Special Section

SEA LEVEL RISE

INTRODUCTION

The Port Gamble S'Klallam Tribe is particularly concerned about how sea level rise will impact its land, resources, infrastructure, and community, and this section therefore dives more deeply into projected changes.

Warming temperatures are causing increased rates of ice melt and thermal expansion of water all over the world [1]. For many coastal regions, these changes have led to rising sea levels that have contributed to increased coastal flooding and changes in habitat structure.

According to the University of Washington Climate Impacts Group, sea level rise in the Puget Sound region is expected to continue throughout the 21st century and will permanently inundate some low-lying coastal areas [2]. Sea level rise will also increase the frequency, magnitude, and duration of flood events and accelerate coastal erosion [2]. These changes will affect coastal habitat and could damage coastal infrastructure that includes, among other assets, fisheries and shellfish-harvesting equipment and operations. As a result of regional differences in vertical land movement (caused by tectonic uplift, isostatic rebound, and/or excessive groundwater withdrawal), sea level rise will not be uniform throughout Puget Sound or the Olympic Peninsula.

SEA LEVEL RISE PROJECTIONS

Data records from tide gauges as far back as the 1880s have made reliable global projections of sea level rise possible [1]. More recently, technological advances (e.g., satellite measurements, sophisticated climate models) have allowed for more accurate sea level rise observations and projections at global and local scales [1]. Most of these projections forecast conditions up to 2100, but researchers believe sea level rise will continue for at least several centuries [1].

Sea level rise projections reflect the statistical relationship between historical sea level, temperature data, and probable future climatic conditions under various greenhouse gas emissions scenarios [3]. However, climate models are not useful for predicting major state shifts of the Earth's physical processes, including shifts in ice sheet dynamics on Greenland and Antarctica that may lead to faster rates of sea level rise (now generally accepted as a possibility within the 21st century) [3]. Accordingly, projected rates of future sea level rise beyond 2100 are uncertain at best and are potentially underestimated [3].

GLOBAL SEA LEVEL RISE

Globally, the annual rate of sea level rise has accelerated in recent decades. Since the mid-1800s, the rate of sea level rise has been larger than in the past two millennia [4]. It is *very likely* that the rate of global mean sea level rise was +1.7 millimeters per year (range: +1.5 to +1.9 mm/year) between 1901 and 2000 [5].[1] Satellite altimetry data became available starting in 1993; those measurements show that between 1993 and 2010, the mean rate was *very likely* higher at +3.2 (range: +2.8 to +3.6) millimeters per year [5].

Antarctic Ice-melt

New concerns have arisen within the climate science community that global sea level rise estimates could be underestimated, mostly due to uncertainty around the contributions from melt on Greenland and Antarctica. For example, research from Joughin et al. published in 2014 showed that the collapse of Antarctic glaciers may already be taking place as a result of warm water circulating around Antarctica [6].

[1] Likelihood of the outcome is 90 to 100%.

This destabilization effect of warm ocean currents on Antarctic ice sheets has been echoed in a 2016 study by DeConto and Pollard [7]. When considering this potential for more drastic Antarctic ice melt, global sea level rise projections nearly double previous estimates, suggesting that 6 feet of sea level rise by 2100 is possible [7].

Greenland Ice-melt

Greenland's contribution to global sea level rise is in the form of melt-water runoff and ice discharge from calving glaciers [8]. Future projections based on multiple RCP scenarios predict that Greenland will continue to contribute to global sea level rise beyond 2100, with the high emissions scenario (RCP 8.5) showing significant increases of Greenland ice-melt and corresponding sea level rise throughout the next century [8]. Kopp et al. concluded that global sea level could rise up to 4 feet by 2100 based on the RCP 8.5 scenario; this estimate includes ice-melt from Greenland and Antarctica as well as thermal expansion of water [9].

For more detail on the science behind what is causing additional ice-melt on Greenland and Antarctica, please refer to the chapter on Nonlinear Changes in Climate.

LOCAL SEA LEVEL RISE

Sea level rise projections vary within Washington State due to regional differences in tectonic activity, isostatic rebound, and subsidence rates. Estimates for Port Townsend and Seattle are among those most useful to understand local sea level rise for the Tribe, given the proximity and the long record of observed data from these stations. See Table 1 for projected ranges of sea level rise for years 2050 and 2100.

Table 1. Projected ranges of sea level rise at Port Townsend and Seattle by 2050 and 2100. Ranges reflect modeling based on various emissions scenarios, including a "business as usual" scenario.

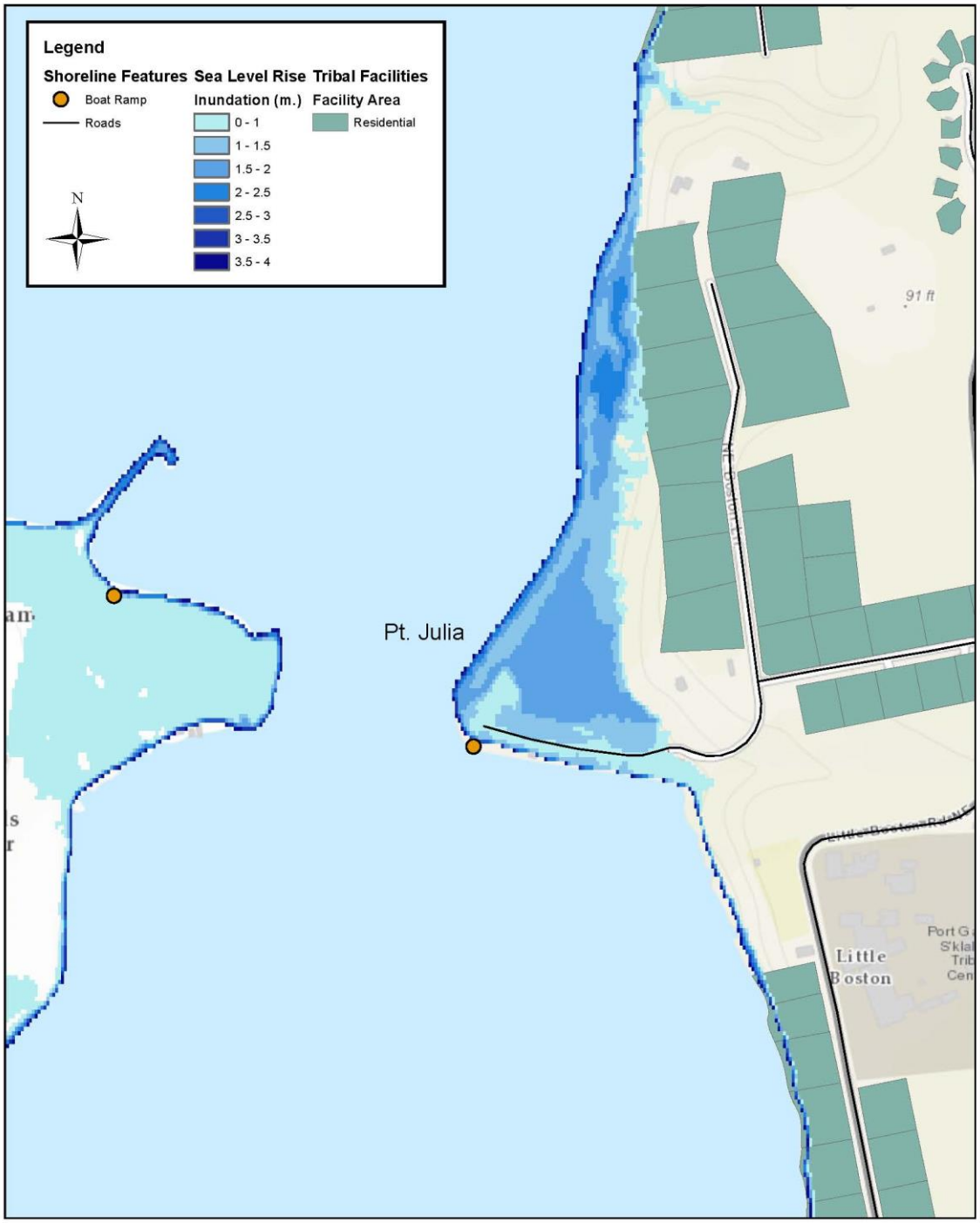
Location	Projected sea level rise by year
Port Townsend [10]	2050: 5 to 18 inches 2100: 12 to 62.5 inches
Seattle [11][2]	2050: 7 to 19 inches 2100: 24 to 56 inches

Changes in local sea level ("relative sea level") reflect changes in global sea level as well as changes in local factors that determine the amount of sea level change at a particular location. King tides and storm surge help to simulate what can be expected in the future. A king tide in the winter of 2015 inundated nearly all of the Point Julia boat launching area (see Figure 1). In addition to inundation, these temporary events give scientists and resource managers a chance to observe what other effects sea level rise may have on bluffs, wetlands, shellfish-harvesting areas, and other important coastal resources [12]. Figure 2 shows expected areas of inundation along the Port Gamble coast with 6 feet of sea level rise.

[2] In Seattle, sea level rose by approximately +9 inches between 1900 and 2008 [2].

Figure 1. Point Julia boat launch inundated during a king tide event in December 2015.
Photo: Hans Daubenberger, Port Gamble S'Klallam Tribe.

Figure 2. Projected inundation of Point Julia and adjacent areas in a scenario with 6 feet (1.83 meters) of sea level rise. The darker blue patch just off the immediate shoreline includes the low-lying wetland area that is directly north of Point Julia Road. This area was flooded during the king tide event in December 2015 (as pictured in Figure 1).



Data Sources: Point No Point Treaty Council and National Oceanic and Atmospheric Administration

The Tribe is currently working with the University of Washington to forecast local relative sea level through 2160, combining regional projections with data from tide gauges and continuous GPS stations in or near Tribal lands. This section will be updated when the new data are available in 2017.

Impacts of Sea Level Rise

Because of variations in the coastal geography of Western Washington, the effects of sea level rise will differ from place to place as well. At many sites, the impacts could include the following:

- Changes in tidal and intertidal zone habitats: More than half of beach land in the upper Hood Canal and Kitsap Peninsula is predicted to be lost and converted to tidal flats by 2050 because of sea level rise [13]. Additional detail can be found in the Wetlands chapter. The Tribe is currently working with the University of Washington to better understand potential impacts on local estuaries and the resulting consequences for shellfish habitat.

- Risk of damage to infrastructure and drainage: Higher groundwater levels and changing hydraulic gradients in stormwater drainage outfalls can affect coastal aquifers and make it more difficult to drain stormwater and wastewater effluent.

- Shoreline and bluff erosion: Storm surges on top of sea level rise will contribute to increased erosion of shorelines. While storm surge is not projected to change, storm surge will reach higher as a result of rising sea levels. Additional information about bluff erosion on and near the reservation can be found in the Infrastructure chapter.

Responses to Sea Level Rise

- Shoreline armoring: Some communities and property owners are increasingly armoring shorelines (that is, using physical structures to reduce coastal erosion) to protect infrastructure and development close to the water. Regrettably, this armoring can further degrade habitats and exacerbate beach erosion in areas without armoring, as it disrupts natural coastal processes that sustain beaches and it prevents beaches from moving inland over time.

  Shoreline armoring projects in Washington are permitted through the Washington Department of Fish and Wildlife's (DFW) Hydraulic Project Approval (HPA) process [14]. Immediately preceding a coastal storm event, the DFW can issue emergency HPAs to homeowners that apply for them [14]. To expedite permitting before an event, these emergency HPAs are exempt from the SEPA process (including public comment) [14]. With the potential for more frequent or rapid coastal erosion expected with sea level rise and storm surges, it is possible that the SEPA-exempt emergency HPAs will become more widely used. More research is needed to determine the impacts to coastal habitat that the increased use of emergency HPAs would have.

- Retreat: For communities experiencing recurrent flooding and bluff erosion, managed retreat away from hazardous areas is perhaps the only way to completely avoid all risk associated with sea level rise [15]. On Washington's outer coast, the Quinault Tribe has begun the planning phase to relocate its Taholah village to higher ground away from the coast after repeated seawall breaches, intense flooding, and culvert failures from storms in 2014 and 2015 [16].

- Accommodation: Accommodating sea level rise includes actions that avoid retreating from the coast but do not change the characteristics of the shoreline and allow sea level rise to occur [17]. In some coastal communities, accommodation can be in the form of elevating structures located in flood zones [17]. The floating bridges, docks, and homes found throughout the Puget Sound region could also be considered a way to accommodate sea level rise [18].

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