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Quinault Indian Nation

Reach Assessment Descriptions

Quinault Indian Reservation Reach Assessments | William E. Schlosser

This **Reach Assessment Descriptions** document
is completed in the fulfillment of a Contract entered into by the
Quinault Indian Nation and
Kamiak Ridge, LLC

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This planning effort has been completed with the consultation by a Planning Committee comprised of representatives of administrative Divisions of the Quinault Indian Nation, including the Division of Community Development, Division of Natural Resources, Division of Centralized Communications, and planning consultants from Kamiak Ridge, LLC.

Cover Photo by Larry Workman, Quinault Indian Nation (Workman 2012). Larry Workman also provided countless advisory recommendations and supplied written materials and photographs used throughout this planning exercise. *Thank you Larry!*

All photos, unless otherwise noted, are taken by Kamiak Ridge, LLC.

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Chapter 1. Introduction & Conveyance

The Quinault Indian Reservation (QIR) is located along the central ocean coastline of the state of Washington. Analysis of marine shorelines is the first stage of a three part process to develop a shorelines management planning framework to aid the Nation's staff and people in the management decisions along these shorelines. The marine coastlines were selected as the starting point for this analysis that will be combined with the shoreline assessments of rivers and Lake Quinault in subsequent planning efforts. This approach was augmented by the assessment of the eminent effects of global climate change on QIR marine shorelines. Those factors are addressed in detail, in the companion document "Relative Sea Level Change Along Quinault Indian Reservation Marine Coastlines" developed simultaneously with this one. This document addresses specific management factors within 'Reaches' of the Marine shorelines.

These reaches are arbitrarily identified starting from the southern exterior marine coastline boundary near the Moclips River, then progressing northerly to the northern exterior marine coastline boundary between Queets and Kalaloch.

This document presents findings of significance to the marine shorelines that can be used for developing management strategies and response to changing conditions. It outlines efforts for current works and future endeavors. These documents serve to give all readers a foundation of information of past and current conditions in order to implement management activities leading to desired future conditions for the marine shorelines of the QIR.

1.1. Information Used in the Development of this Document

This document provides descriptive support to the Reach Assessment Maps and Oblique Photographs presented for individual reaches on the QIR. The Reach Assessment Descriptions document describes the underlying geology, surface soils, and anticipated responses to changes over time. The maps and photographs display changes to the marine coastline during most of the past century for each Reach.

Data Sources:

- Cover Photo: Larry Workman, Quinault Indian Nation (Workman 2012)
- Aerial Imagery / Digital Ortho Photos
  - National Agriculture Inventory Program (NAIP): US Department of Agriculture
  - Obtained from Geospatial Data Gateway: http://datagateway.nrcs.usda.gov/
- Aerial Photography: 1939 - 1954
  - Western United States High Altitude: Army Map Service Corps of Engineers
  - Approximate scale 1:72,700
  - Georectified by Kamiak Geospatial
  - USGS: http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/Single_Frame_Records
  - http://earthexplorer.usgs.gov/
- Soil Data
  - Natural Resource Conservation Service Soil Survey
  - Analysis by Soil Data Viewer (SDV) for users of ESRI ArcMap products to interpret soil survey data (NRCS 2010). SDV version 6.0 running as an extension to ESRI ArcMap 10.1 has been used for the GIS analysis of soils data in this report.
- Fault Lines
  - U.S. Geological Survey (USGS) National Geologic Mapping Program

    - Washington Division of Geology and Earth Resources (DGER)
    - Washington Department of Natural Resources
    - "Quaternary fault and fold database of the United States" (USGS, 2008)
    - Bedrock Outcrops
        - Washington Department of Natural Resources Division of Mines and Geology by Weldon Rau
- Offshore bathymetry
    - NOAA, US Coast Guard, US Navy
- Topography
    - LiDAR – Quinault Indian Nation via Puget Sound LiDAR Consortium
    - http://pugetsoundlidar.ess.washington.edu/lidardata/restricted/projects/2011quinault.html
- Accompanying Maps and Photos
    - A PDF Portfolio is incorporated with this document and is referenced throughout this text. The file "SMP_Maps_Photos.pdf" can be viewed in Adobe Acrobat, version 9.0 or Adobe Acrobat Reader 9, or later versions.

1.2. Authorship

Development of the Reach Assessment Descriptions along the Quinault Indian Reservation's Marine Coastline was completed in association with a Quinault Indian Nation Planning Committee members, and Kamiak Ridge, LLC. Project Management duties and Lead Authorship of this plan have been provided by William E. Schlosser, Ph.D., a Regional Planner and Environmental Scientist. Technical review of this document was provided by Dr. Robin E. Nimmer, P.G., a Professional Geologist registered with the State of Washington (license number 2907).

The undersigned do hereby attest and affirm that the Reach Assessment Descriptions along the Quinault Indian Reservation's Marine Coastline was completed using information available at the time of its writing. Furthermore, analysis techniques were implemented as appropriate to provide a clear and reasonable assessment of Reach Assessment Descriptions along the marine coastlines of the Quinault Indian Reservation.

Kamiak Ridge, LLC

By: William E. Schlosser, Ph.D. Kamiak Ridge, LLC Environmental Scientist & Regional Planner Lead Author and Project Mananger	January 31, 2013 Date
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Chapter 2. Quinault Shoreline Considerations

The Quinault marine shorelines host a composite of factors that must be considered together when determining desired future conditions, or how best to respond to anthropogenic or natural events impacting the shorelines. This section identifies several factors of importance to consider when implementing management actions. Some of these actions are high priority in some areas, where they are less important in others. It is the combination of factors that can determine the attainment of desired future conditions.

2.1. Zoning

Codified zoning regulations on the QIR have been determined by the Quinault Indian Nation (QIN) Business Council (BC). The QIN BC is the governing body with jurisdiction over land uses on QIR lands. These zoning classifications include Commercial, Industrial, Forestry, Residential, and Wilderness. The QIN BC adopted through Resolution on July 25, 2011, a revision to Title 48 Land Use and Development Code for the QIR.

The QIR is divided into zones as shown on the Official Zoning Map, which is adopted and declared to be a part of Title 48 Land Use and Development Code.

Virtually all of the marine shorelines and adjacent properties, with the exception of Taholah community area (Residential), are part of the Wilderness Zoning area. The purpose of the Wilderness Zone is to retain the natural environment. Individual residences are a conditional use in the Wilderness Zone. No individual residences are permitted without full compliance with applicable tribal standards and individual approval by the QIN BC. The Quinault Planning Commission establishes standards for building in the Wilderness Zone.

Selective logging, where conditions are appropriate, are conditional uses in the Wilderness Zone, provided that the aesthetic and wilderness values of the site can be maintained. The QDNR makes recommendations for each site concerning the appropriateness of the proposed operations and conditions to be imposed to ensure the wilderness values are maintained. The Quinault Planning Commission establishes minimum standards for conditional use.

2.2. Ownership Status

Ownership status presented on accompanying maps, show the reader the ownership of parcels within the QIR current to 2012. These ownership classifications were confirmed by Kamiak Ridge with the Grays Harbor and Jefferson County Assessor data for the Fee lands. The data provided by the Quinault Division of Natural Resources (DQNR) GIS Department identified the Trust and Quinault ownership parcels.

These maps display common ownership status categories with some minor modifications. The category “Allotment in Trust” was created by Kamiak Ridge, LLC, in the administration of a project for the Quinault Indian Nation (QIN) to display the Trust lands that matched a database of names for the QIR that contained Indian Allotment Owners with undivided ownership shares held in Trust status. That database of names was last updated by the Bureau of Indian Affairs and provided to the QIN in 1999. These lands are a subset of Trust lands, but contain the most recent database of Indian Allotment Owner Names and undivided interest shares held by the QIN.

2.3. Roads

Roads of the QIR are displayed on maps produced in the accompanying documents. This GIS roads layer was provided by the QDNR GIS Department to Kamiak Ridge in 2011 for the administration of a different project that required a GIS network solution to be implemented. That network solution included "connecting" road segments at end points, and linking orphan road groups to the remainder of the network.

The roads showing on the attached maps (SMP_Maps_Photos.pdf) display 3 categories of road: Surface, Main Haul, and Paved. This roads network allows for a linkage between road segments to be used in the solution of travel distance between points. This GIS roads network layer has not been verified for the currency of the roads displayed. Some roads show connectivity when the bridge is washed out, while others show the presence of a road where the road has been abandoned or eroded away. They should be used for reference only.

2.4. Soils

The Natural Resource Conservation Service (NRCS) completed a soil survey of the QIR in 2007 (NRCS 2011). Those records are used in this report to display the status of surface soils and their parent materials. These data are useful to identify possible constraints to anticipated management actions. Generally, these soil designations and interpretations are not considered mandates of activities, but they are useful to understand certain limitations for certain sites.

A specific soil survey report that applies uniformly across all shoreline sites is the Hydrologic Soil Groups. Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

The soils are assigned to four groups (A, B, C, and D). The groups are defined as follows (NRCS 2011):

- Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.
- Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.
- Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.
- Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

All four groups are found along the Quinault marine shorelines and adjacent slopes or cliffs. These hydrologic soil groups provide insights to expected performance of soils when combined with soil surface texture, typical soil parent materials, and foundation geologic units of the lands.

2.5. Physical Site Characteristics

In 1973, the WaDNR, DGER Geologist, Weldon Rau, completed an insightful analysis of the Geology of the Washington Coast between Point Grenville and the Hoh River (Rau 1973). At the time, it was the most comprehensive analysis completed for the Quinault Marine Shorelines. Since that time, other authors have addressed this area and amplified his findings. Most recently, Daniel L. Orange and Kathleen A. Campbell of the Monterey Bay Aquarium Research Institute and NASA Ames Research Center, Exobiology Branch, respectively, completed research and published reports to further this understanding (Orange and Campbell 1996). The findings of those authors have been summarized in “Relative Sea Level Change Along Quinault Indian Reservation Marine Coastlines” accompanying this document.

Six important characteristics are identified along the Quinault coastal area. From youngest to oldest:

1) Large Woody Debris (LWD) materials accumulate along the marine coastlines in distinct collections and in unique areas. In some locations, such as south of the Quinault River and north of Queets River, the LWD materials are a combination of locally contributed tree stems with root wads combined with logs organically imported from distant locations. On other sites, LWD materials are locally contributed from slides and slumps of the adjacent cliffs. Other reaches of the Quinault marine shorelines are absent of LWD materials.
2) Each major river system emptying into the Pacific Ocean on the QIR contributes a Littoral Cell impact to the adjoining marine shorelines. The largest Littoral Cell in this region is the Columbia River Littoral Cell (CRLC), where sands have contributed to high accretion rates from the Columbia River to the shorelines of the Washington and Oregon coasts. The CRLC extends from Point Grenville to much of the northern Oregon coastlines. Hydroelectric dams along the Columbia River network have decreased the transportation of sand to the mouth of the Columbia River and have led to changes in the deposition along the Quinault Marine Coastlines. These sands are currently deposited on top of the marine shoreline base materials, extending far offshore.
3) Sedimentary rocks of the Quinault Formation, 1.5 to 7 million years old (Pliocene Epoch), such as those at Cape Elizabeth, Pratt Cliff, and between Point Grenville and Taholah;
4) Sedimentary rocks of the Hoh rock assemblage dating to 10 to 15 million years old, (Miocene Epoch) common in the cliffs east of the Hogsback area;
5) Eocene Sedimentary Rocks (36-39 million years before present (yr. B.P.) are highly broken, rhythmically bedded siltstones and sandstones that have been overtopped by glacially deposited outwash. These materials overtop basalt and Hoh Assemblage materials at Point Grenville area, and in turn were overtopped by coarse gravels and glacial outwash that followed.
6) Igneous rocks (basalt) of the Hogsbacks sea stacks and Point Grenville, that may be basalt plate ridgelines, remnants of submarine volcanoes, or hot spot vents (45-50 yr. B.P.), that were sheared off at the Cascadia Subduction Zone interface and caught up in the mix of muds, silt, sand, detritus, basalt remnants, and glacial outwash of the ocean floor that accumulated as long ago as 8 to 10 million yr. B.P., and continues today;

The accompanying document, “Relative Sea Level Change Along Quinault Indian Reservation Marine Coastlines”, describes the formation of the bedrock of this area as a process of the Juan de Fuca plate subducting under the Continental Plate that forms the Cascade Volcanic Ring of Fire further east in the Cascade Range. Closer to the Quinault, it forms the entire Olympic Peninsula (an accretionary wedge) as the mix of muds, silt, sand, detritus, basalt remnants, and glacial outwash of the ocean floor are scrapped off the Juan de Fuca Plate, piled up, tilted, folded, compressed, and crushed into a geologic landfill that is pushed up on the western side consecutively to form the Olympic Mountains. The oldest materials are found adjacent to Hood

Canal on the eastern side of the Olympic Mountains, while relatively new materials are recruited along the western edges.

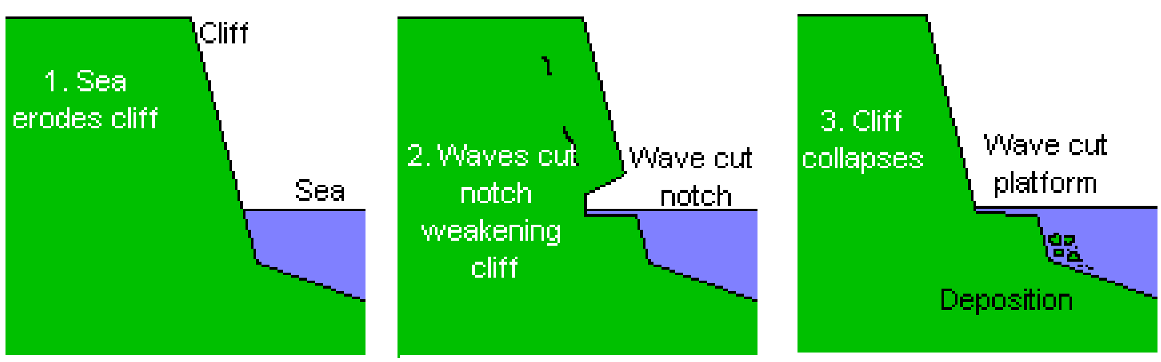
Materials found along the Quinault Marine Coastline are being thrust eastward in a continuous cycle of tectonic force. This force is constant and formidable, while at times it comes with the intensity of an earthquake as stresses between the Juan de Fuca Plate and the North American Continental Plate are released in a violent movement causing a sudden release of stored energy. Basalt landmasses offshore of the coast created by volcanic hotspots may eventually become part of the coastline by the tectonic forces ushering them eastward, if they are not eroded beforehand.

At the time of the last glacial period of the region, the ocean shoreline was located substantially west of its current location. Two factors contributed to this difference and include the action of wave-cut platforms and isostatic rebound. The wave-cut platform actions have incrementally cut the cliffs at the high tide extreme where erosion susceptible materials such as the Quinault Formation, Hoh Assemblage rocks, tectonic mélange rocks, and sedimentary rocks are dominant. Only the erosion resistant basalt rocks resist the repeated cutting of the wave action.

2.5.1. Wave-cut Platform

The wave-cut platform is seen as ocean waves strike against the base of cliffs to erode them incrementally from the cliff. The erosion at the cliff base causes undercutting between the high-tide and low-tide marks, creating a wave-cut notch (Figure 1). Cycles of high energy ocean waves continue to avulse the base of the cliff further and further inland to undermine it. Ultimately, the undercut face of the cliff collapses, resulting in the cliff-face materials falling and becoming incorporated into the platform. These materials become integrated into the wave-cut platform as this attrition causes the collapsed material to be broken down into smaller pieces, while some cliff material may be washed into the sea. This material may be deposited at the end of the platform, be retained near the cliff's base as large remnants (boulders), or form an extended off-shore terrace (Wilson, Curran and White 1998).

Figure 1. Diagram of a wave-cut platform, such as we see along the Quinault Marine Shoreline (Steinsky 2004).



This process is evident along Quinault marine shorelines such as those near Cape Elizabeth, the Hogsbacks area, and other locations. Since the last glacial period, the western extent of the Quinault marine coastline was substantially further west. Because of the wave-cut platform process, the steady avulsion of the shoreline cliffs has been substantial. At one time in history, the shorelines most likely had a formation similar to those seen currently near Moclips, where the shoreline and the sea meet at a 'gradual' interface between land and sea. As the wave-cut process evolved the shorelines migrated easterly converting the sandstone, siltstone, clay, and other avulsed materials into offshore sediments, now found in the platform.

2.5.2. Large Woody Organic Materials

The natural accumulation of large woody organic materials along the Quinault marine shorelines serves a substantial role of protecting shorelines from avulsion during strong winter storms. The collection of these log materials is most prevalent south of the Quinault River entrance to the ocean and north of the Queets River entrance. Other locations benefit from smaller collections of the large woody organic materials associated with river estuaries. In other locations the materials are less dense and appear as a response to localized cliff face avulsions (Figure 2).

Figure 2. Large woody organic materials accumulated along the shorelines north of Whale Creek, with avulsed tree stems recruited at the center of the photograph.

The large woody organic materials include entire tree stems from root wad to crown, intermixed with bucked logs. The bucked logs are assumed to be logs that were converted from standing trees to timber then lost to either a river or while at sea. Some of the logs observed north of the Queets River were of from a warmer climate than this area (Figure 3).

Figure 3. Large tree stem along the marine shoreline north of the Queets River; a naturally distant delivered log.

The benefits to shoreline protection from accumulated tree stems are significant. These log assortments protect the shorelines from avulsion that otherwise could be altered during strong winter storms. Logs can be rearranged, piled, or washed away while providing a reduction in the avulsion of the cliffs along the shorelines.

While the benefits of the large woody organic materials are seen mostly on the surface of the shorelines, in many places the tree stems are present in subsurface layers beneath sand and conglomerate materials for significant depths (Figure 4). As the seasonal rearrangement of shoreline deposits is made, the subsurface large woody organic materials serve to retain structure during advancement or retreat of the tidal zone.

Figure 4. Partially buried tree stems along the shorelines near Taholah.

2.5.2.1. Expected Environmental Responses to Management

Tree stems along the ocean shorelines have been used by people as fuel for heating and cooking fires while at the beach. Some logs have been used for decoration at homes, and others have served as materials for special projects offsite. While it can be stated that incidental use of ‘drift logs’ for cooking and heating fires will not diminish shoreline stability, it is a practice that can lead to harm when taken to the extreme.

As a protection measure, large woody materials along the marine shorelines, and along the top of cliff edges potentially to be converted to shoreline logs, should not be destroyed or taken offsite. They serve a beneficial shoreline stability purpose.

2.5.3. Columbia River Littoral Cell

Historically, the some shorelines of southwest Washington and northwest Oregon accreted at rates exceeding meters per year (Phipps 1990). These high accretion rates have been attributed to large supplies of sand from the Columbia River. This widespread accretion resulted in new coastal lands, on which public and private infrastructure and facilities have been built. This zone extends from the Columbia River northward to Point Grenville with effects seen as far north as Taholah and the mouth of the Quinault River. This zone, in Oregon and Washington, is called the Columbia River Littoral Cell (CRLC).

Average sediment supply from the Columbia River was apparently much greater for the last 10,000 years than it is now, possibly reflecting the contribution of several volcanic eruptions, erosion of glacial deposits, extreme floods, and river flow redirection (hydroelectric dams and other dams). The extensive construction of hydroelectric dams along the Columbia River (eleven major and over 200 smaller dams in the mid-1900s) has interrupted the sediment delivery from the watersheds of the region. Since the 1950s, the amount of sediment from the CRLC delivered to the Pacific Ocean shorelines in Washington and Oregon have dropped considerably. Preliminary calculations suggest an average total discharge for pre-historical time was 20 x 10^6 m^3/yr, compared to 8.7 x 10^6 m^3/yr for early historical time, and 4.3 x 10^6 m^3/yr since the 1950s (Gelfenbaum, et al. 1999).

The CRLC has been segmented into four sub-cells; North Beach extends formally to Point Grenville, but has extended influences, when combined with locally delivered sediments, as far as the mouth of the Quinault River. Marine shoreline beaches in the CRLC are characterized by wide surf zones and large longshore sand bars. Several locations that were historically accreting, however, are presently experiencing avulsion, including Ocean Shores near Grays Harbor. The causes of this reversal from accretion to erosion include dam construction along the Columbia River system, and anthropogenic activities along the coastal zone that have changed wave patterns and sand distribution (Phipps 1990).

CRLC Beach sands are 0.15-0.25 mm in size, with the mean size decreasing with distance from the Columbia River (Gelfenbaum, et al. 1999). The finest sand particles within the CRLC are found the furthest from the mouth of the Columbia River. Point Grenville south to Moclips (within the QIR) shows the finest sand particle sizes averaging 0.10-0.18 mm (Figure 5). Further modifications to the shores of this North Beach CRLC are seen by wave terrace structures resulting from several cycles of differentiated Relative Sea Level Change (RSLC) variations and wave-cut platform formations.

Figure 5. Grenville Bay near Wreck Creek showing CRLC sands.

2.5.3.1. Expected Environmental Responses to Management

The CRLC sands along the Quinault marine coastlines respond to both the rate of contribution of new sands from the Columbia River, and to the geologic substrate under the sandy shorelines. In many places the sands are over 100 meters deep, but at this northern terminus of the CRLC extent, the sand layers are relatively thin, measuring in places only a few meters or less in depth (e.g., near Wreck Creek).

The sand layers along the beach at this extent of the CRLC change annually with the onslaught of high-energy winter storms compared to the moderate summer wave patterns. Shoreline wave scouring can lead to dramatic erosion of sands in the winter. Sand accretion can intensify along the intertidal zone in the summer.

During deposition cycles of new sands along the marine shorelines, there is often a tendency to extend the use of the shoreline with human made structures like houses, roads, and recreational facilities. During avulsion of these sands, the human erected structures can quickly become compromised. This is sometimes attributed to changing sea level, but it is more often the result of changed wave patterns causing an alteration of sand deposition from the source. Sand deposition from the Columbia River has decreased considerably in the past 75 years (>56%). The construction of human made structures near the Quinault Marine Shorelines where the CRLC is present is strongly discouraged. Not only will the structure be vulnerable to damage, but changes to nearby wave patterns can be altered leading to shoreline avulsion or extended deposition in unexpected areas.

2.5.4. Quinault Formation

The Quinault formation is made from sedimentary materials of marine origin. The Quinault Formation is varied in composition ranging from fine-grained rocks, such as massive siltstones, to coarse-grained beds of sandstone and conglomerate (Figure 6). In many places it is overtopped by conglomerate deposits and glacial till and outwash. Both megafossils (Figure 7), mostly of clams and snails, and microscopic fossils (Foraminifera) (Figure 8) are abundant in places within the Quinault Formation. Rau (1973) has determined that the Quinault Formation materials were originally deposited about 1.5 to 7 million years ago. These rocks are much younger than the Hoh rocks- the next oldest rock unit of the area.

These combinations of rock materials are frequently observed with vegetation overtopping the formation in a ‘drunken forest’ appearance, owing to the tilting forest trees of the marine shoreline cliffs as surface soils slide downhill at a rate different from the substrate (Figure 9). Trees tilt, slide, and ultimately fall to the shoreline as they are added to the equation of LWD along the shorelines. This is the response process of the Quinault Formation cliffs to wave-cut platform patterns.

Figure 6. Cape Elizabeth is the most obvious example of the Quinault Formation (Workman 2012).

Figure 7. Clam megafossils of the Quinault Formation.

Figure 8. Calcite mineral deposits found within sandstone of the Quinault Formation between Taholah and Point Grenville.

Figure 9. Drunken Forests of the Quinault Formation near Hogsback.

The absence of rock strata to represent a period of geologic time is called an uncomformity. This indicates that the land was above the sea, and erosion rather than deposition was probably taking place during a latter part of the period of time not represented by rock formations. Additional rocks may have been deposited after the deposition of the Hoh rocks and prior to that of the Quinault Formation, but, if so, they were eroded away before the deposition of the Quinault Formation. Furthermore, much of the complicated folding and faulting (uplift and deformation) of the older Hoh rocks must have taken place during that time.

2.5.4.1. Expected Environmental Responses to Management

The Quinault Formation is generally tilted and frequently broken by faults along the marine shoreline. As an engineering substrate, the Quinault Formation provides a sizable challenge because of the geologically ‘brittle’ reaction of this formation to compaction and vibration. It is not generally viewed as a desired foundation material for roads, heavy structures, or commercial uses. Several of the small ‘cabin like’ structures placed along the coastline north of the Tunnel Island area have slid down the cliff as the addition of water, compaction, and vegetation control, combined with the wave-cut platform avulsion have weakened the cliff face to release the burden of the structure to the shoreline (Figure 10). A similar site response to construction on Quinault Formation bedrock is seen near Cape Elizabeth where a WWII Artillery Bunker Site was erected (Section 3.6.1), resulting in substantial site failures.

Figure 10. Failed cabin along the shoreline cliff located north of Tunnel Island.

2.5.5. Hoh Assemblage

The Hoh Assemblage is a coherent sequence of sandstone and siltstone that has been tilted, broken by tectonic forces, and eroded by rain patterns (Figure 11). Generally the Hoh rock assemblage is seen as layers that have been tilted or broken, but the original formation is generally seen as a horizontal deposition of layers. Intermixed with this assemblage is the "tectonic mélange." Often, this mélange has been forced through semi-porous materials along fault lines where the partially dissolved and viscous substance was reformed and squeezed into places where the pressures were lower.

The tectonic mélange rocks are distinct from the Hoh rock assemblage in that they are a chaotic assemblage of siltstone, sandstone, conglomerate, organic, and volcanic materials (Figure 12). Such rocks are exposed in a number of places but are well known in the cliffs immediately south of Raft River in in the Hogsbacks area, and north of Cape Elizabeth at the Duck Creek Diapir.

Rau (1973) described these forces along the coastlines as “piercement structures”. These extremely distorted arrangements within Hoh mélange rocks may be the result of having been squeezed into, and in some places through, overlying strata of younger formations. Hoh Rocks are conglomerations of various rock types like basalt, sandstone, and metamorphic rocks, which range in size from pebbles to megaton units. Those are surrounded by a matrix of dark-colored, fine-grained mudstone. The mudstone often has a foliated appearance (Orange and Campbell 1996).

Figure 11. Hoh Assemblage and piercement structures near Hogsback (Workman 2012).

2.5.5.1. Expected Environmental Responses to Management

As an engineering substrate, the Hoh rock assemblage and the tectonic mélange (Figure 12) are very unstable. The tectonic mélange is the substrate under SR 109 at Swede Hill. This stretch of the road has been documented for over 100 years as a problematic stretch of the route failing from compression, vibration, and water movement across the compressed materials. Efforts to repave, riprap, place culverts, and otherwise reroute this stretch of the highway, have met with failure. This geologic foundation compacts irregularly and builds up pore water pressure from the compaction within the soil complex. When pressures exceed the holding capacity of the soil, it ruptures water to release the burden. When possible, construction should not be placed over this substrate.

Figure 12. Tectonic Mélange epitomized by the Duck Creek Diapir (Workman 2012).

2.5.6. Eocene Sedimentary Rocks

The western terminus of Point Grenville is basalt, but inland of the point begins a layer of Eocene siltstone and sandstone that accumulated over a normal fault line rift separating the basaltic rock of Point Grenville from the Hoh Assemblage of the mainland (Figure 13). The highly broken, rhythmically bedded siltstones and sandstones have been overtopped by glacially deposited outwash. This mix of materials is seen at Point Grenville on both the northwestern and southeast shores of the mainland.

Figure 13. Eocene Sedimentary Rocks of Point Grenville where the US Coast Guard Station water lines are now exposed to show where they once were buried underground.

The sedimentary rocks of the Point Grenville area represent cyclic deposition in which fine-grained sediments, namely silts, were alternately deposited with coarse-grained sediments of sand, gravel, and cobbles. These sediments are now bedded siltstone and sandstone that dip variably, but generally to the north and northeast. Although these strata were deposited horizontally, or nearly so, as unconsolidated sediments sometime during Eocene time, they have since been lithified, folded, tilted, and fractured by forces starting at the Cascadia Subduction Zone.

Microfossils in the sedimentary layers indicate that deposition was well offshore in substantial depths of the ocean, perhaps at 1,000 feet or more, where water temperatures were relatively cold. The microfossils also indicate that these strata were deposited some 35 to 40 million years ago during early Eocene time. These rocks are younger than the middle Eocene siltstone interbeds of the volcanic rocks that make up Point Grenville. Tectonic faulting may have brought these rocks of different ages in juxtaposition to each other.

This early Eocene age sedimentary rock formation appears to be limited to the Point Grenville area (Rau 1973). Although other rocks along the coast between this area and the Hoh River are similar in appearance, Rau (1973) concluded that none of the other formations have produced fossils of Eocene age.

2.5.6.1. Expected Environmental Responses to Management

As an engineering substrate, the Eocene sedimentary rocks are prone to erosion and scouring from surface water and wave action, especially where exposed to compaction and water saturation. These materials are made from a mixture of fine sands and silts bedded with cobbles deposited with sediments of sand and therefore it is prone to stress failure.

The reader can look to the Aerial imagery photos of Point Grenville in the accompanying "03B_Taholah_Road_at_Point_Grenville.PDF" collection, to find the aerial photo from 2012 with the Bedrock Outcrops mapped (page 17). The "Taholah Road" was built to connect Point Grenville and Taholah, and crossed the area of basalt rocks, late Eocene sedimentary rocks, Hoh Assemblage rocks, and Quinault Formation rocks. The dirt road is visible on the 1939 aerial photo (#1). The road was still visible in the 1953 and 1955 aerial photographs although it appears that the ocean shoreline had started to encroach on the western side of the road in response to slope failure induced by road use. In the 1977 photos (pages 6 & 7), the Taholah Road is mostly abandoned as slope failures surrounding the road closed it permanently.

Maps 16 and 17 show avulsion rates from the original 1939 markings compared with 2012 slope failures surrounding this road's original placement. Map 17 specifically shows the bedrock outcrops the road traversed. A quick comparison of these bedrock formations in relation to the road's placement shows very little impact where the road crossed volcanic basalt rocks. Where the road crossed Late Eocene Sedimentary rocks and Hoh Assemblage rocks the cliff edge shows evidence of evulsion (Figure 13). The rate of cliff face loss exceeds 600' (horizontal) where the Taholah road crossed it.

Within the map book labeled "03A_Reach_Maps_Point_Grenville.pdf", the oblique view photos taken on 8/19/2006 at 3:21 PM (pages 34 & 35), show a slump of the shoreline northwest of the point where once the Taholah Road was located. This slump spanned the Eocene sedimentary rocks and the Quinault Formation rock materials. The weak soils were destabilized by the road vehicle compaction and travel vibrations.

2.5.7. Basalt Rocks

The oldest rocks of the Quinault Marine Coastline are basalt formed at deep sea depths at the Juan de Fuca Ridge as the Juan de Fuca Plate is formed. As the plate moves easterly, it is subducted under the North American plate beginning at the Cascadia Subduction Zone. When entering the Subduction zone the remnant basalt pillars, debris, and submarine lava flows are scrapped off the plate and mixed in with the sedimentary materials of the ocean floor. Uplift and mixing of these materials introduces basalt fragments (some bigger than an office building), to the coastline (Figure 14). Rau (1973) identified that these rocks form most of Point Grenville and the nearby offshore stacks.

Rau recognized that that these rocks were formed some 45 to 50 million yr B.P. during middle Eocene time. In many locations, these rocks are welded together and are referred to as "volcanic breccia." Many of the original cracks or fractures are now filled with veins of secondary light-colored minerals, much of which is calcite, or in places a zeolite mineral.

Figure 14. Basalt promontory of Point Grenville.

2.5.7.1. Expected Environmental Responses to Management

As an engineering substrate, the basalt rocks of the marine shoreline present a stable foundation for roads, heavy structures, or commercial uses. The basalt rocks are not ‘locked’ to the Juan de Fuca Plate but forces do exert to keep these buttresses tight to the coastal platform. It is the materials located inland from the basalt rocks that dictate the stability of access to the basalt and the potential rotation of the material as the onshore materials are eroded, washed away, or sheared off.

2.6. Faults

In geology, a fault is a planar fracture or discontinuity in a volume of rock, across which there has been significant displacement along the fractures as a result of earth movement. Large faults within the Earth's crust result from the action of plate tectonic forces (USGS 2010). Energy release associated with rapid movement on active faults is the cause of most earthquakes, such as those that occur in response to forces associated with the Cascadia Subduction Zone.

The accompanying document, “Relative Sea Level Change Along Quinault Indian Reservation Marine Coastlines” provides several descriptive summaries of the fault line complex of this region. The discussions presented here for each reach, gives reference to the existing faults documented by the WaDNR in cooperation with the USGS National Geologic Mapping Program.

Chapter 3. Marine Shoreline Reaches

Marine shoreline reaches are in reference to segregating the marine shorelines into discrete sections from the southern edge of the external boundaries of the QIR, to the northern extent. This document provides written references and discussions to the findings, while the accompanying document provides full-page maps including time series aerial photographs and imagery, and oblique views of marine shoreline reaches. This accompanying document is named “SMP_Maps_Photos.pdf” and was completed by Kamiak Ridge, LLC, in January 2013.

3.1. Moclips River Reach Assessment

Refer to the “01_Reach_Maps_Moclips_River.PDF” booklet for maps and oblique photographs.

The Moclips River enters the Pacific Ocean near the southern extent of the QIR’s external boundary. This shoreline area is situated within the CRLC zone where the sandy beaches extend within a relatively flat approach from shoreline to ocean (Figure 15). The watersheds of this area consist of highly glaciated terrain of the accretionary wedge of the Olympic Mountains. Specifically, the Moclips River represents the drainage area of the southern-most reaches of the QIR where gravelly outwash parent materials dominate. These materials make the basic foundation of substrate materials under the CRLC sands.

Figure 15. Columbia River Littoral Cell sands of Grenville Bay.

This location serves as a unique combination of geologic strata where several types of geological materials are intermixed. The Moclips River cuts through organic materials, gravelly glacial outwash, silty glaciolacustrine deposits[1], and alpine glacial till. The organic materials located within this substrate include woody debris intermixed with cobbles, sands, silt, and clay (Figure 16). As a substrate, the shorelines show Pleistocene sedimentary materials with features of alpine glacial outwash. These areas are stable to management activities such as timber harvesting and road construction. Much of this stability is aided by the gently sloping mainland terrain.

[1] Sediments deposited into lakes or to the ocean shoreline, that have come from glaciers, are called glaciolacustrine deposits.

Figure 16. Moclips River bank near the entrance to the Pacific Ocean at Grenville Bay.

This sandy layer of Grenville Bay shorelines provide habitat for Razor Clams and other mollusks the QIN relies on (Figure 17). The gently sloping offshore platform provides ample mollusk habitat. In addition to the CRLC nutrients and ecosystem components, the Moclips River littoral cell delivers nutrients beneficial to mollusk populations. These nutrients are derived from the presence of decomposing plant materials dating to the Pleistocene[2] and Holocene[3] Epochs. The nutrient rich waters of the local rivers supply nutrition to the mollusk populations while the CRLC delivers habitat materials suitable for supporting large populations. This unique combination creates the best razor clam habitat of the Pacific Ocean shorelines.

Figure 17. Columbia River Littoral Cell sands of Grenville Bay.

The decrease in CRLC sand deposition has been discussed in this document, and the referenced citations for the companion document “Relative Sea Level Change Along Quinault Indian Reservation Marine Coastlines”. These changes to the sands of Grenville Bay are also impacted by a relative sea level change of lesser magnitude that shows this area within an

[2] The Pleistocene is the geological epoch which lasted from about 2,588,000 to 11,700 years ago, spanning the world's recent period of repeated glaciations.

[3] The Holocene is a geological epoch which began at the end of the Pleistocene (around 12,000 to 11,500 years ago) and continues to the present.

isostatic uplift zone. The accretion of sands within this area is seen with a drop of about 1 meter from the upland side to the shoreline elevation (Figure 18). The annual ebb and flow of sand deposition historically resulted in a net annual deposition of sands along this shoreline. Currently, the balance has turned to accretion as net sand accumulation reduces annually.

Figure 18 shows a photograph (August 2012) at the summer high tide mark along the marine shoreline slightly north of the mouth of the Moclips River. This area has lost about 1 meter of sand depth (vertical).

Figure 18. Avulsing CRLC sands north of the Moclips River along the Grenville Bay shorelines; staff is 2 meters tall, sand loss is about 1 meter in depth.

3.1.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. This land shows ownership categories including Trust and Fee lands. The SR 109 parallels the ocean shoreline.

3.1.2. Soils

Soils of this reach include mainly silty glaciolacustrine soils and alpine glacial till (NRCS 2011). These surface soils include decomposed plant materials (detritus) with high organic matter content and a significant water holding capacity.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

This reach of the shorelines is represented mainly by groups A and C. The former is capable of high infiltration rates even when saturated and is often seen as surface water stream flows are absorbed into the shoreline sands prior to entry into the ocean. Group C has a slower infiltration rate and water movement at saturation is generally seen as impacted stream flow channels.

3.1.3. Aerial Imagery

A series of aerial photographs from 1953, 1955, 1977, 1980, 1985, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the minor changes observed along the coast where SR 109 is located and the vegetation layers between that road and the high tide is found. At the same time, the viewer can recognize the minimal changes to the Moclips River's meandering at the mouth.

This reach of the Quinault Marine Shorelines shows stability to most changes. Recent changes to the CRLC deposition rate are not obvious on the aerial photography, or even on the oblique view photographs of this region. Evidence for those changes will come from site visits and will necessitate site specific recordings during multiple seasons and over continuous years.

3.1.4. Oblique Views

The oblique views collected by the Washington Department of Ecology (WaDoE) give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern reach (at Moclips River), moving northerly.

3.1.5. Cautionary Comments

This area includes some very stable substrate in the form of silty glaciolacustrine soils and alpine glacial till formed since the Pleistocene Epoch. Since the last glaciation period, this reach has been minimally uplifted through isostatic rebound forces. Although CRLC sands are decreasing, it is expected that the impacts of relative sea level change caused by global climate change will be moderated as the land structure lifts and sea level increases.

3.2. Wreck Creek Reach Assessment

Refer to the "02_Reach_Maps_Wreck_Creek.PDF" booklet for maps and oblique photographs.

Wreck Creek enters the Pacific Ocean between the Moclips River and Point Grenville. This shoreline area is situated within the CRLC zone where the sandy beaches extend within a relatively flat approach from shoreline to ocean (Figure 15). The watersheds of this area consist of highly glaciated terrain of the Olympic Mountains accretionary wedge. Specifically, Wreck Creek represents a substantial drainage area where glacially derived gravelly outwash parent materials are located. These materials make the basic foundation of substrate materials under the CRLC sands.

The CRLC contributes fine grained sands to the beaches in this zone (Figure 19) giving Razor clams and Bodega Clams preferred habitat. The wave approach along this segment of the shoreline is partially protected by Point Grenville against storms from the north, but to a lesser extent by the storms delivered from the southern Pacific.

Figure 19. Columbia River Littoral Cell sands of Grenville Bay near Wreck Creek.

Like the Moclips River reach, this area shows a unique combination of geologic strata where several types of materials are intermixed. Wreck Creek cuts through organic materials, gravelly glacial outwash, silty glaciolacustrine deposits, and alpine glacial till. The organic materials located within this substrate include woody debris intermixed with cobbles, sands, silt, and clay. As a substrate, the shorelines show Pleistocene sedimentary materials with features of alpine glacial outwash. The coastal rock formations of this reach are mostly basalt in origin with a few interbeds of ocean siltstone and organic debris. It consists of irregular fragments of volcanic material and some sedimentary rock, all of which are welded together to form solid rock mass: such material is called volcanic breccia. These are often filled with carbonized branches and other plant materials in massive sandstone of the Quinault Formation (Figure 20).

Figure 20. Irregular fragments of volcanic material and some sedimentary rock are welded together to form volcanic breccia.

These areas are stable to management activities such as timber harvesting and road construction. This reach is the transition zone from the CRLC characteristics seen to the south of Point Grenville, to the resistant basalt boulder rock chunks formed by volcanic processes, intermixed with the softer Hoh Rock Assemblage matrix and Quinault Formation rocks seen north of Point Grenville. In this reach, they have been gradually eroded away by wave-cut action and rains, leaving resistant boulders behind (Figure 21).

The transition is evident as SR 109 begins the approach up Swede Hill (south to north) leaving the relatively gently sloping lands along the ocean shorelines to ascend Swede Hill as it crosses over the Hoh Assemblage Rocks that are covered by the glacial outwash of the area. As this transition is made, the shoreline viewer can see evidence of basalt erosional remnants along the shoreline (Figure 21). Because they are generally harder than the surrounding materials, they weather out as irregular nodules.

Figure 21. Siltstone interbedded with volcanic basalt rocks at the northern edge of the Wreck Creek Reach.

3.2.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. In the southern two-thirds of this reach, most parcels are in Trust status with Taholah Ocean Tracts (northern one-third) mainly held in a combination of Fee statuses (Quinault Fee, other Fee). The SR 109 parallels the ocean shoreline.

3.2.2. Faults

Two fault lines are found within this reach. The Quaternary fault transects Point Grenville and extends as far as SR 109, crossing through Grenville Bay. The second fault is located south of Wreck Creek and is also Quaternary, active within the last 130,000 years. They are both considered active.

3.2.3. Soils

Soils of this reach include a combination of alpine glacial till and silty glaciolacustrine soils with the shorelines showing CRLC sands (NRCS 2011). Surface soils include decomposed plant materials (detritus) with high organic matter content and a significant water holding capacity.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

This reach of the shorelines is represented mainly by groups A, C, and D. Group A soils are capable of high infiltration rates even when saturated. Groups C and D have a slower infiltration rate and water movement at saturation is generally seen as impacted stream flow channels.

3.2.4. Aerial Imagery

A series of aerial photographs from 1953, 1955, 1977, 1980, 1985, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the minor changes observed along the coast where SR 109 is located and the vegetation layers between that road and the high tide is found.

This reach of the Quinault Marine Shorelines shows stability to most changes. Recent changes to the CRLC deposition rate is not obvious on the aerial photography, or even on the oblique view photographs of this region. Evidence for those changes will come from site visits and will necessitate site specific recordings during multiple seasons and over continuous years.

3.2.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

3.2.6. Cautionary Comments

This area includes stable substrate in the form of silty glaciolacustrine soils and alpine glacial till formed since the Pleistocene Epoch. Since the last glaciation period, this reach has been moderately uplifted through isostatic rebound forces. We expect that this reach will continue to show isostatic rebound at rates slightly higher than most areas north of Point Grenville. Although CRLC sands are decreasing, it is expected that the impacts of relative sea level change caused by global climate change will be moderated as the land structure lifts and sea level increases.

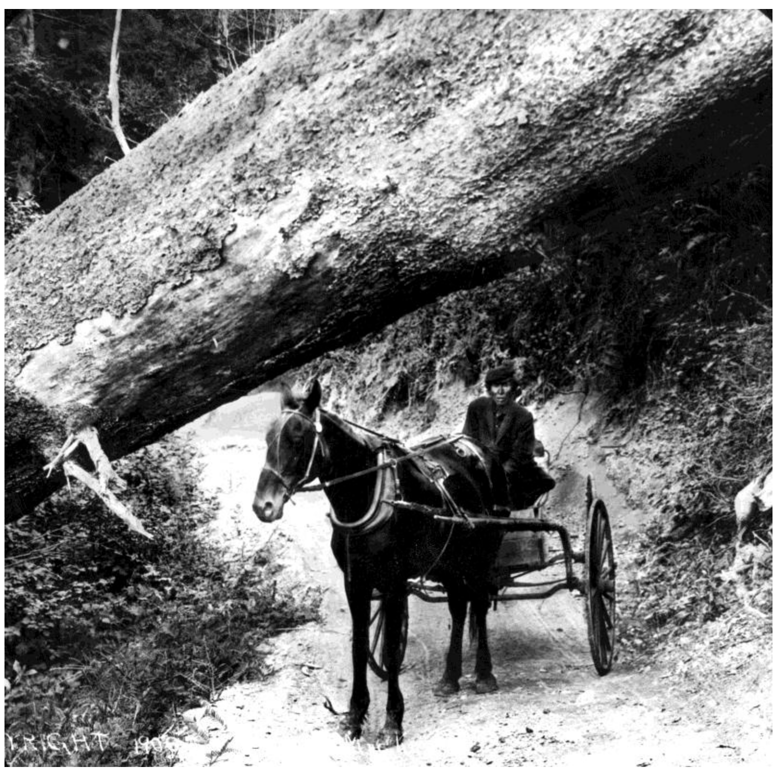
3.3. Point Grenville Reach Assessment

Refer to the “03A_Reach_Maps_Point_Grenville.PDF” for maps and oblique photographs, and “03B_Taholah_Road_at_Point_Grenville.PDF” for maps of the Taholah Road in this reach.

Point Grenville is a conspicuous promontory of basalt materials situated along the Quinault Marine Coastline. This location serves as a unique combination of geologic strata where several types of geological materials come together. Point Grenville marks the northern extent of the CRLC where fine sands blanket the coastline to the south (Figure 15). North of this point, the geologic bedrock materials give rise to the Quinault Formation where fine-grained rocks, such as massive siltstones, to coarse-grained beds of sandstone and conglomerate combine to create steep cliffs adjacent to the beach (Figure 22). This formation has failed in several places from Point Grenville northward, as the “Taholah Road” was built across this substrate then lost to wave-cut platform process shoreline erosion (Figure 23).

Figure 22. Quinault Formation rocks north of Point Grenville where once the Taholah Road was placed.

Figure 23. Point Grenville Cutacross Road 1906 (by O. S. MacKenzie (Workman 2012)).



Finally, the tectonic mélange mixed with Hoh Formation materials are amalgamated landward of the Eocene sedimentary rocks. The sedimentary rocks were deposited between the basalt materials of the point and the Hoh Formation landward of the point. These sedimentary rocks are an unconsolidated mix of sands, cobbles, pebbles, and silt that respond differentially to erosion from surface water, compaction from construction, and vibrations of roads.

When viewing the maps of this site, give attention to the intersection of the two fault lines especially the Quaternary fault line bisecting the point. The cliff face has responded to the construction of the Taholah Road, the Coast Guard Station, and water lines buried in the surface soils (Figure 13) with increased erosion along the fault line and through the cliff face. The slip fault (located southwest to northeast) exacerbated this site's erosion response to the increased use of the point. The rate of erosion within the marine sedimentary rocks and Quinault Formation materials was greater than the erosion rates within the basalt.

The US Coast Guard Station at Point Grenville was built June 1945, and abandoned January 1980 (Figure 24). The waste water treatment solution of the Coast Guard was to pipe all facility refuse directly (untreated) to the ocean (Loran History 2012). Initially the US Coast Guard used the Taholah Road to access the site, in combination with shoreline access. As the road failed, they requested on July 7, 1949, funding of $10,450 for a new road into the station - the one that exists today.

Figure 24. US Coast Guard Station 1974 at Point Grenville (Loran History 2012).

POINT GRENVILLE c.1974 (Found on Fred's Place)

The "03B_Taholah_Road_at_Point_Grenville.PDF" map set of the Point Grenville Cutacross Road shows a focus of the road from 1939 through 2012. These maps include a summary (shown on pages 16 & 17) of the avulsion of the shoreline cliff in response to the road's use, comparing the shoreline cliff's vegetation line of 1939 against the same in 2012. Where the road crossed the Hoh Assemblage rocks, the avulsion was the greatest where approximately 635 feet of shoreline loss is observed. The shoreline changes where the Eocene sedimentary rocks are found show significant losses as well. The actual US Coast Guard station was situated on these soils and resulted in the shoreline losses seen in Figure 13. Further north along this abandoned road, erosion can be seen over the Quinault Formation soils where avulsion is evident, but less than the losses over the other two substrates shown. Here, the losses average about 150’ (vegetated shoreline) over this period, with notable exceptions where losses exceeded 290 feet and 360 feet.

The stability of these soils to support road or building construction near the cliff-edge is extremely limited. A “set-back” distance should be initiated from the point of construction to the nearest cliff-edge. As a general starting-point, a horizontal set-back at least equal to twice the vertical cliff height, and a minimum of 500 feet, should suffice for any site disruption, including roads, structures, or timber harvesting.

3.3.1. Elevation and Relief

Three topographic profile lines are presented for reaches near Point Grenville. The first is drawn along a path named “Point Grenville” following the route of the Grenville Road from the ocean side to SR 109 (Figure 25). This profile shows the vertical cliff face (basalt) climb of 38 meters from sea level to the crest of the point. After attaining the elevation of the point, very little further elevation climb is seen before reaching SR109.

The next topographic profile follows the Quaternary fault line bisecting the point from the northwest to the southeast (Figure 26). This approach follows through the Eocene sedimentary rock and does not display the steep cliff face assent of the basalt cliff face, but instead shows a steeply climbing approach to the crest where erosive forces have mixed with the active fault line.

Finally, the third profile line cuts across Swede Hill with SR109 from the shoreline over the highway and over a river valley (Figure 27). These Hoh Assemblage materials are mostly overtopped along the coast by the CRLC sands and on land by glacial outwash materials. Several outcrops of the Hoh Assemblage materials can be seen along the shoreline (Figure 28) as basalt boulders located within and above the sandy shore. These basalt boulders show signs of extrusion as they were forced by pressure and combined with other extrudable materials to form the structures seen here.

Figure 25. Reach profile of Point Grenville from shoreline over Point, following Grenville Road.

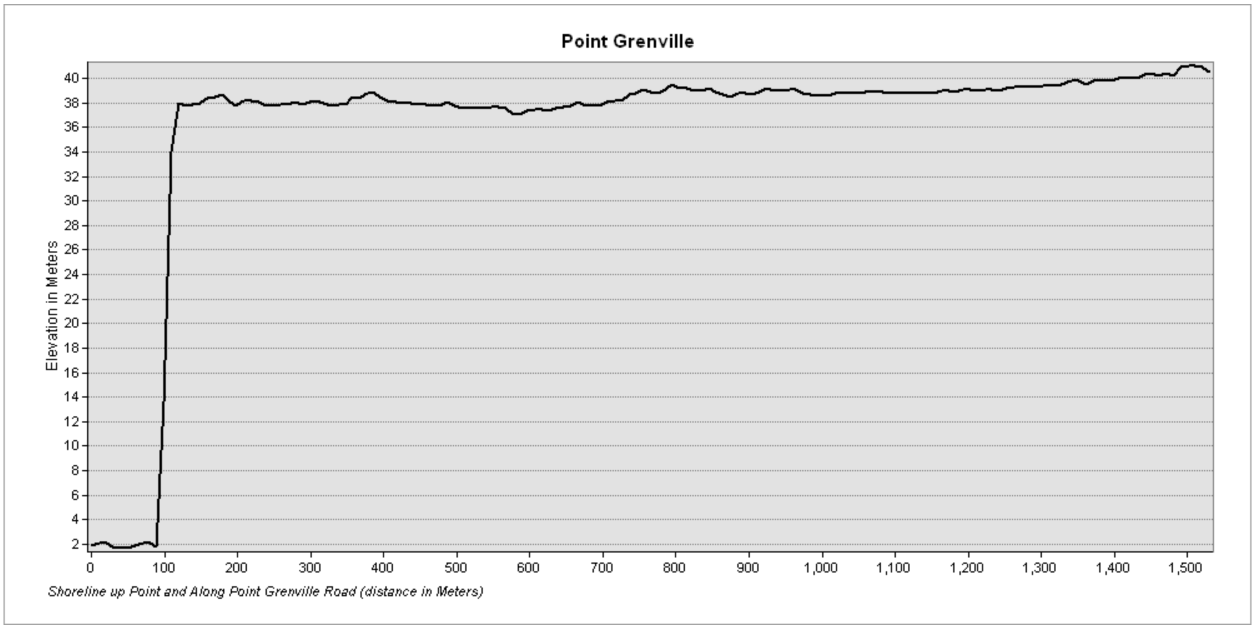


Figure 26. Reach profile of Point Grenville following the Quaternary fault line.

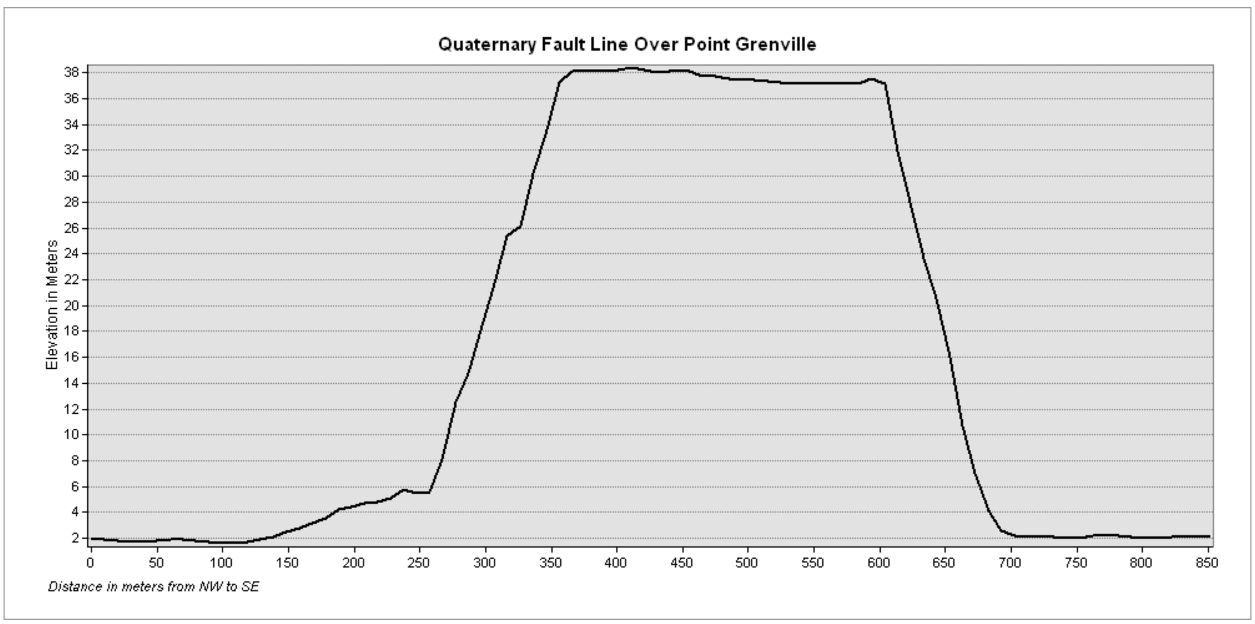


Figure 27. Reach profile of Point Grenville from shoreline over US109 at Swede Hill.

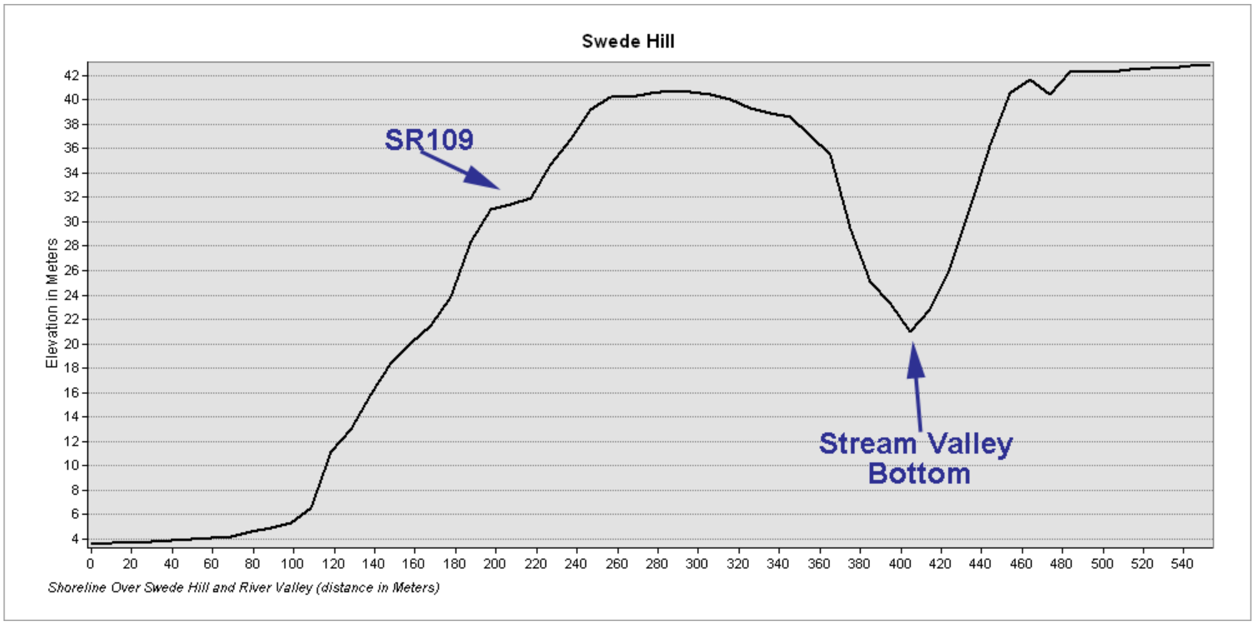


Figure 28. Tectonic mélange materials of extruded basalt masses intermixed with sands, silts, muds, and micro fossil materials.

3.3.2. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. This land shows ownership categories from Quinault (including Quinault Fee and Quinault Trust), Trust, and Fee lands.

3.3.3. Soils

Soils of this reach include mainly silly glaciolacustrine soils and alpine glacial till (NRCS 2011). These surface soils are generally decomposed plant materials (detritus) with high organic matter content and a significant water holding capacity.

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

3.3.4. Aerial Imagery

A series of aerial photographs from 1939, 1953, 1955, 1977, 1980, 1994, 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the different changes observed along the coast where the Point Grenville Cutacross Road was visible in the 1939 and 1953 images, but was mostly obliterated by the time the 1977 image was taken. The viewer can watch the erosive progress of the northwest side of Point Grenville in the sedimentary rock as it eroded from the beginning of this series to current conditions.

3.3.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from 2006. In the image dated (8/19/2006, 3:21 PM – page 34) the reader can see the erosive response of the cliff face near the original location of the US Coast Guard Station, coincident with the Quaternary Fault Line’s crossing. In this same image, the remnants of the Point Grenville Cutacross Road can be seen along the cliff face moving northward (left).

3.3.6. Cautionary Comments

This area includes some very stable substrate in the form of a basalt edifice called Point Grenville. Although this point is solid and substantial, the fault lines crossing near its underpinning and the shore-side accumulation of Eocene sedimentary rocks and Hoh Formation with tectonic mélange combine to create a difficult approach to the solid layers of the point. Both road building and structure establishment will face challenges for stability and longevity. The US Coast Guard station faced similar challenges as the Point Grenville Cutacross Road use increased, and then was abandoned (1949). The station was built on top of the Quaternary fault line of this reach making enduring power and water lines problematic.

Siting structures inland of the Eocene sedimentary rock outcrops and the Hoh Assemblage materials, and landward of both the slip fault and Quaternary fault will increase the longevity of any structures built near the point.

Other concerns for this reach include the placement of the highway crossing over Swede Hill. This site presents over a century of documented problems for vehicular traffic owing to the presence of the tectonic mélange substrate (Schlosser 2010). The substrate of this bedrock is not consistent with this use. Other routes of access should be explored for access from Taholah.

3.4. Upper Taholah Reach Assessment

Refer to the “04_Reach_Maps_Upper_Taholah.PDF” booklet for maps and oblique photographs.

This reach begins north of Point Grenville and extends northward to the edge of the Lower Taholah village. This shoreline area is dominated by the Quinault Formation rock cliffs shaped by the wave-cut platform processes (Figure 29). As the Pliocene Epoch unfolded (1.5 to 7 million years ago), the Quinault Formation was formed in deep sea floor environments from consolidated, stratified, and then tilted sedimentary rocks. These sedimentary rocks are younger in geologic age than the Hoh Assemblage rocks and the basaltic remnants scattered under the Quinault Formation.

The Quinault Formation rocks of this reach are overtopped by alpine glacial outwash materials and organic matter. The stratified sand and gravels within this reach cover the shorelines alternately.

Figure 29. Quinault Formation cliffs located north of Point Grenville. Structural weakness of underlying massive siltstone of the Quinault Formation combined with the wave-cut platform process is part of the cause of landslides in this area.

The features of young sandstone overtopped by the organic matter deposited since the last ice age contain gravels that are intermixed within these strata and ultimately accumulate along the base of the cliffs and along the shoreline (Figure 30). This alternation of materials (sand and gravel) leads to several places of “drunken forests” where trees along the cliff line become unstable, fall en masse, and are converted to local LWD along the shorelines.

Figure 30. Gravel accumulation along a Quinault Formation cliff base.

Also within this reach are several instances of siltstone formed at deep sea depths where mollusks thrived (Figure 31). These siltstones are fragile, and weather quickly as they are exposed to wave action and rains then dried near the surface on the shoreline.

Figure 31. Siltstone with imbedded fossilized mollusk shells.

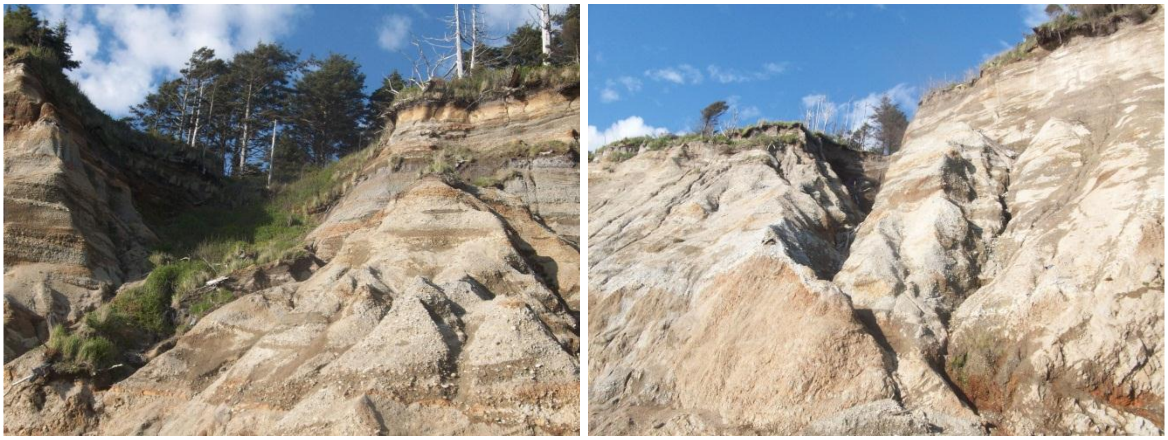
3.4.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. A combination of Fee statuses (Quinault Fee, other Fee, Trust, and Quinault). SR109 parallels the ocean shoreline along the northern two-thirds of this reach. For the most part, this reach shows forestlands along the top of the marine shoreline cliffs.

3.4.2. Faults

The Quinault Formation rocks are crossed by one fault line and four strike dip faults (Figure 32).

Figure 32. Fault line (left) and strike dip bed (right) of the Quinault Formation between Point Grenville and Taholah.



3.4.3. Soils

Soils of this reach include a combination of coastal alpine glacial till, and upslope silty glaciolacustrine soils (NRCS 2011). Surface soils include alpine glacial till with decomposed plant materials (detritus). Through this entire reach, the mixing of soil layers is evident as layers were tilted, overtopped by layers of the same formation, or from older soils. They tend to show characteristics of being fragile to both tensile and compression forces.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

This reach of the shorelines is represented mainly by groups C and D. Group A soils are capable of high infiltration rates even when saturated. Group D has a slower infiltration rate and water movement at saturation is generally seen as impacted stream flow channels. This group (D) also contributes to the cliff-edge failures often seen within the Quinault Formation soils.

3.4.4. Aerial Imagery

A series of aerial photographs from 1939, 1953, 1955, 1977, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the minor changes observed along the entire coastline within this reach.

The Point Grenville Cutacross Road, discussed in the last section, is partially shown along the maps of this reach. That example demonstrates the fragile nature of near-shore-cliff developments (road) placed on these soils.

3.4.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

The reader can study the photography placed on page 25 of the accompanying document, 8/19/2006 3:20 PM, to observe a land formation slump located at approximately 47° 19’ 20” N to approximately 47° 19’ 50” N. This slump is a form of mass wasting resulting from a coherent mass of loosely consolidated materials moving down the slope. This movement is characterized by sliding along a concave-upward or planar surface. Within the Quinault Formation, the movement created a fracture of the consolidated materials paralleling the shoreline. In response to wave-cut platform avulsion actions, the trees located on top of this fractured segment (drunken forest) fall to ultimately reside at the shorelines as LWD (Figure 33).

Figure 33. Site failure and the drunken forest of the Quinault Formation between Point Grenville and Taholah.

3.4.6. Cautionary Comments

When left untouched by road or building construction, or timber harvesting, this reach is fairly stable and resilient to shoreline forces of the wave-cut platform activity. The shoreline cliffs are constantly changing from these ocean advances. The forces of RSLC will have impacts on this reach during the next century, with a continuation of cliff-face evulsion and slumping, as seen on the oblique views discussed here.

When site modifications are considered, this area includes unstable substrate in the form of the Quinault Formation materials. This entire reach shows evidence of wave-cut cliffs formed since the last interglacial period. Since the last glaciation period, this reach has been uplifted through isostatic rebound forces. This uplift is seen within most of this reach with the ocean converting the materials at the base of the cliffs to seafloor silts and sands. Because the materials of the Quinault Formation are sands, silts, and gravels, the materials are rapidly washed away by wave action after they are deposited at the ocean shoreline.

It is expected that the impacts of relative sea level change caused by global climate change will be seen with increased erosion at the base of the cliffs leading to overburden failures and slumps. These impacts will be sped where cliff-top disturbances such as structures, roads, and timber harvesting are found.

3.5. Lower Taholah Reach Assessment

Refer to the “04_Reach_Maps_Lower_Taholah.PDF” booklet for maps and oblique photographs.

This reach is centered on the shorelines of the Taholah village, including the mouth of the Quinault River, and the northern bank of the Quinault River, but not including Cape Elizabeth. This shoreline area is dominated by Quinault Formation substrate that has been cut by the Quinault River approach to the Pacific Ocean. The Quinault River represents a major drainage of the Olympic Mountains and creates the Quinault River Littoral Cell (QRLC) within this local area.

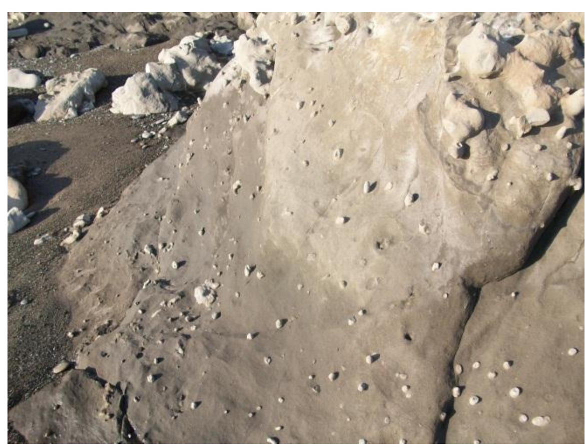
To the south of the Quinault River's entrance to the Pacific Ocean, and along the northern cliffs of the river's banks, the Quinault Formation dominates the substrate. Smaller inclusions of the Hoh Assemblage are identified along the northern banks. The Quinault Formation can be found in association with disruptions such as a perpendicular fault line separating the two discontinuities. The Quinault Formation materials of the northern Quinault River bank are characterized by mass wasting events such as landslides and slumps (Figure 34).

Figure 34. Slumping and wasting north of the Quinault River in Hoh Assemblage rocks.

The Quinault Formation was formed in deep sea floor environments from consolidated, stratified, and then tilted sedimentary rocks. The Quinault Formation rocks of this reach are overtopped by alpine glacial outwash materials and organic matter. The stratified sand and gravels within this reach cover the shorelines alternately.

Where these substrates are found on the beaches near Taholah, there are several unique findings indicating the age of the materials as a combination of Quaternary and Tertiary period formations. The presence of macro fossils embedded in the sandstone of the reach, fossilized clam borings, and concretion structures formed to fill pre-historic mollusk borning holes (Figure 35) show evidence of the temporal genesis of these materials.

Figure 35. Fossilized Piddock clam borings preserved in stones found on an uplifted wave-cut surface near the marine shorelines of Taholah (left). Concretion structures in sandstone of the Quinault Formation where sediments filled boring holes of prehistoric off-shore mollusks giving these light colored structures (right).



The shorelines of Taholah are a combination of coarse gravels and pebbles (Figure 36), intermixed with large woody organic materials (Figure 37). The deposits include coarse-grained sand, grit, and, in places, even conglomerates called greywacke. These may consist of individual grains composed of fragments, or clasts, of pre-existing minerals and rock fragments of other rocks rather than individual mineral grains. In many of the greywacke sandstones seen along the coast, angular fragments of various sizes of dark-gray siltstone occur in a light-colored sand matrix (Rau 1973).

Figure 36. Gravel and pebbles along this reach show sandstones, siltstones, conglomerates (left), and greywacke (right).

The LWD of this reach of the coastline is substantial as locally contributed logs with root wads are combined organically from the Quinault River, from marine shorelines adjacent to the reach, and combined with LWD from distant sources (Figure 37). These LWD materials provide a substantial avulsion limiting amenity to the local marine shorelines. The logs are not only present at the surface of the shorelines, but they are also embedded deep in the shorelines sands, silts, and conglomerates. Their presence here provides the village of Taholah with a level of stability against accelerated shoreline encroachment.

Figure 37. Large woody organic materials of the Taholah marine shorelines, and a steep shoreline approach to the upper limit of high tide.

Several other facets of significance apply to the situation seen along the marine shorelines near Taholah. In combination with the large amount of LWD along these shorelines, there is active isostatic rebound exceeding sea level rise in this area nearest to Taholah (Figure 38). The sandy duff layer, shown on the left side of Figure 38, shows about 2 feet of uplift. The right side of the images shows a Sitka spruce tree with the bottom 2 feet of the tap root exposed above the initial base of the tree at the time of germination. The progression of this uplift was slow enough to allow the tree to continue its growth, year to year, while adding a bark layer to the tap root (a feature not normally covered with bark). By 2012, this tree senesced and will be contributed to the LWD of this shoreline in the near future.

A review of the right side photograph of Figure 37 gives the reader supporting evidence through the steep shoreline approach within the intertidal zone to the upper limit of high tide, identifying the terrain rise in this area. The terrain has lifted faster than sea level has increased, causing this steep intertidal shoreline angle.

Figure 38. Shoreline slope, uplift of the land, and LWD combine within this reach.

3.5.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. A combination of Trust and Quinault parcels dominate this area. The Taholah Village along the southern side of the Quinault River is the largest concentration of habitation on the QIR.

3.5.2. Faults

One major fault is present along the northern side of the Quinault River and is located near the joining of Hoh Assemblage rocks and Quinault Formation rocks. One strike dip bed is collocated with this fault, and two similar faults are located west of the main fault. Another strike dip bed is located near the southern side of this reach within the Quinault Formation rocks.

3.5.3. Soils

Marine shoreline soils of this reach are highly influenced by the Quinault River outwash since the last glacial period and show high concentrations of silty alluvium combined with loess over gravelly glacial outwash (NRCS 2011). A superficial review of the left side photograph of Figure 38, shows the concentration of silty alluvium in this area. North of the Quinault River, the areas are dominated by alpine glacial outwash soils with some inclusions of tectonic breccia, and sedimentary rocks.

The Garfield Gas Mound is located on the northern side of the Quinault River and is a few hundred feet in diameter rising about 50 feet above the terrain. Mud and methane bubbles are extruded through a vent and is likely derived from the Hoh Assemblage rocks scrambled in this region (Rau 1973). Further to the west, along the marine shorelines, these methane bubbles were observed being vented through the ocean waters near the Duck Creek Diapir.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). The southern side of the Quinault River is represented mainly by groups C and D. Group C soils are capable of slow infiltration rates even when saturated. Group D has a slower infiltration rate and water movement at saturation is generally seen as impacted stream flow channels. This group (D) also contributes to the cliff-edge failures often seen within the Quinault Formation soils. These soils are seasonally seen with localized flooding within the Taholah Village that persists as the precipitation rates slow.

North of the Quinault River the forestlands are situated on Hydrologic soil groups B and D. Across this area, the viewer can recognize transitions from evergreen forests to hardwoods in response to the soil moisture profiles of well-drained soils (group B) and slow infiltration soils (group D).

3.5.4. Aerial Imagery

A series of aerial photographs from 1939, 1953, 1955, 1977, 1980, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the changes observed along the Quinault River spit.

3.5.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

The reader can study the photography of the shorelines to observe the high concentrations of LWD along both the southern sides and northern sides of the Quinault River. Also of interest, on page 37, is the presence of the slump on the northern side of the river, and the fault scarp on page 38, both within the Quinault Formation rocks.

3.5.6. Cautionary Comments

The silty alluvium found within the Taholah Village causes slow water infiltration and has annual flooding tendencies during the rainy season. North of the Quinault River, these soils have moderate infiltration rates and provide subsurface water flow into the river. Decomposed organic materials of the soils, coupled with the sands, silts, and composite materials contribute to the overall profile of a populated community and economic center of the QIR. The marine shorelines are bolstered by the presence of the beach sited LWD and situated on top of the sands and gravels. These woody materials should be protected by the QIN from incidental 'beach camp fires', offsite decorative uses, or other consumptions of the woody materials. These resources serve a beneficial purpose of protecting the on-shore habitat and infrastructure of the village. Storms approaching the coastline with strong waves are broken by these barriers to the shoreline.

The apparent isostatic uplift seen along the shoreline exposes silty alluvium and loess soils at the high tide limit interface. The presence of gravels and cobbles on the shoreline protect the silts and alluvium from loss. Without this uplift process currently in effect, it is likely that the marine shoreline advance would mean a substantial onslaught of the Pacific Ocean's high tide limit (movement inland by tens of meters). The presence of the LWD serves to hold this balance 'in check' as it protects the fine grained silts and loess soils from excessive wave-cut platform avulsion, combined with the uplift seen along these shorelines.

It is expected that the impacts of relative sea level change caused by global climate change will be seen with avulsion of the silts and alluvium at the edge of the village and a significant advance of the high tide limit inland.

3.6. Cape Elizabeth Reach Assessment

Refer to the "06_Reach_Maps_Cape_Elizabeth.PDF" booklet for maps and oblique photographs, and "06B_WWII_Bunker_Site.PDF" for maps of a WWII Artillery Bunker site erected along this shoreline.

This reach begins at Cape Elizabeth and extends north to the Duck Creek Diapir geologic structure. This shoreline area is dominated by the Quinault Formation rock cliffs (Figure 39). As the glacial ice retreated from this area, and the accretionary wedge from the Juan de Fuca plate continues its easterly push, the landforms have been uplifted in the process of the isostatic uplift. The cliff faces from Cape Elizabeth to the Duck Creek Diapir show a clearly definable wave-cut platform profile (Section 2.5.1) that has resulted in a cliff crest of approximately 210' above the platform.

Figure 39. Cape Elizabeth from the marine shorelines to the north (left), and Quinault Formation shoreline cliffs (right).

The high energy wave-cut platform patterns that impact these shorelines create a mosaic of shoreline features that combine sand from the eroded cliffs along with the boulders embedded within the cliff walls. These materials are also combined with locally contributed LWD as cliff-crest vegetation is recruited to the shorelines. The Sea Mussel-Gooseneck Barnacle association thrives within this zone (Figure 40).

Figure 40. Sea Mussel-Gooseneck Barnacle association species along the shorelines north of Cape Elizabeth: ochre sea stars (ochre starfish) (left).

3.6.1. WWII Artillery Bunker Site

During World War II, the US military erected an Artillery Bunker Site at the crest of the Cape Elizabeth cliffs to defend the American shorelines against a possible sea attack from Japanese forces. These efforts were rationalized from concerns related to the inability for American forces to access the shorelines in defense.

This bunker site's location is approximated in the referenced map book titled: "06B_WWII_Bunker_Site.PDF". As the reader views this collection of aerial images of Cape Elizabeth, the red circle approximates the location of the bunker. On the first image from 1939, the yellow line approximates the vegetative extent of the cliff's crest. It is not equal to the shoreline of that time, but it is a close reference when the reader considers the nearly vertical cliff face of this area (Figure 39). We assume that the bunker was not built in 1939.

The next aerial photo, 1953, shows the same location of the bunker site as a red circle, and a new yellow line showing the approximate vegetative extent of this cliff's crest. The bunker was erected about ten years prior to this date. Avulsion was already apparent where the bunker was situated. By 1977, the bunker's site was engulfed by slope failure and conducted down the cliff.

This erosion of the Quinault Formation rocks has continued into 2012 as the cliff materials adjust for equilibrium. In February 1993, QIN staff member, Larry Workman, photographed concrete foundation blocks from the bunker site that were being shepherded down the cliff (Figure 41). In May 2012, Kamiak Ridge investigators, William Schlosser and Dan Lawson, photographed the same concrete blocks, with rebar still attached, sitting in the intertidal zone at sea level (Figure 41).

It is important to recognize that the blocks photographed in 1993 and 2012 most likely did not change their horizontal position appreciably during those nearly 20 years. The change is seen from an erosion of Quinault Formation debris at the base of the eroding cliff face in response to the disturbances caused by the bunker's construction. The foundation blocks only settled to sea level as finer materials were washed away by wave-cut action.

Figure 41. Concrete foundations from the WWII Artillery Bunker Site north of Cape Elizabeth, avulsed to the ocean shorelines from 210’ above. Left photograph February 1993 (Workman 2012), right photograph May 2012.

The vegetated cliff crest has horizontally avulsed over 400’ as a result of the disturbances on the top of the cliff. A study of the scenes in the referenced PDF is summarized on page 5 of this set to combine all of the crest lines by reference year. It is clearly demonstrated that disturbances, such as the erection of a structure, accessed by a road, can lead to substantial failure on Quinault Formation rocks when combined with wave-cut platform avulsion.

3.6.2. Duck Creek Diapir

Diapirs are formed as a geologic process, at great depths, and generally extrude vertically upward along fractures, fissures, or faults, through denser overlying rocks. The pressure of the underlying materials causes the rupture through the overlying structures (diapirism). The resulting material extrusion is also referred as piercement structures (Rau 1973). When the diapir erupts to near the surface, the underlying pressures are released and the materials of the diapir become wedged within the surface materials (Schlumberger Limited 2013).

The Duck Creek Diapir is located at the northern part of this reach (Figure 42). The materials of the diapir show combinations of magma, sand, silt, deep-sea muds, boulders, rocks, and organic materials. As these formations avulse, the residual materials are a combination of sandy beaches, with remnant boulders scattered at the cliff base.

Figure 42. Duck Creek Diapir.

3.6.3. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. Most of this reach is held in Trust status.

3.6.4. Faults

This reach has two intersecting fault lines that are located on each side of the Duck Creek Diapir (north and south) (Figure 43). The intersection of these faults is seen offshore of the coastline several hundred feet, but both faults extend inland considerable distances. These are considered active faults. Other strike-dip beds have been located along this reach giving evidence of the highly fractured formations of this area. This fracturing comes from both vertical and horizontal pressures.

Figure 43. Fault line separating the northern edge of the Duck Creek Diapir (right) and the Quinault Formation (left).

3.6.5. Soils

Soils of this reach are dominated by glacial outwash and silty glaciolacustrine soils (NRCS 2011). This entire reach is dominated by Quinault Formation rocks that were created in a nearly horizontal profile, but has been tilted to incline to the north in some places, and to the south in others. In a few locations, the structure has been overturned in response to tectonic and erosion forces.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

This reach of the shorelines is represented mainly by groups B and D. Group B soils are capable of moderate infiltration rates even when saturated. Group D has a slower infiltration rate, especially at saturation. The group D soils also contribute to cliff-face failures often seen within the Quinault Formation. This combination results in subsurface water flows from sites dominated by Group B, which transition to the Group D sites causing inter-structure evacuations of mudflows (Figure 44). The event witnessed in Figure 44 (May 2012) was seen as pulsating surges of water excised through the cliff's soils in the form of a mudflow. The mudflow was not a surface water conveyance, but instead was a subsurface evacuation of water and mud through fractures within the formation.

Figure 44. Quinault Formation mudflow within Hydrologic Soil group D, where subsurface water flow from Hydrologic Soil Group B transitioned into the saturated Group D soils. At the time of this event, no precipitation had fallen over 2 weeks.

3.6.6. Aerial Imagery

A series of aerial photographs from 1939, 1953, 1955, 1977, 1985, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the significant changes observed along the entire coastline within this reach.

The WWII Artillery Bunker Site has been discussed in this section and gives example to the expected response to site alterations.

3.6.7. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

The reader can study the photography placed on page 27 of the accompanying document, 8/19/2006 3:16 PM, to observe a scarp and slump resulting from the WWII Artillery Bunker Site's placement.

Oblique views of the Duck Creek Diapir are shown on pages 28, 29, and 30 of this set. The transition from the lighter colored Quinault Formation rocks on the left side of the image on page 28, the darker colored Duck Creek Diapir approximately matches with the fault line crossing this area. Comparatively, the image on page 30 shows the transition between formations coinciding again with a fault line.

3.6.8. Cautionary Comments

The Quinault Formation materials have been uplifted since the last glacial period by a combination of forces including the expatriation of Olympic Mountain glaciers leading to isostatic uplift. The fragileness of the soils is illustrated by the sheer cliffs created by the high-energy wave-cut action focused on their base. Even incidental disturbances along this reach have resulted in substantial site failures and avulsion. The example given for the WWII Artillery Bunker Site demonstrates the severity of disturbances along this reach and the potentially long-reaching temporal impacts of these actions.

3.7. Duck Creek & Camp Creek Reach Assessments

Refer to the "07_Reach_Maps_Duck_Camp_Creeks.PDF" booklet for maps and oblique photographs along this shoreline.

This reach begins at the northern side of the Duck Creek Diapir geologic structure and extends to Camp Creek. This shoreline area is dominated by the Quinault Formation rock structures (Figure 45). The elevation of the cliff edge crest is approximately 100-120', with several sea-level approaches for the rivers. The shorelines hold a gradual approach to the upper-limit of the intertidal zone and are dominated by sandy beaches. Isostatic uplift in this reach is evident and for the recent period, exceeds RSLC.

Figure 45. Quinault Formation sandstones being tilted and avulsed by wave-cut platform actions.

Avulsion of the shoreline cliffs contributes mainly sands and silts that are integrated into the shoreline beach platform. At both Camp Creek and Duck Creek, the sediment contributions from the rivers include fine-grained materials, cobbles, and boulders that are intermingled with the shoreline substances. Offshore mollusk communities include the bent-nose clam-mossy chiton (*Macoma nasuta-Mopalla muscosa*) association.

Cobbles and boulders are scattered along the shorelines of this reach and generally are associated with river outlets that both eroded the mainland releasing the substrate materials, and transported up-watershed materials downstream. In many of the greywacke sandstones seen along the coast, angular fragments of various sizes of dark-gray siltstone occur in a variable-colored sand matrix (Figure 46).

Figure 46. Sandstone cobble with fossilized clam shell (left) and greywacke sandstone (right).

Along this reach, the presence of LWD is minimal, and is generally contributed from local sources as the shoreline cliffs are avulsed by wave-cut action. In several places, the avulsion leads to the presence of the locally recognized "drunken forest" appearance. The shoreline materials are generally recognized as a sandy substrate with a high content of silt, giving the fine grained grit of dark color (Figure 47). Locally destabilized areas along the cliff lines are common, especially where near cliff-top disturbances such as road building, and timber harvesting have taken place.

Figure 47. Camp Creek (left) and Duck Creek (right) pour points into the Pacific Ocean.

3.7.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. Most of this reach is held in Trust status.

3.7.2. Faults

This reach has the onshore extent of the fault line associated with the Duck Creek Diapir, but it does not span the shoreline segments of this reach. Several strike dip beds are found along this reach, especially where the Quinault Formation structures are tilted, compressed, and uplifted through tectonic pressures (Figure 45).

3.7.3. Soils

Soils of this reach are dominated by glacial outwash and silty glaciolacustrine gravelly outwash (NRCS 2011). This entire reach is dominated by Quinault Formation rocks that were created in a nearly horizontal profile. Much of this reach shows a tilting to the south. In a few locations, the structure has been overturned in response to tectonic and erosion forces.

Much of this reach is heavily influenced by the parent materials of sands and silts generated during the last glacial period. These materials are deposited deep into the structure of the geological profile and are eroded and converted to deposition as Camp Creek and Duck Creek traverse them on their approach to the ocean.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

As with the previous reach (Cape Elizabeth to Duck Creek Diapir), this reach of the shorelines is represented mainly by groups B and D. Group B soils are capable of moderate infiltration rates even when saturated. Group D has a slower infiltration rate, especially at saturation. The group D soils also contribute to cliff-face failures often seen within the Quinault Formation. This combination results in subsurface water flows from sites dominated by Group B, which transition to the Group D sites causing inter-structure evacuations and wasting events (Figure 48).

Figure 48. Drunken forests and avulsing wave-cut platform cliff faces in response to destabilized soils near Duck Creek.

3.7.4. Aerial Imagery

A series of aerial photographs from 1939, 1953, 1955, 1977, 1985, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the moderate changes observed along the entire coastline within this reach.

3.7.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

The reader can study the photography placed on page 22 of the accompanying document, 8/19/2006 3:16 PM, to observe a scarp and slump resulting from wave-cut cliff base avulsion.

3.7.6. Cautionary Comments

The Quinault Formation materials within this reach have been moderately uplifted since the last glacial period by a combination of forces including the expatriation of Olympic Mountain glaciers leading to isostatic uplift. Incidental disturbances from road building and timber harvesting along this reach has resulted in localized site failures and wave-cut avulsion, especially where the terrain attained higher elevations (near 100' or more). The silt dominated beaches surrounding the entry of the creeks to the ocean are fragile. The lack of heavy LWD along this reach is noticeable and facilitates shoreline erosion from high energy ocean waves (Figure 49).

Figure 49. Recreational uses near Duck Creek (recognize the silt dominated layers of the creek's terminal approach to the ocean).

3.8. Pratt Cliff Reach Assessment

Refer to the "08_Reach_Maps_Pratt_Cliff.PDF" booklet for maps and oblique photographs along this shoreline.

This reach begins at the southern side of the Pratt Cliff and extends to the north side of Boulder Point. This reach spans the bedrock materials of both the Quinault Formation (southern) to the Hoh Assemblage rocks (northern). The transition is clearly evident as the viewer traverses this reach. To the south, near Pratt Cliff, the shorelines are sandy and smooth, with a gentle approach from the seaward side, covered by sandstone boulders expatriated from the cliff faces. To the north, boulders cover the beaches near the cliff lines, aptly giving the name for Boulder Point (Figure 50).

Near the transition from the Quinault Formation to the Hoh Assemblage rocks, there is a collection of small parcels in Fee status that have small cabins, or shelters used infrequently. Where these structures were erected near the cliff line, several have collapsed and been moved down the slope in failures. All of that Fee ownership area in this reach is on the Quinault Formation bedrock, demonstrating the unsuitability of this bedrock formation to withstand disturbances near cliff edges.

Figure 50. Boulder Point rock structures in 2005 (left) and 2012 (right) (Workman 2012).

As has been observed in other reaches along the QIR marine shoreline, an active fault line separates the transition between the two bedrock formations. The fault line cuts across offshore lands and onto the terrain at about 45° azimuth. Offshore of this reach are located the Split Rock and Willoughby Rock islands (Figure 51).

Figure 51. Split Rock (left), Willoughby Rock (right).

The southern shoreline (Pratt Cliff area) of this reach is dominated by the Quinault Formation rock structures (Figure 52). These sandstone and siltstone formations are highly tilted and irregularly broken, leading to boulders distributed along the base of the cliffs and within the intertidal zone. These cliffs are not as uplifted as the Quinault Formation rocks of Cape Elizabeth, with only about 100 feet of apparent uplift from shoreline to cliff crest. Tree trunks and other LWD are not abundant in on this reach. As the cliff faces have been disturbed, several rock falls have resulted and remain at the base of the cliff.

Figure 52. Pratt cliff from the north, looking south (Workman 2012) (left). Sandstone boulders liberated from the Quinault Formation cliffs north of Pratt Cliff (right).

As the viewer progresses in the direction of Boulder Point, the bedrock formations transition to the Hoh Assemblage. Within this assemblage, several piercement formation structures are seen. These diapir structures represent a conglomeration of sands, silts, basalt remnants, and carbonized organic matter. Within the intertidal zone near Boulder Point, a release outlet of methane gas was observed. The recruitment of these materials from wave-cut action and to the shoreline is substantial (Figure 53).

Figure 53. Hoh Assemblage structures with diapir arrangements are common near Boulder Point.

3.8.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. Most of this reach is held in Trust status with the northern extent of section 9 (T22N R13W) held in Fee status.

3.8.2. Faults

This reach has the onshore extent of a fault line separating the Quinault Formation and Hoh Assemblage bedrock materials.

3.8.3. Soils

Soils of this reach are dominated by gravelly glacial outwash and silty glaciolacustrine over gravelly outwash materials (NRCS 2011). Much of the southern two-thirds of this reach is heavily influenced by the parent materials of alpine glacial outwash generated during the last glacial period. The northern one-third, where the Hoh Assemblage and the diapir formations are seen, are best represented by a tectonic breccia from the Miocene period.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

This reach of the shorelines is represented mainly by groups B and D. Group B soils are capable of moderate infiltration rates even when saturated. Group D has a slower infiltration rate, especially at saturation. The group D soils also contribute to cliff-face failures often seen within the Quinault Formation. This combination results in subsurface water flows from sites dominated by Group B, which transition to the Group D sites causing inter-structure evacuations and wasting events.

3.8.4. Aerial Imagery

A series of aerial photographs from 1939, 1953, 1955, 1977, 1985, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the moderate changes observed along the entire coastline within this reach. Where the diapir formations are seen, in near the upper one-third of the reach, the viewer can see moderate temporal changes to the cliff crest vegetation line.

3.8.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

3.8.6. Cautionary Comments

The Quinault Formation materials within this reach have been moderately uplifted since the last glacial period by a combination of forces including the expatriation of Olympic Mountain glaciers leading to isostatic uplift and wave-cut platform avulsion creating nearly vertical cliff faces. Incidental disturbances from cabins and recreational camping structures within the Fee lands, and timber harvesting near the cliff faces, has resulted in localized site failures and avulsion. The lack of heavy LWD along this reach is noticeable, but the beneficial features of the LWD are somewhat replaced by the large boulders present on the shorelines.

3.9. Hogsbacks Reach Assessment

Refer to the “09_Reach_Maps_Hogsbacks.PDF” booklet for maps and oblique photographs along this shoreline.

This reach includes both Hogsback and Little Hogsback nearshore structures (Figure 54). This reach from Boulder Point through the Hogsbacks area spans the bedrock materials of the Hoh Assemblage rocks. The cliff crest along this reach attains between 100 and 120 feet, except where cut by streams. The shoreline is mainly overlaid with boulders that originated in the cliffs of the Hoh Assemblage, including the diapir formations. These rocks are a chaotic assemblage of siltstone, sandstone, conglomerate, and volcanic material.

Figure 54. Little Hogsback (left) and Hogsback (right) (Workman 2012).

The Cape Elizabeth road (originally from near Queets to the Cape) once continuously paralleled this shoreline providing access on a single track dirt road. Access across Whale Creek and Raft River (to the north) washed out some time between 1955 and 1977 significantly reducing traffic along this path. Currently, access using this road is possible from Taholah as far as Raft River. Other secondary access roads link this stretch of the road to other access points. The formidable cliffs seen along the Quinault Formation bedrock structures are not seen in this reach. The cliffs are sloped and ridge top vegetation is recruited to the shoreline as locally recruited LWD and boulders from within the formation (Figure 55).

Figure 55. Recruitment of LWD and boulders to the shorelines.

In several locations where diapir structures are located, carbonized wood structures have been incorporated into the bedrock formations. Fossilized mollusk shells and cavities are also memorialized in the sandstones and tectonic breccia found here.

Both Hogsback structures originated from the shoreline formations but have been eroded by wave-cut platform patterns to create these islands, separate from the mainland. The erosional remnants contain conglomerates, stratified sandstone and siltstone, and volcanic materials (basalt) (Figure 56). The process of separation from the mainland is ongoing, but it is concluded that the separation of the Hogsbacks from the mainland has happened within the past 2 centuries (Rau 1973). The basaltic core of these structures remained in place after the fine grained materials of the tectonic mélange were eroded away by the sea. The outcrops of Little Hogsback and Hogsback (Figure 54), and the offshore rocks of Split Rock and Willoughby Rock (Figure 51), are all volcanic in origin and are erosion resistant blocks. These features were once incorporated in the mélange but now are erosional remnants enduring along the coast.

Rau (1973), using land survey findings from 1902 to 1973, concluded that shoreline erosion is proceeding at a rate of about 375 feet per century in this reach. Based on that rate of change, he concluded that Willoughby Rock (Figure 51) was likely the western edge of the mainland about 1,200 years ago.

The entire reach is particularly vulnerable to slumping as the finer grained sands, silts, and clays are eroded by ocean wave-cut patterns, incorporated in the beach materials, and washed out to sea. The expanding nature of clay minerals in this structure after wetting, gives rise to the structural weakness of the bedrock. The extreme structural weakness of these deposits provides the warnings against site disturbances here. Across this geologic structure, the near cliff face sites that receive disturbances, such as timber harvesting, road building, or building constructions, often respond with site failures such as slumping.

Figure 56. Extremely distorted rocks of the tectonic mélange, showing a chaotic mixture of compressed soft silt and clay (Workman 2012).

The Hogsbacks area has many volcanic fragments, mixed with fragments of siltstone and other sedimentary rock types (Figure 57).

Figure 57. Stratified sandstone and siltstone sediment structures formed in a nearly horizontal position as sediments millions of years ago, have been turned, broken, and eventually are incorporated into the shoreline or held in the formation's cliffs.

3.9.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. Most of the shoreline properties are held in Fee status north of Little Hosgback.South of Little Hogsback the properties are a combination of QIN Trust and other Trust.

During site visits to this reach, a collection of parcels in Section 28, Township 23 N Range 13 W, held in Fee status, was visited to view a site where timber was substantially harvested at some time before 2000 and later a camping site was developed (Figure 58 & Figure 59). Several references in this document have been made about the instability of developing structures near the cliff face edges of Hoh Assemblage and Quinault Formation bedrock materials. This property combined substantial timber harvesting with road building and low impact site developments.

Figure 58. Yurt tent site erected near the cliff edge northeast of Hogsback in 2005 (Workman 2012).

The compromise of the cliff edge is seen in Figure 59, where the picnic table protective roof frame in 2005 was fully erect, but in 2012 was already partially compromised by cliff face avulsion. The failure at the crest of the cliff was a response to wave-cut platform erosion at the base of the cliff and the release of the cliff face in response. The bedrock of this area is mainly piercement structure materials.

Figure 59. Picnic table enclosure located along the Hoh Assemblage rock cliff edge in 2005 (left) and 2012 (right) (Workman 2012).

This site is visible at the very top of the reach map along the 47°27’0” latitude parallel, and on pages 26 and 27 showing the oblique view maps of this reach.

3.9.2. Faults

Neither active fault lines nor strike dip beds are evident within this reach.

3.9.3. Soils

Soils of this reach are dominated by gravelly glacial outwash and silty glaciolacustrine over gravelly outwash materials (NRCS 2011). This reach is comprised by Hoh Assemblage and diapir formations, intermixed with tectonic breccia from the Miocene period, especially concentrated along the cliff faces. Decomposed plant materials provide substantial organic detritus to the upper layers of the soils.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

This reach of the shorelines is represented mainly by groups B and D. Group B soils are capable of moderate infiltration rates even when saturated. Group D has a slower infiltration rate, especially at saturation. The group D soils also contribute to cliff-face failures often seen within the Hoh Assemblage. This combination results in subsurface water flows from sites dominated by Group B, which transition to the Group D sites causing inter-structure evacuations and wasting events.

3.9.4. Aerial Imagery

A series of aerial photographs from 1939, 1953, 1955, 1977, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the moderate changes observed along the entire coastline within this reach. Of interest, is the Little Hogsback conduit to the mainland and the changes seen across the aerial photographs, especially between 1994 and 2000.

3.9.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

Attention can be given to the photographs on pages 25 through 28 to recognize the timber harvesting that extended to the cliff edges. The apparent result of these activities is seen as rounded cliff crest slumping as the wave-cut platform avulsion at the base of the cliffs resulted in a rounded cliff face failure. Contrast these images with the cliff crest lines seen on page 20 and 25, where a vegetative buffer was left intact and the cliff crest avulsion does not include slumping features.

3.9.6. Cautionary Comments

The Hoh Assemblage and diapir formation materials within this reach have been moderately uplifted since the last glacial period by a combination of forces including the expatriation of Olympic Mountain glaciers leading to isostatic uplift. The more active and critical feature happening here is the effects of wave-cut platform avulsion along the coastline. Incidental disturbances from cabins and recreational camping structures, and timber harvesting near the cliff edges, has resulted in localized site failures and increased wave-cut platform avulsion. The lack of heavy LWD along this reach is noticeable, but the beneficial features of the LWD are partially replaced by the large boulders deposited on these shorelines.

These shorelines will benefit from an extended setback from the current cliff crest edges where timber harvesting, road building, and even recreational camping are limited. As a mitigation measure, reforestation of the under-forested sites and road retirement to the near cliff face would assist to establish the stability of this area against avulsion.

3.10. Tunnel Island & Raft River Reach Assessment

Refer to the “10_Reach_Maps_Tunnel_Island.PDF” booklet for maps and oblique photographs along this shoreline.

Tunnel Island and Elephant Rock are well known as destination recreational points for local and distant visitors (Figure 60). Geologically, it is a tectonically active setting where bedrock formations transition from the Hoh Assemblage rocks south of Raft River, to the Quinault Formation bedrock north of the river. This separation of bedrock formations is marked by two nearly parallel normal fault lines straddling either side of Tunnel Island, and two nearly perpendicular fault lines, one bisecting the two normal faults. The northern bisecting fault is estimated to have been active within the last 750,000 years. The southern fault line is nearly parallel to the marine shoreline and is estimated to have been active within the last 130,000 years.

Contributions of LWD are significant near the mouth of Raft River. The main source of LWD contributions comes from Raft River and the cliff lines surrounding this reach (Figure 60). These materials are present along the marine shoreline surfaces, and are embedded deep within the shoreline structure.

Figure 60. Tunnel Island and Elephant Rock (left) at the mouth of Raft River (right).

Outcrops of sedimentary materials of the Quinault Formation are scattered along the Quinault Marine Coastlines, with an appearance in the northern half of this reach. Tunnel Island and the off-shore islands (Figure 61) are part of this formation and reside on top of the wave-cut platform formed over the past millennia as shoreline encroachment has materialized. Hoh rock remnants are found along the shorelines south of Raft River in this reach. They form a barrier against the wave-cut platform's eroding edge against the resident cliff materials. Large sandstone blocks and another large block of volcanic rock forms a stack-like feature within this reach. Cliff outcrops of Hoh rocks end at the southern edge of the Raft River valley, south of Tunnel Island.

Figure 61. Seastacks offshore and north of Tunnel Island are sandstone outcroppings firmly established on the wave-cut platform created in this region.

The Cape Elizabeth road (originally from near Queets to the Cape) once continuously paralleled this shoreline providing access on a single track dirt road. Access across Whale Creek and Raft River (to the north) washed out some time between 1955 and 1977 preventing thru-traffic along this path. Currently access using this road is possible from Taholah as far as Raft River. Other secondary access roads link this stretch of the road to other access points.

In several locations where diapir structures are located, carbonized wood structures are incorporated into the bedrock formations. Fossilized mollusk shells and cavities are also memorialized in the sandstones and tectonic breccia found here. Located to the north of Raft River, an isolated formation of a diapir structure is found (Figure 62).

Figure 62. Diapir structure about 1,500 feet north of Raft River, overtopped by conglomerates and glacial outwash.

Cliffs of this entire reach attain a height of between 100 and 120 feet and form cliffs that are sheer faces along the Quinault Formation bedrock, and rounded, slumping cliff crests on the Hoh Assemblage and tectonic breccia bedrocks. Wave-cut platform structures creating near sheer cliff faces are seen along the Quinault Formation bedrock materials location north of Raft River (Figure 63). Within the Hoh Assemblage and the composite material hills adjacent to the shoreline, the shape is not as pronounced and results in lower cliff tops and slumping to the shoreline.

Figure 63. Wave-cut platform characteristics against a Quinault Formation cliff north of Raft River.

Near the northern extent of this reach, in section 21, a couple Fee owner recreational structures have been erected. One of these is located a near the cliff edge (Figure 64). It is probable that the process of the wave-cut platform avulsion of the cliff faces has diminished the distance from cliff edge to structure over time. It is also likely that this structure (and others like it) will be compromised as the cliff faces avulse and fall to the shoreline.

Figure 64. Private recreational cabins and out buildings, north of Raft River, also seen on map book page 31 (left) and page 29 (right).

3.10.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. Most of the shoreline properties are held in Fee status. South of Raft River, the mix of properties are a combination of Quinault and Trust lands.

During site visits to this reach, a collection of parcels in Section 21, Township 23 N Range 13 W, held in Fee status, was visited to view structures that appear to be located close to the cliff face and at risk of falling as the cliff avulses. This situation is documented in Figure 64. On this particular site, the bedrock materials are of the Quinault Formation, but those have been overtopped by glacial outwash composite materials.

3.10.2. Faults

Within this reach, the separation of bedrock formations is marked by two nearly parallel normal fault lines straddling either side of Tunnel Island, and two nearly perpendicular fault lines, one bisecting the two normal faults. The northern bisecting fault is estimated to have been active within the last 750,000 years. The southern fault line is nearly parallel to the marine shoreline and is estimated to have been active within the last 130,000 years.

Strike dip beds are evident within the Quinault Formation bedrock formations. Two of these strike-dip beds are seen in combination with the northern and southern sides of the diapir structure shown in Figure 62.

3.10.3. Soils

Soils of this reach are dominated by gravelly glacial outwash and silty glaciolacustrine over gravelly outwash materials (NRCS 2011). North of Raft River, this reach is Hoh Assemblage and diapir formations, intermixed with tectonic breccia from the Miocene period, especially concentrated along the cliff faces and shorelines.

South of Raft River, gravelly glacial outwash and silty glaciolacustrine soils are again found, but the addition of loess soils finds placement near the surfaces. These soils are mainly formed of Hoh Assemblage bedrock, intermixed with tectonic breccia characteristics, especially along the cliff faces and at their bases. Large boulder remnants are common along the shoreline cliff bases in response to the wave-cut platform activities.

Immediately surrounding the Raft River drainage, the soils show a high concentration of silty alluvium and eolian sands created by the river in the long journey from watershed headlands to the pour point at the ocean.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

Both sides of Raft River are represented mainly by groups B and D. Group B soils are capable of moderate infiltration rates even when saturated. Group D has a slower infiltration rate, especially at saturation. The group D soils also contribute to cliff-face failures often seen within the Hoh Assemblage. This combination results in subsurface water flows from sites dominated by Group B, which transition to the Group D sites causing inter-structure water evacuations and wasting events.

These inter-structure moisture evacuations are more probable in the Quinault Formation bedrocks, especially where gravelly outwash resides on top of the bedrock formations (ex., Figure 64). When moisture accumulates on the gravelly materials, near the top of the cliff face, water is quickly transitioned to lower and moisture-flow resistant soil layers. As the fluids intercept the Group D class soils, ruptures in the cliff face structure can be seen as rapid avulsions and cliff face failure.

3.10.4. Aerial Imagery

A series of aerial photographs from 1939, 1953, 1954, 1955, 1977, 1980, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the moderate changes observed along the entire coastline within this reach.

3.10.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

Attention can be given to the photograph on page 29 showing the small diapir structure within the Quinault Formation soils. Also recognize how the Quinault Formation cliff faces rise and fall in the cliff face structure as the view is extended northerly. Pages 30 and 31 show examples of the drunken forest characteristics as the cliffs avulse through slumps and slides to the shoreline.

3.10.6. Cautionary Comments

The most active process seen along this reach is the effects of wave-cut platform avulsion along the coastline north of Raft River. Incidental disturbances from cabins and recreational camping structures, and timber harvesting near the cliff faces, has resulted in localized site failures and increased wave-cut platform avulsion. Contributions of LWD come mainly from the drunken forests falling from the cliff face crests as avulsion ushers them to the shoreline.

These shorelines will benefit from an extended setback from the current cliff crest edges where timber harvesting, road building, and recreational structures are limited.

3.11. Whale Creek Reach Assessment

Refer to the “11_Reach_Maps_Whale_Creek.PDF” booklet for maps and oblique photographs along this shoreline.

Whale Creek enters the ocean shoreline as two forks aptly named “North Fork” and “South Fork”. By 1939, the Cape Elizabeth Road extended from near Queets to Cape Elizabeth, with crossings of both forks of Whale Creek. The path in the road was given a jog as it approached the forks to descend to near sea level. This descent was accomplished by placing rip-rap on the ocean side of the road between the forks to stabilize it against sea-side erosion. The road’s bridge crossings were compromised on both forks, LWD accumulations in the channels became considerable, and the road between the forks became impassable (Figure 65). Today the North Fork Whale Creek is plugged by LWD logs in the stream channel.

Figure 65. North Fork Whale Creek (left) notice bridge remnants upstream colored red, and rip-rap placed along the road bank between the Whale Creek forks (right), and the South Fork Whale Creek bridge (lower).

Sand and gravel cliff faces are common surrounding Whale Creek. The materials here are mainly Pleistocene sedimentary materials accumulated within the Olympic Mountains and were transported to their present location by glaciers and streams from the glaciers during two different periods of lime in the Pleistocene Epoch (within the last million to million and a half years). Upper layers were deposited around 17 and 70 thousand years ago during the last glacial period (Figure 66).

Across this reach, recreational cabins have been erected with connecting roads. Most of the access comes from the Cape Elizabeth Road with access near Queets along Highway 101. These cabins and cottages are often placed in close proximity to cliff edges where evolution is likely. Several structures have already been compromised as they fall to the shoreline. Other structures are literally "at the edge" of falling to their demise (Figure 66, Figure 67, 0).

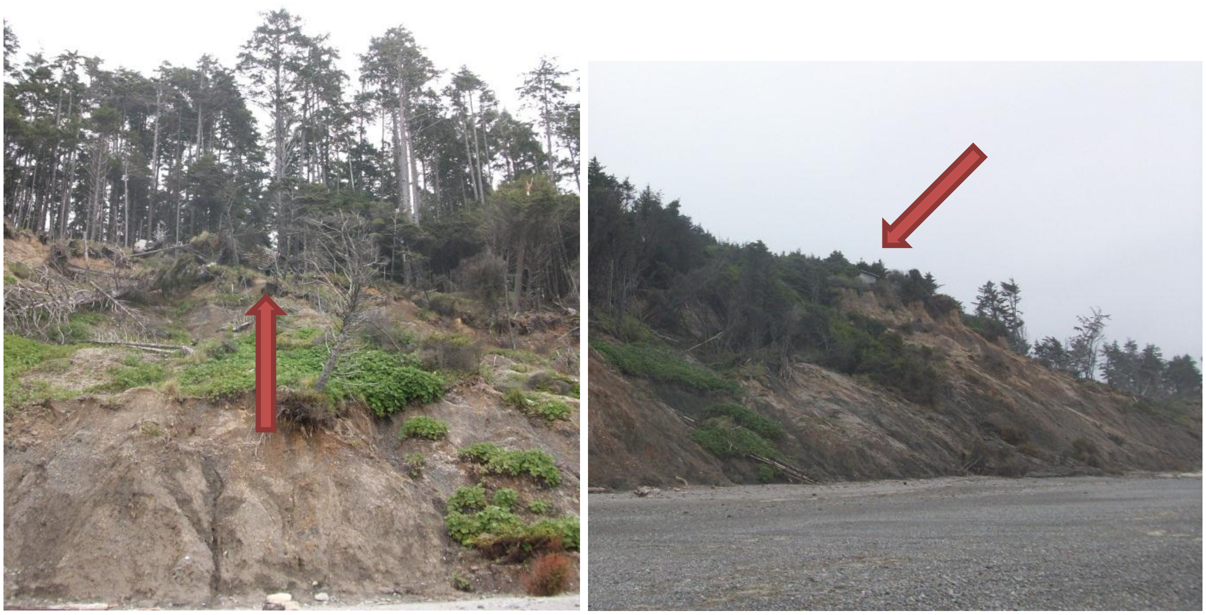
Figure 66. Sand and gravel cliff faces common in the cliffs surrounding Whale Creek.

Evidence of human uses to this reach are seen in the form of camping spots along the shoreline, incidental trails from structures to the shoreline, graffiti (sandstone carvings) in the cliff face, and some debris left on the site. The access to these sites appears to come from the cabins along the cliff crest, although it is uncertain if the owners of those cabins are the shoreline visitors, or if the access is used opportunistically by visitors.

Figure 67. Recreational cabin placed within the avulsing cliff face (left) and slumping Sand and gravel cliff face (right).

The cliff face bases are covered with scattered LWD deposits. Most of those deposits are locally derived tree stems from the avulsing cliff faces. Drunken forests are common along this reach, owing to the low structural integrity of the cliff face materials (sands and conglomerates).

Figure 68. Cliff crest avulsion along the sand and conglomerate cliff tops near Whale Creek that have compromised a cabin (left) and threaten a structure at the crest.



The wave-cut platform against the cliff faces of this reach show signs of equilibrium as the base of the cliffs is eroded by wave-cut action and then rapidly converted to the platform of the ocean shoreline. The slope of the shoreline is moderate to flat, showing little sign of isostatic uplift. Because the basis of these cliffs is sand and gravel, there are no boulders or tectonic mélange materials to be released to the shorelines. The slope of the cliff faces is not perpendicular such as those commonly seen in the Quinault Formation bedrock structures.

Cliffs of this entire reach attain a height of between 80 and 100 feet and form cliffs that are rounded slumping cliff crests on the Pleistocene sedimentary rock structures. The very southern extent of this reach is Quinault Formation bedrock materials that are in thin layers as they yield to the overtopping Pleistocene sedimentary rock structures located to the north.

3.11.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. Most of the shoreline properties are held in Fee status. The areas surrounding the confluence of North Fork and South Fork Whale Creek as it enters the ocean are held in Trust status.

Several cabins and recreational use sites are established on the Fee lands of this reach. Many of the sites have established shoreline access points from their structures. Some of those access points are trails, some are rope ladders, and others are roads. A review of the oblique photos associated with these properties clearly shows access points and apparent uses.

3.11.2. Faults

One major active fault line is dissected in this reach from the ocean side and onland approaching at an angle of about 145^{o} azimuth. This fault is determined to have been active within the last 750,000 years. Strike dip beds are seen within the transition of the Quinault Formation bedrock formations to the Pleistocene sedimentary rock layers. Two of these strike-dip beds are seen in combination within the near shore sedimentary rock structure.

3.11.3. Soils

Near shore soils of this reach are dominated by glacial outwash derived from igneous and metamorphic and sedimentary rock. These layers are mostly loosely organized and collapse when exposed to compaction, erosion, or weight bearing burdens. Onshore from the top of the cliffs, the materials are silty glaciolacustrine over gravelly outwash materials (NRCS 2011). These materials are also loosely organized and collapse when exposed to burdens.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

The riparian areas of both sides of Whale Creek, and the cliff faces of the marine shorelines are represented mainly by Group B soils. Group B soils are capable of moderate infiltration rates even when saturated.

Group D has a slower infiltration rate, especially at saturation. This group of soils is found along the tops of the hillsides and along the marine shoreline. These areas feed surface water to the riparian zones where the creeks transport the water to its ocean destination. This combination of soil hydrologic groups is not burdensome as has been seen in other reaches of the Quinault marine shorelines.

3.11.4. Aerial Imagery

A series of aerial photographs from 1939, 1952, 1953, 1954, 1955, 1977, 1980, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document. The viewer can give attention to the changes observed along the shoreline south of Whale Creek and immediately west of the Cape Elizabeth Road where it turns at a 90^{o} angle from north/south, to east/west. The shoreline cliffs have progressively formed a slump depositing cliff materials to the shoreline. This area is shown on the oblique view on page 27 of the referenced document.

3.11.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

This reach is home to many separate Fee parcels that have been used for recreational purposes during the past century. Cabins and recreational structures are clearly seen across this reach, especially south of Whale Creek.

3.11.6. Cautionary Comments

The recreational uses along this reach have led to cliff crest avulsion, slumps, and other site failures. These site impairments are magnified by the wave-cut platform process that weakens the cliff faces from the shoreline base. At failure, the cliff's materials are escorted to the shoreline and then washed out to sea. The most permanent feature of this process is the cobbles that remain incorporated into the marine near shore environment, and the LWD that remains near the shore-cliff interface.

Because of the structurally incoherent characteristics of these materials, site developments, road building, and even timber harvesting should be extremely limited in this reach. These materials are prone to failure when disturbed. The set-back recommended for the Hoh Assemblage and Quinault Formation bedrock materials may be modified to include 3 times the height of the shoreline cliff crest, or 500 feet from the cliff crest, whichever is greater. This extends the "set-back" from 2 times the cliff crest height, to 3 times, in order to limit the disruptions to the cliff faces from disturbances.

3.12. Cape Elizabeth Road (North) River Reach Assessment

Refer to the "12_Reach_Cape_Elizabeth_Road_North.PDF" booklet for maps and oblique photographs along this shoreline.

This reach extends form the northern extent of the Whale Creek reach to the southern side of the Queets River riparian zone. Although access is provided from the Cape Elizabeth Road's access to Highway 101, actual direct access to the shorelines of this reach is limited from that route. Steep cliffs prevent a person's ability to descend directly from the cliff crest to the shoreline safely. A couple of Fee owners along this reach have extended rope-lines from the crest to the shoreline. At least one temporary trail was placed to traverse the cliff face in a zig-zag pattern to reach the shoreline. That particular trail (at about 47°30'10", and shown on page 24 of oblique views) avulsed from the site disruptions soon after establishment.

In order to reach this area for this assessment, we traveled to Whale Creek along the Cape Elizabeth Road, walked the abandoned road to the shoreline (climbing over the LWD in the river channel), then walked north along the marine coastline. At the northern terminus of this reach, the Queets River, further access was curtailed. The return trip involved retracing our path. There appeared to be no 'easy path' to the shorelines from the Cape Elizabeth Road, except the one we took.

The Pleistocene sedimentary materials of this reach are a continuation of the materials seen within the Whale Creek reach. These are unconsolidated materials and they react unfavorably to site disruptions. Sand and gravel cliff faces are common. These materials accumulated within the Olympic Mountains and were transported to their present location by glaciers and streams from the glaciers during two different time periods in the Pleistocene Epoch.

Fee parcels within this reach have erected recreational structures at the top of the cliff faces. Some have an extended set-back from the cliff edge. This set-back is beneficial to the stability of the cliff structure (Figure 69). Other edifices were erected close to the cliff faces, or with parking areas located very near the cliff edge. Where these are located, cliff crest failure has followed (ex., page 28 of oblique views).

Figure 69. Fee parcel with a significant cabin set-back from the cliff edge, limiting site disruptions.

This shoreline shows an active wave-cut platform structure with the gravelly deposits avulsed from the cliff base materials, eroded by repeated wave actions, and then re-deposited along the near-shore wave platform. Part of the result is to leave a smooth and gravelly shoreline, with a low relief angle out to sea (Figure 70). The accumulation of LWD along this reach is minimal and comes from cliff crest contributions as the sites are avulsed.

Isostatic uplift in this reach is not evident as the near shore approach from the ocean to the cliff crests is generally slight. Further north, past the Queets River and in the direction of Kalaloch, the reader will see evidence of isostatic uplift along the Northern Quinault shorelines in conjunction with the syncline near Kalaloch where the terrain is subsiding. The nearby Northern Quinault shorelines are reacting with uplift caused by the nearby syncline event. The isolation of uplifting versus subsiding to this reach may be in reaction to the active fault line located near the current path of the Queets River. That tectonic attribute may be the moderating force between these features (a pressure relief regulator – of sorts). At this time, this reach appears to be seismically stable.

Cliff crests are generally 80 to 100 feet above the marine shoreline. In some places the cliffs are abrupt (steep) while in others it is a crumbled mix of site failures. These sites react favorably to retained forest vegetation without harvest (Figure 70).

Figure 70. Pleistocene sedimentary materials of this reach are mainly gravels deposited by glacial outwash (Workman 2012).

3.12.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. Shoreline properties along this reach are held in Fee, Trust, and Quinault ownership status. Several cabins and recreational use sites are established on the Fee lands of this reach. Many of the sites have established shoreline access points from their structures. Some of those access points are (failed) trails and some are rope ladders. A review of the oblique photos associated with these properties clearly shows access points and apparent uses.

3.12.2. Faults

There are no fault lines within this reach, although one major fault line is co-located north of this reach with the Queets River.

3.12.3. Soils

Near shore soils of this reach are dominated by glacial outwash derived from igneous and metamorphic and sedimentary rock. These layers are mostly loosely organized and collapse when exposed to compaction, erosion, or weight bearing burdens. Onshore from the top of the cliffs, the materials are silty glaciolacustrine over gravelly outwash materials (NRCS 2011). These materials are also loosely organized and collapse when exposed to burdens.

Hydrologic soil groups are based on estimates of runoff potential (Section 2.4). Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

The cliff faces of the marine shorelines are represented mainly by Group B soils. Group B soils are capable of moderate infiltration rates even when saturated.

Group D has a slower infiltration rate, especially at saturation. This group of soils is found along the tops of the hillsides and along the marine shoreline. This combination of soil hydrologic groups is not burdensome as has been seen in other reaches of the Quinault marine shorelines.

3.12.4. Aerial Imagery

A series of aerial photographs from 1939, 1952, 1953, 1954, 1955, 1977, 1980, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document.

The viewer can give attention to the changes observed along the shoreline at about 47°31’10”, where the access road connects US Highway 101, to Cape Elizabeth Road, and extends to near the shoreline cliff terminus. At the end of this road, the parking area near the cliff face has enlarged since 1977, when the road was rerouted. However, the cliff face edge has not horizontally changed appreciably as a result to those disruptions according to these overhead views. However, a look at pages 28 and 29, the oblique views, shows this area as a crumbled cliff face dissolving under the force of the disrupted surface at the end of the road. The angle of the cliff has collapsed from nearly vertical, to an almost 45° angle of undulating features.

3.12.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

This reach is home to many separate Fee parcels that have been used for recreational purposes during the past century. Cabins and recreational structures are clearly seen across this reach. Attention can be given to the users who apparently tried to gain access to the shorelines from their parcels, causing cliff face rivulets of erosion and other site failures. Parking areas and structures erected near the cliff edges have demonstrated cliff avulsion.

3.12.6. Cautionary Comments

Because of the structurally incoherent characteristics of these materials, site developments, road building, and even timber harvesting should be extremely limited near the cliff edges in this reach. These materials are prone to failure when disturbed. As with the recommendation for Whale Creek Reach, the set-back recommended may be modified to include 3 times the height of the shoreline cliff crest, or 500 feet from the cliff crest, whichever is greater. This extends the “set-back” from 2 times the cliff crest height, to 3 times, in order to limit the disruptions to the cliff faces from disturbances.

3.13. Queets River Reach Assessment

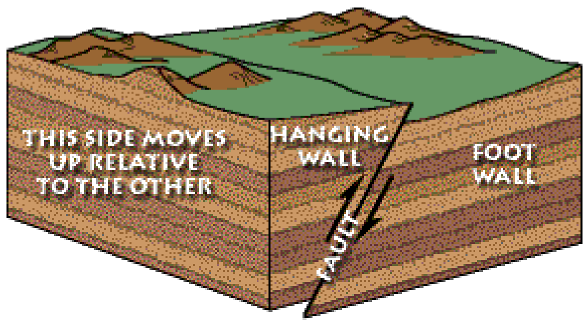
Refer to the “13_Reach_Maps_Queets.PDF” booklet for maps and oblique photographs along this shoreline.

This entire reach spans the Queets River pour point into the Pacific Ocean. The mouth of this river has meandered extensively at this termination point. The changes to the river shoreline and the marine shoreline are linked through sediment delivery, LWD contributions and storage, and vegetative composition. This particular reach is in the status of building tectonic pressures in response to the syncline centered near Kalaloch. The reader is urged to review the accompanying document “Relative Sea Level Change Along Quinault Indian Reservation

Marine Coastlines", Section 3.2.2. "Glacial Load and Isostatic Rebound", and Figure 19, for a detailed discussion of the tectonic forces causing the syncline event. The force of the Syncline happening to the north of the Queets River is first seen in the northern adjacent, and last, reach of the QIN marine shorelines where shoreline uplift is noticeable. However, to the south of this reach, in the "Cape Elizabeth Road (North) River Reach Assessment", the shorelines are relatively level as the wave-cut platform extends into the near shore environment.

We speculate that the moderation of the uplift seen to the north of this reach, and not to the south, is caused by the fault line co-located with the path of the Queets River. This fault line may be releasing pressures between the tectonic plates in a reverse fault manner (Figure 71). Usually faults do not have purely up-and-down or side-by-side movement. It is much more common to have some combination of fault movements occurring together (USGS 2000).

Figure 71. Reverse fault structure speculated for the Queets River fault.



This reverse fault reaction may be responsible for the tectonic deformations to the north, while the geologic features to the south remain mostly unmodified. In time, it is likely that the syncline near Kalaloch and the uplift north of the Queets River will reach balance during and after a tectonic event, such as a rupture of the locked plate feature (earthquake).

3.13.1. Faults

There is one active fault line in this reach, co-located with the general valley of the Queets River. Details about this fault are previously discussed.

3.13.2. Aerial Imagery

A series of aerial photographs from 1939, 1952, 1953, 1954, 1955, 1977, 1980, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document.

The viewer can give attention to the changes observed in the Queets River meanders during these 60+ years. Since about 1994, the outlet into the Pacific Ocean has been fairly constant (where it is today). Prior to this time, the pour-point was consistently north of the current outlet area.

It is likely that the syncline near Kalaloch referenced earlier in this section may have started to take effect about that time. The lifting of the adjacent northern shelf in response to changes near Kalaloch may be the force causing the outlet of the Queets River to be diverted to its current position. This is the reverse fault structure effects demonstrated in Figure 71.

3.13.3. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

3.13.4. Cautionary Comments

There are few anthropogenic activities taking an impact on this particular reach, as it serves as the riparian outlet zone of the Queets River. The biggest cautionary comment is to expect a tectonic event, such as an earthquake, in the near future as the pressures of the syncline near Kalaloch is released. The length of time for that "near future" event is impossible to predict at this point. It may be within the next decade, or it may be within the next century.

3.14. QIR North Beach Reach Assessment

Refer to the "13_Reach_Maps_QIR_North_Beaches.PDF" booklet for maps and oblique photographs along this shoreline.

This reach includes the northern most marine shorelines of the QIR. Most of this area is included in the assessment of the Queets River riparian zone near the pour point into the Pacific Ocean. Discussions have already detailed the uplift seen along these beaches in response to the syncline near Kalaloch.

The uplift of the shorelines here is drastically different from the shorelines south of the Queets River, and ranges from about 11° to 23° (Figure 72 & Figure 74). The shoreline materials are generally glacial outwash materials derived from igneous, metamorphic, and sedimentary rocks. Most of these materials are pre-Fraser period, from the Pleistocene Epoch (Figure 73).

Figure 72. Marine shoreline uplift showing an angle of about 14° from ocean level, to up shore high tide terminus.

Figure 73. Gravels of the North Beach Shorelines include Pleistocene Epoch pebbles, cobbles, stones, and greywacke.

Driftwood along these shorelines exceeds the LWD concentrations found on any other reach of the QIR marine shorelines. The source of these accumulations apparently comes from locally contributed LWD from the Queets River as it meandered from its pre-1977 pour point in the northern extent of this reach. In this area, the LWD was accumulated and mostly remains there today.

Figure 74. Large Woody Debris armoring the shorelines along North Beach.

Since 1977, the Queets River's entry into the Pacific Ocean has been contained to the area near the active fault line found there. The delivery of LWD is still obvious along this river, and the LWD materials are still being delivered to the marine shorelines. Additional LWD materials are taken on from nearby and distant sources. These are combined with the local accumulation of LWD to account for the high degree of armoring found along these shorelines.

A few recreational uses of these shorelines were observed in the form of camping spots, picnic areas, driftwood art (Figure 75), and active journeying of the shorelines. Although the QIR marine shorelines are closed to non-permitted users, there are no signs identifying this to incidental users along the shorelines, nor was the activity patrolled by QIN authorities while we were on the site. The recreational sites at Ashenbrenner Picnic Area and the NPS South Beach Campground give visitors easy access to these areas.

Figure 75. Driftwood art found along the North Beaches marine shorelines.

3.14.1. Owner Status

Parcel ownership status shows the current database of parcels on the QIR for this reach. The northern extent of this marine shoreline reach is held in Fee status. Although many of the southern reaches are populated with recreational cabins, these areas have permanent homes and at least one commercial lodging facility. Roads to the shorelines are not found, although trails give many people easy access to the QIR shorelines.

3.14.2. Faults

There are no fault lines within this reach, although one major fault line is co-located south of this reach with the Queets River.

3.14.3. Soils

Near shore soils of this reach are dominated by glacial outwash derived from igneous, metamorphic, and sedimentary rock. When found on slopes, these layers are mostly loosely organized and collapse when exposed to compaction, erosion, or weight bearing burdens. Onshore from the top of the bluffs, the materials are silty glaciolacustrine over gravelly outwash materials (NRCS 2011). The bluffs adjacent to this shoreline are only about 40’ above the marine shorelines, and decrease to only 20’ as moving southward.

The residential structures located here are placed on top of unconsolidated gravels, but the low relief of these sites reduces site failure risks.

3.14.4. Aerial Imagery

A series of aerial photographs from 1939, 1953, 1954, 1955, 1977, 1980, 1994, and 2000, and color aerial imagery from 2005, 2006, 2009, 2011, and 2012 are presented in series in the accompanying document.

The viewer can give attention to the changes observed in the Queets River meanders prior to about 1994, when the outlet into the Pacific Ocean was fairly constant (north of where is it today). After that time, 1994, the pour-point has been consistently south of this reach.

3.14.5. Oblique Views

The oblique views collected by the WaDoE give the reader visions of the coastal surfaces from August 2006. These images are consecutively ordered from the southern edge of this reach moving northerly.

This reach is home to many separate Fee parcels that have been used for permanent home and business purposes. Structures are obvious to the viewer of these images. Also obvious, are the heavy accumulations of LWD along this shoreline, extending into the former river bed slightly inland and where the Queets River once meandered.

The oblique view photographs are extended to the NPS North Beach campground (off-Reservation).

3.14.6. Cautionary Comments

These shoreline beaches are made from unconsolidated conglomerates currently being uplifted by the syncline located near Kalaloch. It is predictable that the stresses accumulating in that tectonic discontinuity will eventually be released in an earthquake that may be felt most directly in this area.

The heavy accumulations of the LWD materials along this coast are beneficial to shoreline stability in this reach. It is strongly recommended that these resources are protected from defacement or transportation off the site.

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