SECTION 9

How Will Climate Change Affect the Coast and Ocean in Washington?

A major driver of climate change impacts on Washington's coasts is sea level rise, which is expected to affect most locations in Washington State. Key impacts include inundation of low-lying areas, increased storm surge reach, flooding, erosion, and changes and loss of habitat types. These impacts are likely to affect a wide range of communities, species, and infrastructure. Since 2007, studies have provided more regional specificity about how coastal ocean conditions may change in the Pacific Northwest, particularly with respect to sea level rise and ocean acidification.

1. **Changes in Pacific Northwest coastal waters are strongly influenced by changes in global sea level and ocean conditions.**[1] 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.[A][2] This will cause Washington's marine waters to rise, although how much change occurs at a specific location depends on a variety of local factors, as described below. Additionally, coastal sea surface temperatures and the acidity of Washington's marine waters are projected to increase.[B][3][4]

2. **Sea level is projected to continue rising in Washington through the 21st century, increasing by +4 to +56 inches by 2100, relative to 2000.**[5]

    - *Multiple factors affect local sea level.* The amount of sea level change at a given location and time will depend both on how much global sea level rises and on local factors such as seasonal wind patterns, vertical land movement associated with plate tectonics, and sediment compaction. These local factors may result in higher or lower amounts of local sea level rise (or even declining sea level) relative to global projections depending on the rate and direction of change in these local factors.

    - *Sea level rise is expected to continue in most of Washington's coastal areas (Table 9-1).* Most areas in Washington are expected to experience sea level rise through 2100. This includes the Puget Sound region and the central and southern outer coast.[6]

    - *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 caused by plate tectonics continues to exceed the rate of global sea level rise.[6] Although most *current* global projections would result in sea level rise for the northwest Olympic Peninsula, it is not yet possible to conclusively rule out a decline in sea level for that region.

[A] Sea level rise projections vary with greenhouse gas scenarios. The average and associated ranges reported in IPCC 2013[2] 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 3 for more details on greenhouse gas scenarios and Sections 4 and 5 for more on global and Pacific Northwest sea level rise projections.

[B] See Section 5 for more on projected changes in regional sea surface temperatures and ocean acidity.

Table 9-1. Sea level rise projections for Washington State and sub-regions. Projections are in inches, for 2030, 2050, and 2100 (relative to 2000), from two regionally-specific studies: Mote et al 2008[6] and NRC 2012[5]. Values shown are the central (for NRC 2012), or medium (for Mote et al. 2008) projections, with the projected range shown in parentheses. *Table and caption adapted from Reeder et al. 2013.*[1]

Domain	2030	2050	2100
Washington State (NRC 2012)[C],[D]	+3 inches *(-2 to +9 in.)*	+7 inches *(-1 to +19 in.)*	+24 inches *(+4 to +56 in.)*
Puget Sound (Mote et al. 2008)[E]	---	+ 6 inches *(+3 to +22 in.)*	+13 inches *(+6 to +50 in.)*
NW Olympic Peninsula (Mote et al. 2008)	---	0 inches *(-5 to +14 in.)*	+2 inches *(-9 to +35 in.)*
Central & Southern WA Coast (Mote et al. 2008)	---	+5 inches *(+1 to +18 in.)*	+11 inches *(+2 to +43 in.)*

- *Sea level rise is not expected to occur in a consistent, linear fashion*. Episodes of faster and slower rise, as well as periods of no rise, are likely due in part to natural variability, especially as you move to regional (e.g., the Pacific Northwest) and smaller scales.[7]

3. **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 low-lying areas.* Where and how much inundation occurs will depend on the rate of sea level rise and shoreline characteristics. Communities and organizations that have mapped sea level rise inundation zones include the City of Olympia,[8] City of Seattle, King County,[9] the National Wildlife Federation (mapped for Puget Sound, southwestern Washington, and northwestern Oregon), [10] the Swinomish Indian Tribal Community,[11] and the Jamestown S'Klallam Tribe.[12]

[C] Calculated for the latitude of Seattle, Washington (NRC 2012).[5] The mean value reported in NRC 2012 is based on the A1B greenhouse gas emissions scenario. The range values are projections for a low (B1) to a high (A1FI) greenhouse gas emissions scenario. See Section 3 for more details on greenhouse gas scenarios.

[D] Regional comparisons between Mote et al. 2008[6] and NRC 2012 differ due to the different approaches taken by the studies to estimate global sea level rise and local influences on the relative rate of rise. Also, Mote et al. 2008 does not provide projections for 2030 and NRC 2012 did not provide projections for sub-regions of Washington State.

[E] The sub-regional sea level rise projections for Washington State in Mote et al. 2008 integrate projected changes in global sea level rise, potential changes in wind direction (which can push waves onshore or off shore for prolonged periods of time depending on wind direction), and different rates of vertical land motion. 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 3 for more details on greenhouse gas scenarios.

- *Sea level rise will exacerbate coastal river flooding*. Higher sea level can increase the extent and depth of flooding by making it harder for flood waters in rivers and streams to drain to the ocean or Puget Sound. Projected increases in both the size and frequency of high river flows due to climate change will compound this risk.[13]

- *Sea level rise increases the frequency of today's extreme tidal/storm surge events.* Higher sea level amplifies the inland reach and impact of high tides and storm surge, increasing the likelihood of today's extreme coastal events. For example, +6 inches of sea level rise[F] in Olympia shifts the probability of occurrence for the 100-year flood event from a 1% annual chance to 5.5% annual chance (1-in-18 year) event.[8] With +24 inches of sea level rise,[G] the 100-year flood event would become an annual event (Table 9-2).

- *Sea level rise can increase coastal erosion.* Higher sea level and storm surge reach exposes more areas to erosion, which can affect the stability of coastal infrastructure. For example, analysis of beach erosion rates in Oregon for the period 1967-2002 found that significant beach erosion occurred in areas where relative sea level (north-central Oregon) increased. In contrast, beaches were relatively stable in areas experiencing sea level decline (e.g., along the southern Oregon coast, where the rate of uplift is greater than observed sea level rise).[14]

Table 9-2. Impact 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. *Figure and caption adapted from Simpson 2012.*[8]

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%

[F] A +6 inch increase in regional sea level is currently near the average value (+6.5 inches) projected in NRC 2012 for Seattle for 2050, and within the range of values projected for Seattle as early as 2030 (range of -1.5 in. to +8.8 in.). See Table 9-1 for more detail.

[G] A +24 inch increase in sea level is currently the average value (+24.3 inches) projected in NRC 2012 for Seattle for 2100 (range: +4 in. to +56 in.). See Table 9-1 for more detail.

4. Sea level rise and changes in coastal ocean conditions[H] impact human, plant, and animal communities in important ways.

- *Economic and cultural impacts on human communities are expected.* Efforts to better understand and adapt to coastal impacts are occurring in a variety of organizations and coastal communities.

  - *Projected impacts.* Impacts on human communities include the potential for increased damage to coastal infrastructure from storm surge or flooding [8][9][15] permanent inundation of important commercial and industrial areas, [8][11][16] loss of culturally important sites,[11] and impacts on commercial fishing and shellfish harvesting.[1]

  - *Adapting to sea level rise.* Adaptive decisions based on sea level rise projections have already been made by the City of Olympia,[17] City of Seattle,[I] King County,[18] Port of Bellingham,[19] and the Swinomish Indian Tribal Community.[20] Analyses of sea level rise impacts have also been completed by the Port of Seattle,[21] the Jamestown S'Klallam Tribe,[12] and Sound Transit.[J] For more on some of these efforts, see this Section 10 on infrastructure and the built environment.

- *Sea level rise and changes in the marine environment will affect the geographical range, abundance, and diversity of Pacific Coast marine species and habitats*.[K][22]

  - *Coastal 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.[10]

  - *Coastal species.* Species potentially affected by sea level rise and changes in ocean conditions include key components of the marine foodweb (phytoplankton and zooplankton) as well as juvenile Chinook salmon and commercially important species such as Pacific mackerel (*Scomber japonicus*), Pacific hake (*Merluccius productus*), oysters, mussels (*Mytilus edulis*), English sole (*Pleuronectes vetulus*), and yellowtail rockfish (*Sebastes flavidus*).[4][23] A species' ability to adapt to climate change will vary based on physiology and life cycle traits. How quickly climate changes, how large the change is, and the impact of other non-climate stressors such as fishing or pollution will also influence adaptive capacity.

H This includes changes sea surface temperature, salinity, pH, ocean circulation patterns and other factors that can affect species.

I See http://sdotblog.seattle.gov/2013/01/23/sea-level-and-the-seawall/ for more details on how the Seattle Department of Transportation evaluated sea level rise projections for the new Seattle sea wall.

J As announced by the U.S. Federal Transit Administration, http://www.fta.dot.gov/sitemap_14228.html. Final project report scheduled for release by FTA in winter 2014.

K For more on impacts to Pacific Northwest species and ecosystems, including projected percentage losses of specific coastal habitat types, see Section 8 on species and ecosystems.

Additional Resources for Evaluating Coastal Impacts. The following tools and resources are suggested in addition to the reports and papers cited in this document.

- **NOAA Tides and Currents** (http://tidesandcurrents.noaa.gov/): for information on observed trends in sea level
- **NOAA Coastal Services Center** (https://csc.noaa.gov/): provides technical information and support for managing coastal hazards. 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.
- **Georgetown Climate Center Adaptation Clearinghouse: Rising Seas and Flooding** (http://www.georgetownclimate.org/adaptation/rising-seas-and-flooding): provides links to a variety of case studies and regulatory analyses related to sea level rise.

[1] Reeder, W.S. et al. 2014. Coasts: Complex changes affecting the Northwest's diverse shorelines. Chapter 4 in M.M. Dalton, P.W. Mote, and A.K. Snover (eds.) *Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities*, Washington D.C.: Island Press.

[2] (IPCC) Intergovernmental Panel on Climate Change. 2013. *Working Group 1, Summary for Policymakers.* Available at: http://www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved27Sep2013.pdf

[3] Mote, P.W. and E.P. Salathé. 2010. Future climate in the Pacific Northwest. *Climatic Change* 102(1-2): 29-50, doi: 10.1007/s10584-010-9848-z.

[4] Feely, R.A. et al. (eds.). 2012. *Scientific Summary of Ocean Acidification in Washington State Marine Waters*. NOAA OAR Special Report. Seattle, Washington.

[5] (NRC) National Research Council 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future.* Washington, DC: The National Academies Press.

[6] Mote, P.W. et al. 2008. *Sea Level Rise in the Coastal Waters of Washington State*. Report prepared by the Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, Washington and the Washington Department of Ecology, Lacey, Washington.

[7] Bromirski, P. D. et al. 2011. Dynamical suppression of sea level rise along the Pacific Coast of North America: Indications for imminent acceleration. *Journal of Geophysical Research* 116: C07005. doi: 10.1029/2010JC006759.

[8] Simpson, D.P. 2012. *City Of Olympia Engineered Response to Sea Level Rise*. Technical report prepared by Coast Harbor Engineering for the City of Olympia, Public Works Department, Planning and Engineering.

[9] King County Wastewater Treatment Division. 2008. *Vulnerability of Major Wastewater Facilities to Flooding From Sea Level Rise.* Report prepared by the King County Wastewater Treatment Division, Department of Natural Resources and Parks. July 2008. 13 pp.

[10] Glick, P. et al. 2007. *Sea-Level Rise and Coastal Habitats in the Pacific Northwest: An Analysis for Puget Sound, Southwestern Washington, and Northwestern Oregon*. National Wildlife Federation.

[11] Swinomish Indian Tribal Community. 2010. *Swinomish Climate Change Initiative: Climate Adaptation Action Plan.* La Conner, WA.

[12] Jamestown S'Klallam Tribe. 2013. *Climate Change Vulnerability Assessment and Adaptation Plan.* Petersen, S. and J. Bell (eds). A collaboration between the Jamestown S'Klallam Tribe and Adaptation International.

[13] Tohver, I. et al. 2013. Impacts of 21st century climate change on hydrologic extremes in the Pacific Northwest region of North America. *Journal of the American Water Resources Association*, In press.

[14] Ruggiero, P. et al. In press. *National Assessment of Shoreline Change: Historical Shoreline Change along the Pacific Northwest Coast.* US Geological Survey Open-File Report 2012–1007, 55 pp.

[15] Washington State Department of Transportation. 2011. Climate Impacts Vulnerability Assessment. Report prepared by the Washington State Department of Transportation for submittal to the Federal Highway Administration, Olympia, Washington.

[16] Seattle Public Utilities Sea Level Rise Map, released January 2013, available at: http://www.seattle.gov/util/AboutUs/SPU_&_the_Environment/ClimateChangeProgram/index.htm , accessed November 8, 2013

[17] "Addressing Sea Level Rise and Flooding in Olympia" case study, prepared for the Successful Adaptation in the Coastal Sector: Washington Practitioners Workshop, sponsored by the Climate Impacts Group at the University of Washington, March 20, 2013.

[18] King County. 2013. *2012 Annual Report of King County's Climate Change, Energy, Green Building and Environmental Purchasing Programs*. Seattle, WA.

[19] "Adapting to Sea Level Rise at the Port of Bellingham" case study, prepared for the Successful Adaptation in the Coastal Sector: Washington Practitioners Workshop, sponsored by the Climate Impacts Group at the University of Washington, March 20, 2013.

[20] "The Swinomish Indian Tribal Community" case study, prepared for the Successful Adaptation in the Coastal Sector: Washington Practitioners Workshop, sponsored by the Climate Impacts Group at the University of Washington, March 20, 2013.

[21] Huang, M. 2012. *Planning for Sea Level Rise: The Current State of Science, Vulnerability of Port of Seattle Properties to Sea Level Rise, and Possible Adaptation Strategies.* Report prepared for the Port of Seattle, WA.

[22] Tillmann, P. and D. Siemann. 2011. *Climate Change Effects and Adaptation Approaches in Marine and Coastal Ecosystems of the North Pacific Landscape Conservation Cooperative Region: A Compilation of Scientific Literature - Phase 1 Final Report.* Produced by the National Wildlife Federation for the U.S. Fish and Wildlife Service North Pacific Landscape Conservation Cooperative.

[23] Kaplan, I.C. et al. 2010. Fishing catch shares in the face of global change: A framework for integrating cumulative impacts and single species management. *Canadian Journal of Fisheries and Aquatic Sciences* 67 (12): 1968–1982. doi: 10.1139/F10-118.