4 Observed and Projected Changes in Washington's Climate

Human activities have caused a considerable increase in the concentration of greenhouse gases in the atmosphere, relative to pre-industrial times, and have been the primary cause of global warming since 1950 (Bindhoff et al. 2013). Without significant reductions in greenhouse gas emissions, climate change will accelerate, leading to significant challenges at both the global and local level.

Observed Changes in Washington & Pacific Northwest Climate

Warming temperatures. Average annual temperature in Washington has warmed nearly 1.8°F since 1895, and the observed rate of warming since 1950 (~+0.3°F /decade) has been about double the rate of warming since 1895 (~+0.15°F /decade). Statistically significant warming has been observed during all seasons.[14,]

No discernable trend in average or seasonal precipitation. Long-term trends in observed annual precipitation in Washington and the Pacific Northwest are not statistically significant, with the exception of spring precipitation (Snover et al. 2013, Abatzoglou et al. 2014). Over the past century there has been a statistically significant long-term increase in spring precipitation (March-May) in the Pacific Northwest (Abatzoglou et al. 2014) and in the Puget Sound lowlands (Mauger et al. 2015).

Changes in heavy precipitation. There are no consistent, statistically significant trends in heavy precipitation (Snover et al. 2013). Some individual station records may exhibit increasing trends for a specific measure of precipitation (e.g., the amount of rain falling in 48 hours; Rosenberg et al. 2010) and over specific time periods (e.g., comparing recent decades to mid 20th century; Snover et al. 2013). However, no coherent changes in heavy rainfall across the region have been detected.

Changes in streamflow.

Changes in annual streamflow. Observed declines in annual streamflow have been documented in some locations, however, these trends are small in comparison to year-to-year variability. One study

[14] Data source: Monthly and Annual Temperatures for Climate Divisions and the State, Climate at a Glance, NOAA (http://www.ncdc.noaa.gov/cag/). Significance was tested with a 95% confidence threshold.

evaluating 43 streamflow gauges throughout the Pacific Northwest observed declines in annual streamflow volume ranging between 0% change to –20% at individual sites (Luce and Holden 2009). In the Puget Sound region, some rivers have shown statistically significant declines in annual streamflow during dry years (Luce and Holden 2009, Luce et al. 2013, Dettinger 2014). In other words, dry years have become drier in the Puget Sound region.

Changes in peak streamflow. Mass et al. (2011)'s assessment of extreme precipitation for the outer coast of Washington and Oregon found an increase in peak discharges for the top 60 average daily peak flow events between 1950 and 2009 for unregulated rivers north of 45°N (including the Dungeness, Quinault, and Satsop Rivers in Washington), although decadal trends varied. Trends in the top 20 peak flow events for those rivers are dominated by the large events in the 1990s; if that decade is removed, there is little trend in the top 20 daily discharge events.

Streamflow shifted earlier in some locations. The timing of peak streamflow in the Pacific Northwest and in western Washington has also shifted earlier in some locations, largely due to declining snowpack and earlier spring snowmelt. These earlier shifts ranged between no shift to 20 days earlier between 1948 and 2002 (Stewart et al. 2005).

Box 1. Observed Changes: Fire Risk, Tree Health & Non-Native Invasive Species

- ***Fire.*** Washington's forests have experienced a strong and persistent increase in wildfire activity over the past several decades, due in part to a century of active fire suppression (Abatzoglou and Williams 2016). In the Pacific Northwest, the length of the fire season has extended during each of the past four decades, lengthening from 23 days between 1973-1982 to 43 days between 1983-1992, 84 days between 1993-2002, and 116 days between 2003-2012 (Westerling 2016). In addition to a longer fire season, the Pacific Northwest region has also experienced an increase in mean fire burn time[15] from seven days in the 1970s to 13 days in the 1980s, 41 days in the 1990s, and 54 days in the 2000s (Westerling 2016).
- ***Insects & Disease.*** Over the past several decades, insect and disease damage to Washington's forests have increased drastically, doubling from 600,000 acres per year during the 1980s to exceeding 1.2 million acres in 2000s (Dozic 2015). While forest damage in recent years has been more modest, with approximately 600,000 acres damaged in 2013 and ~550,000 damaged acres in 2014, widespread damage to Washington's forests will continue to occur from insect, disease, and fire (Argyropoulos 2017).[16]
- ***Non-Native Invasive Species.*** Non-native, invasive plants, animals, fungi, and bacteria (terrestrial and aquatic), are both challenging to locate and remove in many areas of the park system. They displace or destroy native plant communities, wildlife habitats, and in some instances, are toxic to people and livestock (e.g., poison hemlock, tansy ragwort). Many have their origins in Mediterranean climates; conditions that are becoming more common in areas of WA as the climate changes. Non-native invasive species have been introduced and spread in Washington State following escape from personal gardens, agricultural operations, or after being transported to the region via human travel and/or trade.

[15] Rounded to the nearest whole day, excluding years with no large fires.
[16] Note: these estimates are based on data from the annual insect and disease aerial survey, which are likely an underestimate of actual on-the-ground damage.

Snowpack. Snowpack in the Washington and Oregon Cascades has declined approximately 25% since the mid-20th [17] century through 2007 due to both natural variability and long-term regional warming trends (Mote et al. 2008, Stoelinga et al. 2010). Snow loss at lower elevations has been greater than the loss at higher elevations, a finding that is consistent with long-term warming. Over shorter time periods, natural variability in precipitation can dominate trends. For example, in recent decades there has been an observed (though not statistically significant) increase in spring snow accumulation (Stoelinga et al. 2010).

Table 2. Observed trends in sea level for Washington State tide gauges. Trends are reported in feet/century to facilitate comparison of trends between stations with different periods of record. *Source: NOAA*

Tide Gauge (period of record)	**Trend** (ft/century)
Seattle (1899-2016)	+ 0.67 ft/century
Friday Harbor (1934-2016)	+ 0.38 ft/century
Port Townsend (1972-2016)	+ 0.62 ft/century
Cherry Point (1973-2016)	+ 0.11 ft/century
Neah Bay (1934-2016)	- 0.56 ft/century
Toke Point (1973-2016)	+ 0.14 ft/century

Sea Level Rise*.* Sea level is rising in most coastal areas of Washington State, with the amount of sea level rise varying by location due largely to differences vertical land movement (i.e., subsidence and uplift) caused by plate tectonics (Table 2). Between 1900-2008 sea level rose by +8.6 inches (0.8 in./decade) at the Seattle tide gauge, which is one of the longest running tide gauges in Puget Sound. The notable exception to local rising sea level trends is Neah Bay, where the rate of uplift in the northwest Olympic Peninsula currently exceeds the rate of global sea level rise.

Projected Changes in Regional Climate

Washington climate is expected to change more rapidly in the coming decades than compared to the 20th century. These changes, which include increasing temperature, more extreme precipitation, and rising sea level, will affect Washington State Parks' properties, facilities, operations, and state-wide programs.

MODELING FUTURE CLIMATE

Projecting changes in 21st century climate requires the use of global climate models and scenarios of future greenhouse gas emissions, which incorporate assumptions about future changes in global population, technological advances, and other factors that influence the amount of carbon dioxide and other greenhouse gases emitted into the atmosphere as a result of human activities. Differences in the greenhouse gas scenarios, combined with differences in how individual models respond to those scenarios, result in a range of possible futures (referred to as climate scenarios) that can be used to evaluate climate impacts. Two greenhouse gas scenarios frequently modeled to bracket a range of potential future conditions are a high "business as usual" greenhouse gas scenario (known as RCP 8.5) and a low greenhouse gas scenario (RCP 4.5). While annual greenhouse gas emissions will vary from year to year, current greenhouse gas emissions are considered to be generally tracking RCP 8.5.

[17] Mote et al. 2008 analyzed the linear trend in observed snowpack in the Washington Cascades for different start years through 2003, beginning in 1935 and ending in 1975 (e.g., 1935-2003, 1936-2003…1975-2003; see Table 3 in Mote et al. 2008). Stoelinga et al. 2010 also looked at different time periods, e.g., 1930-2007, 1950-1997, and 1976-2007. Both studies found statistically significant declines in precipitation for the Washington Cascades for trends beginning in mid-century, i.e., trends for time series starting between 1945 and 1954 and ending in 2003 (Mote et al. 2008) and the trend for 1950-1997 (Stoelinga et al. 2010).

Air temperature. All climate models project increases in annual and seasonal temperatures for Washington State, with the amount of warming dependent on how quickly greenhouse gas emissions rise (Table 3; Figure 8). While natural variability will remain an important feature of the state's climate, Washington is likely to regularly experience average annual air temperatures by mid-century that exceed the range observed during the 20th century.

Table 3. Projected changes in average annual temperature and summer temperature in Washington State for the 2050s and 2080s (*Data source: Mote et al. 2015*)

		2050s *(2040-2069, relative to 1970-1999)*		**2080s** *(2040-2069, relative to 1970-1999)*	
Change in…	**Greenhouse gas scenario***	**Mean**	**Range**	**Mean**	**Range**
Average annual air temperature	Low (RCP 4.5)	+4.4°F	3.0°F – 5.6°F	+5.6°F	4.2°F – 7.3°F
	High (RCP 8.5)	+5.7°F	4.5°F – 7.3°F	+9.4°F	7.6°F – 11.7°F
Summer (Jun-Aug) air temperature	Low (RCP 4.5)	+5.3°F	3.6°F – 7.8°F	+6.6°F	4.7°F – 9.5°F
	High (RCP 8.5)	+7.1°F	5.1°F – 10.1°F	+11.7°F	9.3°F – 15.9°F

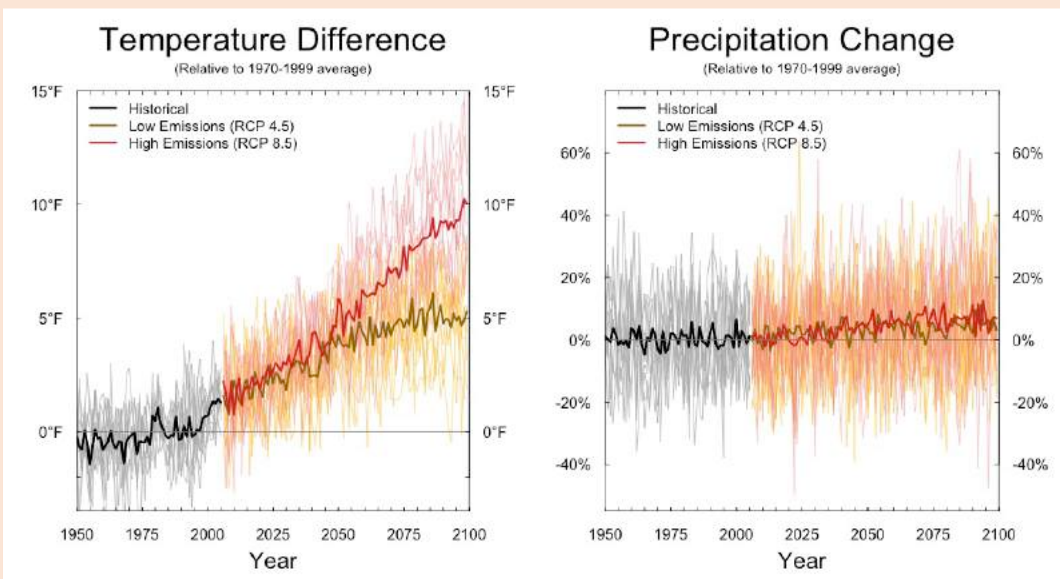

Figure 8. All scenarios project warming in Washington State for the 21st century. These graphs show average yearly air temperature (left) and precipitation (right) for Washington State, relative to the average for 1970-1999. The black line shows the average simulated air temperature or precipitation for 1950–2005, based on the individual model results indicated by the thin grey lines. The thick colored lines show the average among model projections for two emissions scenarios (low: RCP 4.5, and high: RCP 8.5), while the thin colored lines show individual model projections for each scenario. Figure source: Climate Impacts Group).

Increases in extreme heat. More extreme heat is also expected for Washington State, although the frequency and intensity of extreme heat events may be slightly moderated along the coast and in areas adjacent to Puget Sound. Data analysis by the Climate Impacts Group (data source: Mote et al. 2015) found that Washington State is projected to experience an increase in the number of days above various warm thresholds (90°F and 100°F) relative to what has been observed historically. Findings are reported for the each of the State Park regions in the regional climate summaries, located in Appendix B.

Changes in annual & seasonal precipitation. Most models project wetter fall, winter, and spring seasons (+6.2% to +7.9% on average for the 2050s, relative to 1970-1999) for a low and high greenhouse gas scenario, respectively. However, some individual models project drier conditions during some of these seasons. Models consistently project drier summers (−16.8% and −17.8% on average, by the 2050s for a low and high emissions scenario). The net result of these seasonal changes is a relatively small increase in annual average precipitation (+4 to +5% on average, for the 2050s; Figure 8). Given the large differences in annual precipitation between wet and dry years in our Pacific Northwest climate, it may be difficult to detect these changes of only a few percent.

Increases in heavy precipitation. Extreme precipitation is expected to increase. The heaviest (top 1%) 24-hour rain events – so-called "Atmospheric River" events – in western Washington and Oregon are expected to be +22% more intense, on average, by the 2080s for a high warming scenario (Mauger et al. 2015). Today's heaviest 24-hour rain events is also projected to become more frequent, occurring seven days per year by the 2080s, on average, compared to two days per year historically (1970-1999). Unlike other projected changes in precipitation, the considerable changes in heavy precipitation events exceed the range of natural variability in precipitation shortly after mid-century. In contrast to western Washington where extreme precipitation events are driven by Atmospheric Rivers, heavy rainfall events east of the Cascades are typically induced by convective systems. Downscaled climate models are currently too coarse to capture these small-scale convective systems. Therefore, projected changes in extreme precipitation for eastern Washington are unavailable at this time.

Changes in seasonal streamflow. Winter streamflow (Oct-Mar) in Washington is projected to increase between +25% and +34%, on average, by the 2080s (relative to 1970-1999)[18] (Snover et al. 2013). Conversely, summer streamflow (Apr-Sep) is projected to decline between –34% to –44%, on average, for the same period. These changes will be most pronounced in mid-elevation rain/snow mix watersheds, where average winter temperatures are close to freezing and therefore most sensitive to increasing winter temperatures (Klos et al. 2014, Elsner et al. 2010). More information regarding these projected changes can be found in Appendix B.

Changes in streamflow timing*.* The timing of spring peak runoff is also expected to shift earlier as temperatures warm. By the 2080s, spring peak streamflow is projected to occur two to six weeks earlier, on average, in 12 major Puget Sound watersheds, relative to historic conditions (1970-1999) (Mauger et al. 2015).[19]

Increasing flood risk. The shift to more winter rain and less snow also increases the risk of winter flooding in many watersheds. More intense heavy precipitation events will amplify this risk, particularly west of the Cascades. Sea level rise may also exacerbate flooding in coastal watersheds by impeding floodwater drainage into the ocean or Puget Sound.

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[18] Average projected change for ten global climate models, averaged over Washington State. Range spans from a low (B1) to a medium (A1B) greenhouse gas scenario.

[19] Projected change for ten global climate models for a moderate (A1B) greenhouse gas scenario.

Flood risk is not projected to increase in all watersheds, however. Flooding in colder, snow-dominant watersheds is most often associated with rapid snowmelt in spring. As a result, flood risk related to rapid snowmelt in snow-dominant watersheds is projected to decline slightly due to lower spring snowpack (Hamlet and Lettenmaier 2007).

Changes in summer low flows. Changes in summer low flows are also expected. Warmer air temperatures, earlier peak runoff, lower snowpack, and declining summer precipitation are expected to result in more severe low summer streamflow conditions in ~80% of Washington's watersheds (Snover et al. 2013). The projected declines are expected to be greatest and most consistent in rain dominant and mixed-rain-and-snow-basins. The projected changes in summer streamflow conditions are expected to be more prominent west of the Cascades. East of the Cascades, summer streamflows are already extremely low even in today's climate.

Changes in snow. The Washington Cascades and Olympic Mountains contain the highest fraction of "warm snow", or snow falling close to freezing, in the continental United States (Mote et al. 2008). As a result, warming winter temperatures associated with climate change will have a significant impact on snowpack accumulation and snow season length in Washington. Projections for changes in snow quality are not available.

Declining snowpack. Warming air temperatures will lead to more winter precipitation falling as rain rather than snow, particularly at lower and middle elevations where projected warming pushes average winter temperatures above freezing for longer periods of the winter season. Average spring snowpack across Washington State (as measured on April 1) is projected to decline in the 21st century for a high (RCP 8.5) and low (RCP 4.5) greenhouse gas scenario (Table 4) (Mauger et al. 2015). Snow accumulation at other points in the winter season is also affected (Table 4; Figure 9). See Appendix C for maps showing projected monthly changes in Dec 1 – April 1 snow water equivalent (SWE) in Washington State for the 2050s and 2080s for a low and high greenhouse gas scenario.[20]

Table 4. Projected changes in average (with range) winter season snow water equivalent (SWE) in Washington State for the 2050s (2040-2069) and 2080s (2070-2099) for a low and high greenhouse gas scenario, relative to 1970-1999. Results for any single month are reflective of seasonal snow accumulation through that date. *Source:* Mauger et al. 2015; *Data Source: Mote et al. 2015*

	December 1	**January 1**	**February 1**	**March 1**	**April 1**
2050s (2040-2069)					
Low emissions (RCP 4.5):	**–53.0%** (-64 to -26%)	**–45%** (-61 to 31%)	**–44%** (-57 to 27%)	**–50%** (-59 to -39%)	**–48%** (–58 to –32%)
High emissions (RCP 8.5):	**–64%** (-81 to -40%)	**–51%** (-67 to -40%)	**–48%** (-66 to -37%)	**–55%** (-70 to -45%)	**–56%** (–71 to –41%)
2080s (2070-2099)					
Low emissions (RCP 4.5):	**–58.3%** (-73.6 to -39.5%)	**–51%** (-67 to -26%)	**–52%** (-68 to -25%)	**–61%** (-70 to -53%)	**-61%** (–72 to –52%)
High emissions (RCP 8.5):	**–81.1%** (-87.0 to -70.8)	**–69%** (-79 to -57%)	**–73%** (-82 to -60%)	**–76%** (-81 to -67%)	**–76%** (–88 to –61%)

[20] Snow Water Equivalent, or 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.

Shorter snow season. Warming seasonal temperatures also contribute to a shorter snow season overall (Figure 10). Warmer fall temperatures delay the start of accumulation in the fall while warmer spring temperatures contribute to earlier spring snowmelt. Snow season length in Washington State is projected to shorten by -33 days on average (range: -45 to -21 days) and -55 days (range: -68 to -39 days) on average by the 2050s and 2080s, respectively, under a high greenhouse gas scenario (RCP 8.5).[21] As with snowpack, natural variability will continue to produce above average and below average conditions on a year-to-year basis. However, what is considered above average and below average will be redefined over time as the long-term effects of warming winter temperatures are realized.

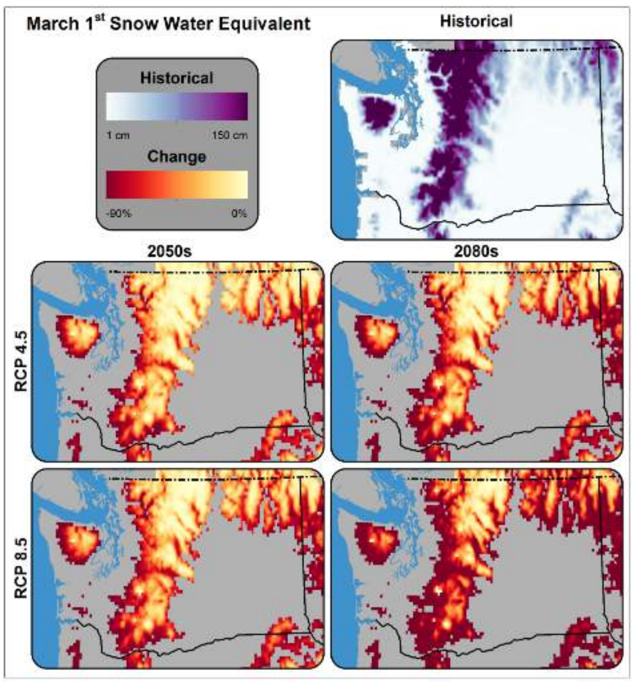


Figure 9. Projected change in March 1 snow water equivalent (SWE) for the 2050s (2040-2069) and 2080s (2070-2099), relative to 1970-1999. Changes are for a low (RCP 4.5) and high (RCP 8.5) greenhouse gas scenario. Areas with deeper reds and oranges indicate areas with greater loss of SWE. *Figure source: R. Norheim, UW Climate Impacts Group.*

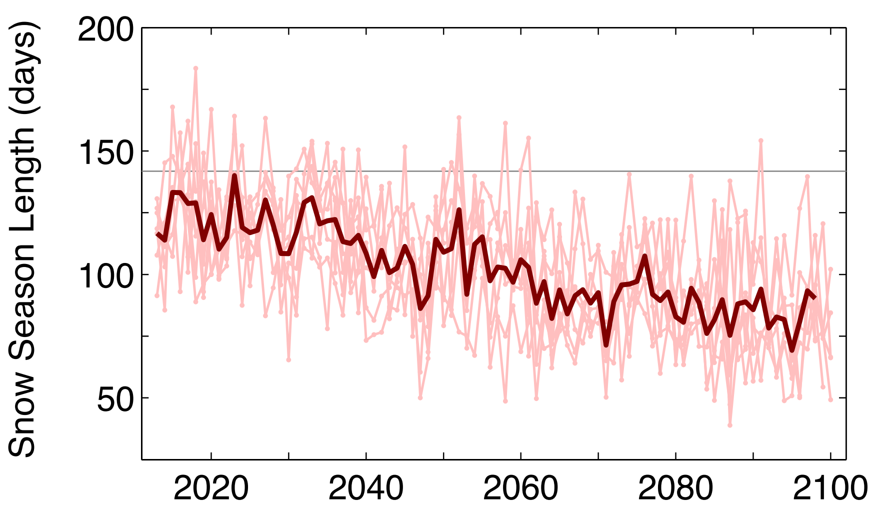


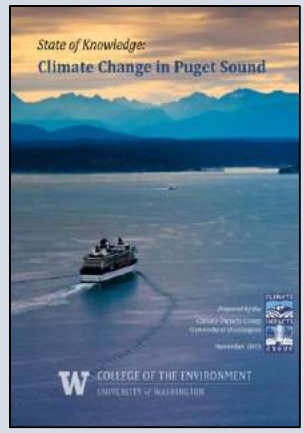
Figure 10. Projected length of the snow season, in days, for middle elevations (4,000 to 5,000 ft) for the Oregon and Washington Cascades, relative to average snow season length for 1950-1999 (142 days; gray horizontal line). Figure shows the results for seven individual climate models (thin red lines) and the average of the seven models (thick line). *Figure source: Snover et al. 2013.*

[21] The projected change in snow season length for a low greenhouse gas scenario (RCP 4.5) is -25 days (range: -32 to -18) for the 2050s and -35 days (range: -46 to -24 days) for the 2080s, relative to 1970-99. See the Statewide Climate Summary in Appendix B for more details.

Sea level rise. Sea level along coastal Washington and in Puget Sound is projected to continue to rise throughout the 21st century due to the combined effects of global sea level rise, land subsidence related to plate tectonics, ocean currents, wind patterns, and the distribution of both global and regional glacier melt (Mauger et al. 2015). Sea level in Seattle is projected to rise +6 inches, on average, by 2050 (range of –1.0 to +19 inches, relative to 2000) and +24 inches, on average, by 2100 (range of +4 to +56 inches, relative to 2000; NRC 2012).[22] A recent assessment of change in coastal flooding in Island County due to sea level rise concluded there was a 50% probability of at least nine inches of sea level rise by 2050 and at least 2.2 feet of sea level rise by 2100 for a high (RCP 8.5) greenhouse gas scenario (Miller et al. 2016). At the 1% probability level, Miller et al. (2016) projected +1.4 feet and +4.9 feet of sea level rise by 2050 and 2100, respectively. Updated sea level rise scenarios that take these factors into account for different regions of the state are expected in 2018.

Sea level change at a specific location will be largely dependent on the rate and direction of vertical land movement, and regional wind and ocean circulation patterns (Mauger et al. 2015). While the majority of Washington State is projected to experience rising sea level, continued high rates of uplift along to northwest Olympic Peninsula may result in a localized decline in sea level in the near future. However, one study determined the there is less than a 5% chance that sea level at Neah Bay will continue to fall through the 21st century (Petersen et al. 2015).

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,* available at cig.uw.edu.



Rising seas will also exacerbate the frequency and impact of coastal flooding, inundation of low-lying areas, wave energy, storm surge, and erosion. MacLennan et al. (2013) projected that coastal bluffs in the San Juan Islands could recede 26 to 43 ft. by 2050 and 75 to 115 ft., relative to the year 2000, for a moderate and high sea level rise scenario.[23] This loss corresponds to a doubling of the current rate of recession for the San Juan Islands. Coupled with increasing coastal inundation, increased erosion rates are likely to result in loss of coastal habitat and shifts in coastal ecosystems (e.g., coastal wetlands, tidal flats, and beaches) (NWF 2007, NRC 2012, Thorne et al. 2015, Hamman et al. 2016, Miller et al. 2016).

[22] Average based on a moderate warming scenario (A1B), relative to 2000.
[23] The moderate sea level rise scenario used in MacLennan et al. (2013) was 0.54 ft for 2050 and 2.03 ft for 2100. The high sea level rise scenario was 1.57 ft for 2050 and 4.69 feet for 2100.

Box 2. Projected Changes: Fire Risk, Forest Health, & Non-Native Invasive Species

Wildfire. Drier and warmer summer conditions in Washington State are expected to increase the annual area burned, and the frequency and intensity of wildfires on both the west and east sides of the Cascades. As temperatures rise, snowpack declines, and summer precipitation decreases, fuel sources will dry out, facilitating ignition and spread of fire across the landscape (Abatzoglou and Williams 2016). Additionally, earlier spring snowmelt is expected to lengthen the fire season. By the 2040s, the average annual area burned in forested ecosystems (i.e., Western and Eastern Cascades, Blue Mountains, Okanogan Highlands) is projected to increase by a factor of 3.8 (relative to 1980-2006) for a low and high warming scenario. In non-forested ecosystems (i.e., Columbia Basin and Palouse Prairie) mean area burned is projected to increase by a factor of 2.2 (Littell et al. 2010).

Projected changes in fire risk for wet areas with a low historic incidence of fire (e.g., Puget Trough, Olympic Mountains) are more difficult to assess relative to drier areas in eastern Washington. In general, fire risk in western Washington is expected to increase and lead to an expansion of annual area burned in regions of western Washington previously not considered fire prone (Littell et al. 2010). Two studies suggest that area burned west of the Cascades could double by the 2080s, relative to 1971-2000 (Littell et al. 2010; Rogers et al. 2011).

Insect and Disease Outbreaks. As forests become increasingly stressed due to warmer and drier summers, trees will become more susceptible to insect and disease outbreaks. Making generalized statements about insect and disease response to changing climate conditions is challenging, however. Many pests and pathogens typically have climate mediated-behaviors, making them sensitive to shifts in temperature and precipitation. As a result, responses will be site-, species-, and host-specific (Mauger et al. 2015). For example:

- *Mountain Pine Beetle.* The amount of forest susceptible to mountain pine beetle (*Dendroctonus ponderosae*) is projected to increase early in the 21st century (+27% higher in 2001-2030, relative to 1961-1990) as rising temperatures enable mountain beetles to infest higher elevation forests that were previously too cool, and then decrease (-49 to -58% lower by 2071-2100, relative to 1961-1990) as rising temperatures exceed the thermal optimum of the mountain pine beetle (Bentz et al. 2010).
- *Laminated Root Rot.* Laminated root rot is caused by a fungus (*Phellinus sulphurascens*) which kills patches of Douglas-fir in Washington State. Fungal infections start within a patch of forest (i.e., the infection center) and expand radially outward at a rate of approximately 12 inches per year (Washington State Academy of Sciences 2013). The fungus spreads underground via root systems and can persist for decades in dead roots and stumps. Climate change could increase the rate of fungal expansion and may also increase the susceptibility of Douglas-fir to fungal infection (Washington State Academy of Sciences 2013).
- *Armillaria, Mistletoe, & Sudden Oak Death* (Figure 11). Warming temperatures and changes in precipitation (either decreasing or increasing) may increase the risk of forest damage from dwarf mistletoes and *Armillaria* root disease (Kliejunas, 2011). Studies suggest that warming and increasing annual precipitation may increase the risk of sudden oak death in the Pacific Northwest (Kliejunas, 2011; Sturrock et al. 2011).

Non-Native Invasive Species. Warming temperatures and declining summer water availability are expected to stress many ecosystems throughout the Pacific Northwest (Snover et al. 2013), likely increasing the susceptibility of these communities to invasion by non-native species (Alpert et al. 2000). This increased vulnerability to non-native invasive species may pose new management challenges to Parks.

Figure 11. Dwarf mistletoe growing on a pine tree (left; source: Craters of the Moon National Monument and Preserve). Canker on an oak tree with sudden oak death (right; source: Joseph O'Brien, Forest Service).

5 Key Findings: Cross-cutting Issues for Regions and Statewide Programs

The Washington State Parks climate change vulnerability assessment was structured to explore climate change impacts on park properties, infrastructure, and operations at the regional level and to a subset of statewide programs. The results of the individual workshops are in Appendix A. While each region and program is unique, staff opinions on which changes in climate were likely to be most important to State Parks were largely consistent. Those were: changes in precipitation and hydrology, declining snowpack, changes in vegetation, and sea level rise.

5.1 Changes in Precipitation and Hydrologic Extremes:

Enhanced Seasonal Precipitation, More Intense Heavy Rain Events, Flooding, and Related Effects

Managing water, whether it is too much (flooding, erosion, landslides) or too little (drought, extreme summer low streamflows), is an ongoing challenge for State Parks that is likely to be exacerbated by climate change. Key concerns related to changes in precipitation and hydrology include increased winter flooding, landslides, mudslides, erosion, higher groundwater tables, and low water issues during summer.

Observed Changes: Precipitation and Hydrologic Extremes | As discussed in Section 4, there have been no discernable trends in annual precipitation, with the exception of extreme precipitation events west of the Cascades. Observed, long-term changes in streamflow reflect the influence of warming temperatures on Washington's hydrology.

Impacts on Parks: Current Variability in Precipitation and Hydrologic Extremes | Winter flooding, heavy precipitation events, and low water levels during the summer are already common issues in Washington State Parks.

Winter flooding has resulted in campsite closures at Potlatch, Belfair, Twanoh, Ocean City, Twin Harbors, and Grayland Beach state parks. Flooding was also flagged as a recurring issue at Schafer State Park and Rainbow Falls State Park. For example, Chehalis River flooding in December 2007 destroyed a $1 million[24] foot and vehicle entrance bridge at Rainbow Falls State Park when the bridge was struck by woody debris and a dislodged park footbridge carried downriver by floodwaters (Figure 12) (AECOM 2012). A water line serving the park was also destroyed. The damage closed the park completely for almost six months and severed the northern and southern parts of the park, effectively closing off access to the south end of the park.[25] During the Eastern Region workshop, Parks staff noted that numerous flood-related repairs have been required throughout the region, including Mount Spokane State Park and Pearrygin Lake State Park.

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[24] "Rainbow Falls State Park Back Open Today", *The Chronicle,* May 23, 2008, http://www.chronline.com/news/article_ab157cf8-134d-5f10-aca5-eee723edd1c8.html

[25] AECOM 2012. *Final Environmental Assessment: Rainbow Falls State Park Entrance Project Lewis County, Washington.* FEMA-1734-DR-WA (Public Assistance). Prepared by AECOM for the U.S. Department of Homeland Security, FEMA Region X. Available at: https://www.fema.gov/media-library-data/20130726-1831-25045-9010/rainbow_falls_sp_final_ea.pdf

Figure 12. Flooding at Rainbow Falls State Park, December 2007. *Image sources: Washington State Parks (top), AECOM 2012 (bottom)*

Heavy precipitation events create additional challenges for Parks beyond flooding. During pre-workshop interviews, Winter Recreation staff noted that heavy precipitation events in winter 2015/16—described by staff as a winter when "precipitation came on like a fire hose"—resulted in a record-breaking number of downed trees for Winter Recreation. According to staff, the program did not fully recover until February. These events also resulted in several road washouts. For example, the Orr Creek Sno-Park has been closed since December 2015 due to a washout of Forest Road 23.[26] The same storm event led to multiple washouts, downed trees, and landslides at other nearby Sno-Parks.

Landslides, mudslides, and high groundwater tables are also challenging for Parks. Prolonged and/or intense heavy rain events have triggered damaging slides affecting access to trails and parks (Figure 13). Sequim Bay, Manchester, Lake Sylvia, and Cape Disappointment state parks have all been impacted by landslide issues. Staff also noted that the impact of high groundwater on septic systems at Dosewallips State Park. The park was required to replace 11 septic systems, built in the 1960s, with a $6 million membrane bioreactor treatment system.[27]

Low water issues seem to be less prevalent for Parks than the problems associated with flooding and heavy precipitation, but they do create problems. Staff from the Southwest Region noted that recreation on Mayfield Lake at Ike Kinswa State Park has been negatively affected in years with low water levels. Drought conditions and the need to conserve water have also required reducing irrigation, prompting complaints from park visitors. Water supply in the San Juan Island marine parks can also be affected by drought given the reliance on seasonal precipitation to recharge wells in those parks (where available).

[26] Removal of natural debris slides (e.g., rock, mud, tress) is the responsibility of the landowner, such as the US Forest Service or private landowners. In these cases, the Winter Recreation Program is dependent on the landowner's ability to make a timely repair.

[27] Additional details from Washington Dept. of Ecology, 2015, "Dosewallips State Park Fact Sheet for Public Notice - 12-16-15", Dosewallips State Park Fact Sheet for Public Notice - 12-16-15.pdf, accessed June 25, 2017.

Figure 13. A before and after picture of renovations made to the Hamilton Mountain Trail in Beacon Rock State Park following winter mudslides. Volunteers from the Washington Trails Association helped rebuild the trail. *Photo credit: Washington State Parks, via Twitter post on April 3, 2017.*

Projected Changes: Precipitation and Hydrology | *Seasonal Streamflow and Hydrologic Extremes.* Warming temperatures, declining snowpack, and changing seasonal precipitation are expected to alter the hydrologic behavior of rivers and streams in Washington State. As temperatures across Washington State continue to rise, a greater fraction of winter precipitation will fall as rain rather than snow, resulting in higher winter streamflows, lower snowpack, and lower summer streamflows (see Section 4 for information on projected changes in precipitation and hydrology).

Workshop Concerns About Projected Changes in Precipitation and Hydrology | The potential impacts of changes in seasonal precipitation, extreme rainfall, and streamflow on park properties, infrastructure, and operations are diverse but also consistent across regions and programs. The most frequently discussed concerns during project workshops were issues related to increasing winter precipitation and more intense heavy rain events. These included the potential for more erosion, landslides, washouts, flooding, and issues with stormwater management. Issues related to drier summers and lower summer streamflows were also identified. Potential impacts identified by staff are summarized below.

Potential impacts related to increasing cool season (fall, winter, spring) precipitation and more intense heavy rain events:

- Increasing winter precipitation and more intense heavy rain events are likely to increase the frequency and/or extent of **erosion, landslides, and road washouts.** These impacts may block or limit access to parks, specific park features (e.g., a beach, snowmobile or hiking trails), or park infrastructure (e.g., restrooms, historic sites) until repaired by Parks, landowners, or other entities. Related financial impacts include the cost of rerouting trails and roads, and the cost of replacing or repairing infrastructure. The potential for erosion, landslides, and road washouts can be exacerbated in areas affected by wildfire, which is projected to increase with climate change. Erosion potential increases after a wildfire due to destruction of the organic matter in the upper soil layer. The loss of organic matter reduces the soil's moisture holding capacity, reducing soil stabilization and increasing erosion (DeBano 1981; McNabb and Swanson 1990).

- Higher soil saturation due to more winter precipitation can lead to **more downed trees**, especially during wind events. This risk is exacerbated by projected increases in fire risk and changes in tree health, which may leave more trees susceptible to falling. Downed trees can lead to park closures, blocked trails and roads, safety hazards, and higher operating costs (for downed tree removal). Revenue can be lost if downed trees keep an area out of service for an extended period. It can take days to restore access to small amounts of trail after large blowdown events.
- Heavier extreme precipitation events will **require rethinking how stormwater is managed.** Most stormwater facilities are designed to deal with historical precipitation extremes. More intense heavy rain events may require going above minimum permit requirements, which can be difficult and expensive.
- More winter precipitation, more winter precipitation falling as rain, and an earlier onset of spring snowmelt **could raise groundwater levels** in winter, contributing to localized flooding in low elevation areas and problems with septic systems (particularly older systems). Relocating septic systems compromised by higher groundwater may be difficult and/or require moving restroom facilities farther from parking lots, creating inconveniences for visitors. As noted previously, higher groundwater can also create challenges for construction.
- Increasing fall, winter, and spring precipitation or more frequently saturated soils may affect the **window for construction** at Parks. This can affect project schedules and construction budgets. Delays may push construction projects to summer (peak park usage) or lead to closures when maintenance issues cannot be addressed in time.

Potential impacts related to higher winter streamflows and increased winter flooding:

- Higher winter streamflows may **increase streambank erosion**, contributing to more **bridge scour and erosion** of roads, trails, and other areas adjoining rivers and streams. Depending on the location and severity of erosion, roads into parks and/or access to trails may be cut off until repaired by Parks, landowners, or infrastructure owners. Historic structures and archaeological sites may also be affected. As archaeological sites are exposed, the potential for vandalism of those sites becomes are concern.
- Increased winter flooding may cause more frequent or extensive **damage to park infrastructure, historic sites, and regional trail systems**. This includes damage to park buildings, historic structures and archaeological sites, campgrounds, septic systems, road infrastructure, and culverts. Trails and footbridges can also be washed out by flooding. The damage associated with flooding may require temporary or extended closures while under repair. Flooding can also create temporary access problems when blocking roads and trails. Staff noted that the potential for flood damage increases in areas affected by wildfire.
- Increased winter flooding and the potential for more erosion may require **relocating park facilities and campgrounds** and/or **changing assumptions about where to locate facilities and public access** in relation to rivers, streams, and bluffs.

- Increasing flood risks and more intense heavy rain events may require **changing infrastructure design**. For example, Parks may need to consider increasing culvert sizes or widening bridge spans to accommodate higher peak flows.

Potential impacts related to decreasing summer precipitation and lower summer streamflows:

- Lower summer water levels can **affect summer recreation opportunities** tied to water features such as river rafting and fishing. This may shift recreation preferences in ways that may require Parks to adjust or accommodate.
- Lower summer streamflow **would negatively affect salmon and vernal pools**. Warmer summer stream temperatures will likely reduce the amount of habitat suitable for salmon while increasing suitable bass habitat. This could incur high ecological consequences while also affecting recreational opportunities.
- Warmer, drier summers **could increase water demand** for parks maintenance or visitors. Increasing demand may be difficult to accommodate in parks where water supplies are already limited (e.g., San Juan Island marine parks) or at parks with junior water rights. Meeting water demand may necessitate trucking water into parks, seeking out alternative water supplies, and/or limiting water use onsite (e.g., reducing irrigation, changing to composting toilets). Parks that are dependent on municipal water suppliers could be forced to close a park if water is not available for parks due to drought.
- In some locations, **lower summer groundwater levels** may also affect groundwater quality and/or require additional well maintenance (for example, due to more sand or grit in the well casing, and increase the need for pumping, which can tax equipment).
- Impacts on summer water supplies may make it more difficult to open new parks in eastern Washington.

Adapting to changes in precipitation and shifting hydrologic regimes is anticipated to be challenging and expensive for Parks. In most regional workshops, Parks staff categorized these impacts as hard to adapt to with high consequences; however, classifications vary slightly by region and will also vary park-to-park depending on the context (see Appendix A for more details).

Repairing or restoring infrastructure, historic sites, and trail systems that are damaged by winter floods are anticipated to be expensive for Parks. In addition to the financial hurdle these issues pose, replacing and updating park facilities and infrastructure often involves complex permitting procedures and design considerations that may limit the ability to repair or replace damaged property. Staff also noted that access to FEMA post-disaster recovery funds may be unavailable if a facility or structure has a documented history of recurring flood damage. This may limit the financial resources available to recover from more frequent and larger winter flood events.

Modifying infrastructure design has been suggested as a way to accommodate projected increases in winter flood risk (widening culverts, raising freeboard). However, Parks staff note that going above current permitting requirements (e.g., raising freeboard to accommodate *projected* increases in winter streamflow) would likely increase project costs and be challenging to justify.

While relocation of existing facilities, historic sites, and trails could reduce the impacts of increased winter flooding, staff noted that there are also challenges associated with relocation. Successful relocation of facilities, historic sites, campgrounds, or trails, is dependent on the availability of adequate space within the affected park. If suitable space is not available, Parks may need to acquire additional land to accommodate relocation. Re-routing trails may also present ecological and financial challenges, as new trail locations may affect sensitive species and habitats and can be costly to relocate. Additionally, while relocating campgrounds to higher ground may mitigate campsite closures due to floodwater inundation, experience to date suggests that the public may object to these kinds of moves. Visitors are drawn to campsites in close proximity to water.

Preservation of historic sites presents a unique challenge to Parks. As noted in discussions about sea level rise (see Section 5.4), State Parks is required to protect historic sites and structures. However, robust guidance on how these structures should be protected from climate change impacts does not exist at this point in time. In many cases, relocation of historic sites is not a viable solution because the site location is an integral component of a structure's historical value.

The punctuated nature of some climate impacts is challenging for State Parks to adapt to from a logistical and budgeting standpoint. For example, while it is possible to estimate the risk of landslides, rockslides, or mudslides, predicting exactly when and where these events will occur is challenging. This lack of predictability makes it difficult for State Parks to budget for these types of events yet when they occur an immediate response if often needed (e.g., for sediment removal, road clearance, etc.). Furthermore, repairs or permanent solutions to slides can be difficult to fund and permit. Particularly for the Winter Recreation Program, mitigating future landslide risk is contingent on other landowners (e.g., private land owners, Forest Service) taking action to adapt.

While discussions surrounding State Parks' ability to adjust to projected changes in precipitation and hydrology were mainly focused on projected increases in winter precipitation and flood risk, a few challenges to adapting to declining summer precipitation and streamflow were discussed. For example, to alleviate increased water demand during dry summer months, State Parks could limit onsite water use by reducing irrigation. This may be unpopular with visitors who expect State Parks to provide areas of green grass, even during the dry summer months, but staff felt that additional outreach would help address visitor concerns. More limited summer water supplies may also make it difficult to open new parks or expand existing supplies, particularly in eastern Washington.

5.2 Changes in Snowpack

Changes in snowpack can affect recreation activities throughout the Washington State Parks system but are particularly impactful on the Winter Recreation Program, which relies on annual sales of daily and seasonal Sno-Park permits and snowmobile registrations to support maintenance and operation of the Sno-Park system (Figure 14).

Observed Changes: Snowpack | As discussed in Section 4, spring snowpack in the Washington and Oregon Cascades varies substantially year-to-year, but has declined since the mid-20th century.

Impacts on Parks: Current Snow Variability | Seasonal variation in snow cover, snow duration, and snow quality affects annual operating costs and Winter Recreation Program revenue associated with permit sales and registrations. Low snow years (such as the winter of 2014-2015) generally lead to lower permit sales and snowmobile registrations, while high snow years (such as the winter of 2016-2017) generally lead to higher sales. Staff noted that revenue during the snow drought of 2014-15 declined 30%. Because the Winter Recreation Program is self-funded with an operating budget based on the previous season's revenue, variability in snowpack and snow quality can create both challenges and opportunities for the program. For example, if a low snowpack year is followed by a high snowpack year, operating expenses for plowing and trail grooming may exceed available budget. Plowing costs for years with more rain-on-snow events can also be higher than budgeted, since rain-on-snow makes snow heavier and more difficult to clear and groom. Winter Recreation may have to stop plowing some locations before the season ends, limiting access to affected

Figure 14. Freshly groomed snow on Rex Derr Trail at Pearrygin Lake State Park. Photo credit: *Washington State Parks, via Twitter post on February 23, 2017.*

Sno-Parks or leading to pre-season closures. In other cases, funds may be pulled from budgets for equipment replacement/repair to maintain access. On the positive side, high snowpack years create an opportunity to place extra funds in an emergency reserve.

Staff noted that managing the Winter Recreation Program is becoming more challenging as winter snowpack and access to Sno-Parks becomes more variable and as population growth creates more demand. These factors create what staff considered a “double whammy” for the program.

Projected Changes: Snowpack & Snow Season Length | As discussed in Section 4, snowpack is projected to decline substantially and the snow season is projected to shorten.

Workshop Concerns About Projected Changes in Snowpack and Snow Season Length | Declining snowpack and a shorter snow season are likely to lead to a drop in Sno-Park permit purchases and snowmobile registrations over time. Lower sales would affect annual revenue for the Winter Recreation Program and may reduce emergency budget reserves, leaving the program more vulnerable to year-to-year variability in snowpack and funding. A shorter snow season also amplifies the impact of Sno-Park closures on user access and revenue generated at those locations. With a shorter operating season, closures affecting sites for multiple days or weeks may end up being a significant portion of the operating season. Lower winter recreation revenue would also affect staffing in regional offices supported by winter recreation revenue.

Other anticipated impacts related to declining snowpack include more road washouts, downed trees, and problems with access as areas previously armored by snow become exposed to increasing winter rain and more extreme precipitation events. The Planning Program noted that lower snowpack may impact relationships with recreation advocacy groups if program priorities have to shift. For example, while recreation advocacy groups may want to see an increase in the number of winter sport facilities, declining snowpack may shift Parks’ priorities and ability to maintain and develop new winter recreation facilities. On the positive side, plowing costs could decease with lower snowpack.

Changes in snowpack are expected to affect recreation in other seasons as well. Southwest Region staff noted that projected changes in snowpack and earlier snowmelt could reduce summer lake levels, particularly in years with low rainfall. This may lead to closure of freshwater boat facilities if water levels drop too low, as seen in the past at Ike Kinswa State Park. Earlier snowmelt and later snowfall (due to warmer spring and fall temperatures) could increase park use in the shoulder seasons and increase and/or shift the demand for other recreational activities such as mountain biking. These changes could offset potential impacts to traditional winter recreational activities and benefit revenue. However, these changes may also create staffing challenges, which may require shifting park staffing levels or hiring seasonal staff for an extended season.

Adapting to most of the recreation-related impacts resulting from a declining snowpack and earlier snowmelt were considered moderately difficult. The consequences varied from low to high, partially in recognition that while the consequences for an individual park may be significant (e.g., Mt. Spokane), the consequences for operations and revenue system-wide will be limited to parks that are reliant on snowpack for winter visitation. A notable exception was the related issues of more erosion, landslides, and washouts, which were rated hard to adapt to and high consequence primarily because of the costs associated with repairing these problems and impacts on access (see Appendix A for more information).

Winter Recreation staff noted that adapting program operations to decreasing snowpack may require moving Sno-Park access points (e.g., parking lots) to higher elevations. This kind of shift would create several challenges. First, moving Sno-Parks may require building new roads at a time when the US Forest Service is focusing more on decommissioning roads. Second, moving Sno-Parks to higher elevation will reduce usable trail miles. Staff estimated that moving the system up in elevation could shrink the amount of usable trail miles from 3,300 miles to 1,500 miles. Moving to higher elevation would also push more trail users into avalanche territory, increasing safety risks. Parks that have traditionally relied on winter recreation as the main-draw (e.g., Mount Spokane, Lake Easton, and Iron Horse state park) may ultimately have to transition over to a more traditional park management system that operates with a year-round workforce structure.

For more details on how declining snowpack may affect specific parks programs and regions, see the workshop summaries in Appendix A.