SECTION 10

How Will Climate Change Affect Infrastructure in Washington?

Climate change is expected to increase the potential for infrastructure damage and service disruptions, and may also lead to higher operating costs and reduced asset life. Some minor benefits may also be realized, including the potential for fewer snow-related road closures. The specific nature of impacts on infrastructure will vary depending on infrastructure location, age, design tolerances, and other factors. Studies completed since 2007 have increased our understanding of how climate change may affect transportation and coastal infrastructure in Washington State. However, more detailed studies are needed to assess potential costs and to understand the implications for asset management.

1. **Most climate change impacts are likely to increase the potential for damage and service disruptions to infrastructure in Washington State, although some risks may decrease.** Studies to date on infrastructure impacts in Washington State and the Northwest have primarily focused on transportation infrastructure and coastal infrastructure (particularly as it relates to sea level rise). In general:

   - *Most climate change impacts evaluated are expected to increase risks to infrastructure.* Impacts that can increase risks to infrastructure include projections for more frequent or more severe flooding, extreme heat, extreme precipitation, storm surge, salt water intrusion, mudslides, erosion, wildfire, and inundation of low-lying areas.[1][2][3] Projected changes in extreme events are more likely to damage infrastructure than are changes in average conditions. [1][2][3]

   - *Some climate change impacts may slightly decrease risks or otherwise create minor benefits.* Projections for lower winter snowpack and warmer winter temperatures may decrease the frequency of snow-related closures on mountain highways.[1][2] However, extreme snowfall events will still occur, requiring continued maintenance of emergency response capacity.[2] Warmer spring and fall temperatures may extend the construction season, possibly improving cost efficiencies.

   - *Understanding the specific nature of climate change impacts on infrastructure often requires detailed, locally-specific studies.* Similar types of infrastructure can have very different responses to climate change, depending on its specific location, age, and how it is designed, maintained, and operated.[1][3] For example, while a small amount (+3 inches) of sea level rise may have important effects on flooding and stormwater management in Olympia, sea level rise impacts on State-owned coastal transportation infrastructure do not begin to emerge until much higher amounts (>+2 feet) of sea level rise occur.

2. **Analysis by the Washington State Department of Transportation (WSDOT) finds that the majority of State-owned and operated transportation infrastructure is resilient to a range of projected climate change impacts, including sea level rise under +2 feet.[3]**

   However, all regions of the State include transportation infrastructure identified by WSDOT as being moderately or highly vulnerable to climate change (Figure 10-1).

   - *Climate change exacerbates many issues already affecting WSDOT infrastructure*. This includes unstable slopes, flooding, and coastal erosion. In many cases, areas most likely to be affected by climate change are areas already experiencing problems or on "watch lists," such as bridges or roads that are being undercut by fast moving waters ("scour critical" transportation infrastructure) or chronic environmental deficiency sites.[A][3]

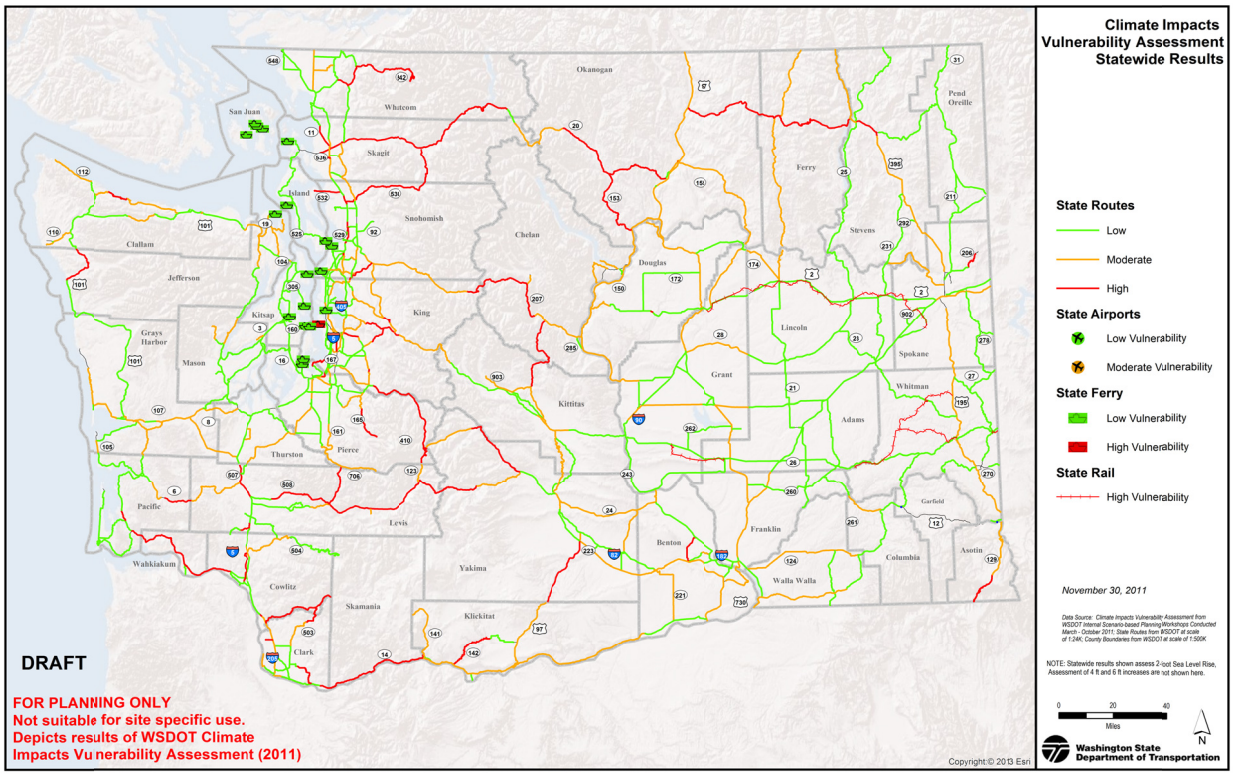

Figure 10-1. Summary of WSDOT's climate impacts vulnerability assessment for State-owned infrastructure. Results are for a range of temperature and precipitation changes and +2 feet of sea level rise. Red denotes roads or facilities that may be vulnerable to catastrophic failure along some portion of the road or at the facility. Yellow denotes roads or facilities that could experience temporary operational failures at one or more locations. Green indicates roads that could experience little or negligible impact. *Figure source: WSDOT 2011[3]*

[A] Chronic environmental deficiencies (CED) are locations along the state highway system where recent, frequent, and chronic maintenance repairs to the state transportation system are causing impacts to fish and fish habitat.

- *Climate change impacts on state highway, ferry, aviation, and rail operations may result in more frequent travel delays, closures, and re-routes.* For example, projected increases in wildfires and the potential for more dust storms tied to drought may cause more frequent temporary closures of airports and roads due to decreased visibility.

- *Vulnerability to climate change is higher in certain locations.* State-owned infrastructure is most likely to be impacted by climate change when located:

    - in the mountains,
    - above or below steep slopes,
    - in low-lying areas subject to flooding,
    - along rivers that are aggrading[B] due to glacier melt, and
    - in low-lying coastal areas subject to inundation from sea level rise.[3]

- *Many ongoing infrastructure improvements benefit climate resilience.* Many infrastructure improvements made for other reasons, such as seismic retrofits, fish passage improvements, culvert replacement, and drilled shaft bridges, also make infrastructure more resistant to climate change impacts.[3]

- *Newer infrastructure is generally more resilient to climate impacts, although the resilience of individual pieces of infrastructure can be affected by vulnerabilities in other parts of the system.* For example, most of WSDOT's newer bridges were found to be resistant to climate change impacts, including some that were resilient to up to +4 feet of sea level rise.[3] Road approaches to bridges are often more vulnerable than the bridges themselves, however.[3] As infrastructure ages, it becomes more vulnerable to extreme weather events and other climate related stressors affecting the structure.[1]

3. **Sea level rise increases the potential for damage to stormwater and wastewater systems, ports, and other public and private coastal infrastructure**.[C] Studies to date have focused on infrastructure in the Puget Sound region. Similar impacts are likely on the outer coast, however.

    - *Coastal wastewater and stormwater collection systems are likely to experience more problems with saltwater intrusion, corrosion, flooding, and inundation.*

        - *King County.* Sea level rise is projected to temporarily or permanently inundate three or more King County Wastewater Treatment Division facilities as early as 2050, depending on the combined effects of different sea level rise projections and the return frequency of specific storms sizes.[D][4] The County has also identified 20

[B] Aggrading refers to the raising of a stream or river bed due to sediment deposition. Glacial recession can cause aggradation below a glacier by exposing unstable sediments to erosion by rain or other factors.

[C] See Section 5 and Section 9 for more details on projected sea level rise.

[D] Periodic or permanent inundation of the Division's three lowest facilities occurs as early as 2050 with +1.8 feet (22 inches) of sea level rise and a +2.3 foot storm surge, currently considered a 50% probability (once every 2 years) storm surge event. As many as 14 facilities would be periodically or permanently inundated by 2100 with +4.17 feet of sea level rise (currently near the high-end of projections for Puget Sound) and a +3.2 foot storm surge (today's 1% annual probability storm surge).

facilities that are at risk of saltwater inflow into the conveyance system due to sea level rise, high tides, and storm surge by 2050.[5][6] This additional inflow can increase the volume of wastewater that has to be conveyed and treated, shortening equipment lifespan and increasing treatment costs.[7] King County estimates the current cost of treating saltwater already entering the system[E] during high tides to be $0.5 to $1.0 million annually.[F]

- *City of Olympia.* Modest amounts of sea level rise (as little as +3 inches) increase the likelihood that saltwater will enter the city's combined sewer system and be conveyed to the Lacey, Olympia, Tumwater, and Thurston County (LOTT) wastewater plant for treatment, potentially increasing operating costs.[8]

- *Low-lying urban and commercial infrastructure is likely to experience more frequent flooding or permanent inundation due to sea level rise.*
  - *Swinomish Indian Tribal Community.* Approximately 15% (over 1,100 acres) of Swinomish Indian Tribal Community Reservation lands are potentially at risk of inundation from sea level rise, including the tribe's primary economic development zone at the north end of Fidalgo Island and more than $100 million in residential and non-residential/commercial structures.[9]
  - *City of Olympia.* A small amount of sea level rise greatly increases the probability of flooding in downtown Olympia, potentially affecting public infrastructure, high-density development, and the City's historic district (Figure 10-2).[8][10]

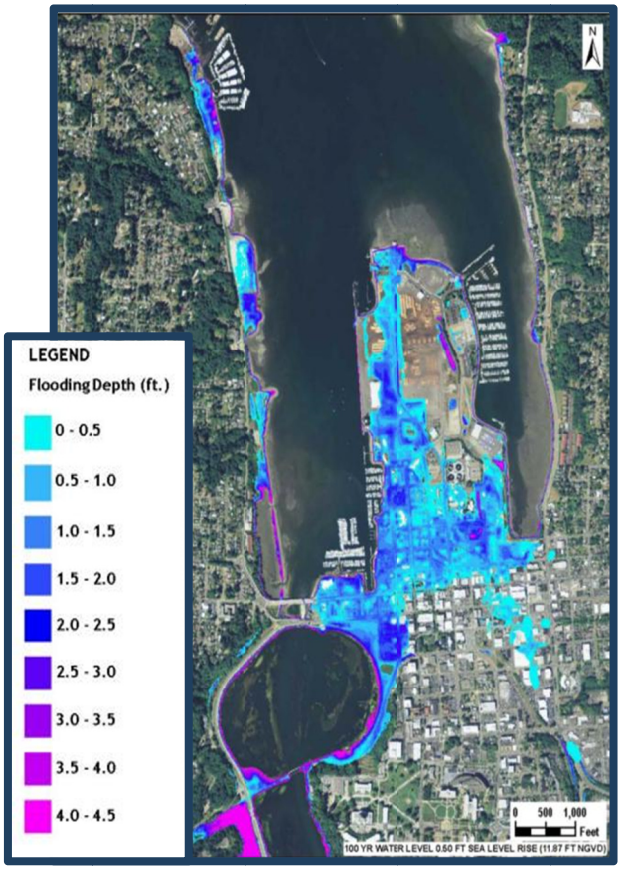

Figure 10-2. Projected flooding in the City of Olympia during a 100-year flood event with +6 inches of sea level rise. The projected depth of flood waters ranges from less than 6 inches to 4.5 feet, as indicated by the map colors. *Figure source: Simpson 2012*

[E] Sources for saltwater intrusion are leaky gates, overflow weirs, groundwater infiltration, and local sewer connections. Intrusion already occurs during high tides in the industrial area along the Duwamish Waterway, the Downtown Seattle Waterfront, and the Salmon Bay area near the Ballard Locks.[7]

[F] This cost estimate is specifically for saltwater treatment at the West Point Treatment Plant and does not include the cost of repairing and replacing damaged equipment. King County estimates that 3 to 6 million gallons of salt water enters the system each day, totaling about 1 to 2 billion gallons each year.[7]

- A +3-inch rise in sea level makes it impractical to use common emergency response measures (sand bags and sealing catch basins) to control flooding associated with the 1-in-10 year (10% annual chance) flood event.[8]
- A +6-inch rise in sea level shifts the probability of occurrence for the 100-year flood event in Olympia from a 1% to a 5.5% annual chance event.[8]

- *Port operations and infrastructure, including access to port facilities, are likely to be affected by sea level rise and increased coastal flooding.*[11][12] Climate-related impacts in other parts of the world[G] may also affect Washington's marine trades, although little is known about the specific nature and potential size of those impacts on port business.[1][11]

  - *Direct sea level rise impacts identified by the Port of Seattle:*[11]

    - Increasing rates of corrosion in docks and other infrastructure (e.g., piles, pile caps, and beams) exposed to saltwater more frequently as a result of sea level rise and increased tidal and storm surge reach.
    - Increased difficulty draining stormwater from port facilities due to increasing extreme precipitation and sea level rise.
    - Increased storm surge damage to port facilities.

  - *Impacts on low-lying areas serving Port of Seattle facilities.* Low-lying rail yards and roads serving the Port of Seattle are vulnerable to permanent inundation if sea level rise is +3 feet or greater. Lower amounts of sea level rise would likely result in more frequent temporary flooding of low-lying rail yards and roads. These impacts may affect the movement of goods in and out of port facilities regardless of how the port adapts its own infrastructure.[12]

4. **Projected increases in river flooding increase the risk of damage and service interruptions for infrastructure located in or near current floodplains.** In coastal drainages, sea level rise can exacerbate existing flood risks.[H]

   - *Larger flood events can reduce the effectiveness of existing levees and tide gates.* Flood flows in the Skagit basin are expected to more frequently exceed the design capacity of many of the basin's current dikes and levees, which are designed to the current 30-year return interval.[13] Sea level rise is also expected to reduce the effectiveness of tide gates for draining low lying cropland in the Skagit Valley.[13]

   - *The ability of dams to mitigate increasing flood risk may be limited.* Initial research for the Skagit basin suggests that reducing community vulnerability to increasing flood risk

[G] Reduced sea ice in Alaska and the Arctic is likely to extend the shipping season and create new opportunities for shipping, although it is unknown at this time if, when, and how these changes could affect Washington's ports. Climate impacts on trading partners in Asia may also affect traffic in and out of Washington's shipping ports, although it is not known how traffic would be affected specifically.

[H] 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. Because of this, even modest river flooding can produce larger flood impacts in the lower portion of a river basin in the future relative to today's flood events.

and sea level rise will be more effective if those efforts focus primarily on improving management of the floodplain rather than on increasing flood storage in headwater dams (e.g., Upper Baker Dam).[I][13] This is because most of the streamflows causing the increased flood risk originate *below* the headwater dams.

- *Climate change increases the risk of flooding in Green River communities.* By the 2080s, streamflow volume for the 100-year (1%) flood event in the Green River as measured at Auburn could increase +15% to +76% relative to historical (1916-2006) climate for a medium greenhouse gas scenario.[J] A change of this upper magnitude shifts the probability of today's 1-in-500 year (0.2% annual probability) flood event on the Green River to a 1-in-100 year (1% annual probability) flood event.[14] Potential inundation mapping of the current 500-year flood event by the U.S. Army Corps of Engineers projects flood depths of 0-15 feet in the Kent-Auburn area.[K] This could affect residential and commercial properties, local roads, access to SR 167, and rail services in the area.

- *More sediment and flood debris in coastal rivers could affect port and ferry facilities.* Increased river flooding and reduced snow and ice cover in mountain watersheds is projected to increase the amount of sediment and flood debris carried by coastal rivers.[13] As a result, more frequent dredging near port facilities and ferry terminals is likely to be needed.[3][11] Damage to port facilities and ferry terminals is also possible due to the potential for more flood debris.[3]

5. **Many Washington communities, government agencies, and organizations are preparing for the impacts of climate change on infrastructure.** Most are in the initial stages of assessing impacts and developing response plans; some are implementing adaptive responses. For example:

   - *Increasing the resilience of State-owned transportation infrastructure:*

     - *Considering climate change and extreme weather events in project-level environmental review.* WSDOT is integrating the results of its vulnerability assessment into the environmental review of proposed projects. For example, the

[I] Preliminary results based on use of an integrated daily time step reservoir operations model built for the Skagit River Basin. The model simulated current operating policies for historical streamflow conditions and for projected flow for the 2040s and 2080s associated with the Echam5 global climate model run with the A1B greenhouse gas emissions scenario. For more on climate scenarios, see Section 3 of this report.

[J] Range based on data from the University of Washington Climate Impacts Group's Columbia Basin Climate Change Scenarios Project website (http://warm.atmos.washington.edu/2860/) for the A1B greenhouse gas emissions scenario. Greenhouse gas scenarios were developed by climate modeling centers for use in modeling global and regional climate impacts. These scenarios are described in this report as follows: "very low" refers to the RCP 2.6 scenario; "low" refers to RCP 4.5 or SRES B1; "medium" 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 3 for more details.

[K] See "Potential Inundation, Shown as Simulated Water Depth, in Kent for a Peak Flow at Auburn Gage of 25,000 cubic feet Per Second" map produced by the U.S. Army Corps of Engineers. Existing levees are assumed to be intact but the map does not reflect ongoing levee fortification efforts, which could reduce flood risk. Map available at: http://www.nws.usace.army.mil/Missions/CivilWorks/LocksandDams/HowardHansonDam/GreenRiverFloodRiskMaps.aspx

Mukilteo Multimodal Terminal environmental impact statement evaluated impacts of sea level rise and increased rainfall.

- *Long-term planning for corridor improvements.* Recent studies for US 2, SR 516 and SR 520 include vulnerability ratings developed by WSDOT in 2011. These plans discuss the level of risk, emergency response and hazard reduction strategies, and options for increasing resilience.

- *Preparing interstate and state routes in the Skagit River basin for climate change.* A federally funded pilot project will support development of a series of site-specific adaptation options to improve the resilience of Interstate 5 and state routes in the Skagit basin (Figure 10-3). These will complement flood hazard reduction strategies proposed by the U.S. Army Corps and Skagit County.

- *Increasing the resilience of King County infrastructure to increased flooding and sea level rise:*

  - *Levee improvements and flood-risk reduction activities.* King County formed a new Flood Control District in 2007 to increase capacity for addressing regional flood risks due to climate change and other factors. The creation of the new District resulted in a

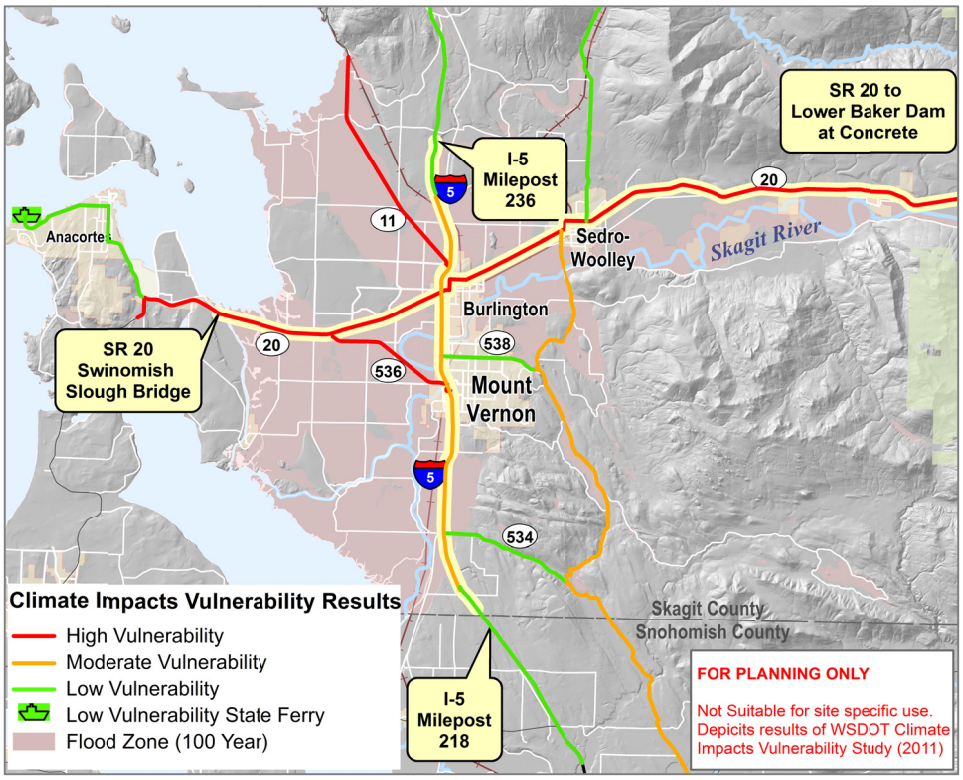

Figure 10-3. Study area for WSDOT's Preparing Interstate and State Routes in the Skagit River Basin pilot project, funded by the Federal Highway Administration. *Figure source: WSDOT.*

ten-fold increase in local funding[L] for flood risk reduction efforts. Accomplishments in 2012 included mapping flood hazards on the Sammamish River and the coastal shoreline, completing five levee repair projects and six projects that raised structures in flood zones, and purchasing sixty acres of floodplain on the Tolt, Snoqualmie, Cedar, and White rivers. Public ownership of this land and removal of structures will reduce flood risks and preclude development in these flood prone areas.[6]

- *Widening bridge spans.* King County has replaced 15 short span bridges with wider span structures (including the Tolt Bridge over the Snoqualmie River) and 42 small culverts with large box culverts. These changes will increase resilience to major flooding. In many cases these wider structures also allow for the movement of a variety of wildlife along the river's edge during normal flows and elevated flood events thereby protecting wildlife connectivity between critical habitats.[6]

- *Redesigning the Anacortes Water Treatment Plant to reduce the potential for flooding.* Projections for increased flooding and sediment loading in the Skagit River led to design changes for the City of Anacortes' new $65 million water treatment plant (under construction in 2013). The altered design includes elevated structures, water-tight construction with minimal structural penetrations, no electrical control equipment below the (current) 100-year flood elevation, and more effective sediment removal processes.[10]

- *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 (shown previously in Figure 10-2), incorporated sea level rise considerations into the City's Comprehensive Plan and Shoreline Management Plan, and develops annual work plans to address key information needs.[15]

- *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.[16]

- *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 three feet above the new still water level[M] with 50 inches of sea level rise. 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.[N]

- *Increasing capacity to manage extreme precipitation events in Seattle.* Seattle Public Utilities' RainWatch system[O] provides operators and decisions makers with 1-hour precipitation forecasts and 1- to 48-hour rain accumulation totals that can be used to

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L Funding for the Flood Control District comes from a county-wide property levy of 10 cents per $1,000 assessed value. This amounts to $40 per year on a $400,000 home. The levy raises roughly $36 million a year (http://www.kingcountyfloodcontrol.org/).

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

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

O See http://www.atmos.washington.edu/SPU/

manage extreme precipitation risks at the neighborhood- or basin-scale in real-time. RainWatch represents a "no regrets" climate change adaptation strategy by improving operations response to extreme events today and in the future.

- *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 of and impacts of climate change within the tribal community.[9]

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[1] MacArthur, J. et al. 2012. *Climate Change Impact Assessment for Surface Transportation in the Pacific Northwest and Alaska.* Region X Northwest Transportation Consortium, OTREC-RR-12-01, WA-RD #772.1.

[2] Hamlet, A.F. 2011. Impacts of climate variability and climate change on transportation systems and infrastructure in the Pacific Northwest. White Paper prepared for the Western Federal Lands-Highway Division by the Climate Impacts Group, University of Washington, Seattle.

[3] (WSDOT) 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.

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

[10] Reeder, W.S. et al. 2013. 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.

[11] 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.

[12] Huppert, D.D. et al. 2009. Impacts of climate change on the coasts of Washington State. Chapter 8 in *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate,* Climate Impacts Group, University of Washington, Seattle, Washington.

[13] Hamlet, A.F. and S-Y. Lee. 2011. *Skagit River Basin Climate Science Report*. Prepared for Envision Skagit and Skagit County. The Climate Impacts Group, University of Washington, September, 2011.

[14] (USACE) U.S. Army Corps of Engineers. 2012. *Assembly of Design Flood Hydrographs for the Green River Basin: Summary Report for Flood Plain Management Services Program*. Seattle District Army Corps of Engineers, September 2012.

[15] "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.

[16] "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.