Climate Change Impacts on Puget Sound Floodplains

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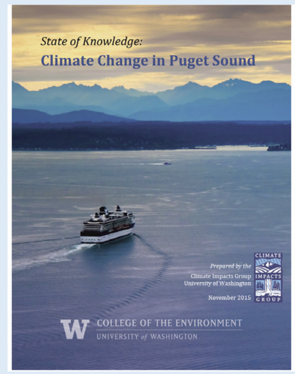
Puget Sound floodplains produce a wealth of ecological, social, and economic services, including habitat for salmon, groundwater recharge, and land for pasture and agriculture. Floodplains are also prime areas for commercial, industrial, and residential development in the Puget Sound region.

Climate change is expected to affect floodplains and the natural services they provide, requiring shifts in the way communities think about and manage floodplains. This fact sheet describes how climate change affects floodplains and the multiple benefits they provide.

More details on the impacts of climate change on the Puget Sound region and ongoing climate risk reduction efforts can be found in *State of Knowledge Report: Climate Change in Puget Sound* (Mauger et al 2015; available at cig.uw.edu).



A Warming Climate

All scenarios show warming as a result of rising greenhouse gas emissions.

Annual and seasonal temperatures in the Puget Sound region are expected to increase rapidly in the coming decades as a result of rising greenhouse gas emissions. By mid-century, annual average air temperature is projected to rise +4.2°F to +5.9°F, on average, for a low and high greenhouse gas scenario.

While natural variability will remain an important feature of regional climate, by mid-century the region is likely to regularly experience average annual air temperatures that exceed the range observed in the 20th century.

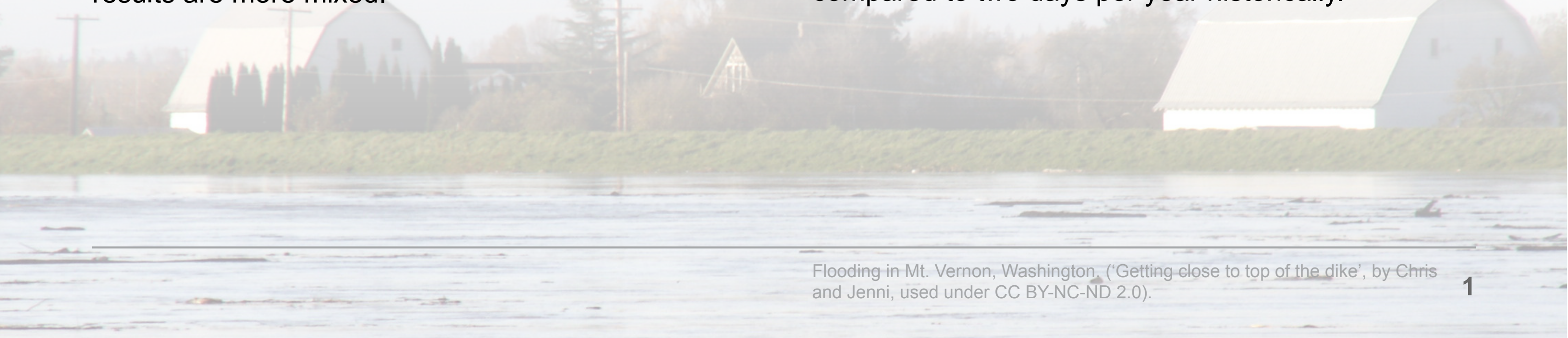
Projected changes in precipitation vary by season. All scenarios show a decline in summer precipitation of -22%, on average, for the 2050s. In contrast, fall, winter, and spring are likely to be wetter, although results are more mixed.

Winter Flooding

Climate change increases both the frequency and magnitude of flood events in the Puget Sound region. More intense heavy rains, shifts from snow to rain at higher elevations, sea level rise, and greater sediment transport are key factors.

Extreme precipitation events (often caused by "atmospheric rivers") frequently result in substantial winter rainfall and major flooding west of the Cascades. Although climate scenarios show little change in annual precipitation, **heavy rainfall events are expected become more severe**, leading to higher peak streamflows and flood risk.

Models project that the heaviest 24-hour rain events in western Washington and Oregon will intensify by +22% on average by the 2080s. These events are projected to occur more frequently as well, occurring eight days per year by the 2080s, on average, compared to two days per year historically.



Flooding in Mt. Vernon, Washington. ('Getting close to top of the dike', by Chris and Jenni, used under CC BY-NC-ND 2.0).

Another factor elevating winter flood risk is **the shift to more rain and less snow** in many Puget Sound watersheds (Figure 1). As temperatures increase, a greater proportion of winter precipitation will fall as rain rather than snow. This shift results in reduced winter snowpack and higher winter streamflows in watersheds where snow has historically been important.

For example, April 1st snow water equivalent (SWE)[1] is projected to decline by an average of –29% by the 2040s and –55% by the 2080s in the Puget Sound region for a moderate warming scenario. At the same time, **flows associated with the 100-year flood event are projected to increase by +18% to +55%, on average, by the 2080s in the 12 largest Puget Sound watersheds** (Table 1). These changes do not take into account the effects of reservoir operations, which may mitigate some of the increased flood risk.

Another way to see the impact of climate change on flood risk is to consider how **increasing winter peak flows affect the frequency of today's extreme flood events**. Scenarios show that by the 2040s, the streamflow associated with the 100-year flood flows in the Skagit River become 22-year flood flows; the historical 30-year flood flows become 7-year flood flows. Similarly, by the 2040s, the historical 100-year flood flows for the Snohomish River become 30-year flood flows, and the historical 10-year flood flows becomes 5-year flood flows.

Sea level rise and higher sediment loading will also affect flood risk. **Sea level is projected to increase by +28 inches on average** in the Puget Sound region by 2100 (Table 2). Rising sea levels will increase the extent, depth, and duration of river flooding by making it more difficult for flood waters to drain into Puget Sound. For example, the area flooded in the Skagit River floodplain during a 100-year event is projected to increase by +74% on average by the 2080s when considering both sea level rise and larger flood flows. A similar study found that the 10-year flood event would flood +19% to +69% more area in the Snohomish River floodplain by the 2080s.

Sediment loading—already an issue in many Puget Sound rivers—**is expected to increase** as receding snow and ice expose more soil and intensifying heavy rains act to accelerate erosion.

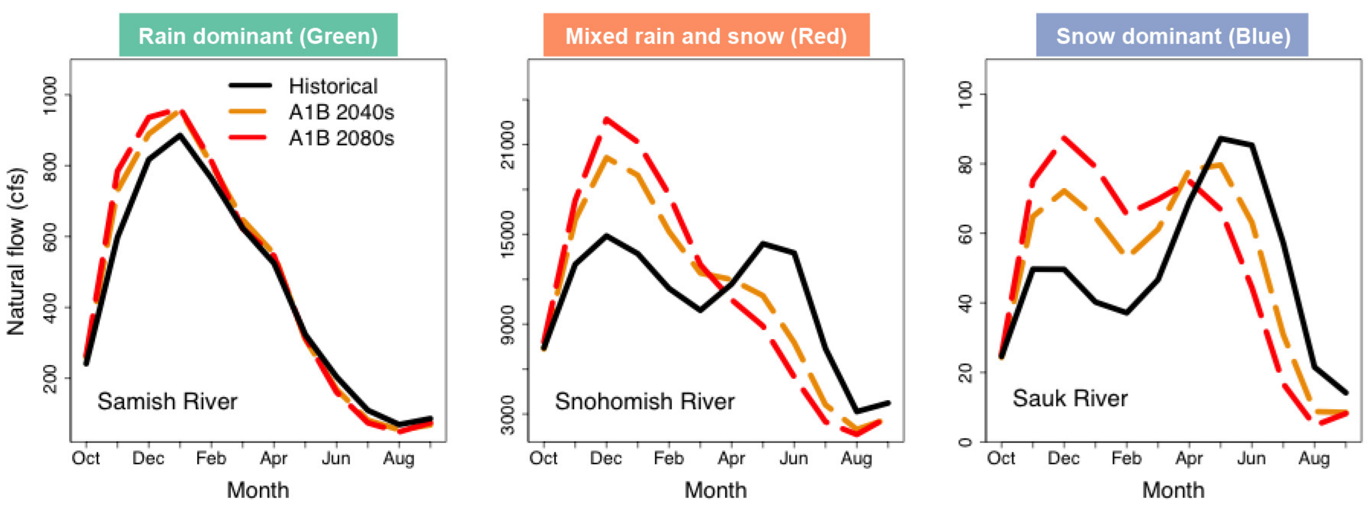


Figure 1. *Streamflow is projected to increase in winter and decrease in spring and summer for all basin types. "Rain dominant" basins (left) are generally too warm to accumulate significant snow. As a result, warming is projected to have little effect. In contrast, high elevation "snow dominant" basins (right; basins that receive >40% of their winter precipitation as snow) are likely to experience more pronounced increases in winter streamflows as more precipitation falls as rain rather than snow. The basins most sensitive to warming are the "mixed rain and snow" watersheds (center) that are near the current snowline. These basins are projected to experience significant increases in winter flows and decreases in spring and summer flows as a result of warming. These results do not include changes in extreme precipitation events, which are a major cause of flooding in rain dominant and mixed rain and snow watersheds.*

[1] SWE is a measure of the total amount of water contained in the snowpack. April 1st is the approximate current timing of peak annual snowpack in the mountains of the Northwest.

Table 1. *Projected long-term change for streamflow timing, streamflow volume, and stream temperatures for the 2080s for 12 watersheds in the Puget Sound region. Results are for unregulated flows and a moderate warming scenario (A1B).*

Watershed	Streamflow Timing	Streamflow Volume 100-yr Flood	Streamflow Volume 10-yr Flood	Summer Minimum Flows (7Q10)	River Miles in Excess of Salmon Thermal Tolerance
Nooksack	−27 days (-40 to -19 days)	+27% (+9 to +60%)	+39% (18 to +82%)	−27% (-38 to -13%)	+136 mi. (>64 °F)
Samish	−40 days (-53 to -30 days)	+23% (-9 to +101%)	+22% (-6 to +90%)	−18% (-26 to -7%)	+27 mi. (>64 °F)
Skagit	−22 days (-36 to -13 days)	+42% (+4 to +86%)	+57% (+22 to +109%)	−51% (-65 to -38%)	+121 mi. (>64 °F)
Stillaguamish	−37 days (-48 to -29 days)	+29% (+2 to +76%)	+30% (+8 to +72%)	−22% (-32 to -7%)	+103 mi. (>64 °F)
Snohomish	−37 days (-49 to -29 days)	+23% (+1 to +58%)	+40% (+18 to +77%)	−26% (-33 to -17%)	+262 mi. (>64 °F)
Cedar	−37 days (-49 to -30 days)	+19% (+2 to +37%)	+29% (+8 to +60%)	−25% (-32 to -13%)	+5 mi. (>64 °F)
Green	−38 days (-50 to -31 days)	+32% (+15 to +73%)	+35% (+14 to +73%)	−16% (-21 to -7%)	+73 mi. (>64 °F)
Nisqually	−34 days (-45 to -25 days)	+18% (-7 to +58%)	+26% (-1 to +65%)	−27% (-35 to -17%)	+24 mi. (>64 °F)
Puyallup	−18 days (-30 to -9 days)	+37% (+10 to +88%)	+40% (+12 to 85%)	−27% (-39 to -16%)	+9 mi. (>64 °F)
Skokomish	−46 days (-56 to -38 days)	+23% (+4 to +59%)	+16% (-3 to +44%)	−18% (-22 to -8%)	+3 mi. (>64 °F)
Dungeness	−15 days (-35 to -6 days)	+55% (+20 to +116%)	+71% (+27 to 141%)	−35% (-45 to -27%)	+0 mi. (>64 °F)
Elwha	−28 days (-41 to -20 days)	+29% (+5 to +50%)	+38% (+11 to +74%)	−39% (-49 to -27%)	+0 mi. (>64 °F)

Table 2. *Regional absolute sea level rise projections for Puget Sound for 2030, 2050, and 2100 (relative to 2000; NRC 2012).*

Year	Projected Sea Level Rise: Puget Sound
2030	+4 inches (+1 to +8 in.)
2050	+9 inches (+4 to +18 in.)
2100	+28 inches (+14 to +54 in.)

Annual sediment transport in areas of the Skagit River basin is projected to more than double (+149%, on average) by the 2080s. Higher sediment loads exacerbate flood risk when rivers deposit excess sediment in stream beds ("aggradation"). This process reduces channel capacity, and increases the likelihood of flooding, even during relatively minor flood events.

Summer Low Flows and Stream Temperature

Summer streamflows are expected to be lower and warmer due to increasing summer air temperature, drier summers, and reductions in snow and ice.

While flooding is a dominant concern for floodplain management, summer low flows and water temperature are also important issues. Low summer streamflow conditions are projected to become more acute in all Puget Sound watersheds due to the combined effects of lower summer precipitation and warmer summer air temperatures.

Low summer streamflow conditions are projected to become more acute in all Puget Sound watersheds due to the combined effects of lower summer precipitation and warmer summer air temperatures. Declining snowpack, glacier loss, and a shift towards earlier melt will also contribute to lower summer streamflows in watersheds that historically accumulated snowmelt.

Figure 2. *Low flow conditions expose the streambed in the Nooksack River. Photo: Julie Morse, The Nature Conservancy.*

Analysis of changes in the lowest summer streamflows (known as “7Q10 flows”; Table 1) finds that **minimum streamflows for 12 Puget Sound watersheds are projected to decline by –16% to –51%, on average, for the 2080s**. Rain-dominant and mixed rain and snow watersheds show the greatest and most consistent decreases in minimum flows, with smaller changes in snow dominant basins.

The same factors that influence summer streamflow volume also affect stream temperature. **Stream temperatures in the Puget Sound region are projected to increase +4.0°F to +4.5°F by the 2080s** in response to increasing air temperature and declining summer streamflow. The length of time during which stream temperatures are elevated also increases; by the 2080s, 12 of 37 Puget Sound stream monitoring sites are expected to experience weekly average stream temperatures above thermal tolerances for salmon (64°F), with these conditions persisting for as much as 7.5 weeks longer than today (Table 1).

Implications for Floodplain Management

Climate change impacts on flooding, summer low flows, and stream temperature have implications for many of the services and benefits provided by floodplains.

Community Impacts

Larger and/or more frequent flooding increases risks to communities and infrastructure located in or near areas affected by flooding. Potentially affected infrastructure includes homes and businesses, health services, transportation infrastructure, groundwater wells, septic systems, water and wastewater treatment plants, and electricity transmission and distribution equipment.

Flooding can also reduce the effectiveness of existing levees and tide gates. For example, 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 commonly designed to the current 10-, 30-, or 100-year flood interval.

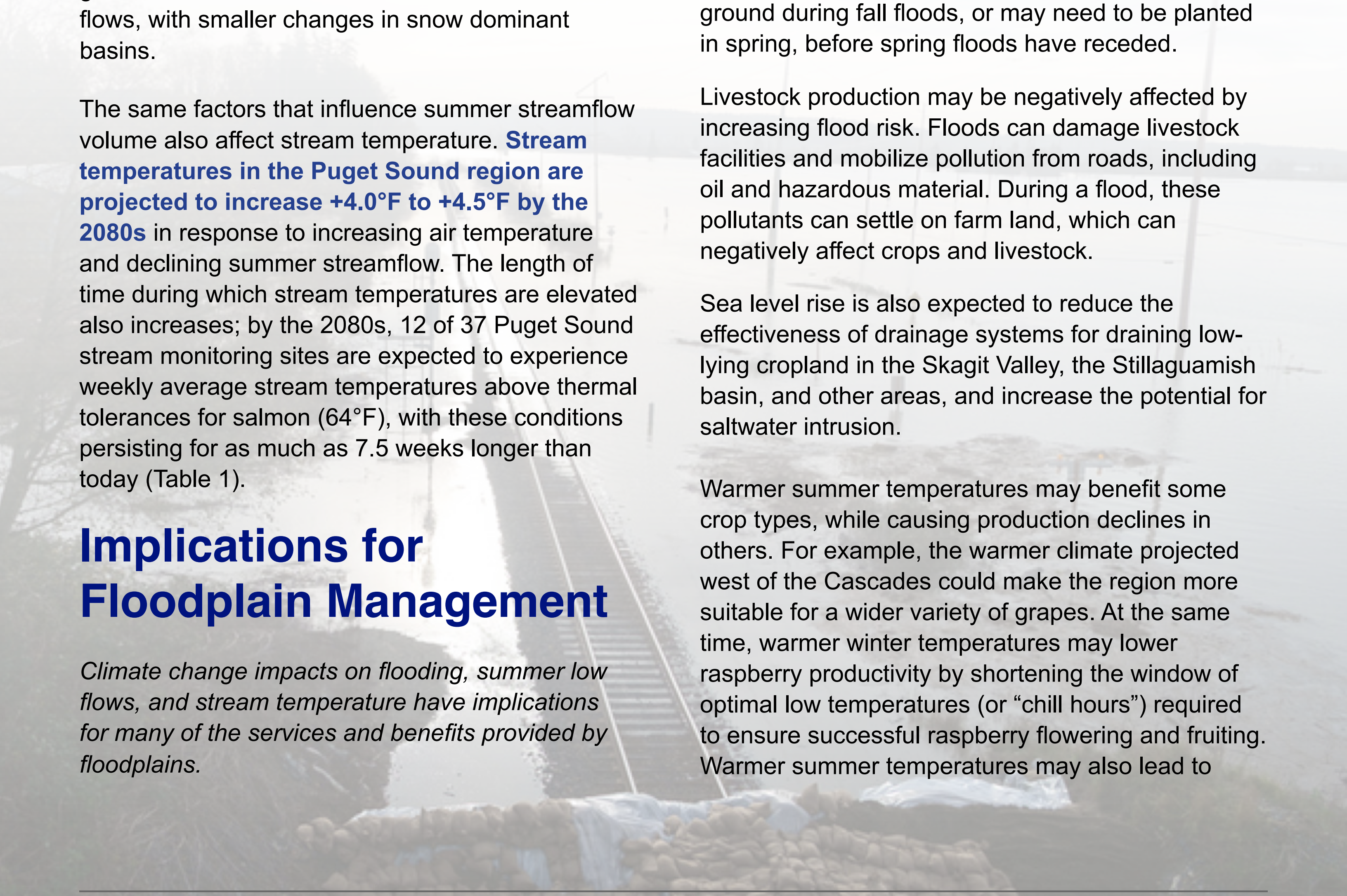
Agricultural Production

Increases in peak river flows are projected to substantially increase flood risk for agricultural lands. Flower (tulips) and vegetable crops are especially vulnerable to floods, as they may still be in the ground during fall floods, or may need to be planted in spring, before spring floods have receded.

Livestock production may be negatively affected by increasing flood risk. Floods can damage livestock facilities and mobilize pollution from roads, including oil and hazardous material. During a flood, these pollutants can settle on farm land, which can negatively affect crops and livestock.

Sea level rise is also expected to reduce the effectiveness of drainage systems for draining low-lying cropland in the Skagit Valley, the Stillaguamish basin, and other areas, and increase the potential for saltwater intrusion.

Warmer summer temperatures may benefit some crop types, while causing production declines in others. For example, the warmer climate projected west of the Cascades could make the region more suitable for a wider variety of grapes. At the same time, warmer winter temperatures may lower raspberry productivity by shortening the window of optimal low temperatures (or “chill hours”) required to ensure successful raspberry flowering and fruiting. Warmer summer temperatures may also lead to



more water stress and increased demands for summer irrigation in the region.

Public Health

Possible human health impacts of increased flooding range from impacts on mental health to more direct impacts related to mold growth and the conveyance of biological and chemical agents by floodwaters to drinking, storm, and recreational waters. Conversely, lower summer flows can concentrate contaminants in both surface and well waters, increasing the risk for bacterial and/or chemical (e.g., nitrates) exposure when drinking or bathing in untreated waters.

Figure 3. *Salmon eggs in a streambed at Mt. St. Helen's National Volcanic Monument on the Gifford Pinchot National Forest. Photo: US Forest Service, used under CC BY_NC-ND 2.0.*

Salmon

Increased flooding is projected to lead to higher salmon egg and fry mortality by increasing streambed scour and removing or crushing salmon eggs. Flooding events also increase the extent of fast-flowing habitat, potentially washing juvenile salmon downstream prematurely.

Projected declines in summer minimum flows are expected to increasingly disconnect floodplains from rivers, preventing some migrating salmon populations from accessing off-channel spawning and rearing habitat. Lower flows also create physical barriers to migration when there is not enough water to migrate back to spawning grounds.

The impacts of lower summer streamflow will be exacerbated by increasing stream temperatures, which can stress adult salmon.

Figure 4. *A kokanee salmon migrates upstream through a section of low flow. Photo: Kare Ware, used under CC BY_NC-ND 2.0.*

Warmer stream temperatures can also slow or impede salmon migration and increase the risk of disease transmission.

Reducing Climate Risks

Growing awareness of how climate change can affect infrastructure, programs, and communities is leading to more interest in—and specific actions related to—preparing for climate change. This idea is commonly referred to as "climate adaptation" or "increasing climate resilience."

Reducing climate risks asks public and private entities to consider the following fundamental question:

> *How does climate change affect what I am trying to accomplish, and what would I need to do to address those risks?*

More specifically, preparing for climate change requires:

- Assessing climate change vulnerabilities,
- Working collaboratively with partners to identify actions to address climate change impacts,
- Incorporating evaluation of climate impacts into planning and decision-making processes,
- Implementing adaptive actions via changes in policies, practices, and infrastructure (see Policy "Red Flags"), and
- Evaluating and adjusting those actions over time to ensure that objectives can be met in a changing climate.

Preparing for climate change in the context of floodplain management requires addressing each of these, with special attention paid to the dynamic nature of changing river flows.

For example, the definition of a "100-year flood" or "100-year floodplain" underpins many policies and planning efforts and has traditionally been treated as a static definition. With increasing peak flow volumes, substantial changes in key definitions could have important policy implications.

It's important to recognize that climate change may require doing some things differently, but not necessarily all things. Many ongoing activities, such as habitat restoration, levee setbacks, and restoring instream flows, already provide some degree of adaptation benefit (at least in the near term) by increasing the resilience of human and natural systems to today's extreme events. However, some activities may become less effective or even maladaptive (i.e., exacerbating climate impacts) over time without identifying and adjusting for the impacts of climate change.

Policy "Red Flags"

Climate risks may be created or perpetuated by regulations, policies, practices, and procedures that:

- do not allow regular re-evaluation and adjustment in accordance with changing conditions;
- require planning based strictly on the past, or pin certain decisions to certain periods or seasonal patterns; or
- reinforce trends that increase vulnerability or reduce adaptive capacity (e.g., development along floodplains).

From Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments (Snover et al. 2007)

Examples of climate adaptation in Puget Sound floodplains are growing. For example:

- Since 2012, King County has been widening bridge spans and replacing culverts to increase the resilience of bridges and roads to major flooding.
- Climate change 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, including more effective sediment removal processes.
- Through the Floodplains by Design program, the Washington State Department of Ecology is beginning to incorporate climate risk into state funding programs by prioritizing floodplain infrastructure projects that provide holistic solutions that consider the effects on people, agriculture, and ecosystems.

More examples of current adaptation activities in the Puget Sound region are available in *State of Knowledge: Climate Change in Puget Sound* (Mauger et al. 2015).

For More Information

For more information on climate impacts on Puget Sound and what agencies, organizations, and communities are doing to prepare for climate change, see *State of Knowledge: Climate Change in Puget Sound* (Mauger et al. 2015) or contact the University of Washington Climate Impacts Group (https://cig.uw.edu/; cig@uw.edu).

Acknowledgments

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Sources

Sources are available for download from https://cig.uw.edu/resources/publications/

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