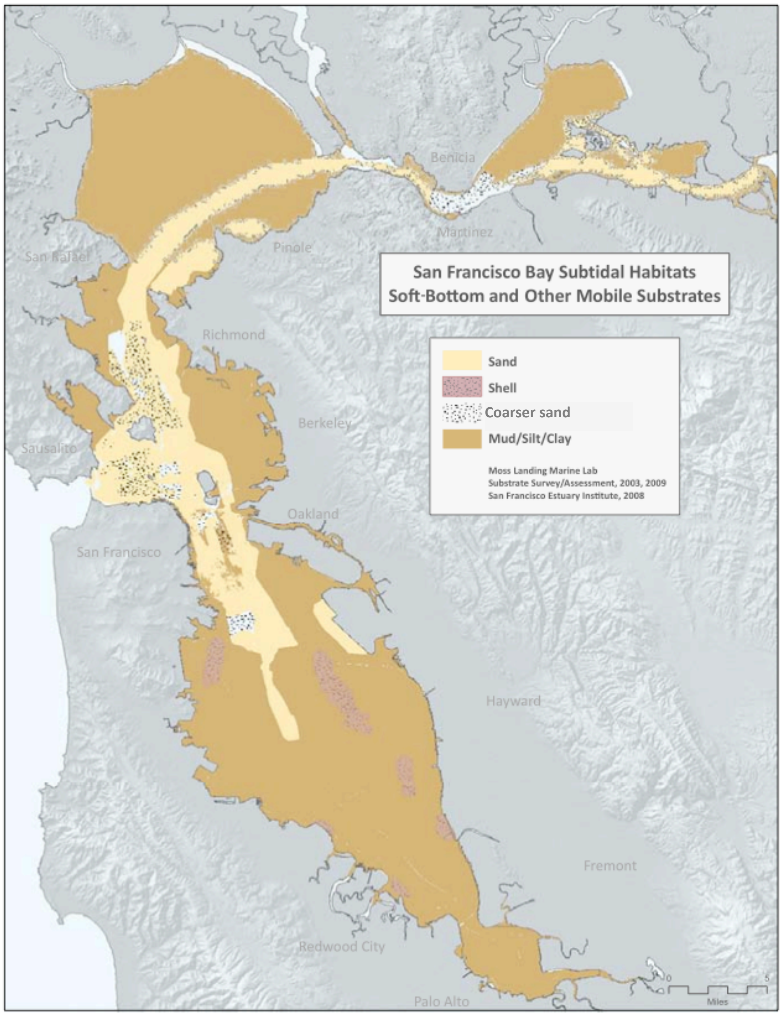

Figure 1a. Distribution of soft bottom habitats in San Francisco Bay.[7]

[7] Figure modified from: California State Coastal Conservancy, *San Francisco Bay Subtidal Habitat Goals Report*, 2010.

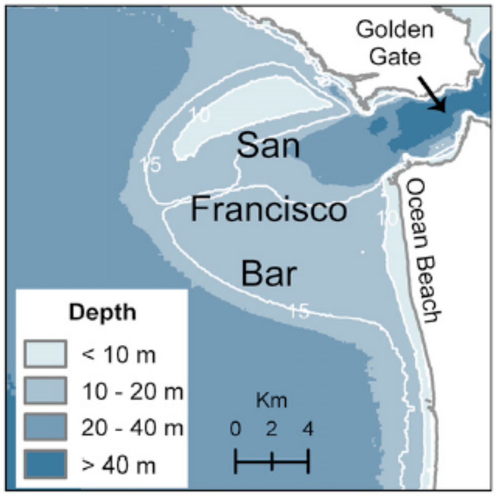

Figure 1b. Location of the large underwater sand deposit known as the San Francisco Bar, or ebb-tidal delta.[8]

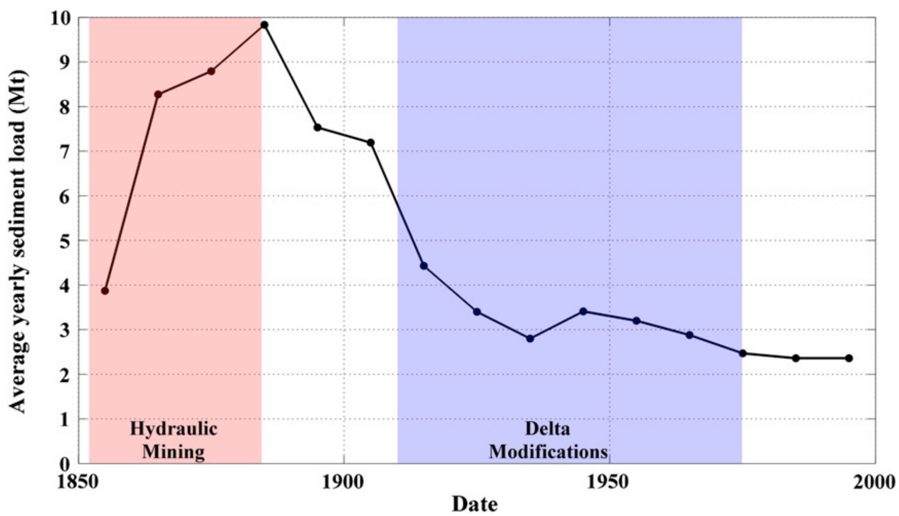

Figure 2. Reconstructed decadal sediment load from the Sacramento and San Joaquin rivers with the major periods of hydraulic mining (1852–1884) and Delta modifications (1910–1975) highlighted.[9]

Sand in San Francisco Bay

1. **Main Sources of Sand.** Most sand in San Francisco Bay originates in the Sierra Nevada mountains and is transported by the Sacramento River.[10] This sand, composed of broken down granitic and metamorphic rock, travels as bedload through Suisun Bay, San Pablo Bay, and Central Bay. A smaller amount of sand originates from local sources, such as Bay watersheds, coastal bluffs and cliffs, and from the Pacific Ocean via the Golden Gate. The volume of sand currently entering the Bay on a yearly basis is unknown; during the 1960s, sand discharge from the Sacramento River was estimated at 1.2 million cubic yards per year[11], which would be enough to fill half of a large football stadium.

[8] Kate L. Dallas and Patrick L. Barnard, "Anthropogenic Influences on Shoreline and Nearshore Evolution in the San Francisco Bay Coastal System," *Estuarine, Coastal and Shelf Science* 92, no. 1 (2011): 195–204.
[9] Barnard et al., "Sediment Transport in the San Francisco Bay Coastal System."
[10] Patrick L. Barnard et al., "Integration of Bed Characteristics, Geochemical Tracers, Current Measurements, and Numerical Modeling for Assessing the Provenance of Beach Sand in the San Francisco Bay Coastal System," *Marine Geology* 336 (2013): 120–45.
[11] George Porterfield, "Sediment Transport of Streams Tributary to San Francisco, San Pablo, and Suisun Bays, California, 1909-66," 1980.

Because sand travels primarily as bedload (it is larger, and thus heavier, than other sediment components), the majority is delivered to the Bay during high flow events. Thus, during extreme flows, sand may comprise as much as 50% of the suspended load entering the Bay,[12] but during average or low flows likely accounts for only a few percent of sediment inflow. On average, it is estimated that bedload accounts for 10% of total sediment inflow.[13] As described below, the reduction in sand supply to the Bay (as part of the overall reduction in sediment) has been significant.[14]

2. **Sand Pathways and Sinks.** Though sediment transport in the Bay is complex, sand transport has recently become better understood.[15] After entering Central Bay, sand from Sierran and local Bay watershed sources mix. The dominant sand pathway continues out of the Golden Gate to the San Francisco Bar and open ocean. From the San Francisco Bar, some sand moves alongshore to open coast beaches, including Baker Beach and northern Ocean Beach.[16] Additionally, local South Bay tributaries (mainly Calaveras Creek and Alameda Creek) deliver smaller amounts of sand that tend to remain in the South Bay.[17] Outside of the Bay, sand from the Russian River is transported south to Point Reyes and from there to the San Francisco Bar and southern coast.[18] Though more sand exits from the Golden Gate than enters through it, some sand moves north from Ocean Beach to Baker Beach, and then through the Golden Gate to Crissy Field and Point Knox Shoal.[19] Major sand transport pathways are depicted in Figure 3.

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[12] Ibid.

[13] L. J. McKee et al., "Comparison of Sediment Supply to San Francisco Bay from Watersheds Draining the Bay Area and the Central Valley of California."

[14] Patrick L. Barnard et al., "Sediment Transport in the San Francisco Bay Coastal System: An Overview," *Marine Geology* 345 (2013): 3–17.

[15] "A Multi-Discipline Approach for Understanding Sediment Transport and Geomorphic Evolution in an Estuarine-Coastal System: San Francisco Bay" (Marine Geology Special Issue, volume 345, 2013).

[16] James R. Hein, Kira Mizell, and Patrick L. Barnard, "Sand Sources and Transport Pathways for the San Francisco Bay Coastal System, Based on X-Ray Diffraction Mineralogy," *Marine Geology* 345 (2013): 154–69.

[17] Barnard et al., "Integration of Bed Characteristics, Geochemical Tracers, Current Measurements, and Numerical Modeling for Assessing the Provenance of Beach Sand in the San Francisco Bay Coastal System."

[18] James R. Hein, Kira Mizell, and Patrick L. Barnard, "Sand Sources and Transport Pathways for the San Francisco Bay Coastal System, Based on X-Ray Diffraction Mineralogy."

[19] Patrick L. Barnard et al., "Integration of Bed Characteristics, Geochemical Tracers, Current Measurements, and Numerical Modeling for Assessing the Provenance of Beach Sand in the San Francisco Bay Coastal System."

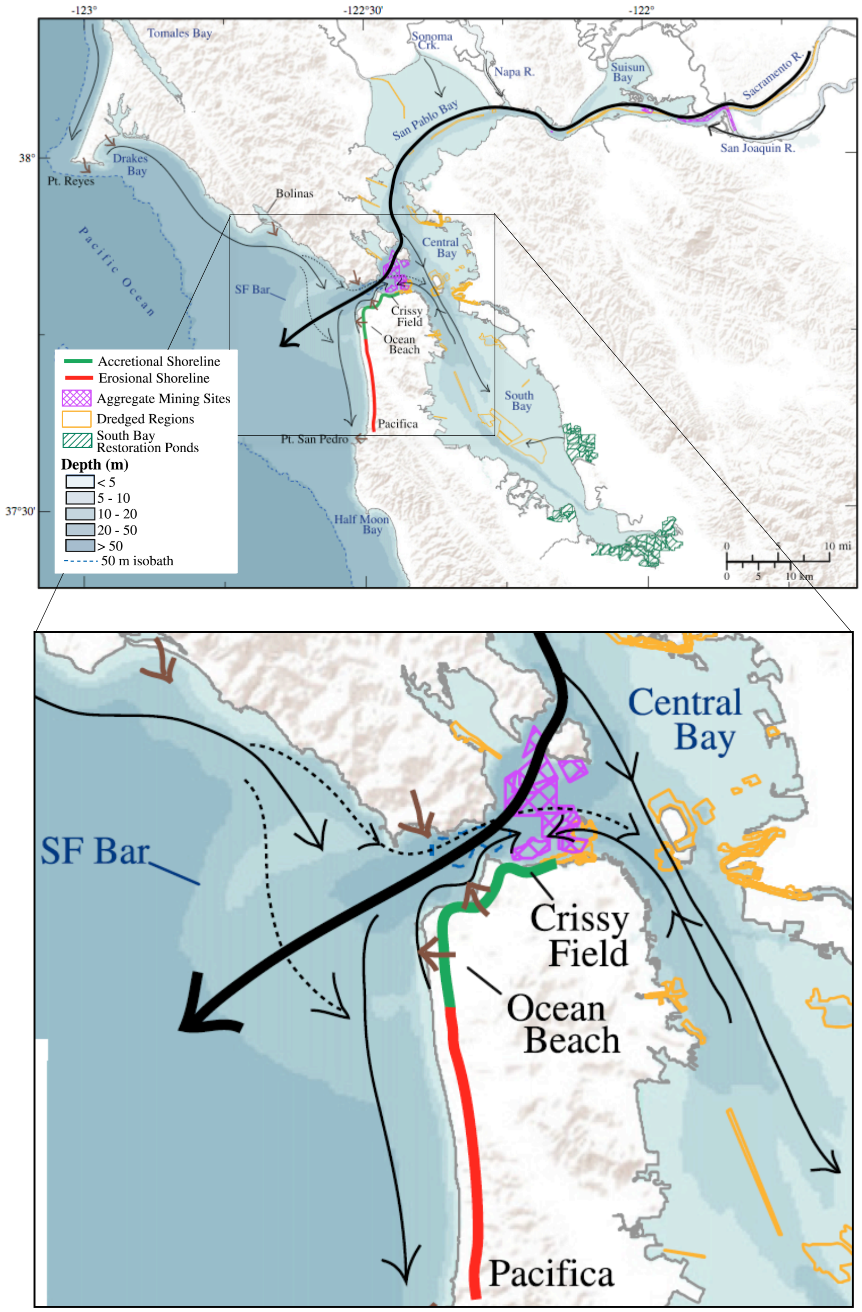

Figure 3. Model of sand transport pathways in the San Francisco Bay Coastal System. Heavier and longer arrows indicate more dominant pathways.[20]

[20] Ibid.

3. **Bay Sandy Habitats.** Inside the Bay, sand is deposited in deepwater sandy habitats (Figure 1a) and on Bay beaches. Sandy habitat tends to form in deep water and along channel edges where high water velocities prevent lighter mud from settling. Similarly, beaches are high-energy environments where smaller particles are continually resuspended by wind-driven waves, leaving only sand sized particles along the shoreline.

   a. **Sandy Beaches.** Historically, the west side of San Francisco had broad beach and dune systems, and the east side of Central Bay had many beaches as well[21] (Figure 4). Though most of the Bay shoreline has been altered, some sandy beaches still exist, including Keller Beach (Richmond), Candlestick Point (South San Francisco), and at China Camp State Park (San Rafael). These beaches provide shoreline protection, habitat, and recreational and public access opportunities.

Figure 4. Historic sandy beaches inside of the Golden Gate, c. 1850.[22] Points indicate locations of beaches and do not represent the sizes of individual beaches.

   b. **Sandy Subtidal Habitat.** By area, at least 8% of the Bay floor is occupied by sandy habitat.[23] In Suisun Bay, sandy habitat is mainly found in and along the edges of the main channel. In Central Bay, where water is deeper and currents are faster, sandy deepwater shoals are found throughout the basin west of Angel Island (Figure 1a). Some of these sandy areas are mixed with gravel and cobble, particularly near the Golden Gate, or contain pockets of mud.[24] The total volume of sand in these areas is unknown: sediment deposits in the Bay can be over 300 feet thick,[25] but the composition of these deposits has not been studied in detail.

   c. **Ecology of Subtidal Sandy Habitat.** Compared to other habitats in the Bay, the ecology of sandy areas is extremely under-studied.

[21] R. Olmstead and N. Olmstead, *Ocean Beach Study: A Survey Of Historic Maps And Photographs* (City of San Francisco, California, February 23, 1979., n.d.); EcoAtlas, California Wetlands Monitoring Workgroup (CWMW), accessed June 27, 2014, http://www.ecoatlas.org.
[22] EcoAtlas.
[23] BCDC, *Staff Report: San Francisco Bay Ecology and Related Habitats*, 2002.
[24] California State Lands Commission, *San Francisco Bay and Delta Sand Mining Project Final Environmental Impact Report*, 2012.
[25] P. R. Carlson and D. S. McCulloch, "Bedrock-Surface Map of Central San Francisco Bay," *US Geological Survey-HUD Basic Data Contribution*, 1970.

Though much is unknown about sandy areas, we do know that several organisms use them as habitat, living in, on, and above the sand in the water column. Because sandy areas are physically dynamic and have lower organic content than areas of fine sediment, they often exhibit a lower abundance and diversity of organisms than fine sediment habitats.[26]

In the Central Bay, a benthic (Bay bottom) survey conducted for the EIR mainly found nematodes (roundworms), polychaetes (bristled worms), amphipods (small marine crustaceans), and bivalves (in this case, clams) living within the sand grains.[27] The presence of some of the organisms was highly correlated with a specific grain size, such as fine sand, medium sand, or coarse sand. In Suisun Bay, the invertebrate community is even less diverse, as it is dominated by two species of invasive clams.

This benthic survey also addressed how these organisms respond to disturbance, in this case from sand mining. In Central Bay, similar densities of organisms and numbers of species were found in areas that had been mined in the past three years compared to areas that had not been mined or had possibly been mined during that timeframe. In Suisun Bay, similar densities of organisms and number of species were found in the two sites that had been mined in the past three years compared to sites that may have been mined or were not mined during that timeframe. This survey gives a useful snapshot in time, but more extensive studies would be needed to understand how organisms living in the sandy habitats change over space and time, and how they respond to recent and repeated disturbance.

The primary larger mobile invertebrates in Central and Suisun Bays include several species of shrimp, crabs, a nudibranch ("sea slug"), and an invasive snail. Of these, the Dungeness crab is an important commercial fisheries species that spends key parts of its life cycle in San Pablo Bay and Central Bay. Juveniles are reared in protected estuarine environments such as eelgrass beds, and then travel along the Bay floor through Central Bay to reach the ocean each year.

Many fish species use deep and open water habitats on and above sandy shoals, and feed on organisms that live in and on the sand. Important fisheries species include California halibut, striped bass, Pacific herring, Northern anchovy, English sole. Common non-fisheries species include Pacific staghorn sculpin, speckled sand dab, gobies, and big skate (a type of ray). Listed species include green sturgeon (federally-listed as threatened), Delta smelt (federally-listed as threatened and state-listed as endangered), longfin smelt (state-listed as threatened), two populations of steelhead trout (federally-listed as threatened), and four runs of Chinook salmon (two state and federally-listed runs, and two Species of Concern under the federal Endangered Species Act.).[28]

Decreasing Sand Supply. Like overall sediment supply, sand supply to the Bay has decreased in recent years. Furthermore, due to its larger grain size, sand is readily impounded behind dams.[29] Dams and other water control structures also diminish the peak water flows required to move large amounts of sand, further decreasing the amount of sand reaching the Bay.

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[26] BCDC, *Staff Report: San Francisco Bay Ecology and Related Habitats*.
[27] California State Lands Commission, *San Francisco Bay and Delta Sand Mining Project Final Environmental Impact Report*, 2012.
[28] Ibid.
[29] Matthew J. Slagel and Gary B. Griggs, "Cumulative Losses of Sand to the California Coast by Dam Impoundment," *Journal of Coastal Research*, 2008, 571–84.

The trend of overall sediment loss in San Francisco Bay, and sand loss in particular, has been well-documented by researchers. From 1959 to 2009, the total amount of sediment in San Francisco Bay fell by 190 million cubic yards.[30] From 1997 to 2008, the rate of sediment loss in Central Bay (3 centimeters per year across the Bay floor) was nearly three times higher than during the 1947-1979 period[31]; most of this erosion was from sandy areas. In sediments found at the mouth of the Bay, the percentage of sand decreased while the percentage of mud increased from 1997 to 2008.[32] Finally, a recent analysis of bedforms (underwater sand dune formations) found that they are shorter than would be predicted by local water currents and hydrodynamics, indicating that the system is erosional.[33]

From 1873 to 2005, the San Francisco Bar lost an average of 80 centimeters in elevation across its entire area, contracted in diameter, and migrated an average of 1 kilometer towards the shoreline.[34] This likely resulted from reduced tidal flows due to historic filling, diking, and sedimentation of the Bay, and from decreased amounts of sediment leaving the Bay as a result of hydrologic modifications upstream, mining, and dredging.[35] The erosion and contraction of the San Francisco Bar has effectively resulted in more sand being delivered to northern Ocean Beach, and less to southern Ocean Beach.[36] Additionally, modeling has demonstrated that changes to the Bar affect wave energy reaching the shoreline, with northern Ocean Beach being protected, and southern Ocean Beach being more exposed.[37] These changes help explain recent accretion at Baker Beach, Crissy Field, and northern Ocean Beach, and partially explain erosion at southern Ocean Beach. (Historically, the mean high tide line at Ocean Beach was landward of the Great Highway; the beach was artificially extended seaward in the early 1900s.[38])

With less sand in the Bay system, we may see increased coastal erosion, as less sand will be supplied to beaches, and smaller sand bars along the shore and at the mouth of the Bay are less effective at buffering the coast from wave energy. This has already been observed for the San Francisco Bar with respect to Ocean Beach;[39] accretion and erosion patterns for beaches inside the Bay are not well-studied. A decrease in sand supply to the Bay may also lead to impacts for organisms living in sandy habitats, as well as reduced need for navigational dredging. As is the case for Bay sediment in general, sand is increasingly being viewed as an ecological, societal, and economic resource.

Dredging and Sand Mining in San Francisco Bay. Navigational dredging is conducted to maintain sufficient channel depth for ships to access harbors, marinas, and berths, both in deep water channels along the stem of the Bay and along the shoreline. Annual maintenance dredging volume is currently 1.5 to 2 million cubic yards, with periodic deepening projects increasing this average to as much as 3 million cubic yards annually. Dredged sediment is either placed at in-Bay disposal sites, beneficially reused (i.e. in tidal marsh restoration projects), or taken to the San Francisco Deep Ocean Disposal Site. While most dredged material consists of mud, two federal projects dredge significant volumes of sand: the Main Ship channel, which cuts through the San Francisco Bar, and Suisun Channel (Figure 5). The dredged material from these two projects is placed back into the system: Suisun Channel sand is placed directly adjacent to the channel; and Main Ship Channel sand is placed south and east of the channel, and, more recently, adjacent to southern Ocean Beach in an effort to slow localized erosion.

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[30] Patrick Barnard and Rikk Kvitek, "Anthropogenic Influence on Recent Bathymetric Change in West-Central San Francisco Bay," *San Francisco Estuary and Watershed Science* 8, no. 3 (2010).
[31] Ibid.; Theresa A. Fregoso, Amy C. Foxgrover, and Bruce E. Jaffe, *Sediment Deposition, Erosion, and Bathymetric Change in Central San Francisco Bay: 1855-1979* (U. S. Geological Survey, 2008).
[32] Patrick L. Barnard, Jeff E. Hansen, and Li H. Erikson, "Synthesis Study of an Erosion Hot Spot, Ocean Beach, California," *Journal of Coastal Research* 28, no. 4 (2012): 903–22.
[33] Patrick L. Barnard et al., "Sediment Transport Patterns in the San Francisco Bay Coastal System from Cross-Validation of Bedform Asymmetry and Modeled Residual Flux," *Marine Geology* 345 (2013): 72–95.
[34] Kate L. Dallas and Patrick L. Barnard, "Anthropogenic Influences on Shoreline and Nearshore Evolution in the San Francisco Bay Coastal System," *Estuarine, Coastal and Shelf Science* 92, no. 1 (2011): 195–204.
[35] K. L. Dallas and P. L. Barnard, "Linking Human Impacts within an Estuary to Ebb-Tidal Delta Evolution," *Journal of Coastal Research Special*, no. 56 (2009): 713–16.
[36] Jeff E. Hansen, Edwin Elias, and Patrick L. Barnard, "Changes in Surfzone Morphodynamics Driven by Multi-Decadal Contraction of a Large Ebb-Tidal Delta," *Marine Geology* 345 (2013): 221–34.
[37] Dallas and Barnard, "Anthropogenic Influences on Shoreline and Nearshore Evolution in the San Francisco Bay Coastal System."
[38] Patrick L. Barnard, Jeff E. Hansen, and Li H. Erikson, "Synthesis Study of an Erosion Hot Spot, Ocean Beach, California."
[39] Dallas and Barnard, "Anthropogenic Influences on Shoreline and Nearshore Evolution in the San Francisco Bay Coastal System."

The purpose of sand mining is different from navigational dredging; it occurs to provide sand to the construction industry in an efficient and cost-effective manner. Thus, mined sand is not "disposed of" as are dredged sediments, and sand mining is not regulated under the LTMS program.

Figure 5. Federal dredging projects with primarily sandy sediments.

1. **Sand Mining in San Francisco Bay.** Sand mining has occurred in Central Bay and Suisun Bay since the 1930s (Figure 6). Over the years, many companies have held permits to mine leases on state and privately-granted submerged lands. Reported volumes of sand mined over time are shown in Figure 7; the total volume mined since 1974 is over 36 million cubic yards. Currently, Jerico, Hanson, and Suisun Associates mine within seven lease areas; two of these leases are privately owned and five are leased from the SLC. The combined proposed projects would allow 2.04 million cubic yards of sand extraction annually.

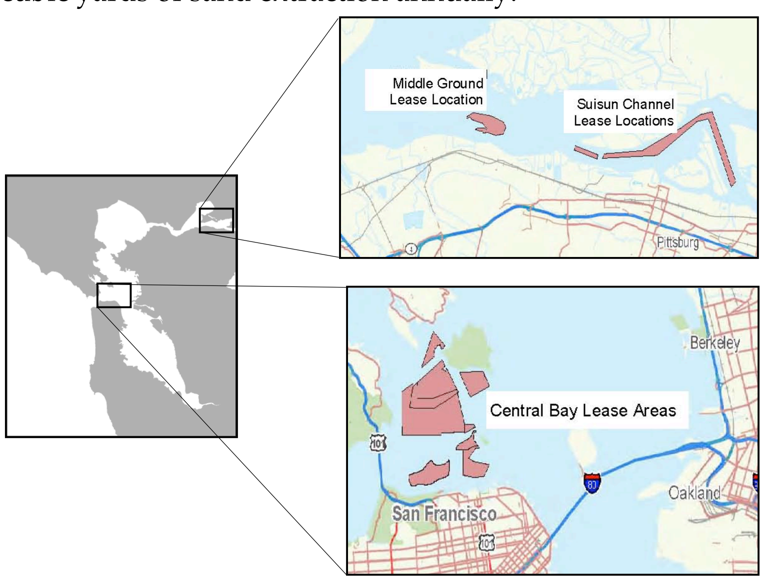

Figure 6. Current sand mining lease areas.[40]

[40] Basemap: Bay Area Aquatic Resource Inventory,San Francisco Estuary Institute, Richmond, CA, 2014, www.sfei.org/baari; lease area maps: California State Lands Commission, *San Francisco Bay and Delta Sand Mining Project Final Environmental Impact Report*, 2012.

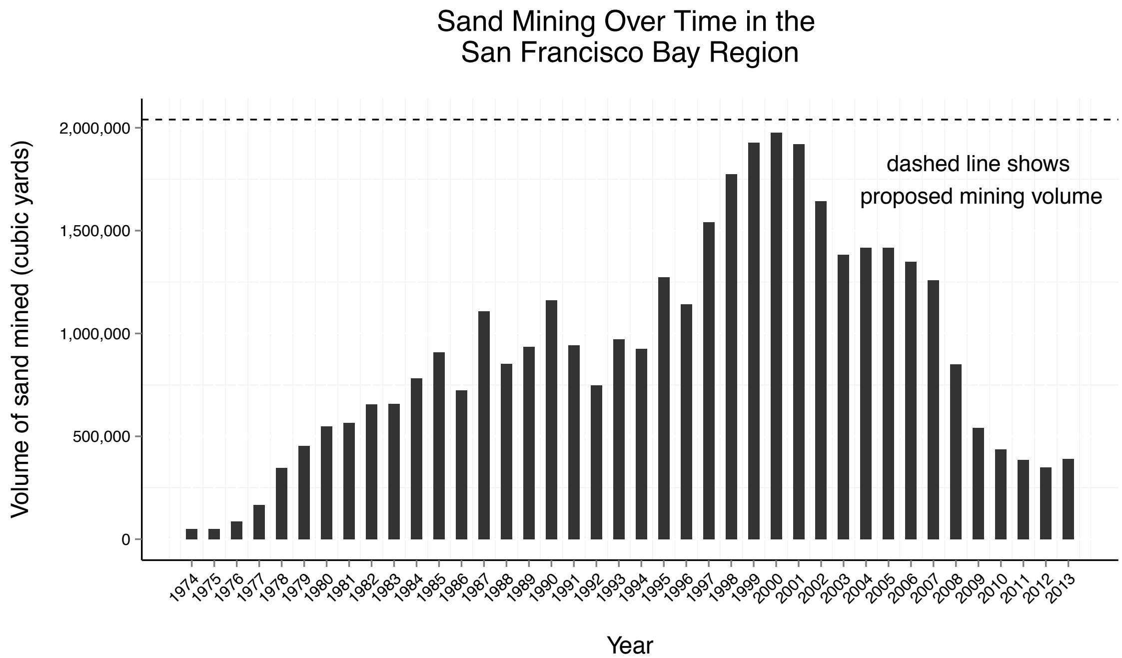

Figure 7. Sand mining volumes reported to BCDC. Reporting was incomplete in 14 of the 40 years shown (mainly during the 1980s and early 2000s), so actual volumes are likely greater.

2. **Sand Mining Methods.** Sand mining occurs to fill discrete construction orders for specific volumes and grain sizes. Sand mined from Suisun Bay and Central Bay has varying grain sizes and is used in cement concrete for buildings and paved surfaces, in asphalt, roadbase, and subbase fill, and as general fill. Equipment limitations and permitting requirements to protect shallow habitats require that sand mining take place at depths of 30 to 90 feet mean low lower water (MLLW) in Central Bay and 15 to 45 feet MLLW in Suisun Bay-western Delta.

In Bay sand mining, a tugboat positions a barge over a certain area to obtain the desired sand. Hanson's barge has a hydraulic suction dredge system consisting of a drag arm (120 feet long, 2 feet in diameter) fitted with a drag head (3 feet by 3 feet) that is kept flat against the mining surface (Figure 8a). The drag head is covered with crossbars that screen out oversized material, and a water intake pipe "fish screen" designed to the specifications of the resource agencies to reduce entrainment.

In both Central Bay and Suisun Bay, Hanson uses the "moving potholing" method, in which the drag head is inserted six to 18 inches below the surface and is pulled along the bottom (Figure 9a). Once the targeted grain size is found, a slurry of sand and water is pumped into the barge. As sand fills the barge, water is displaced by sand. The water is returned to the Bay along with suspended fine sediment, which makes up approximately 10% of the suctioned sediment. While transiting between mining locations, adjacent sand slumps into the mining tracks and is also removed.

Jerico's barge is similar to Hanson's; however, the drag arm is shorter and smaller in diameter (40 feet long; 14 inches across). Jerico only operates in Suisun Bay, and exclusively uses the "stationary potholing" method (Figure 9b). In this method, the barge is anchored in one location during the mining operation. The suction pipe is not fitted with a drag head (Figure 8b); instead, the suction pipe is inserted 5 to 8 feet into the substrate during mining. The suction pipe is also covered with crossbars and water intake pipe "fish screen," as described above. As sand is pumped to the barge, adjacent sand is mobilized and falls into the pothole created by the suction pipe.

The pipe is lowered to keep it buried in the substrate as the pothole is deepened. If the sand is unsuitable or the substrate too difficult to mine, the operator shuts down the pump, picks up the suction pipe and anchor, and proceeds to another location. Mining events typically last from three to six hours. Jerico's barge can hold 1,850 cubic yards of sand; Hanson's can hold 2,400 cubic yards. Mined sand is transported by tug and barge to offloading sites around the Bay (Figure 10).

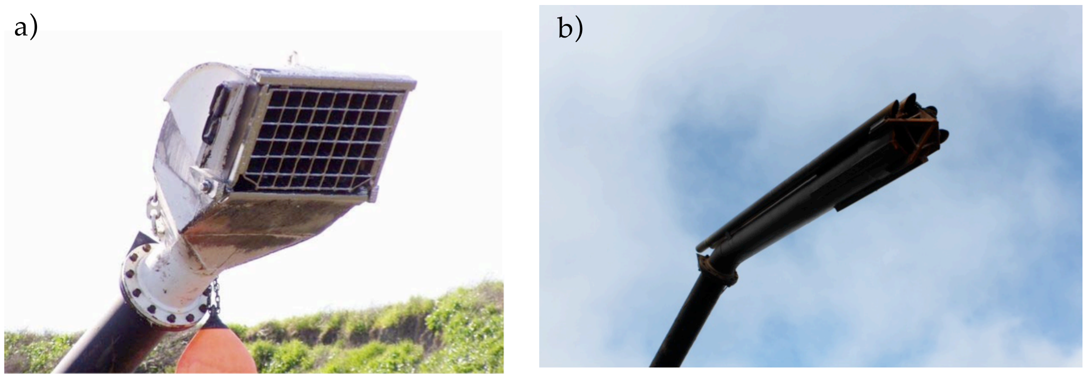

Figure 8.(a) Hanson's hydraulic suction drag head showing "grizzly" screen (six inches by six inches) used to exclude large material during sand mining;[41] (b) Jerico's hydraulic suction pipe assembly.[42]

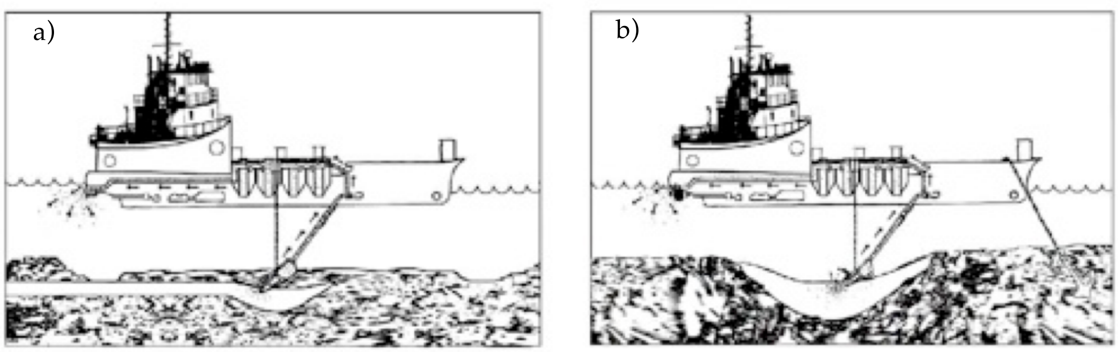

Figure 9. Drawing showing two sand mining methods: (a) moving potholing, and (b) stationary potholing.[43]

[41] California State Lands Commission, *San Francisco Bay and Delta Sand Mining Project Final Environmental Impact Report*.
[42] *Jerico BCDC Permit Application*, 2013.
[43] California State Lands Commission, *San Francisco Bay and Delta Sand Mining Project Final Environmental Impact Report*.

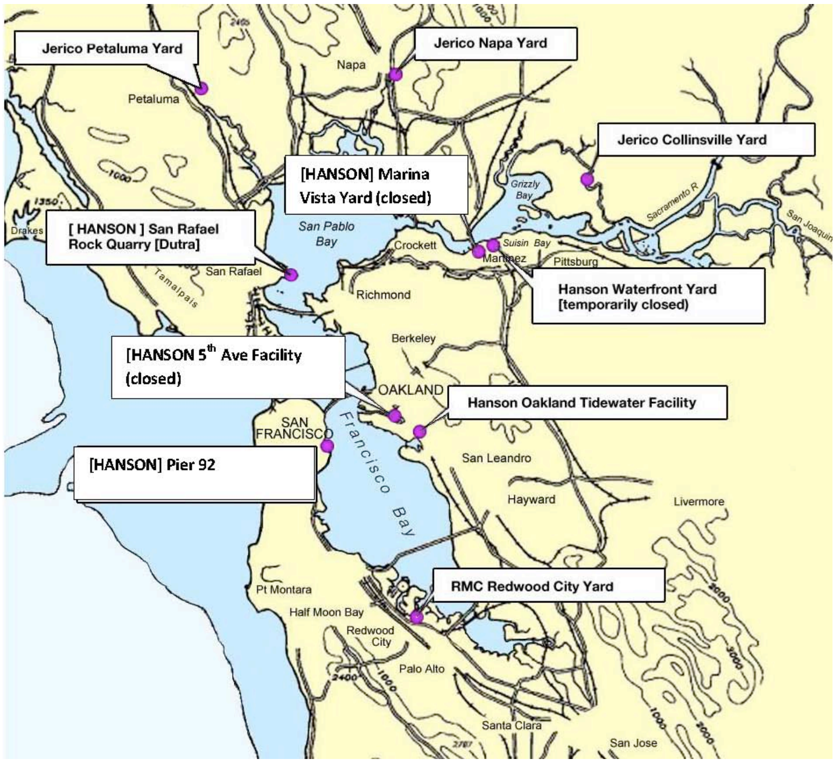

Figure 10. Bay sand offloading locations.[44]

3. **Natural Replenishment of Mined Sand.** Sand removed from the Bay is not replenished at a constant rate, because the amount of sand entering the Bay changes each year, as does the amount of sand removed. Because the sand flux is unknown, the best available method to estimate how much sand is gained or lost over time is to compare bathymetric surveys of the Bay floor taken during different years.

   From 1997 to 2008, Central Bay lost substantially more sand than it gained. This net loss of sand was five times greater within mining lease boundaries compared to non-lease areas[45]. During this time, 13.5 million cubic yards of sand were mined from Central Bay; within mining lease boundaries, approximately five percent of this was replaced by natural processes.[46]

   Between 2008 and early 2014, the opposite trend was observed: Central Bay gained more sand that it lost. Mining volumes during this period were 2.2 million cubic yards. Due to noise in the data, it is not possible to directly estimate the volume of sand that replenished naturally. However, we can compare lease areas to non-lease areas; accumulation was 79% faster outside of mining leases compared to inside lease boundaries.[47] It is unknown why the overall patterns of sand gain and loss were different between these two time periods.

[44] Ibid.
[45] Barnard and Kvitek, "Anthropogenic Influence on Recent Bathymetric Change in West-Central San Francisco Bay."
[46] Scott Fenical et al., *Technical Report: Analysis of Impacts of Sand Mining in the San Francisco Bay on Sediment Transport and Coastal Geomorphology in San Francisco Bay, Suisun Bay, and Outside the Golden Gate*, 2013.
[47] Patrick Barnard, *Draft Report: Bathymetric Change Analysis for West-Central and Suisun Bay, 2008-2014* (U. S. Geological Survey, 2014).

Figure 11 shows the depth change inside and outside of mining lease areas in Central Bay from 1997 to early 2014. Over this longer timeframe, which included the periods of varied mining activity described above, large areas of net sand loss persisted in repeatedly mined areas (red-colored regions in Figure 11).

For Suisun Bay, less information is available, but in certain lease areas sand has been shown to replenish more quickly than in Central Bay. Between 2004 and 2007, 1.2 million cubic yards were mined. Generally, there were no clear patterns of erosion or accretion.[48] Between 2008 and 2014, excluding the Middle Ground area, there was an overall signal of accretion with similar depths of sediment accreting in lease and non-lease areas.[49] During this time period, 0.13 million cubic yards were mined in Suisun Bay. Changes in bathymetry for Middle Ground sandy shoal lease areas were not assessed in either period due to survey equipment limitations and site conditions.

4. **Sand Transport to Beaches.** As mentioned above, recent studies have documented the transport pathway connecting Bay sandy shoals, the San Francisco Bar, and outer coast beaches.[50] Though there are many large and small scale factors affecting sand supply and transport in the Bay system, removing sand from sandy shoals, particularly those along the northwest San Francisco waterfront such as Presidio Shoals, could affect sand supply to outer coast beaches.[51] The magnitude of this effect may be small; one model showed that the annual proposed mining in Central Bay would likely contribute 0.2 to 0.3 % of the annual observed erosion of the Bar.[52]

East Bay beaches are supplied by both local cliff-derived sands and subtidal Central Bay sand.[53] While detailed sand transport pathways to Bay beaches have not been identified, removing sand from the Bay could potentially decrease supply to these beaches as well. With sea level rise, increasing amounts of sand may be needed to prevent erosion and landward migration of Bay beaches and of the outer coast beaches that protect infrastructure and development.[54] Additionally, the San Francisco Bar will require increased sand input to maintain its volume and wave-sheltering benefits.[55]

[48] California State Lands Commission, *San Francisco Bay and Delta Sand Mining Project Final Environmental Impact Report*.
[49] Barnard, *Draft Report: Bathymetric Change Analysis for West-Central and Suisun Bay, 2008-2014*.
[50] Barnard and Kvitek, "Anthropogenic Influence on Recent Bathymetric Change in West-Central San Francisco Bay"; Hein, Mizell, and Barnard, "Sand Sources and Transport Pathways for the San Francisco Bay Coastal System, Based on X-Ray Diffraction Mineralogy"; Barnard et al., "Integration of Bed Characteristics, Geochemical Tracers, Current Measurements, and Numerical Modeling for Assessing the Provenance of Beach Sand in the San Francisco Bay Coastal System"; Barnard et al., "Sediment Transport Patterns in the San Francisco Bay Coastal System from Cross-Validation of Bedform Asymmetry and Modeled Residual Flux"; Dallas and Barnard, "Anthropogenic Influences on Shoreline and Nearshore Evolution in the San Francisco Bay Coastal System."
[51] Patrick L. Barnard et al., "Integration of Bed Characteristics, Geochemical Tracers, Current Measurements, and Numerical Modeling for Assessing the Provenance of Beach Sand in the San Francisco Bay Coastal System,"; Patrick L. Barnard et al., "Sediment Transport Patterns in the San Francisco Bay Coastal System from Cross-Validation of Bedform Asymmetry and Modeled Residual Flux."
[52] Scott Fenical et al., *Technical Report: Analysis of Impacts of Sand Mining in the San Francisco Bay on Sediment Transport and Coastal Geomorphology in San Francisco Bay, Suisun Bay, and Outside the Golden Gate*, 2013.
[53] Hein, Mizell, and Barnard, "Sand Sources and Transport Pathways for the San Francisco Bay Coastal System, Based on X-Ray Diffraction Mineralogy."
[54] Patrick L. Barnard et al., "Integration of Bed Characteristics, Geochemical Tracers, Current Measurements, and Numerical Modeling for Assessing the Provenance of Beach Sand in the San Francisco Bay Coastal System."
[55] Kate L. Dallas and Patrick L. Barnard, "Anthropogenic Influences on Shoreline and Nearshore Evolution in the San Francisco Bay Coastal System."

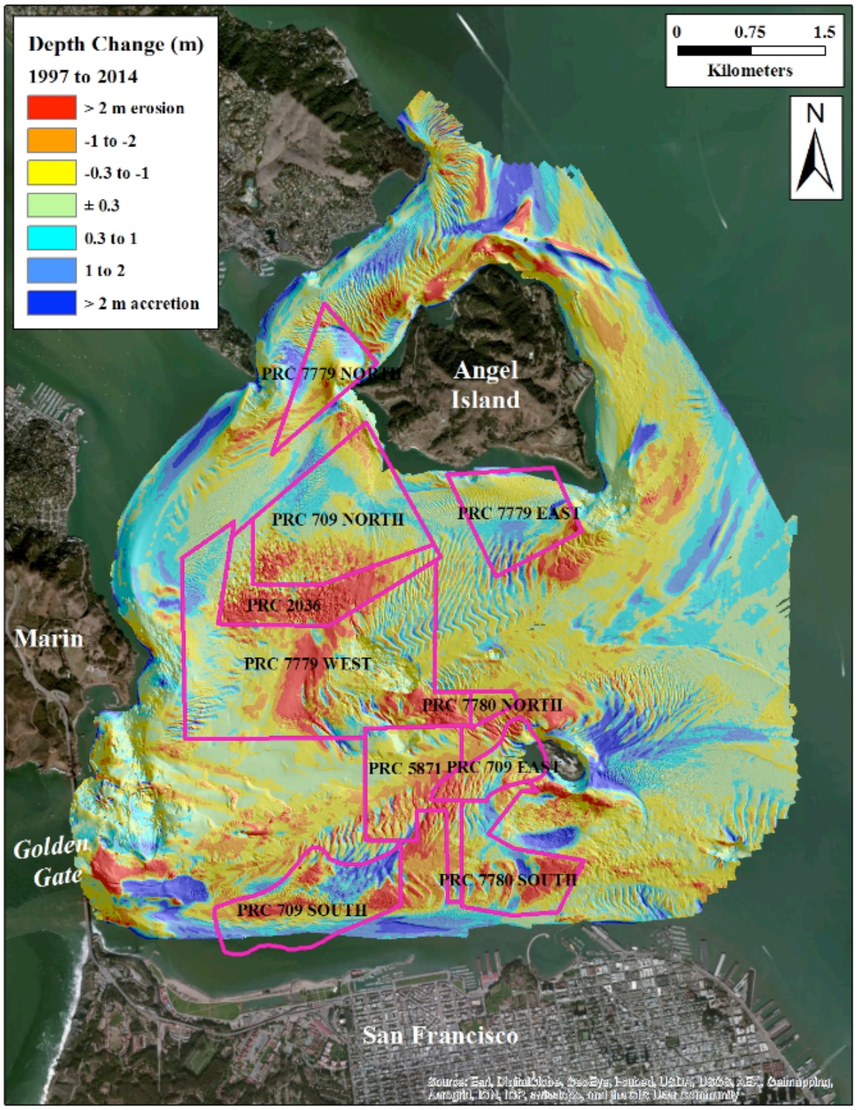

Figure 11. Changes in Central Bay bathymetry from 1997 to 2014. Pink lines indicate sand mining lease boundaries.[56]

5. **Markets and Economics of Bay Sands.** Natural aggregate materials include sand, gravel and crushed stone. The construction aggregate industry is characterized by the transportation of large volumes of materials with relatively low intrinsic values but relatively high weights per unit volume.[57] As a result, the transport and distribution costs of construction aggregates can comprise more than half of the final consumer cost, and to a large extent determine the practicality and economic feasibility of supplies.[58]

   Demand for aggregate is expected to increase as the state's population continues to grow and infrastructure is maintained, improved, and expanded. The California Geological Survey projects that the 50-year demand for all aggregate (including sand, crushed stone, and gravel) in the South San Francisco Bay and North San Francisco Bay Regions will be approximately 1,902,000,000 tons.[59] There exists a substantial shortfall in total permitted aggregate capacity; local land-based aggregate

[56] Barnard, Patrick, U. S. Geological Survey, 2014.
[57] John P. Clinkenbeard, *Aggregate Sustainability in California* (California Geological Survey, 2012).
[58] Economic and Planning Systems, Inc., *Assessment of Economic Impacts Associated with Sand Mining in San Francisco Bay*, 2014.
[59] Clinkenbeard, *Aggregate Sustainability in California*.

reserves contain enough permitted resources to last through 2023 in the North Bay and through 2023 to 2032 in the South Bay. Reserves also exist that currently are not permitted for mining.[60] The above projections are for supply and demand of all aggregates; about 25% of total aggregates are estimated to be used for high strength concrete (Portland Cement Concrete).[61] Other projections specific to sand, and for types of sand equivalent to Bay sand, have not been made by the California Geological Survey.

In addition to Bay sand and local land-based reserves, the construction and transportation industries in the Bay Area also purchase aggregate from foreign producers in Mexico and British Columbia. California imported about 3.3 million tons of sand and gravel in 2004 and 2.4 million tons in 2005.[62] With respect to sand in particular, the Bay Area imported 1.7 million tons of British Columbia sand in 2012.[63] The Bay Area is the largest market for British Columbia (BC) sand, which is preferred for major construction projects requiring high-strength concrete due to its high quality.[64] Currently, large capital improvement projects such as Doyle Drive, the Transbay Transit Center, and the new Bay Bridge span primarily use BC sand.[65] Due to differences in composition and its higher base material cost (currently estimated at $19.00 per ton as compared to an average $13.50 per ton from Bay Area land-based quarries, before transport), BC sand is not competitive with Bay or other locally-produced sand for private housing construction and neighborhood infrastructure projects, road base or subbase fill, or for general fill purposes.[66]

Closing

This overview of sediment transport, sand mining, and economics of the aggregate market has been prepared for the Commission's review to provide background information and context for considering upcoming sand mining permit applications. BCDC staff is reviewing information provided by the Applicants, analyzing the potential impacts of the proposed projects and consistency with the Bay Plan, and coordinating with our sister agencies. Staff continues to work closely with the Applicants to prepare a matrix of the policy and technical issues associated with these applications and their resolution. Analysis of the proposed projects with respect to BCDC laws and policies will be provided as part of the Staff Summary and Recommendations to the Commission, as is customary. Staff anticipates bringing the proposed projects to the Commission in Fall 2014.

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[60] Ibid.; John G. Parrish, *Update of Mineral Land Classification: Aggregate Materials in the North San Francisco Bay Production-Consumption Region, Sonoma, Napa, Marin, and Southwester Solano Counties, California* (California Geological Survey, 2013).

[61] Ibid.

[62] Susan Kohler, *California Non-Fuel Minerals, 2005* (California Geological Survey, 2007)

[63] Economic and Planning Systems, Inc., *Assessment of Economic Impacts Associated with Sand Mining in San Francisco Bay*.

[64] Polaris Minerals Corporation, *Management's Discussion and Analysis Year Ending December 31, 2013*, 2013; Economic and Planning Systems, Inc., *Assessment of Economic Impacts Associated with Sand Mining in San Francisco Bay*.

[65] California Department of Transportation, personal communication, 2014.

[66] Polaris Minerals Corporation, *Annual Information Form for the Fiscal Year Ended December 31,2012*, March 15, 2013; Economic and Planning Systems, Inc., *Assessment of Economic Impacts Associated with Sand Mining in San Francisco Bay*.