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Natural Resource Stewardship and Science

Inventory of Coastal Engineering Projects in San Francisco Maritime National Historical Park

Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2013/735

ON THE COVER
Aquatic Park, San Francisco, CA
Photograph by: Kate Dallas

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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This report is available from the Geologic Resources Division and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). The report and accompanying Geographic Information System (GIS) project can also be accessed through the Integrated Resource Management Applications Portal website (http://irma.nps.gov).

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Abstract

Reconnaissance-level investigations, analyses and inventories of coastal engineering projects in eight coastal national parks were completed by Oregon State University with funding provided by the National Park Service Geologic Resources Division. The coastal national parks inventoried in this study include:

1. Cape Hatteras National Seashore
2. Colonial National Historical Park
3. Fort Matanzas National Monument
4. Fort Raleigh National Historic Site
5. Gateway National Recreation Area
6. Golden Gate National Recreation Area
7. Olympic National Park
8. San Francisco Maritime National Historical Park

This report includes information on coastal engineering projects identified in, or immediately adjacent to, San Francisco Maritime National Historical Park (SAFR). The report serves as a supplement to a Geographic Information Systems (GIS) database (the GIS data are available online at http://irma.nps.gov).

Twelve coastal engineering projects were identified within SAFR. Of these, nine are coastal structures that span 2,275 m (7,465 ft) (this includes 324 m [1,063 ft] of a breakwater that is outside SAFR). The Aquatic Park Seawall armors roughly 88% of the total shoreline within the park. Aquatic Park Cove was filled with an unknown volume of material from 1906–1914 and again in the 1930s. In 1941, 2.3 million m^3 (3 million yd^3) of sand was placed along the beach.

Coastal engineering projects have greatly altered the physical landscape and ecosystem in and adjacent to SAFR. Historic filling operations have transformed the once low-lying marshlands into a prime recreational venue by extending the shoreline roughly 120 m (400 ft) since the mid-1800s. Filling, coupled with shoreline armoring and nourishment activities, has altered local wave and circulation patterns, sediment dynamics, and the natural ecosystem.

Acknowledgments

This project was funded by the National Park Service's Geologic Resources Division through the Pacific Northwest Cooperative Ecosystem Studies Unit Task Agreement (J8W07110009) to Oregon State University. Leslie Ewing, Courtney Schupp, Steven Skartvedt, and Tamara Williams provided valuable peer reviews.

Jodi Eshleman, formerly of the NPS, helped organize the project and arrange meetings with local experts. Park staff at SAFR were very supportive and helped us throughout the project. John Cunnane, Robbyn Jackson, and others met with us during our field visit. John, Robbyn, Rob Kier, and Stephen Canright provided historical knowledge and references. Stephen Skartvedt and Craig Dalby helped us acquire the current SAFR GIS boundary.

Introduction

The Coastal Engineering Inventory (CEI) project aims to inventory, catalog and map coastal engineering projects in and adjacent to coastal units of the National Park Service (NPS). The primary projects that were inventoried include coastal structures, dredge and fill projects, and beach nourishment and dune construction projects. In this phase of the inventory coastal engineering projects were identified in eight coastal national parks. Prior to this study another report (Coburn et al. 2010) documented coastal engineering projects in ten additional coastal national parks. The report and GIS data are available online at http://irma.nps.gov.

In this phase of the NPS CEI project, a qualitative impacts analysis was also performed to help better understand the extent of human-altered coastal areas within each respective park. This section describes the impacts of coastal engineering projects and their influence on natural sediment transport processes. In addition to highlighting major engineering projects that are impacting local and regional sediment transport, we have also included related information pertaining to current park management concerns as expressed during the site visit.

Coastal engineering projects are usually motivated by a desire to protect the backshore environment from erosion or alter the coastal zone for a particular purpose (i.e. maintain a navigation channel, develop roadways, or restore wetlands). In order to fulfill project objectives, a suite of engineering solutions are available that are typically categorized into hard and soft engineering projects. Coastal engineering solutions often combine both hard and soft engineering approaches, such as when beaches are nourished following breakwater construction.

Hard engineering solutions include the construction of seawalls, revetments, breakwaters, sills, and bulkheads to protect the backshore from coastal erosion and sometimes flooding (see the Glossary in Appendix A for definitions). Jetties and groins are also classified as hard engineering projects and are used to alter the sediment transport regime by trapping sediment. Impacts from hard structures are highly site dependent, but may include the loss of sediment supplied to downdrift areas, localized scour in front of and at the downdrift end of structures, visual impacts, placement losses, reduction in beach access, and the alteration or reduction of habitat.

Soft engineering solutions include non-structural means of stabilizing the backshore or changing coastal environments through beach nourishment, dune construction, dredging, or filling. These methods add or redistribute sediment within the system and are used to widen sediment-starved beaches, maintain navigable waterways, protect coastal infrastructure, and restore wetlands. As with hard solutions, impacts vary significantly by project and location. Soft engineering projects may impact hydrodynamic and sediment transport processes, beach morphology, aquatic ecosystems, and/or beach habitats.

The overall goal of this project is to develop a greater understanding of the coastal engineering modifications in the National Park System. Along coastlines expected to be impacted by climate change, structurally modified shorelines will likely respond differently than natural coastlines, which may have a more dynamic response to coastal erosion and sea level rise. An inventory of coastal engineering modifications will provide information to allow resource managers to make better decisions about how to preserve NPS resources, establish baselines, develop desired future conditions, and balance the protection of historic resources and infrastructure with the

preservation of natural systems. All of these actions will improve the ability of the NPS to manage coastal park units in accordance with NPS policies. The main NPS policies relevant to coastal engineering projects are summarized below (see NPS *Management Policies 2006* for more detail).

Maintenance of Natural Processes

Generally, NPS policy requires that natural coastal processes in parks, such as erosion, shoreline migration, deposition, overwash, and inlet formation, be allowed to continue without interference (NPS *Management Policies* § 4.8.1.1 2006). The NPS may intervene in these processes only in limited circumstances, such as when there is no other feasible way to protect natural resources, park facilities, or historic properties (NPS *Management Policies* § 4.8.1 2006).

Restoration of Natural Processes

In parks where pre-existing or new activities or structures have altered and/or are currently altering coastal dynamics, ecosystems, tidal regimes, and sediment transport rates, the NPS policy is to investigate, in consultation with appropriate state and federal agencies, alternatives for mitigating the effects of such projects and for restoring natural conditions (NPS *Management Policies* § 4.8.1.1 2006). NPS restoration actions in human-disturbed areas seek to return the area to the natural conditions and processes characteristic of the ecological zone in which the damaged resources are situated, as called for by park management plans (NPS *Management Policies* § 4.1.5 and § 4.4.2.4 2006). An example would be the restoration of shoreline processes.

Park landscapes disturbed by natural events, such as hurricanes, are allowed to recover naturally unless manipulation is necessary to 1) mitigate for excessive disturbance caused by past human effects, 2) preserve cultural and historic resources as appropriate based on park planning documents, or 3) protect park developments or the safety of people. (NPS *Management Policies* § 4.1.5 and § 4.4.2.4 2006).

Construction of Facilities

Generally, the NPS must avoid the construction of buildings, roads, and other development that will cause unacceptable impacts on park resources and values (NPS *Management Policies* § 9.1 2006). Development will not compete with or dominate park features or interfere with natural processes (NPS *Management Policies* § 9.1.1.2 2006). In shoreline areas, this means that new developments will not be placed in areas subject to wave erosion or active shoreline processes unless 1) the development is required by law; or 2) the development is essential to meet the park's purposes, as defined by its establishing act or proclamation, and

- no practicable alternative locations are available;
- the development will be reasonably assured of surviving during its planned life span without the need for shoreline control measures; and
- steps will be taken to minimize safety hazards and harm to property and natural resources (NPS *Management Policies* § 4.8.1.1 2006).

Replacement of Facilities

Park development that is damaged or destroyed by a hazardous or catastrophic natural event will be thoroughly evaluated for relocation or replacement by new construction at a different location. If a decision is made to relocate or replace a severely damaged or destroyed facility, it will be

placed, if practicable, in an area that is believed to be free from natural hazards (NPS *Management Policies* § 9.1.1.5 and § 4.1.5 2006).

Cooperative Conservation

Under NPS policy, park superintendents are required to monitor state government programs for managing state-owned submerged lands and resources within NPS units. When there is potential for such programs to adversely impact park resources or values, superintendents will make their concerns known to appropriate state government officials and encourage compatible land uses that avoid or mitigate potential adverse impacts. When federal acquisition of state-owned submerged lands and resources within NPS units is not feasible, NPS will seek to enter into cooperative agreements with state governments to ensure the adequate protection of park resources and values (NPS *Management Policies* §3.4 2006).

In addition, the NPS has the authority under 36 C.F.R. §1.2(a)(3) to apply general NPS regulations, such as special use permit requirements, on or in waters that are subject to the jurisdiction of the United States, or in areas within their ordinary reach up to the mean or ordinary high water line, even if the submerged lands are non-federally-owned and regardless of whether the park has exclusive, concurrent, or proprietary jurisdiction. Waters subject to the jurisdiction of the United States refers to three types of waters: (1) navigable (as defined in 33 C.F.R. § 2.36(a), (2) non-navigable but located on lands for which the U.S. has acquired title or control and has accepted or retained exclusive or concurrent jurisdiction, and (3) waters made subject to U.S. jurisdiction by certain international agreements and statutes (33 C.F.R. § 2.38).

Methods

Coastal engineering terminology was adapted from the NPS Coastal Engineering Inventory pilot project (Coburn et al. 2010) and through discussion with the NPS Geologic Resources Division. The NPS selected eight coastal national parks in which coastal engineering projects were identified, inventoried and mapped. Projects in the inventory include coastal structures, dredging, filling, beach nourishment, and dune construction.

A digital park boundary shapefile for all of the inventoried parks was downloaded from the NPS Integrated Resources Management Applications Portal (https://irma.nps.gov). Georeferenced digital orthophoto imagery was obtained from each park and added to ArcMap 10.0 to create a basemap.

A visual inspection of the orthophoto imagery was completed and locations of all discernible coastal structures were digitized using ArcMap. A site visit to the park in February 2012, along with staff correspondence, was used to complement and confirm initial findings based on examination of the imagery and to identify other coastal engineering projects. A comprehensive online and hardcopy literature search was undertaken to obtain attribute data for each project (year of construction, material, year of maintenance, lead construction agency, and volume). Unless otherwise specified, costs presented in the report are in project-year dollars.

A coastal engineering project was considered distinct if there was any discernible, physical separation between it and an adjacent engineering project. A series of bulkheads constructed by individual interests, for example, would be classified as one structure as long as no identifiable gaps were observed between them. Some projects, such as dredge projects that place dredge spoil on the beach, serve multiple purposes (i.e., dredging and beach nourishment). In these cases, the primary reason for the project was ascertained and the project was classified accordingly. Projects that occurred repeatedly in one place (e.g. inlet dredging) were counted as one project.

Overview statistics were calculated to summarize the coastal engineering projects within each park. The percentage of shoreline armored by coastal structures was found by totaling the length of bulkheads, breakwaters, groins, revetments, seawalls, and sills and dividing it by the total length of shoreline. Structure length and shoreline length were determined using ArcMap. The structure length used in calculating the percentage of shoreline armored for individual structures was merely the length of the structure. For groin fields (defined here as three or more groins) the length was set as the length of the groin field along the shoreline, while for jetties the width of the mouth of the inlet was used.

An ArcGIS 10.0 file geodatabase for each park was compiled using ArcMap. Each geodatabase includes a park boundary feature class and identified coastal engineering projects separated into three feature classes: 1) coastal structures 2) dredge and fill projects and 3) beach nourishment and dune construction projects. The GIS projects also contain an ArcMap document for data viewing (.mxd), data layer files (.lyr), FGDC-compliant metadata (.xml and.txt), FAQ metadata (.html), a table attribute file (.pdf), and a README file (.pdf). Location information for dredge, fill, beach nourishment, and dune construction projects was often non-existent or vague. Therefore, not all of these projects are included in the GIS data, and those that are included have only approximate locations.

Results

Nine coastal structures were identified within the San Francisco Maritime National Historical Park (SAFR) (Table 1 & Figure 1). Together these structures extend for 2,275 m (7,465 ft), however, 324 m (1,063 ft) of the total breakwater length is located outside the park's boundary. At 556 m (1,824 ft), the park's single seawall armors 88% of the roughly 640-meter (2,010 ft) long shoreline within the park. The entire park is built on fill placed between 1906 and 1914 and in the 1930s (volume unknown). In 1941, 2.3 million m^3 (3 million yd^3) of sand was placed along the park's beach.

Table 1. Coastal structures in San Francisco Maritime National Historical Park.

[1]Structure	Total	Length (m)
[2]Breakwater	1	470
Groin	1	47
Pier	5	907
Revetment	1	285
Seawall	1	566
TOTAL	**9**	**2,275**

[1]See the Glossary in Appendix A for coastal structure definitions.
[2]Only part of the breakwater is within SAFR (see Figure 4).

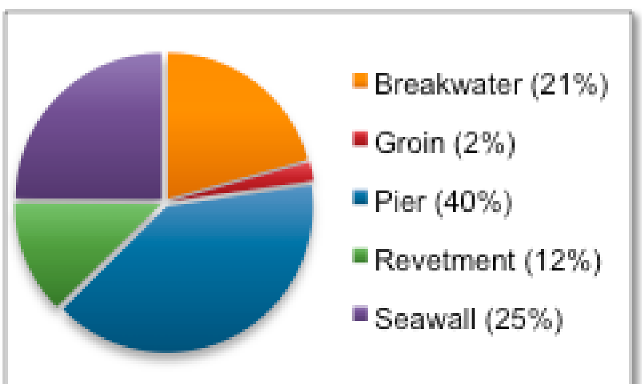

Figure 1. Percentage of total coastal structure length (by structure type) within SAFR (includes 324 m [1,063 ft] of the breakwater that is outside of SAFR).

Background

SAFR encompasses about 0.14 km^2 (35 ac) along San Francisco's northern waterfront (Figure 2) (NPS 1997). The park includes Hyde St. Pier with its historic vessels, the Aquatic Park Historic District, and Building E at Fort Mason. Hyde St. Pier opened to the public in 1963 as the San Francisco Maritime State Historical Park and it became part of the Golden Gate National Recreation Area in the 1970s. In 1988 the park became established as SAFR, a separate administrative unit of the National Park Service (NPS 1997).

Figure 2. Map of SAFR (from NPS 2012).

Setting

SAFR is on the San Francisco Bay, the largest estuary on the west coast of the United States (Chin and Graymer 2001). The bay is an urbanized estuary, and with the surrounding area home to over 7 million people, is widely considered to be the estuary most impacted by human activities in the United States (Nichols et al. 1986).

The geology of the area is complex due its position along the boundary of the North American Plate and the Pacific Plate. The plates move past each other at an average rate of about 5 cm/yr (2 in/yr) (Pendleton et al. 2005). However, earthquakes can cause sudden, large displacements, such as the magnitude 7.7 Great 1906 San Francisco Earthquake that moved the Pacific Plate 6 m (20 ft) to the northwest along the San Andreas Fault (Waldo et al. 1993). SAFR rests on the Franciscan Formation, a group of marine sedimentary and volcanic rocks (NPS 2001).

Wave energy in the bay is mainly generated by local winds. However, the north-facing San Francisco shoreline, which includes SAFR, is exposed to ocean swell arriving through the Golden Gate Inlet. Bottin (1991) reports wave heights ranging up to 1.7 m (5.6 ft) in the area. The offshore bathymetry of the San Francisco Bar, an ebb-tidal delta, and the Golden Gate Inlet (Figure 3) cause a large degree of wave refraction at the mouth of the Golden Gate (Hanes et al. 2011). This refraction results in waves that arrive oblique to the northern San Francisco shoreline, driving high rates of littoral sediment transport for relatively small waves (Hanes et al. 2011).

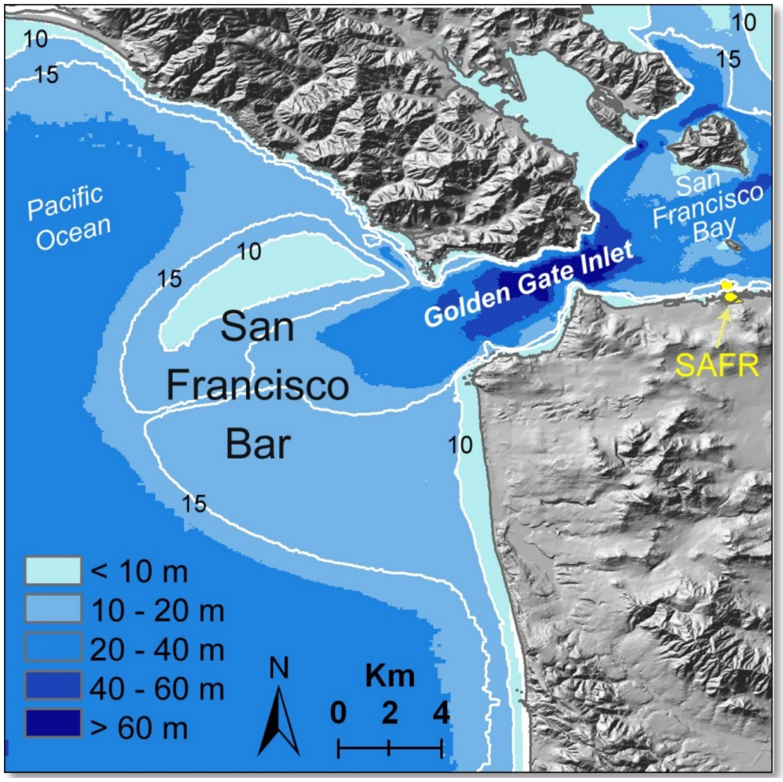

Figure 3. Bathymetric map of the entrance to San Francisco Bay. The 10 and 15 m contours are shown in white (image from ESRI Bing Maps basemap layer 2012).

Tides in the region are mixed, semi-diurnal, with a maximum tidal range of 1.78 m (5.84 ft). Due to the large surface area of the Bay, the spring tidal prism is roughly 2 billion m^3 (528 billion gallons) (Barnard et al. 2013). The Fort Point tide gauge shows a 2.01 $\pm$ 0.21 mm/yr (0.8 $\pm$ 0.01 in/yr) rise in sea level from 1897 to 2006 (NOAA 2012), in comparison to the 20th century global average of 1.7 mm/yr (0.07 in/yr) (Church and White 2006).

Hyde St. Pier Area

A 469-meter (1,540 ft) long concrete sheet-pile breakwater protects the Hyde St. Pier and Hyde St. Harbor (#1 Figure 4). The first breakwater constructed in this location was built in May 1917 to provide a shelter for a harbor (CDE 1917). The current breakwater was built by the U.S. Army Corps of Engineers in 1986 with an elevation of 3.7 m (12 ft) mean lower low water (Bottin 1991).

The concrete and timber Hyde Street Pier (#2 Figure 4) was built in 1922, with additions completed in 1931 and 1932, and was originally used for ferry service to Sausalito. The pier was restored in 1957 by the State of California and opened to the public in 1963 (NPS 2010). The docks immediately to the east of Hyde St. Pier (Figure 4) are part of the Hyde St. Marina and were installed circa 2000.

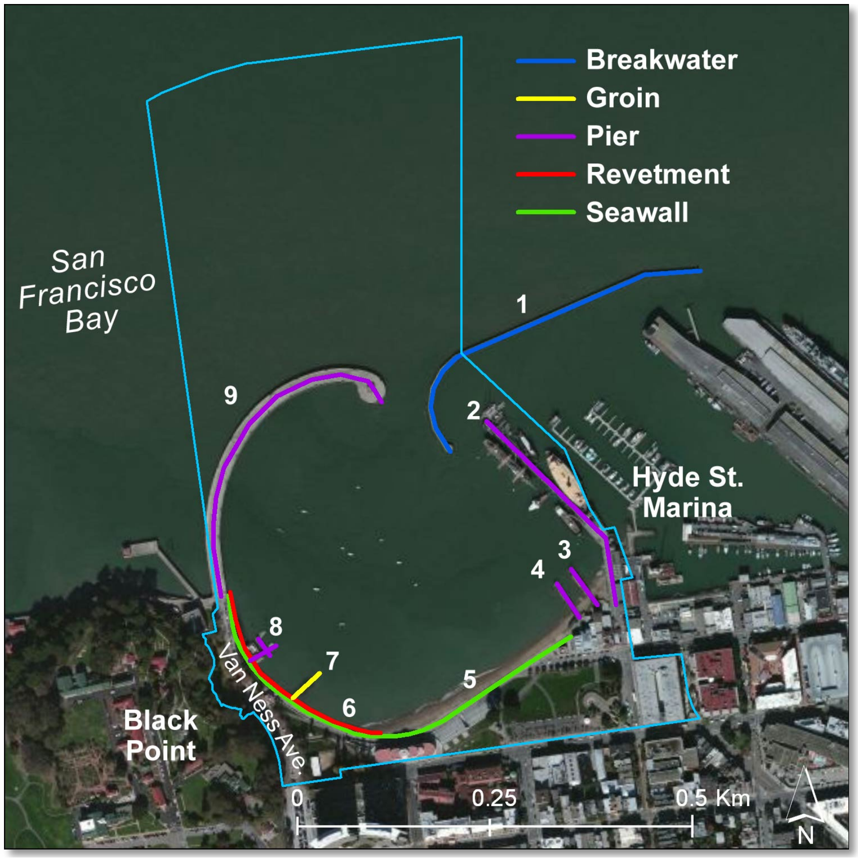

Figure 4. Structure map for SAFR. Light blue line shows park boundary (image from ESRI Bing Maps basemap layer 2012).

The west side of Hyde St. Pier was dredged in 1962 or 1963 to accommodate the berthing of historic vessels. Similarly, the outer end of the pier was likely dredged in the late 1960s or early 1970s for another ship (Stephen Canright, NPS, email, 2-20-13).

The timber piers on the east side of the cove belong to the South End Rowing Club (#3 Figure 4) and the Dolphin Club (#4 Figure 4), athletic clubs founded in the late 1870s. The piers were built in 1938 or 1939 when the clubs moved to their current locations from the western side of the basin (Stephen Canright, NPS, email, 2-20-13).

Aquatic Park

Prior to 1900, the present-day Aquatic Park area was a natural lagoon known as Black Point Cove (Figure 5) (ARG 2005). Following the 1906 San Francisco Earthquake, Black Point Cove became a dumping ground for tons of debris and rubble (NPS 2010). In order to build a railroad to the Marina district, the Panama Pacific International Exposition Company tunneled through Black Point (Figure 4) and built an elevated trestle across the cove in 1914, dumping much of the excavated material into the cove (NPS 2001). Filling ended in 1914, but the city continued dumping activities into the following year. After years of filling and dumping much of the cove became dry land and the original sandy beach was covered with rubble (NPS 2001). Recognizing the need to preserve the cove, the City of San Francisco purchased the surrounding lands in 1917 to create an aquatic park (NPS 2001).

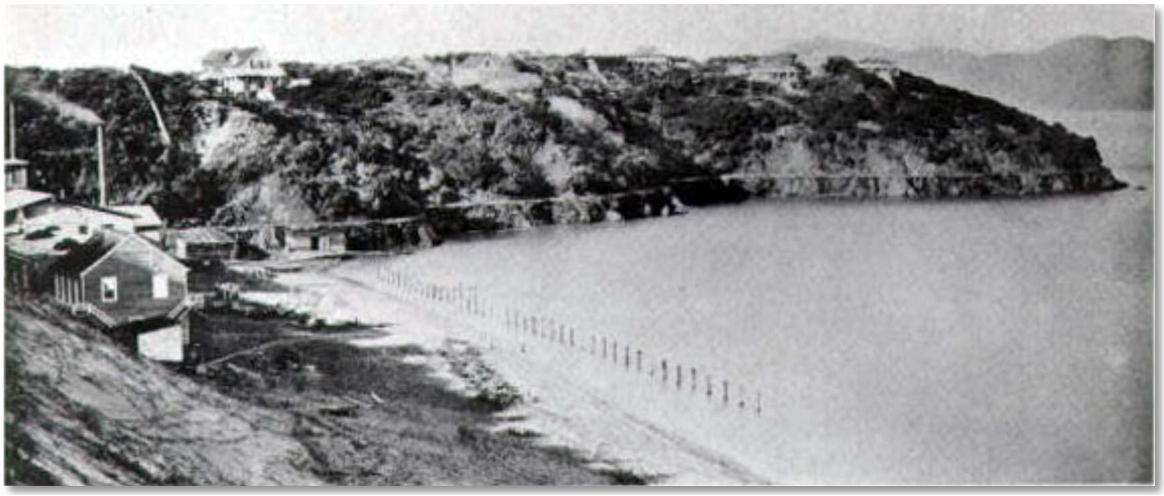

Figure 5. Black Point Cove in 1893, view looking north (from NPS 2001, courtesy of San Francisco Public Library Historic Photograph Collection, AAB-6718).

Unconsolidated fill was placed along the western side of the park in 1931 to extend Van Ness Avenue (Figure 4) northward. A temporary rubble and concrete seawall was built at the same time to maintain the fill (NPS 2001). The rubble seawall was demolished and used as the foundation for the current concrete and stone stepped seawall (#5 Figure 4 & Figure 6), built by the Works Progress Administration (WPA) in 1936–1939 (NPS 2001) (#9 Figure 4). The stones for the seawall were taken from city streets, which were being widened to accommodate an expected increase in traffic after construction of the Golden Gate and Bay Bridges (NPS 2001).

Figure 6. Aquatic Park's seawall, revetment, and Sea Scout building (#5, 6, 8 Figure 4). View is to the northwest (image by Kate Dallas).

After the seawall was completed, additional fill was placed to extend Van Ness Avenue to the Municipal Pier (#9 Figure 4) (NPS 2001). Reshaped tombstones were used to fill the gap between an older seawall to the northwest and the new WPA seawall (NPS 2001). Rock was added to the front of the seawall as early as 1938 (NPS 2001). In 1998 the seawall was repaired and rock revetment was added to the front of the wall (#6 Figure 4) (Robbyn Jackson, NPS, email, 3/14/12).

The City of San Francisco constructed the 549-meter (1,800 ft) long curving Municipal Pier from 1931 to 1933 (#9 Figure 4 & Figure 7) (NPS 2001). Concrete baffles were incorporated into the original design between the pier's pilings to act as a breakwater, sheltering the cove. The concrete pier was repaired in 1947 and 1953 following boating accidents (NPS 2010) and rubble was added beneath the pier at some point (NPS 2001). Currently, the pier is in fair condition and half of the pier has been closed to the public since about 2009 (Stephen Canright, NPS, email, 2-20-13).

Figure 7. Construction of Municipal Pier in 1932 (from NPS 2010, photo courtesy of San Francisco History Center, San Francisco Public Library, AAC-2288).

Strong currents within the cove caused sand to pile up at the eastern end of the beach in the 1930s (NPS 2001). In June of 1939 sand was pumped onto the beach, followed by placement of roughly 2.3 million m^3 (3 million yd^3) of sand in July 1941 (Figure 8) (NPS 2010). Most of the 1941 sand came from excavations for the Union Square underground parking garage in downtown San Francisco (NPS 2001). Erosion of the beach continued, however, and the seawall was undermined only three years later. Timber groins were installed in 1941 to help trap the shifting sand (NPS 2001), but they no longer remain and their exact history is unknown. SAFR's Cultural Landscape Inventory report (NPS 2001) documents repeated beach replenishment, but no further information could be found. Roughly every year sand is moved from the east end of the beach to the west end (Stephen Canright, NPS, email, 2-20-13).

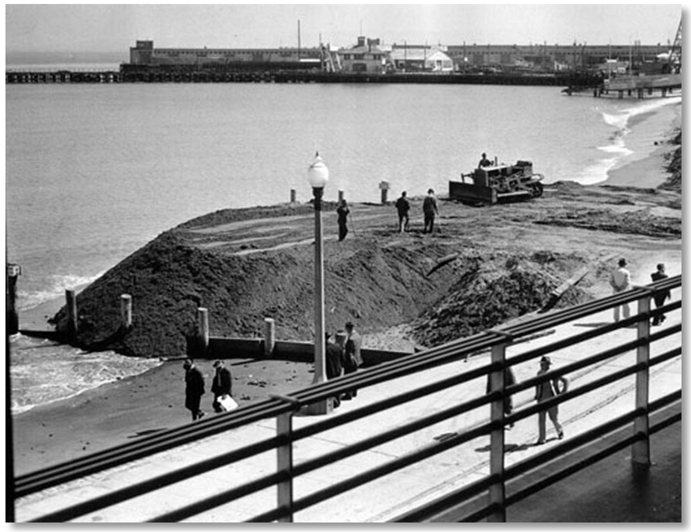

Figure 8. Beach nourishment on Aquatic Cove Beach, May 1941 (from NPS 2010, photo courtesy of San Francisco History Center, San Francisco Public Library, AAC 6699).

The concrete Sea Scout pier (#8 Figure 4) was built by the Army in 1943 during the military's presence in the area during WWII (NPS 2001). A rock groin, known locally as Fort Sutter Shoals, was built east of the Sea Scout pier (#7 Figure 4) in the late 1960s by a private individual who carried the rock down from the seawall (Stephen Canright, NPS, email 2-20-13).

Impacts

San Francisco Maritime National Historical Park lies along one of the most manipulated coastal waterfronts in the United States. The broader San Francisco Bay Delta is considered to be one of the most diverse and productive ecosystems in the world (Weeks 2006), while also being one of the most modified estuaries in the country (Nichols et al. 1986). Impacts within the park are due to historic filling operations and the construction of coastal structures associated with the creation of Aquatic Park, a significant recreational and cultural venue along the San Francisco Bay waterfront.

Black Point Cove Filling

The park's unique landscape describes a narrative of a complete transformation from low-lying coastal marshlands to a hardened shoreline designed to meet the recreational needs of an expanding city. The site is thought to have been a favorite recreation spot dating back to the Civil War (NPS 2001). As detailed within the inventory, the park sits atop a vast quantify of fill that was placed beginning in the early 1900s and was completed by the 1930s with the formation of Aquatic Park (Figure 9) (NPS 2001). The modern day shoreline is approximately 110 m (360 ft) bayward of its original location on account of the filling.

Figure 9. Aerial view of SAFR in (A) 1857 and (B) 2011 (1857 image part of a U.S. Geological Survey map from NOAA (2013) with approximate 2011 shoreline overlay, 2011 image from Google Earth (2013)).

Impacts to the local ecology are likely consistent with modifications related to regional filling practices that have effectively eliminated 92% of historic tidal habitats within San Francisco Bay (Windham-Myers et al. 2010). These actions have drastically reduced bioproductivity, initiated species loss, and reduced aquatic surface area, which has ultimately decreased tidal flushing rates within the bay and contributed to air and water quality degradation (BCDC 2013).

Shoreline Armoring and Beach Nourishment

Eighty-eight percent of the SAFR shoreline is armored by coastal engineering structures. These structures serve to disconnect the land from the nearshore environment, potentially reducing the terrestrial sediment input into the system and available habitat and transfer of nutrients (Coyle and Dethier 2010).

The 549-meter (1,800 ft) long Municipal Pier and 469-meter (1,540 ft) long Hyde St. breakwater (#1, 9 Figure 4), have altered the wave and circulation patterns within the cove. These alterations are likely linked to changes in sediment transport and erosion/shoaling patterns within the park, the extent of which is unknown. However, Bottin (1991) reports that the concrete sheet-pile breakwater is not thought to adversely impact sediment movement within the Aquatic Park area.

The beach within Aquatic Park was created by placement of over 2.3 million m^3 (3 million yd^3) of sand in 1941, along with possible later renourishment (volumes unknown) in order to maintain a recreational beach (NPS 2001). In general, beach nourishment can impact beach and nearshore environments by burying habitat, changing beach morphology and altering the preferential placement of organisms (Speybroeck et al. 2006), though the exact impacts at SAFR have not been studied.

Discussion and Recommendations for Further Study

Coastal modifications along the SAFR shoreline have provided the means and stability for the existence of the Aquatic Park Historic District, a National Historic Landmark. The same activities (i.e. filling, armoring and nourishment) that have allowed recreational access have also likely contributed to alterations of native habitat, local hydrodynamics, and sediment transport dynamics.

The National Academy of Sciences (NRC 2012) has predicted that sea level within the San Francisco area will rise between 0.42 to 1.67 m (1.38 to 5.48 ft), with 0.92 m (3 ft) likely by the year 2100, which is considerably higher than the Intergovernmental Panel on Climate Change projections that global sea level will rise 0.19 to 0.59 m (0.62 to 1.92 ft) by the year 2100 (IPCC 2007). Climate change poses a significant threat to SAFR as increased sea level and possibly changing storminess patterns may cause damage to coastal infrastructure and park ecosystems.

It is recommended that the park continue to focus efforts on providing sustainable, environmentally responsible ways of promoting its unique recreational and cultural resources, while simultaneously supporting its commitment to conserve natural processes. To prevent infrastructure damage, management should continue to take sea level rise and the possibility of changing wave and current patterns into consideration during planning and development.

Literature Cited

Architectural Resources Group (ARG). 2005. Aquatic Park Amphitheater Focused Historic Structure Report. San Francisco Maritime National Historic Park. Architectural Resources Group, San Francisco, California.

Barnard, P. L, A. C. Foxgrover, E. P. L. Elias, L. H. Erikson, J. R. Hein, M. McGann, K. Mizell, R. J. Rosenbauer, P. W. Swarzenski, R. K. Takesue, F. L. Wong, and D. L. Woodrow. 2013. 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* 226:120–145.

Bottin, R. Jr. 1991. Fisherman's Wharf: Hydraulic Design of a Successful Harbor Project. *Journal of Coastal Research* (7)1:1–9.

California Department of Engineering (CDE). 1917. Fifth Biennial Report of the Department of Engineering of the State of California. California Department of Engineering. Available at http://books.google.com/books?id=Kc83AAAAIAAJ&lpg=PA22-IA84&ots=Z_Crh82Cr9&dq=hyde%20st%20breakwater&pg=PA22-IA84#v=snippet&q=%22hyde%20street%22&f=false (accessed 8 Feb 2013).

Chin, J. L. and R. W. Graymer. 2001. Regional Setting. Pages 8–11 *in* H. Karl, J. Chin, E. Uebuer, P. Stauffer, and J. Hendley II, editors. Beyond the GGNRA - oceanography, geology, biology, and environmental issues in the Gulf of the Farallones, U.S. Geological Survey Circular 1198.

Church, J. A. and N. J. White. 2006. A 20th century acceleration in global sea-level rise. *Geophysical Research Letters* 33(1).

Coburn, A. S., A. D. Griffith, and R. S. Young. 2010. Inventory of Coastal Engineering Projects in Coastal National Parks. Natural Resource Technical Report NPS/NRPC/GRD/NRTR—2010/373. National Park Service, Fort Collins, Colorado.

Coyle, J. M. and M. N. Dethier. 2010. Review of Shoreline Armoring Literature. Pages 245–265 *in* H. Shipman, M. N. Dethier, G. Gelfenbaum, K. L. Fresh, and R. S. Dinicola, editors. Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop, May 2009: U.S. Geological Survey Scientific Investigations Report 2010-5254.

Environmental Systems Research Institute (ESRI). 2012. ESRI ArcGIS Bing Maps basemap data layer.

Google Earth. 2013. Image of Northern San Francisco shoreline from 2011. Google Earth.

Hanes, D. M., K. Ward, and L. H. Erikson. 2011. Waves and tides responsible for intermittent closure of a small, sheltered tidal wetland at San Francisco, CA. *Continental Shelf Research* 31:1682–1687.

Intergovernmental Panel on Climate Change (IPCC). 2007. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller, editors. Cambridge University Press, Cambridge, United Kingdom and New York, New York, USA.

National Oceanographic and Atmospheric Administration (NOAA). 2012. Tides and Currents web site. http://tidesandcurrents.noaa.gov/ (accessed 30 July 2012).

National Oceanographic and Atmospheric Administration (NOAA). 2013. NOAA Historical Map & Chart web site. http://historicalcharts.noaa.gov/ (accessed 10 February 2013).

National Park Service (NPS). 1997. General Management Plan San Francisco Maritime National Historical Park. San Francisco, California.

National Park Service (NPS). 2001. Cultural Landscape Inventory, Aquatic Park, San Francisco Maritime National Historical Park. National Park Service.

National Park Service (NPS). 2010. Cultural Landscape Report, Aquatic Park San Francisco Maritime, National Historical Park. National Park Service.

National Park Service (NPS). 2012. San Francisco Maritime National Historical Park website. http://www.nps.gov/safr/index.htm (accessed 4 Feb 2013).

National Research Council (NRC). 2012. Committee on Sea Level Rise in California, Oregon, and Washington, Board on Earth Sciences and Resources, Ocean Studies Board, Division on Earth and Life Studies, Washington, D.C.

Nichols, F. H., J. E. Cloern, S. N. Luoma, and D. H. Peterson. 1986. The modification of an estuary. *Science* 231:567–573.

Pendleton, E. A., E. R. Thieler, and S. J. Williams. 2005. Coastal Vulnerability Assessment of Golden Gate National Recreation Area to Sea-Level Rise. United States Geological Society Open-file Report 2005-1058, Reston, Virginia.

San Francisco Bay Conservation and Development Commission (BCDC). 2013. San Francisco Bay Plan website. http://www.bcdc.ca.gov/laws_plans/plans/sfbay_plan.shtml (accessed 8 February 2013)

Speybroeck, J., D. Bonte, W. Courtens, T. Gheskiere, P. Grootaert, J. Maelfait, M. Mathys, S. Provoost, K. Sabbe, E. W. Stienen, V. Van Lancker, M. Vincx and S. Degraer. 2006. Beach nourishment: an ecologically sound defense alternative? A review. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16:419–435.

Waldo, D. J., H. Kanamori, and D. V. Helmberger. 1993. Source study of the 1906 San Francisco Earthquake. *Bulletin of the Seismology Society of America* (83):981–1019.

Weeks, D. 2006. Golden Gate National Recreation Area California: Water Resources Foundation Report. Technical Report NPS/NRWRD/NRTR- 2006/348. National Park Service, Fort Collins, Colorado.

Windham-Myers, L., M. C. Marvin-DiPasquale, J. L. Agee, L. H. Kieu, E. Kakouros, L. Erikson, and K. Ward. 2010. Biogeochemical processes in an urban, restored wetland of San Francisco Bay, California, 2007–2009; methods and data for plant, sediment, and water parameters. U.S. Geological Survey Open-File Report 2010-1299.

Appendix A. Glossary

Accretion: The accumulation of sediment on a beach, deposited by natural fluid flow processes.

Beach Nourishment: The introduction of sediment along a shoreline to increase or protect the size of a beach (includes dune and berm construction and nearshore disposal of sediment for the purpose of shoreline stabilization).

Breakwater: Shore-parallel structures that reduce the amount of wave energy reaching a harbor or stretch of shoreline located behind the structure. Breakwaters are similar to natural bars, reefs or nearshore islands and are designed to dissipate wave energy. The reduction in wave energy results in gradients in littoral drift, causing sediment deposition in the sheltered area behind the breakwater. Some longshore sediment transport may continue along the coast behind the breakwater. Structures can be detached, attached or utilized as a headland control feature depending on design and functionality characteristics.

Bulkhead: Vertical structures or partitions, usually running parallel to the shoreline, for the purpose of retaining upland soils while providing protection from wave action and erosion. Bulkheads are either cantilevered or anchored sheet piles or gravity structures such as rock-filled timber cribs and gabions, concrete blocks or armorstone units.

Dike: Earthen structures (dams) that keep elevated water levels from flooding interior lowlands. The protected area is often below sea level. In open coast areas, dikes that separate low-lying areas from open water are often constructed with a revetment or similar armor layer on the open waterside to protect the dike from wave action and erosion.

Dredging: The mechanical removal of sediment, often used to increase or maintain the depth of a navigable waterway.

Erosion: The wearing away of land and the removal of beach or dune sediments by wave action, tidal currents, wave currents, or drainage.

Groin: Structures that extend perpendicular or at nearly right angles from the shore and are relatively short when compared to navigation jetties at tidal inlets. Often constructed in groups called groin fields, their primary purpose is to trap and retain sand. Groins can be constructed from a wide range of materials including armorstone, pre-cast concrete units or blocks, rock-filled timber cribs and gabions, steel sheet pile, timber sheet pile, or grout filled bags and tubes.

Headland Control: The concept of systematically placing structures (typically breakwaters) to create artificial headlands in an effort to promote equilibrium beach formation. Bays are sculptured between these headlands, such that diffraction and refraction cause waves to develop perpendicular to the coast. This is intended to result in a stable shoreline even if sediment is still passing through a system of headlands. This concept is often employed as a regional approach to shore protection.

Jetty: Structures that extend perpendicular or at nearly right angles from the shore commonly used to limit the volume of sediment deposited in inlet channels and prevent inlet migration.

Levee: Flood protection structure that holds back water during flood stage, typically built along a river to protect against flooding.

Pier: A platform extending over water from a shore that is supported by piles or pillars, used to secure, protect, and provide access to ships or boats.

Revetment: A cover or facing of material placed directly on an existing slope, embankment or dike to protect the area from waves and strong currents. Revetments are designed to armor and protect the land behind them and are commonly constructed using armorstone (high wave energy environments) or riprap stone (lower wave energy environments) in combination with smaller stone and geotextile fabrics. Other construction materials include gabions, poured concrete (usually in stepped fashion), pre-cast concrete blocks, and grout filled bags. Structures can be partially detached from the shore (spur) depending on design considerations.

Seawall: Vertical structures used to protect backshore areas from heavy wave action, and in lower wave energy environments, to separate land from water. They can be constructed using a range of materials including poured concrete, steel sheet pile, concrete blocks, gabions, sandbags, or timber cribs.

Sill: Combination of elements from offshore breakwaters and rock revetments, typically built relatively close to shore, continuous and low-lying. Sills are generally built in lower wave energy regimes with the intent of reducing the wave climate and establishing marsh ecosystems or beaches.

Appendix B. Coastal Structure Data

ID	Location	Structure	Material	Year Built	Year Maintained	Length (m)	Source
1	Hyde St. Marina	Breakwater	Concrete	1917	1986	470	CDE 1917, Bottin 1991
2	Hyde St. Pier	Pier	Concrete	1922	1931, 1932, 1957	299	Sign at pier
3	South End Club	Pier	Wood	late 1930s		57	Stephen Canright (NPS)
4	Dolphin Club	Pier	Wood	late 1930s		52	Stephen Canright (NPS)
5	Aquatic Park	Seawall	Concrete	1936-1939	1998	566	NPS 2001
6	Aquatic Park	Revetment	Rock	1928	1998	285	NPS 2001, Robbyn Jackson (NPS)
7	Aquatic Park	Groin	Rock	late 1960s		47	Stephen Canright (NPS)
8	Aquatic Park	Pier	Wood	1943		66	NPS 2001
9	Municipal Pier	Pier	Concrete	1931-1933	1947, 1953	434	NPS 2010

Appendix C. Beach Nourishment Data

Location	First Year	Renourishment Year	Total Volume (m^3)	[1]Length (m)	Source
Aquatic Park	June 1939	July 1941	[2]2,300,000	905	NPS 2010

[1]Length is very approximate
[2]Volume includes 1941 project only (the 1939 project volume is unknown).

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