National Park Service
U.S. Department of the Interior

Inventory of Coastal Engineering Projects in Olympic National Park

Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2013/705

ON THE COVER
Rialto Beach, La Push, Washington
Photograph by: Michael Berry

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March 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

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).

Please cite this publication as:

Dallas, K., M. Berry, and P. Ruggiero. 2013. Inventory of coastal engineering projects in Olympic National Park. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2013/705. National Park Service, Fort Collins, Colorado.

NPS 149/119987, March 2013

Contents

Contents (continued)

Figures

Tables

Page

Appendices

Page

Abstract

A reconnaissance-level investigation, analysis and inventory 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, Olympic National Park (OLYM). The report serves as a supplement to a Geographic Information Systems (GIS) database (the GIS data are available online at http://irma.nps.gov).

Fifteen coastal engineering projects were identified in and adjacent to OLYM. Within the park there are four coastal structures comprised of three driftwood bulkheads and one revetment that together extend 124 m (407 ft). Eleven projects were found adjacent to the park at the mouth of the Quillayute River in the town of La Push, Washington. Ten of these projects are coastal engineering structures that span 2,915 m (9,564 ft). Since 1963, one dredging project at the mouth of the Quillayute River has removed over 1,000,000 m^3 (1,307,950 yd^3) of sediment.

The Quillayute River Navigation Project has likely altered riverine hydrodynamics, restricted natural sediment transport to ocean beaches, and adversely impacted terrestrial and aquatic habitats. Coastal structures along the Kalaloch shoreline are thought to have only a minor impact on local erosion rates. The Elwha River dam removal project has initiated a wide suite of impacts including alterations to local biologic habitat and nearshore zones due to sediment accumulation on a variable temporal and spatial scale.

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. Andy Coburn, Ian Miller, and Steve Fradkin provided valuable peer reviews.

We would like to thank Steven Fradkin of Olympic National Park for his help acquiring imagery and relevant background documents. Nancy Gleason at the U.S. Army Corps of Engineers provided Quillayute River dredging data and structure information. Tom Roorda of Roorda Aerial (http://www.roordaaerial.com) provided an aerial image of the sediment plume at the mouth of the Elwha River.

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, 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, cost, 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

A total of fifteen coastal engineering projects, comprised of fourteen coastal structures (Table 1 and Figure 1) and one dredging project, were identified in and adjacent to Olympic National Park (OLYM). Four small coastal structures were found within the park, which include three short driftwood bulkheads and one 28-meter (92 ft) long revetment. Ten coastal structures and one dredging project were found adjacent to the park in the town of La Push, Washington. The structures in La Push extend a total of 2,915 m (9,564 ft), while dredging at the mouth of the Quillayute River has removed over 1,000,000 m^3 (1,307,950 yd^3) of sediment since 1963. See Appendix B for detailed data on all of the coastal structures.

Table 1. Coastal structures in, and adjacent to, Olympic National Park.

[1]Structure	Total	Length (m)	In OLYM
Breakwater	2	424	No
Bulkhead	3	96	Yes-3
Jetty	2	632	No
Pier	5	620	No
Revetment	3	1,267	Yes-1, No-2
TOTAL	**14**	**3,039**	**4**

[1]See the Glossary in Appendix A for coastal structure definitions.

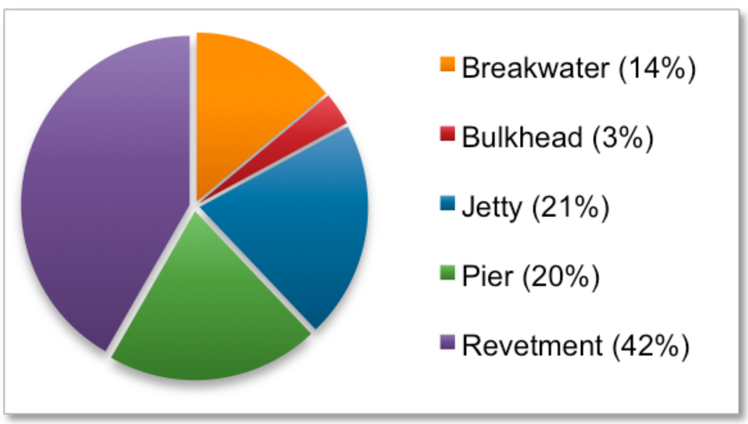

Figure 1. Percentage of total coastal structure length (by structure type) in and adjacent to Olympic National Park.

Background

Olympic National Park was established on June 29, 1938 "for the benefit and enjoyment of the people" (NPS 1990). The park was expanded in 1953 and 1986 and now includes 3,733 km^2 (922,444 ac) with 117 km (73 mi) of coastline (Figure 2). The park's coastline is primarily comprised of rocky and cliffed coast with intermittent sand, gravel, or cobble pocket beaches. Roughly 95% of the park is designated as wilderness and the coastline is mostly undeveloped and pristine (Pendleton et al. 2004). The Pacific coast of OLYM is considered to be one of the great scenic coasts of the world.

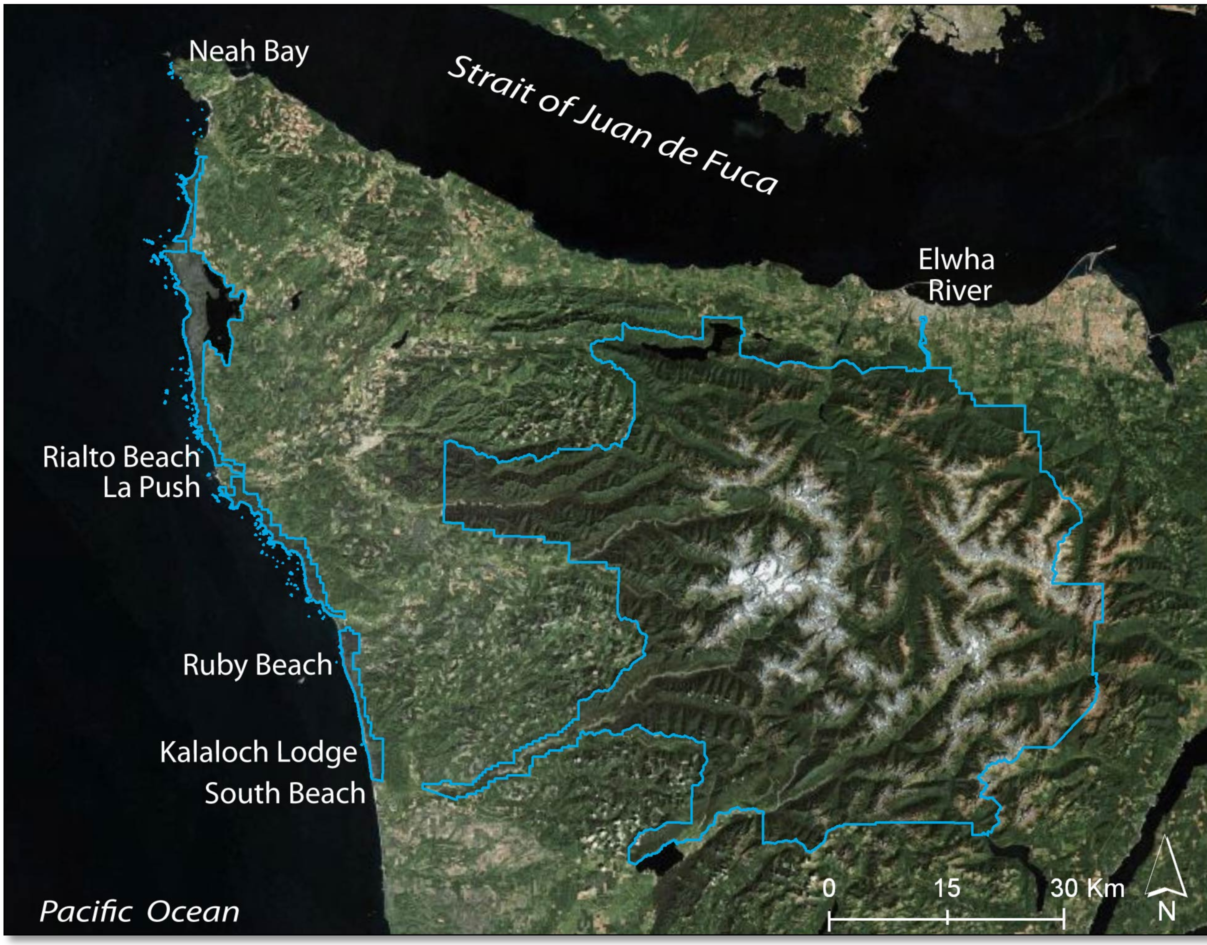

Figure 2. Map of Olympic National Park and locations mentioned in the report. The blue line shows the park boundary (image from ESRI Bing Maps basemap layer 2012).

Setting

The landscape of OLYM is a product of subduction of the Juan de Fuca oceanic plate under the North American plate, which began around 35 million years ago. The geomorphology of the park was further modified by large ice sheets during Pleistocene glaciations (2 million to 13,000 years ago). Most of the rocks within the park are basalt, sandstone, shale, or slate (Lillie 1999). The coastal shoreline of OLYM is vulnerable to tsunamis created by earthquakes along the Cascadia Subduction Zone, located roughly 110 km (70 mi) off the Washington coast, as well as from distant sources.

Tides along the park's open ocean coastline are semidiurnal (two high tides and two low tides every 24 hours 50 minutes) and have a mean range between 2 and 4 meters (6.4 and 12.8 ft) (Pendleton et al. 2004). Wave energy is high in the region, with mean significant wave heights ranging from 2.0 to 2.5 m (6.4 to 8.3 ft) (Pendleton et al. 2004).

The National Oceanographic and Atmospheric Administration (NOAA) tide station in Neah Bay, Washington (Figure 2) shows a decrease of -1.63 $\pm$ 0.36 mm/yr (-0.06 $\pm$ 0.01 in/yr) in water levels from 1934 to 2006 (NOAA 2012), indicating a rise in land elevation in the region due to tectonics. However, the tide gauge in Toke Point, Washington (located approximately 100 km

[62 mi] south of the park) shows a sea-level rise rate of 1.60 ± 1.38 mm/yr (0.06 ± 0.05 in/yr) from 1973 to 2006 (NOAA 2012). The different rates of sea-level rise illustrate the variability in subsidence and uplift in the region.

Analysis of historic shorelines along 75 km (47 mi) of the central Washington coast from the 1920s to 2002 by Ruggiero et al. (in press) shows an average shoreline erosion rate of -0.03 m/yr (-0.10 ft/yr) with an uncertainty of ±0.02 m/yr (±0.06 ft/yr). Their study region spanned from La Push, Washington to Point Grenville, located approximately 30 km (19 mi) south of the park. Ruggiero et al. (in press) report that most of the erosion occurred in the southern portion of the region outside of the park.

La Push, Washington

Coastal Structures

The Quillayute River Navigation Project is located at the town of La Push, Washington. The project includes a small boat basin and navigation channel, two jetties, and maintenance of the Quillayute spit along Rialto Beach (Figures 3 & 4). The mouth of the Quillayute River has changed over time due to both natural and anthropogenic impacts. In 1882 the river mouth was approximately in its present location, but by 1889 the mouth of the river was located 2 km (1.2 mi) to the north at the northern end of the spit (McKay and Terich 1992). In 1910 a new mouth formed north of James Island (Winz 2004). Since 1916 the river has discharged east of James Island (Figure 4). Two jetties were constructed in 1931 to stabilize the mouth of the river for safe navigation (Figure 3).

Figure 3. Coastal structures at the mouth of the Quillayute River. View is to the southwest (image from WDOE 2012).

The 404-meter (1,325 ft) long rubble-mound jetty on the eastern side of the river mouth (#3 Figure 4) was originally built in 1931 to 1.5 m (5 ft) above Mean Lower Low Water (MLLW) with 15,627 metric tons (17,226 tons) of rock (Ward 1988). At this low elevation, large volumes of sediment passed over the jetty into the river channel (USACE 2011a). Ward (1988) reports that the jetty was repaired in 1932, 1939, and 1941. In 1957 the jetty was raised to 4.6 m (15 ft) MLLW and raised again in 1960, changing the alignment of the channel.

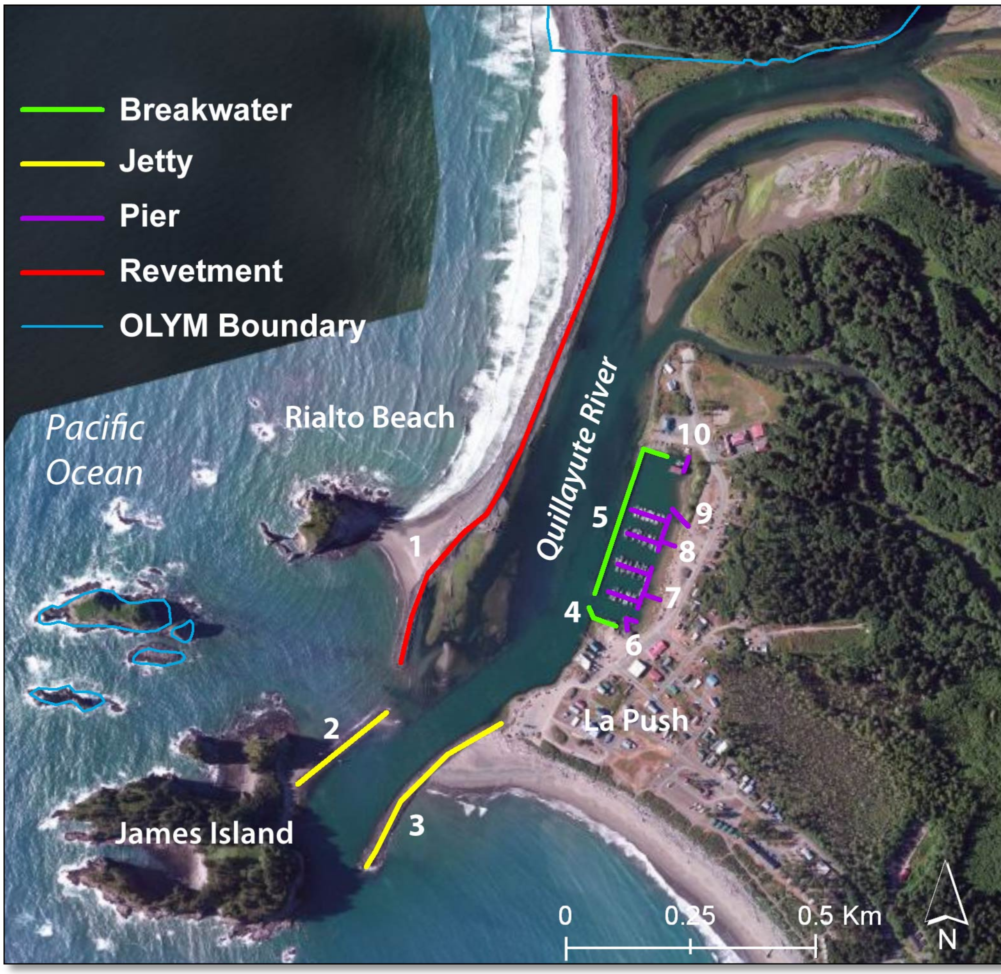

Figure 4. Structure map for the mouth of the Quillayute River at La Push, WA within the Quileute Indian Reservation (image from ESRI Bing Maps basemap layer 2012).

Increased flow adjacent to the eastern jetty ultimately caused a breach in 1961 and required additional rock placement along the jetty in January 1962 (USACE 1974). Minor repairs of the eastern jetty also occurred in 1979 and in 1982 when a low spot was repaired with 1,810 metric tons (2,000 tons) of rock (USACE 1986). Heavy surf caused severe erosion of the jetty in January 2012, requiring repairs by the USACE on January 7, 2012 (Ollikainen 2012).

The western jetty (referred to as a “sea dike” in the literature) was built in 1931 with 563 m^3 (737 yd^3) of rock and originally connected James Island to the spit (#2 Figure 4) (Ward 1988, USACE 2011a). This jetty was regularly breached in winter and was repaired often over time, including repairs in 1932, 1933, 1939, 1941, 1944, 1946, 1950, 1953, 1956, 1957, and 1961 (Ward 1988, USACE 2011a). Attempts to maintain the jetty's connection to the spit were abandoned after the eastern jetty was raised in 1957 (USACE 2011a). The crest of the western jetty is presently at 0.6 to 1.2 m (2 to 4 ft) MLLW, which is considerably lower than the authorized height of 2.4 m (8 ft) MLLW (USACE 2011a). The current condition of the western jetty permits wave transmission into the navigation channel, creating a challenging inlet to navigate and maintain.

The La Push boat basin was constructed in 1957 and was dredged every 10 to 15 years through the 1980s (USACE 1986). In 1962 a timber training wall at the southwestern edge of the boat basin was built, but it was soon undercut by the river and failed (Ward 1988). The training wall was rebuilt in 1963 to an elevation of 2.4 m (8 ft) MLLW (labeled as a breakwater, #4 Figure 4) (Ward 1988, USACE 2011a).

When high tides coincide with west to northwesterly waves the training wall is submerged, providing limited protection to vessels in the boat basin (USACE 2011a). Another timber training wall was built on the western side of the boat basin in June 1963 to prevent shoaling of the basin (labeled as a breakwater, #5 Figure 4). Sections of both training walls were repaired in 2012 (Gene Harrison, Quileute Harbor Marina, phone 12/5/12).

Five timber piers exist within the boat basin (#6–10 Figure 4). The northern pier (#10 Figure 4) is part of the U.S. Coast Guard Station Quillayute River. The remaining piers belong to the Quileute Harbor Marina and were built in the 1980s (Gene Harrison, Harbor Master Assistant, phone 12/3/12). In 2011 the fuel dock (#6 Figure 4) was replaced and sections of the boat piers (#7–8 Figure 4) were repaired.

The Rialto Beach spit stretches north for roughly 1 km (0.6 mi) from the mouth of the Quillayute River (Figure 4). The spit is continually being eroded by ocean waves and currents on its western side and by the Quillayute River on its eastern side (USACE 1986). The spit has been breached at least five times, with documented breachings in 1) 1954, 2) November 1955, 3) December 1956, 4) 1980, and 5) 1996 (USACE 1986, Ward 1988, Winz 2003).

The U.S. Army Corps of Engineers (USACE) has used bulkheads, dredged material placement, and a revetment to maintain the spit since federal acceptance for maintenance in 1957 (USACE 1974, McKay and Terich 1992). Since 1956, sediment dredged from the adjacent Quillayute River Navigation Channel has been placed on the central and southern sections of the spit (Ward 1988).

In 1968 logs were cabled and buried in the spit (Ward 1988) and in 1974, a rock revetment consisting of 45,360 metric tons (50,000 tons) of rock was constructed along 490 m (1,600 ft) of the central spit (#1 Figure 4). An additional 82,190 metric tons (90,600 tons) of rock was added to the revetment in 1978–1979 (Ward 1988).

In 1980, a 700-meter (2,297 ft) long breakwater was built seaward of the revetment (McKay and Terich 1992), but the breakwater was destroyed in less than three months. The USACE rebuilt and extended the revetment in 1982 using 85,275 metric tons (94,000 tons) of quarry rock and 50,360 metric tons (55,510 tons) of armoring rock (Winz 2004). Following a breach in 1996, the revetment was lengthened northward an additional 518 m (1,700 ft) (Winz 2004).

Dredging

Dredging of the Quillayute River Channel and boat basin has removed over 1,000,000 m^3 (1,307,950 yd^3) of sediment from 1956 to 2009 (Table 2). The river channel upstream of the boat basin was historically dredged, but has not been maintained since 1971 (USACE 2011a). Dredged material is generally placed on the ocean side of the spit along Rialto Beach. The Quillayute River Spit Rehabilitation Report (1974) documents that an average of 38,230 m^3 (50,000 yd^3) of dredged material was placed on the spit annually from 1963 to 1970 (USACE 1974). Placement of dredged material also occurs at an upland location on the Quileute Tribal Reservation (USACE 2011b).

Table 2. Dredging volumes for the mouth of the Quillayute River.

Year	Total (m^3)	[1]Source
1956	?	1
1959	?	1
1963–1970	[2]~305,824	2
July–Sept 1971	267, 594	2
June 1973	34,405	2
1981	20,643	3
1982	39,757	4
1984	51,225	4
1985	67,281	3
1993	39,259	3
1995	68,425	3
1998	40,874	3
1999	63,526	3
2003	25,858	3
2007	42,866	3
2009	46,067	3
TOTAL	**~1,073,848**	

[1]Source: 1: Ward 1988, 2: USACE 1974, 3: Nancy Gleason (USACE), 4: USACE 1986
[2]Approximately 38,230 m^3 was dredged annually from 1963–1970.

Southern Pacific Coast

Coastal bluff erosion between Ruby Beach and South Beach (Figure 2) currently threatens sections of U.S. Highway 101, a vital transportation corridor. Bluff erosion is driven by storm surges during the winter months and averages -0.3 to -0.6 m/yr (-1 to -2 ft/yr) (Parametrix, Inc. 2002). As a short-term solution, the NPS has constructed driftwood bulkheads to help slow the erosion (Figure 5 and #12–14 Figure 6). The bulkheads typically last about 10 years, are generally located at beach access points, and are backfilled with large rocks. When a bulkhead begins to fail or rot, a new bulkhead is built seaward of the existing one (Parametrix, Inc. 2002).

In addition to the bulkheads, rock has been placed along the bluff adjacent to Highway 101 north of Kalaloch campground, the history of which is unknown (#11 Figure 6). In partnership with the Washington State Department of Transportation, the NPS is considering relocation of the highway (Parametrix, Inc. 2002).

Figure 5. Driftwood bulkhead in the Kalaloch area along U.S. Highway 101 (image by Mike Berry).

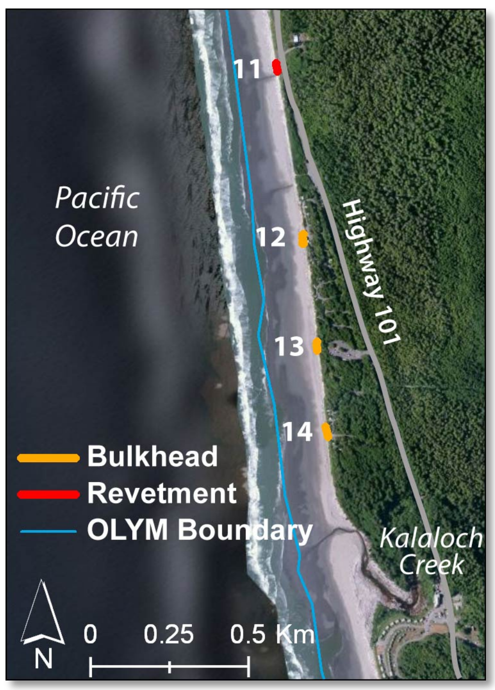

Figure 6. Structure map for the Kalaloch area (image from ESRI Bing Maps basemap layer 2012).

Elwha River

The Elwha River lies mostly within OLYM and flows north from the Olympic Range to the Strait of Juan de Fuca (Figure 2). The Elwha and Glines Canyon Dam, built in 1912 and 1927, respectively, have altered the physical and biological characteristics of the river, including its estuarine and nearshore environments. While the dam removal project is outside of the scope of this coastal engineering inventory, it is addressed briefly here and in the following Impacts section due to its significant, anticipated impact to the coastal zone.

The Elwha River is home to the largest river restoration project in the United States in terms of the projected release of sediment and the size of the existing hydroelectric projects (Duda et al. 2011). The Department of the Interior removed the Elwha Dam, located outside of OLYM, and the Glines Canyon Dam (Figure 7), located within the park, in 2011–2012.

Figure 7. Glines Canyon Dam in September 2011 before dam removal (left) and in July 2012 after dam removal (right) (images from EVS 2012).

Dam removal will reopen more than 145 km (90 mi) of pristine habitat to salmon populations and release some of the 19 million m^3 (25 million yd^3) of sediment impounded behind the dams. The U.S. Geological Survey (USGS) estimates 7 to 8 million m^3 (9.2 to 10.5 million yd^3) of sediment will be transported from the reservoirs, while the remaining sediment will become revegetated in the former reservoirs (USGS 2011). One-half to two-thirds of the sediment will be fine-grained silt, clay, and sand and one-quarter to one-third will be coarse-grained cobbles and gravels (USGS 2011). This massive input of sediment is expected to slow or reverse coastal erosion and modify habitats near the river's mouth.

Impacts

Olympic National Park is unique in that most of the coastal shoreline is not directly impacted by coastal engineering structures. As a result, this section will focus on the coastal engineering influences adjacent to the park and on environmental restoration efforts.

Quillayute River Navigation Project (La Push, Washington)

The Quillayute River Navigation Project (Figures 3, 4 & 8) has continued to manipulate the landscape since its conception in the 1930s. The construction of jetties and a revetment, coupled with the use of dredging and sand placement, has altered the natural flow of sediment.

Figure 8. Quillayute River at La Push, Washington (image from USCG 2012).

The Quillayute River channel has been altered to support the Quileute Harbor Marina, U.S. Coast Guard station, and flood protection features. In its current state, the modifications have disconnected the river from part of its historic floodplain, changing the formation of the delta (Smith 2000). The river is now channelized such that sediment is no longer naturally delivered to the adjacent ocean beaches (USACE 2009). While the natural longshore drift is thought to be southward north of the river and northward south of the jetty (Schwartz and Mahala 1984), the lack of sediment influx from the river has likely contributed to erosion of Rialto Spit and the need for sediment placement along the spit (USACE 2009). An environmental study conducted by the Science Application International Corporation concluded that the construction and repair of the Quillayute River navigation features from 1931 to 2000 are linked to the loss of 27,520 m^2 (6.8 ac) of beach habitat, 13,760 m^2 (3.4 ac) of beach grass, 11,330 m^2 (2.8 ac) of sandbar, and a gain of 30,760 m^2 (7.6 ac) of rocky habitat (SAIC 2003).

Upper watershed activities, which are dominated by forestry practices, also contribute to these changes as well as alterations in estuarine habitat, most notably sedimentation linked to the reduction in eelgrass and kelp habitat (Smith 2000, USACE 2009). However, the extent of biologic and sediment related impacts to this area are not fully understood (Smith 2000, Klinger et al. 2008, USACE 2009). It is likely that the sediment input from dredge/nourishment activities over the last several decades has prevented the spit from further erosion, curtailing perceived risks to both habitat and infrastructure.

Since the Quillayute River supports a healthy salmon population (with 10 runs annually), fish habitat is of high concern to the Quileute Tribe and local population. The ongoing dredging operations potentially adversely affect local fisheries by destabilizing sediments and increasing water flows, which may contribute to poor spawning habitat (Smith 2000). These effects are not fully understood and some reports note that surf smelt egg density varies considerably on a yearly basis (Fradkin 2001, ICF 2010). It has also been found that smelt spawning habitat is related to substrate composition (Middaugh et al. 1987). Subsequently, dredging activities and landform modifications may play a role in changing productivity of localized spawning grounds. With plans to continue maintaining the harbor system, additional dredging and repair of coastal structures will likely continue to affect the local sediment transport pathways as well as the biota.

Elwha River Restoration Project

The Elwha and Glines Canyon Dams have impounded an estimated 19 million m^3 (25 million yd^3) of sediment, which have effectively reduced the Elwha River sediment discharge from historic levels approaching 250,000 m^3/yr (327,000 yd^3/yr) to 20,000–40,000 m^3/yr (26,160–52,300 yd^3/yr) (Duda et al. 2011). Since dam impoundment has cut off the majority of sediment supply to the delta, it has likely contributed to coastal erosion problems. Downdrift beach erosion rates have varied over time ranging from -0.8 to -1.4 m/yr (-2.6 to -4.6 ft/yr) from 1936 to 1990, to more recent rates of -3.8 m/yr (-12.5 ft/yr) during the last decade (Warrick et al. 2009). Figure 9 illustrates the extent of erosion within the delta based on shoreline change data and a conceptual model of eastward sediment transport within the region before and after dam construction.

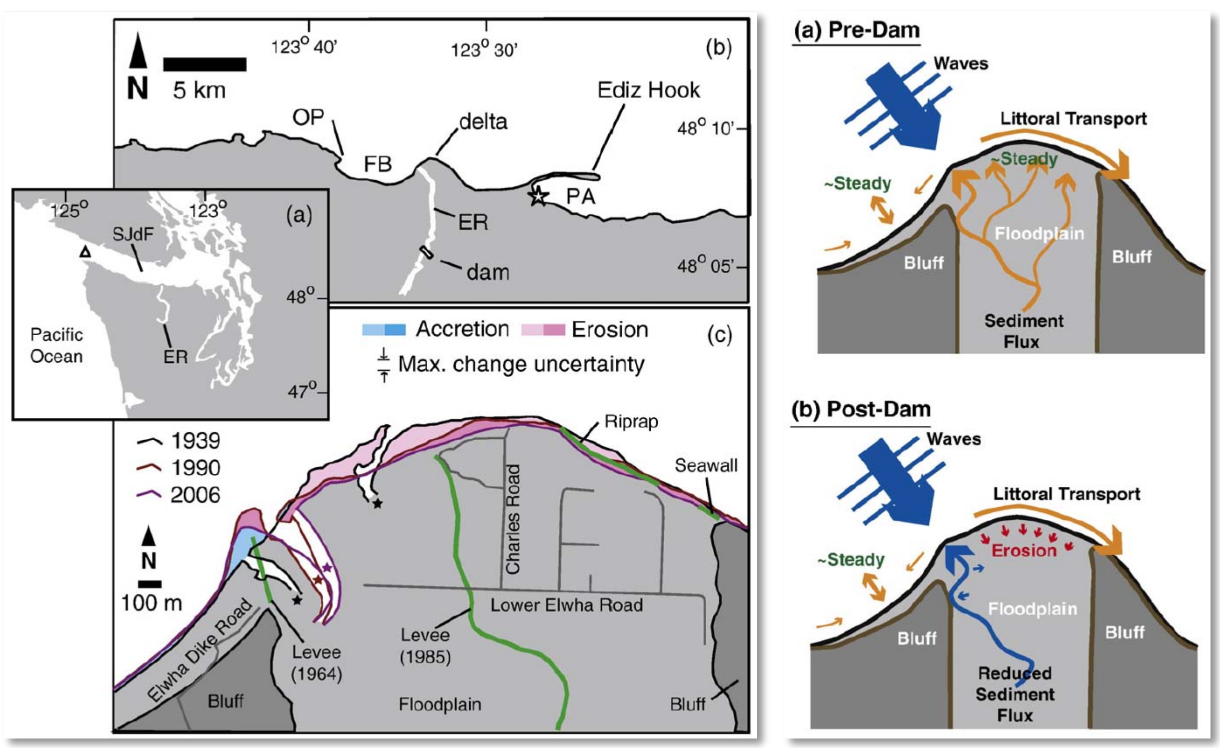

Figure 9. Elwha River delta shoreline change map (left) and conceptual sediment transport model before and after dam construction (right). OP, FB, PA, SJdF, and ER refer to locations mentioned in Warrick et al. (2009) and are not addressed in this report (from Warrick et al. 2009).

Based on the region's hydrodynamics, much of the material is traveling eastward within a 1 km (0.6 mi) band offshore of the Washington coast in the Strait of Juan de Fuca (Warrick and Stevens 2011) (Figure 10). Tracer studies in the region indicant that the bulk of nearshore sediment transport is comprised of coarse grained sediment conveyed through surf zone processes (Miller et al. 2011, Miller and Warrick 2012). It is anticipated that the increased post-dam sediment load will nourish beaches and reverse local coastal erosion as well as alter the physical extent of the estuary (Figure 11) (Duda et al. 2011).

Figure 10. Elwha River sediment plume on March 30, 2012 following the Elwha Dam removal (image by Roorda Aerial, email, 9/10/2012).

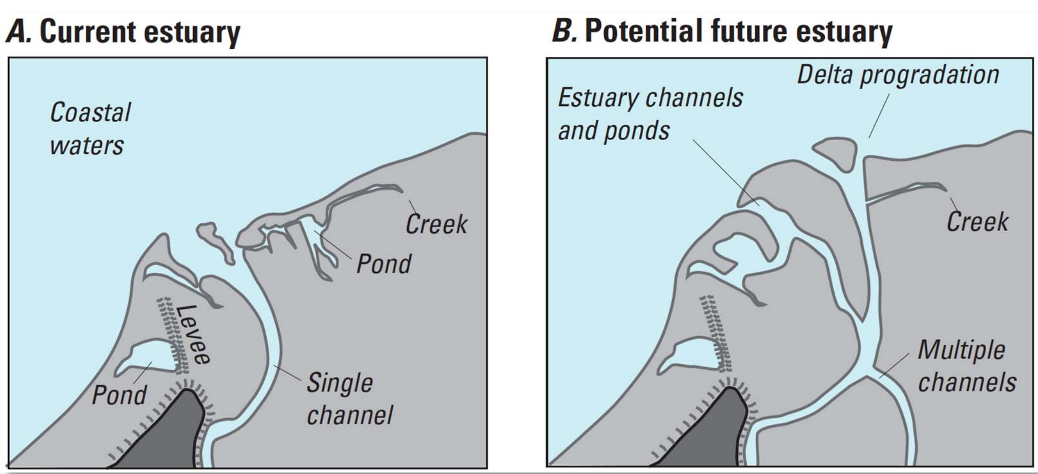

Figure 11. Potential morphologic changes to the Elwha River estuary (from Duda et al. 2011).

Beyond the anticipated morphological changes generated by the additional sediment, local vegetation and wildlife will be impacted as increased sedimentation occurs along the shoreline. This process can bury plants and influence the establishment of new vegetation depending on substrate thickness, grain size, and location (USGS 2011). It has been found that the current substrate, consisting of material relatively coarser than what is expected after dam removal, has developed benthic communities characteristic of this altered (coarser) substrate. The impact of the relatively finer material post-dam is not yet understood (Duda et al. 2011).

With the removal of both dams, the Elwha River will now be open to anadromous fish passage (pink and Chinook salmon) in addition to bull trout and other trout varieties (USGS 2011). It is anticipated that the salmon population will increase from roughly 3,000 to nearly 400,000 in the next 20–30 years (NPS 2012). Wildlife, also linked to the productivity of the local fisheries, will likely benefit from dam removal as additional nutrients are delivered to upriver food webs (USGS 2011).

At present, many public entities and researchers are actively monitoring the impacts of dam removal on all facets of the environment. Information from these studies will continue to inform both science and policy.

Timber Bulkheads and Shoreline Armor (Kalaloch, Washington)

The Kalaloch timber bulkheads and small rock revetment were installed adjacent to Highway 101 (Figures 6 & 12) in an effort to stabilize the backshore. These structures play a minor role within the local and regional sediment budget as terrestrial sediment supply is negligibly impacted given the spacing and scale (<10 m [33 ft]) of these installations. Structure failure has occurred due to local instabilities such as breakage, toe scour, or block failure associated with incident wave attack (USACE 2002).

Figure 12. Driftwood bulkhead (left) and small rock placement (right) along U.S. Highway 101 near Kalaloch (images by Mike Berry).

Discussion and Recommendation for Further Study

While the OLYM coastline is largely pristine, there are coastal engineering projects within the park and adjacent to the park that manipulate sediment transport and impact the natural environment. For the most part, coastal structures have a relatively minor footprint. However, they do contribute to local erosion issues and impact local fisheries. Societal and political trends toward environmental stewardship have placed an emphasis on river restoration and a return to natural ecosystem balance (Lowry 2003). The Elwha Dam removal project is a prime example of this movement.

Given the geologic setting of the park, current uplift conditions are likely to continue into the foreseeable future. Current, relative sea-level rise is on the order of -1.63 mm/yr (-0.06 in/yr) within the northern portion of the park at Neah Bay, Washington (Figure 2) (NOAA 2012). This negative relative sea-level rise is the product of a number of factors. The melting of the North American ice sheets, which began 20,000 years ago, contributes to uplift at a rate of around 1 mm/yr (0.04 in/yr) in Northwest Washington (NRC 2012). This, combined with the tectonic uplift caused by the subduction of the Juan De Fuca plate under the North American plate, outpaces the rise in global sea level within the northern portion of Olympic National Park.

However, the Toke Point, Washington tide gauge (located approximately 100 km [62 mi] south of the park) reports a relative sea-level rise rate of 1.60 mm/yr (0.06 in/yr) (NOAA 2012), indicating a positive trend. These two rates illustrate the regional sea-level rise variability, which is correlated to different rates of subsidence and uplift. Mote et al. (2008) estimated a sea-level rise trend of -3 mm/yr (-0.4 in/yr) along the NW Olympic Coast and -0.5 mm/yr (-0.02 in/yr) along the Central and Southern Washington coasts (until 2100), further supporting the notion that regional uplift has a prevailing influence on relative sea-level rise rates. While sea-level rise is not currently a major issue within the park, some projections of accelerated sea-level rise (NRC 2012) show the rate of water rise exceeding the rate of land level rise in most portions of the park at some point later this century.

The same geologic forces causing coastal uplift also leave the area vulnerable to tsunami inundation. Studies show that the region is susceptible to partial subduction zone ruptures that are capable of producing a tsunami wave ≥10 m (33 ft) in height (Satake et al. 2003, Goldfinger et al. 2012). This threat is the current impetus for the legislative action taken by the Quileute Tribe to move their land holdings further within the park outside the tsunami hazard zone.

In general, there is limited knowledge of the sediment transport systems within the park and a better understanding of the sediment dynamics at the mouth of the Quillayute River would be beneficial for future planning and assessment. Future research should continue to focus on alternative means of maintaining navigable ocean/river access to the Quileute Harbor Marina as well as to support ongoing studies related to sediment transport properties and habitat impacts due to infrastructure removal.

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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	Length (m)	Material	Year Built	Year Maintained	Source
1	La Push	Revetment	1,239	rock	1974	1978–1979, 1982, 1996	USACE 1986, McKay and Terich 1992, Winz 2004
2	La Push	Jetty	228	rock	1931	1932, 1933, 1939, 1941, 1944, 1946, 1950, 1953, 1956, 1957, 1961	USACE 1974, Ward 1988
3	La Push	Jetty	404	rock	1931	1932, 1939, 1941, 1957, 1960, 1961, 1979, 1982, 2012	USACE 1974, USACE 1986, Ward 1988
4	La Push	Breakwater	70	wood	1962		Ward 1988
5	La Push	Breakwater	354	wood	June 1963		USACE 1974
6	La Push	Pier	44	wood	2011		Gene Harrison (Quileute Marina)
7	La Push	Pier	253	wood	1980s	2011	Gene Harrison (Quileute Marina)
8	La Push	Pier	247	wood	1980s	2011	Gene Harrison (Quileute Marina)
9	La Push	Pier	47	wood	1980s		Gene Harrison (Quileute Marina)
10	La Push	Pier	29	wood			
11	Kalaloch	Revetment	28	rock			
12	Kalaloch	Bulkhead	35	wood			Parametrix, Inc. 2002
13	Kalaloch	Bulkhead	29	wood			Parametrix, Inc. 2002
14	Kalaloch	Bulkhead	32	wood			Parametrix, Inc. 2002

NPS 149/119987, March 2013

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