

SECTION 4

How will Climate Change affect Sea Level?

The Puget Sound region is projected to experience continued sea level rise throughout the 21st century, increasing the potential for more frequent coastal flooding and increased erosion. These changes, which have significant implications for human, plant, and animal communities, will be most pronounced for places such as Seattle, where land elevations are subsiding. Sea level rise will permanently inundate some low-lying areas and will increase the frequency, depth, and duration of coastal flood events by increasing the reach of storm surge and making it harder for flood waters in rivers and streams to drain into Puget Sound. In addition to expected shifts in coastal and marine habitats, sea level rise is expected to damage coastal infrastructure, inundate commercial and industrial areas, and reduce harvest for fisheries and shellfish operations. Efforts to address sea level rise are increasing, particularly with respect to infrastructure, where sea level rise projections are being incorporated into local and regional planning.

Climate Drivers of Change

DRIVERS *Local sea level variations are driven by global, regional, and local factors.*

- *Multiple factors affect regional sea level.*^A The rate of sea level rise in Puget Sound^B depends both on how much global sea level rises and on regionally-specific factors such as ocean currents, wind patterns, and the distribution of global and regional glacier melt.^C These factors can result in higher or lower amounts of regional sea level rise (or even short-term periods of decline) relative to global trends, depending on the rate and direction of change in regional factors affecting sea level.^{1,2,3,4,5}
- *Differences in land movement affect local rates of sea level rise.* Due to the active tectonics of the Pacific Northwest, land elevations are changing. For example, in

^A This is often referred to as the “eustatic” sea level, which refers to the height of the water surface irrespective of land elevation (i.e., relative to a fixed point, such as the center of the earth).

^B Throughout this report, the term “Puget Sound” is used to describe the marine waters of Puget Sound and the Strait of Juan de Fuca, extending to its outlet near Neah Bay. The term “Puget Sound region” is used to describes the entire watershed, including all land areas that ultimately drain into the waters of Puget Sound (see “How to Read this Report”).

^C Large ice sheets and glaciers exert a gravitational pull. In the same way that the tides are a response to the pull of the moon and the sun, glaciers can result in slightly elevated sea level within their vicinity, and slightly lower sea level elsewhere. As these glaciers melt (e.g.: in Antarctica, Greenland, and Alaska), the gravitational pull of each changes, resulting in regional changes in the height of the ocean surface.

Neah Bay the land elevation is rising at a rate of about +1 in./decade, whereas in Seattle it appears to be falling at a rate of about -0.5 in./decade.^{D,3} In areas where the land is rising, the local rate of sea level rise will either be slowed or reversed. In areas where the land is subsiding, the pace of local sea level rise will increase.¹

- *Short-term sea level variations can temporarily offset or accelerate trends.* Sea level can be temporarily elevated or depressed by up to a foot in winter as a result of natural cycles in climate patterns such as El Niño (see Section 6).^{1,6,7}
- *A large earthquake could result in an abrupt increase in sea level along the outer coast, including Neah Bay.* The last great earthquake (magnitude greater than 8) to have occurred along the Cascadia Subduction zone resulted in a sudden drop in land elevation – and resulting rise in sea level – of up to 6 ft. along Washington’s outer coast and the Northwest Olympic Peninsula. Although the associated rise in land elevation (drop in sea level) for interior Puget Sound will be much smaller, earthquakes occurring on other faults (e.g., the Seattle fault) could lead to an abrupt drop in land elevation in some areas.^{1,8,9,10,11}

Observed Changes

OBSERVED Global sea level is rising, and the same is true in most of Puget Sound.

Trends vary from location to location, including a decline in sea level in Neah Bay.^B

- *Global sea level is rising, and the rate of rise is unprecedented.* Global average sea level rose about +8 inches from 1900-2009. Since the mid-1800s, the rate of sea level rise has been larger than in the past two millennia.¹
- *Sea level is rising at most locations in or near Puget Sound.* At the Seattle tide gauge, one of the longest-running gauges in Puget Sound, sea level rose by +8.6 inches from 1900 to 2008 (+0.8 in./decade).² Although sea level is rising at most locations, records show a decline in sea level for the northwest Olympic peninsula, a region experiencing uplift. At the Neah Bay tide gauge, for example, relative sea level dropped by -5.2 inches from 1934 to 2008 (-0.7 in./decade).²

OBSERVED There is no evidence of a change in storm surge in Puget Sound, and research is lacking regarding changes in wave heights.

- *There is no evidence of a long-term trend in storm surge.*^E No study has comprehensively analyzed observations of storm surge heights across Puget Sound. However, one study found that trends in extreme high water levels along the Pacific

^D In addition to tectonics, land elevation can fall as sediments become more compact over time, in response to groundwater or fossil-fuel extraction, or due to increased drainage on newly-cultivated agricultural lands. Sediment compaction is most commonly associated with wetlands or river deltas.

^E Storm surge is the result of the high winds and low surface pressures that accompany storm events. Neither waves nor seasonal changes in sea level (e.g., due to El Niño) are included in the definition of surge.

Northwest^F coast are simply a reflection of increases in sea level, rather than resulting from an increase in surge.¹²

- *It is not known how waves within Puget Sound will change in the future.* Previous studies have evaluated wave heights measured by offshore buoys,^{13,2} but waves within Puget Sound are primarily driven by local winds as opposed to ocean swell.^G
- *Observed trends in wind speed are ambiguous.* Some studies find increases, others find decreases, and others conclude that there is no significant trend in winds for the Pacific Northwest region: results depend on the data and methods used for the analysis.^{14,15,16,17}

Projected Changes

PROJECTED *Sea level is projected to continue rising through the 21st century, increasing by +14 to +54 inches in the Puget Sound region by 2100 (relative to 2000).²* Local rates of rise could be higher or lower than this range, depending on the local rate of vertical land motion. For example, the relative rise in sea level projected for Seattle ranges from +4 to +56 inches by 2100 (relative to 2000).²

- *Global sea level is projected to increase by +11 to +38 inches by 2100* (relative to 1986-2005), depending on the amount of 21st century greenhouse gas emissions.^{H,I,1} All studies project an increase in global sea level for all greenhouse gas scenarios, although different approaches result in different estimates of the exact amount of sea level rise projected (Figure 4-1).
- *Differences among projections are primarily due to different methods for estimating the rate of ice melt on Greenland and Antarctica.* There are many factors that influence the range among regional sea level rise projections, including global models, greenhouse gas scenarios, and estimates of the rate of vertical land motion. The most important of these is the method used to estimate future changes in ice sheets on Greenland and Antarctica. All three of the estimates shown in Figure 4-1 employ different approaches to estimating the rate of ice sheet melt.^{J,1,18}

^F Many characteristics of Puget Sound's climate and climate vulnerabilities are similar to those of the broader Pacific Northwest region. Results for Puget Sound are expected to generally align with those for western Oregon and Washington, and in some instances the greater Pacific Northwest, with potential for some variation at any specific location.

^G "Swell" is the term used for waves that are generated by some distant weather event (e.g.: a low pressure system). These are still generated by winds, but at some remote location from which the swell originates.

^H Greenhouse gas scenarios were developed by climate modeling centers for use in modeling global and regional climate impacts. These are described in the text as follows: "very low" refers to the RCP 2.6 scenario; "low" refers to RCP 4.5 or SRES B1; "moderate" refers to RCP 6.0 or SRES A1B; and "high" refers to RCP 8.5, SRES A2, or SRES A1FI – descriptors are based on cumulative emissions by 2100 for each scenario. See Section 1 for details.

^I Sea level rise projections vary with greenhouse gas scenarios. The average and associated ranges reported in IPCC 2013¹ are +17 in. (range: +11 to +24 in.) for the very low (RCP 2.6) greenhouse gas scenario to +29 in. (range: +21 to +38 in.) for the very high (RCP 8.5) scenario. See Section 1 for more details on greenhouse gas scenarios.

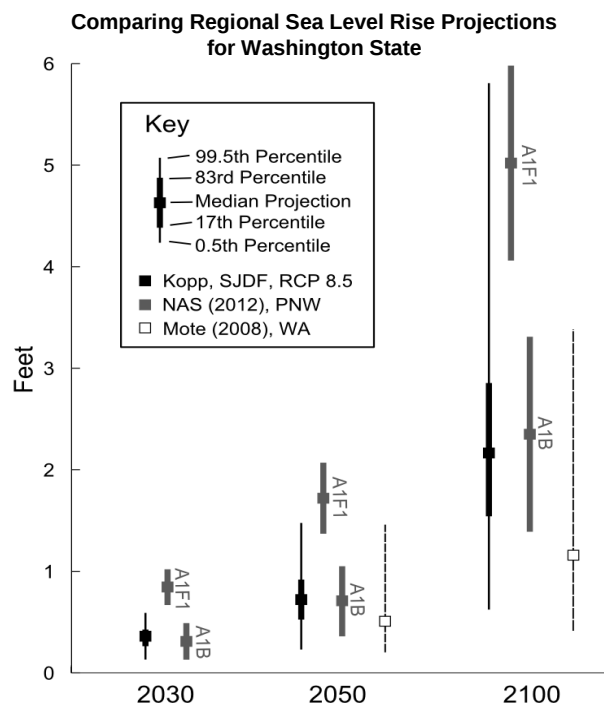


Figure 4-1, Table 4-1. Regional absolute^A sea level rise projections for Puget Sound are roughly similar among different studies, but there are important differences. Projections are for “eustatic” sea level,^A which is independent of changes in land elevation. Results are shown in inches for 2030, 2050, and 2100 (relative to 2000), from three regionally-specific studies:^K Petersen et al. 2015^{L,3} (based on Kopp et al. 2014),¹⁸ NRC 2012,^{M,1} and Mote et al. 2008.^{O,5} Values shown are the central (for NRC 2012), medium (for Mote et al. 2008), or median (for Petersen et al. 2015) projections, with the projected range included for each (for Petersen et al. 2015, the range corresponds to the 99% confidence limits). For simplicity only the results for the high (RCP 8.5, see Section 1) scenario from Petersen et al. 2015 are included in the table. *Figure Source: Petersen et al. 2015.³ Reproduced with permission.*

Domain	2030	2050	2100
Strait of Juan de Fuca (Petersen et al. 2015) ^{3,18}	+4 inches (+1 to +6 in.)	+7 inches (+1 to +14 in.)	+23 inches (+6 to +55 in.)
Washington State (NRC 2012, without uplift ^N) ¹	+4 inches (+1 to +8 in.)	+9 inches (+4 to +18 in.)	+28 inches (+14 to +54 in.)
Puget Sound (Mote et al. 2008) ⁵	---	+ 6 inches (+4 to +15 in.)	+13 inches (+7 to +37 in.)

^J Studies take different approaches to estimating the rate of melt for the major ice sheets on Greenland and Antarctica. Some use statistical relationships to extrapolate from past trends (e.g., NRC 2012¹), others use physical models of ice sheet dynamics (e.g., IPCC 2013¹) and others incorporate expert judgment (e.g., Kopp et al. 2014¹⁸).

^K Regional projections between Mote et al. (2008)⁵, NRC (2012)¹, and Petersen et al. (2015)^{3,18} differ due to the different approaches to estimating global sea level rise and local influences on the relative rate of rise. Among other differences, the Petersen et al. (2015) projections assign probabilities, whereas the others are scenario-based. Mote et al. 2008 do not provide projections for 2030.

^L The regional sea level rise projections for the northern Olympic Peninsula in Petersen et al. (2015)^{3,18} combine global sea level rise with regional factors affecting trends. They apply the probabilistic approach developed by Kopp et al. (2014).¹⁸ Kopp et al. combined multiple projections of sea level rise and incorporated expert surveys to develop a new set of probabilistic sea level rise projections. Results listed in Table 4-2 show the median and the 99% confidence limits, based on a high (RCP 8.5) greenhouse gas scenario.

^M Calculated for the latitude of Seattle, Washington (NRC 2012), assuming that the land elevation is uplifting at a rate of 1 ± 1.5 mm/yr ($\sim 0.4 \pm 0.6$ inch/decade).¹ This is likely an underestimate of sea level rise for Seattle, since most observations of vertical land motion suggest either subsidence or no motion at all. The mean value reported in NRC (2012) is based on the moderate (A1B) greenhouse gas emissions scenario. The range stems from projections for a low (B1) to a high (A1FI) greenhouse gas emissions scenario, as well as the upper and lower estimates of vertical land motion for the region.

- *Regional absolute sea level^A is projected to rise.* According to a recent report by the National Research Council (NRC), regional absolute sea level is projected to rise an additional +14 to +54 inches in the Puget Sound region by 2100 (relative to 2000).¹
- *Sea level rise is expected to continue for most of Puget Sound's shorelines (Tables 4-1, 4-2).* Most areas in Puget Sound are expected to experience sea level rise through 2100.^{3,4,1} For example, assuming the land is uplifting at a rate of about $+0.4 \pm 0.6$ inch/decade (a middle estimate for Puget Sound, see Table 4-3),³ the relative rise in sea level projected for the latitude of Seattle is +24 inches (range: +4 to +56 inches) by 2100 (relative to 2000).^{M,2} How much water levels change at each specific location depends on a variety of factors, including the rate and direction of local land motion, and regional wind and ocean circulation patterns. Although some studies have quantified regional variability in sea level,^{6,7} very little work has been done to comprehensively evaluate rates of vertical land motion along the coast of Puget Sound.
- *A few locations may experience declining sea level.* Previous research indicates that declining sea level is possible in the Northwest Olympic Peninsula if the rate of global sea level rise is very low and if the rate of uplift remains high.^{4,5} Based on one recent analysis,³ there is less than a 5% chance that sea level will continue fall in Neah Bay through 2100. Although unlikely, it is not yet possible to conclusively rule out a decline in sea level for that region.
- *Although the change in sea level resulting from an earthquake could be substantial, it is not possible to predict when one will occur.* Earthquakes can result in abrupt changes in land elevation, resulting in a sudden change in sea level. Long-term rates of vertical land-motion^P may also change over time.
- *Sea level rise is not expected to occur in a consistent, linear fashion.* Based on past observations, episodes of faster and slower rise, as well as periods of no rise, are expected to continue to occur just as they have in the past.^{1,7}
- *Storms that produce damaging surges are not projected to change.* Climate models do not project a change in wind speed or the strength of low pressure systems affecting the Puget Sound region.^{19,20,21}

^N The most commonly-cited projections from the NRC (2012) report incorporate an assumed uplift rate of 1.0 ± 1.5 mm/yr (~ 0.4 in./decade) for all of the Pacific Northwest. The vertical rate estimate was removed from the numbers shown in this table, in order to compare projections for absolute sea level rise.

^O The regional sea level rise projections for Washington State in Mote et al. (2008)⁵ integrate projected changes in global sea level rise and potential changes in wind direction (which can push waves onshore or off shore for prolonged periods of time depending on wind direction). Low to high projections for each of these components were used to develop the low, medium, and high sub-regional sea level rise estimates. The global sea level rise projections used in these calculations range are based on a low greenhouse gas scenario (B1; for the low projection), a high greenhouse gas scenario (A1FI; for the high projection), and an average of six greenhouse gas emissions scenarios (B1 through A1FI; for the medium projection). See Section 1 for more details on greenhouse gas scenarios.

^P Often described as "inter-seismic", referring to the time between earthquakes.

PROJECTED *Sea level rise increases the potential for higher tidal/storm surge reach and increased coastal inundation, erosion, and flooding.* Even small amounts of sea level rise can shift the risk of coastal hazards in potentially significant ways.

- *Sea level rise will permanently inundate some low-lying areas.* Where and how much inundation occurs will depend on the rate of sea level rise and shoreline characteristics. Communities, tribes, and organizations that have mapped sea level rise inundation zones within the Puget Sound region include the City of Olympia,²² City of Seattle,²³ City of Tacoma, the Port of Seattle,²⁴ King County,²⁵ Sound Transit,²⁶ the National Wildlife Federation (Puget Sound),²⁷ the Swinomish Indian Tribal Community,²⁸ the Jamestown S’Klallam Tribe,²⁹ the North Olympic Development Council,³ and the Friends of San Juan.³⁰
- *Sea level rise will exacerbate coastal river flooding.* Higher sea level can increase the extent, depth, and duration of flooding by making it harder for flood waters in rivers and streams to drain to Puget Sound. In the Skagit River floodplain, for example, the area flooded during a 100-year event is projected to increase by +74% on average by the 2080s (2070-2099, relative to 1970-1999), when accounting for the combined effects of sea level rise and increasing peak river flows (see Section 3).^{Q,20,21,31}
- *Sea level rise will increase the frequency of coastal flood events.* Higher sea level amplifies the inland reach and impact of high tides and storm surge, increasing the likelihood of events that are considered extreme today. For example, +6 inches of sea level rise^R in Olympia shifts the probability of occurrence for the 1-in-100-year flood event from a 1% annual chance to 5.5% annual chance (1-in-18 year) event.²² With +24 inches of sea level rise,^S the 1-in-100-year flood event would become an annual event (Table 4-1).

Coastal bluffs are projected to erode more rapidly. Over one quarter of Puget Sound’s shorelines are “armored”.^T Increased erosion is expected to affect many of the remaining coastal areas as sea levels rise, although the effects depend on the geology and exposure of each location. Coastal bluffs are projected to be particularly sensitive. One study projects that coastal bluffs in San Juan County will recede by

^Q Sea level rise projections were obtained from Mote et al. (2008);⁵ streamflow projections were based on 10 global climate model projections and a medium (A1B) greenhouse gas scenario. Flood simulations assume all levees would remain intact, although they could be overtopped. When levee failure scenarios are included, the increase in flooded area is much less pronounced. With levee failure, much of the floodplain would be inundated even in the absence of climate change – increased flows and higher sea levels do increase water depths, but do not significantly change the area flooded.

^R A +6 inch increase in regional sea level is currently near the median value projected in Petersen et al. (2015)³ for Seattle for 2030.

^S A +24 inch increase in sea level is currently within the range (+14 to +63 inches) projected in Petersen et al. (2015)³ for Seattle for 2100 (relative to 2000). See Table 4-4 for more detail.

^T Shoreline “armoring” refers to any engineered structure used to reduce the effects of coastal erosion.
http://www.psp.wa.gov/vitalsigns/shoreline_armoring.php

–75 to –100 ft. by 2100 (relative to 2000).^{U,30} This corresponds to a doubling, on average, of the current rate of recession.

PROJECTED *Sea level rise affects human, plant, and animal communities in important ways.*

- *Economic and cultural consequences for human communities are expected.* Impacts on human communities include the potential for increased damage to coastal infrastructure from storm surge or flooding,^{22,25,32} permanent inundation of important commercial and industrial areas,^{22,28,33} loss of culturally important sites,²⁸ and a reduced harvest for commercial fishing and shellfish operations.⁴
- *Sea level rise and changes in the marine environment will affect the geographical range, abundance, and diversity of Pacific Coast marine species and habitats.* Increased inundation and erosion due to sea level rise are expected to cause habitat loss and shifts in habitat types. Locations more likely to experience habitat loss include low-lying areas, locations with highly erodible sediments, and areas where inland migration of coastal habitats is hindered by bluffs or human development. Vulnerable habitat types include coastal wetlands, tide flats, and beaches (see Section 11).^{27,34}

Table 4-2. Effect of sea level rise on the probability of today's 100-year coastal flood event in Olympia, WA. As sea level rises, the probability of today's 100-year flood event increases from a 1% annual probability to a 100% probability if sea level rises +24 inches or more. *Table and caption adapted from Simpson 2012.*²²

Sea level rise amount	0 inches	+3 inches	+6 inches	+12 inches	+24 inches	+50 inches
Return frequency for a storm tide reaching the current 100-year flood level	100-yr event	40-yr event	18-yr event	2-yr event	< 1-yr event	<< 1-yr event
Equivalent annual probability of occurrence	1%	2.5%	5.5%	50%	100%	100%

Climate Risk Reduction

CLIMATE RISK REDUCTION *Many Puget Sound communities, government agencies, tribes, and organizations are preparing for the effects of sea level rise.* Most are in the initial stages of assessing impacts and developing response plans; some are implementing adaptive responses. Since most of the documented efforts are designed to protect infrastructure, these examples are also included in Section 12. For example:

^U Projections are based on an empirical model that assumes that the equilibrium rate of shoreline erosion is proportional to the rate of sea level rise. Projections are based on the NRC (2012)¹ report and a moderate (A1B) and high (A1FI) greenhouse gas scenario.

Washington State

- *New regulatory guidance for addressing the risks posed by sea level rise.* Washington State Department of Ecology provides guidance to local government jurisdictions on addressing sea level rise along shorelines in Appendix A of their Shoreline Master Program Handbook.³⁵ The guidance includes: anticipated sea level rise and sediment impacts; coastal landform inventory and vulnerability; public participation, access, and use; shoreline environmental designations, modification, and restoration policies, and some specific jurisdictional examples.

Sound Transit

- *Assessing the vulnerability of the Sound Transit system to the effects of climate change.* The Sound Transit Climate Risk Reduction Project assessed the vulnerability of Sound Transit assets and services to climate change while creating a process and a model for transit agencies across the United States. The analysis found that while climate change exacerbates many existing issues such as sea level rise, extreme precipitation events, heat stress, mudslides, and river flooding, Sound Transit already possesses some degree of climate resilience and capacity to address climate impacts, both of which will be further enhanced by integrating climate considerations into decision making.²⁶

King County

- *Building floating docks and gangways that are able to accommodate several feet of sea level rise.* In 2010, King County Marine Division replaced the existing dock and gangway in West Seattle used by the Water Taxi (owned and operated by WSDOT) with a new floating dock and gangway, which is able to handle rising sea levels.³⁶
- *Incorporating sea level rise into the Wastewater Treatment Division facility siting and design procedure.* A 2008 study evaluating the effects of sea level rise on King County's Wastewater Treatment Division facilities recommended that sea level rise should be incorporated in planning for major asset rehabilitation or conveyance planning that involves the facilities included in the analysis.³⁷ Since the release of the report King County has modified the conveyance system and outfalls of the Wastewater Treatment Division facilities to reduce or eliminate seawater intrusions, even during high tide.^{38,36} Additional preparations for limiting saltwater intrusion include installing flap gates, raising weirs, and other similar controls.³⁶

Cities

- *Planning for sea level rise in the City of Olympia.* In an effort to reduce flood risk in association with sea level rise, the City of Olympia conducted GIS mapping of projected inundation zones, incorporated sea level rise considerations into the City's Comprehensive Plan and Shoreline Management Plan, and develops annual work plans to address adopted goals and priorities, key information needs, improve emergency response protocols, and survey and identify shorelines, structure elevations, and sewer basins that are vulnerable to flooding.³⁹

- *Planning for sea level rise at the Port of Bellingham.* Plans by the Port of Bellingham to redevelop the 228 acre Georgia Pacific site near downtown Bellingham include raising site grades approximately +3 to +6 feet in areas with high value infrastructure as a buffer against sea level rise.⁴⁰
- *Evaluating the robustness of the Seattle sea wall design to sea level rise.* An evaluation of sea level rise impacts on design considerations for the new Seattle sea wall found that the current sea wall height would be able to accommodate +50 inches of sea level rise and a +3 foot storm surge (a 100-year event surge).^v As a result, the City determined that it was not necessary to build a higher structure to accommodate sea level rise over the next 100 years.^w
- *Considering sea level rise in facilities master planning.* Seattle City Light is reviewing a facility in the Duwamish River basin for potential flooding impacts associated with sea level rise and storm surge.

Tribes

- *Adaptation planning for multiple climate-related hazards: the Swinomish Indian Tribal Community.* The Swinomish Indian Tribal Community is implementing adaptation recommendations developed in 2010. This includes revisions to shoreline codes, development of a detailed coastal protection plan for the most vulnerable 1,100 low-lying acres on the north end of the Reservation, development of a Reservation-wide wildfire risk reduction program, and development of a system of community health indicators to measure knowledge and impacts of climate change within the tribal community.⁴¹
- *Vulnerability assessment and adaptation plan: Jamestown S’Klallam Tribe.* The climate vulnerability assessment and adaptation plan identified key tribal resources, the expected effects of climate change, and created adaptation strategies for each resource. Moderate and high severity sea level rise scenarios project potential flooding on Highway 101 near Discovery Bay, preventing the Tribe’s access to the highway for 12-24 hours. The adaptation plan recommends that the Tribe work with Washington Department of Transportation to discuss raising the vulnerable infrastructure, especially in conjunction with future repairs.⁴²

^v The Mean Higher High Water, which is the average of the highest daily tide at a place over a 19-year period.

^w See <http://sdotblog.seattle.gov/2013/01/23/sea-level-and-the-seawall/> for more details.

Additional resources for evaluating and addressing the effects of sea level rise in the Puget Sound region.

The following tools and resources are suggested in addition to the reports and papers cited in this document.

- **Coastal Hazards Resilience Network (CHRN).** Convened by Washington Sea Grant and the Department of Ecology, CHRN is a network of researchers and practitioners focused on climate change and coastal hazards. The goal of the network is to improve regional coordination and, ultimately, to make Washington's coastal communities, including those in Puget Sound, more resilient. <http://www.wacoastalnetwork.com/>
- **Coastal Resilience.** The Nature Conservancy has created a web-based mapping tool that combines sea level projections with other information on land use, infrastructure, and ecosystems. Users can also upload their own data for viewing alongside existing layers.⁴³ <http://maps.coastalresilience.org/pugetsound/>
- **Puget Sound Coastal Resilience.** Developed by Western Washington University, The Nature Conservancy, and USGS, this tool incorporates data on future sea level, high tides, and storm surges, to map projected inundation in the Nooksack, Skagit, Stillaguamish, Snohomish, Nisqually, and Skokomish River deltas. <http://spatial.wvu.edu/coastal/resilience/>
- **NOAA Tides and Currents.** Central resource for information on observed trends in sea level. <http://tidesandcurrents.noaa.gov/>
- **NOAA Coastal Services Center.** Provides technical information and support for managing coastal hazards. <https://csc.noaa.gov/> Tools and products include:
 - Sea Level Rise Viewer: creates maps of potential impacts of sea level rise along the coast and provides related information and data for community officials.
 - Coastal County Snapshots: allows users to develop customizable PDF fact sheets with information on a county's exposure and resilience to flooding; its dependence on the ocean for a healthy economy; and the benefits received from a county's wetlands.
 - Coastal LiDAR: a clearinghouse of LiDAR datasets contributed by many different entities and groups that can be used for mapping sea level rise inundation.
- **Surging Seas.** This tool, created by Climate Central, integrates sea level rise projections with topographic data to identify areas that are likely to be inundated in the future. The tool includes other information in order to identify populations and infrastructure that are particularly vulnerable to sea level rise. <http://sealevel.climatecentral.org/ssrf/washington>
- **Georgetown Climate Center Adaptation Clearinghouse: Rising Seas and Flooding.** Provides links to a variety of case studies and regulatory analyses related to sea level rise. <http://www.georgetownclimate.org/adaptation/rising-seas-and-flooding>

Table 4-3. Observed trends in sea level, vertical land motion, and surge.

<i>Variable</i>	<i>Observed Change</i>
Sea Level	
<i>Global</i>	Rising: +0.7 in./decade (1901-2010) +1.3 in./decade (1993-2010)¹ Rate of rise since mid-1800s is larger than in the last two millennia.¹
<i>Local</i>	Mixed. ▪ Neah Bay, WA: -0.7 in./decade (1934-2008) ▪ Friday Harbor, WA: +0.4 in./decade (1934-2008) ▪ Seattle, WA: +0.8 in./decade (1900-2008)¹
Vertical Land Motion	Both the rate and direction of vertical land movement vary from location to location across Puget Sound. ▪ Neah Bay, WA: +1.0 (±0.1) in./decade (1975-2015)¹ ▪ Port Angeles, WA: +0.4 (±0.1) in./decade (1975-2015) ▪ Port Townsend, WA: -0.3 (±0.1) in./decade (1975-2015) ▪ Friday Harbor, WA: -0.05 (±0.1) in./decade (1972-2015) ▪ Seattle, WA: -0.5 (±0.1) in./decade (1972-2015)
Storminess	There is no evidence of a trend in the intensity of winds and storms that cause damaging surge in Puget Sound. There are no published studies that have evaluated trends in storm surge within Puget Sound. However, one study found that trends along the Northwest coast are simply a reflection of increases in sea level, as opposed to an intensification of storms.^{1,12}
Waves	It is not known how waves within Puget Sound will change in the future. Previous studies have evaluated wave heights measured by offshore buoys,^{13,2} but waves within Puget Sound are primarily driven by local winds as opposed to ocean swell.⁶

Table 4-4. Projected changes in sea level.

<i>Variable</i>	<i>Projected Change</i>
<i>Sea Level</i>	<i>Global</i> Rising: +11 to +38 in. (2100 relative to 1986-2005)^{H,I,1} Rate of rise depends on the amount of 21st century greenhouse gas emissions. <i>Local</i> Relative to vertical land motion, local sea level is projected to rise everywhere by 2100, with the possible exception of Neah Bay, where only the lowest scenario projects a continued drop in sea level.⁵ Assuming the land is uplifting at a rate of about 0.4±0.6 inch/decade (a middle estimate for Puget Sound),³ the relative rise in sea level projected for the latitude of Seattle, relative to 2000:^{M,2} ▪ 2030: +3 in. (–2 to +9 in.) ▪ 2050: +7 in. (–1 to +19 in.) ▪ 2100: +24 in. (+4 to +56 in.)
<i>Storminess</i>	No change projected. Climate models do not project a change in wind speed or the strength of low pressure systems affecting the Puget Sound region.
<i>Shoreline Erosion</i>	Coastal bluffs are projected to erode more rapidly as a result of sea level rise (see Section 5). Projected retreat of coastal bluffs in San Juan County (2100 relative to 2000):³⁰ ▪ Moderate (A1B) scenario, < 5 mi. of fetch:^X 75 ft. ▪ High (A1FI) scenario, < 5 mi. of fetch: 115 ft. ▪ Moderate (A1B) scenario, > 5 mi. of fetch: 101 ft. ▪ High (A1FI) scenario, > 5 mi. of fetch: 155 ft.
<i>Coastal Habitats</i>	Increased inundation and erosion due to sea level rise are expected to cause habitat loss and shifts in habitat types. Vulnerable habitat types include coastal wetlands, tide flats, and beaches (see Section 11)

^X In their analysis, MacLennan et al.³⁰ distinguished between coastal areas with high exposure (more than 5 miles of “fetch”: open water over which wind can generate waves) and areas with less exposure (less than 5 miles of fetch).

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