Appendix B:
Northwest Region Climate Summary

Prepared by

Harriet Morgan, Lara Whitely Binder, and Dan Siemann
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Climate[60]

Temperature. The northwest region of Washington State is projected to warm rapidly throughout the 21st century, as a result of greenhouse gases associated with human activities. This warming is projected to occur across all seasons, with the most warming occurring during summer. Average annual temperature in the northwest region of Washington is likely to increase +5.6 to +9.4°F by the 2080s[61], with extreme heat events becoming more frequent and extreme cold events less frequent.

Precipitation. Changes in annual and seasonal precipitation will continue to be primarily driven by year-to-year variations rather than long-term trends, but heavy rainfall events are projected to become more frequent and severe throughout the 21st century.

Water Resources

Northwest Washington is projected to experience a declining snowpack, a shifting balance between snow and rain, changes in streamflow timing, increasing flood risk, and lower summer minimum flows as a result of warming temperatures. The largest changes are projected for mid-elevation basins with significant snow accumulation (today's so-called "mixed rain and snow" watersheds; Figure 1).

Snowpack. As air temperatures warm, snowpack is projected to decline in winter and melt more rapidly during spring and summer. Average spring snowpack (April 1 SWE) in northwest Washington is projected to decline between –55% and –73% by the 2080s (2070-2099, relative to 1970-1999), on average, for a low (RCP 4.5) and a high (RCP 8.5) greenhouse gas scenario.

Warming air temperatures will drive the freezing level to higher elevations, which will result in a greater proportion of winter precipitation falling as rain rather than snow (Figure 1). This increase in winter rainfall will increase winter flood risk in mid-elevation, transient basins.

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[60] Information in this summary sheet is from: Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover, 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle. doi:10.7915/CIG93777D

[61] Under RCP 4.5 and RCP 8.5, respectively.

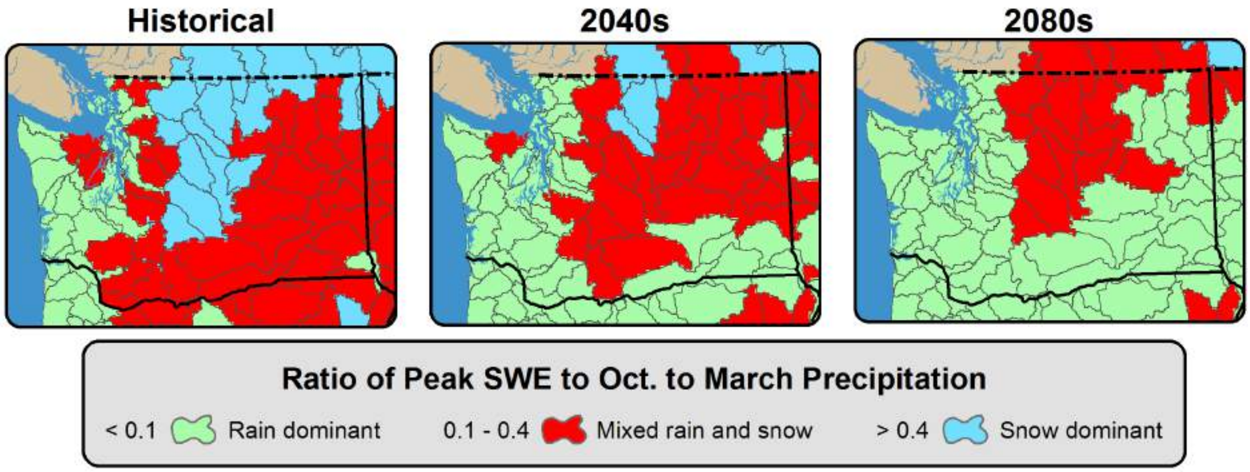
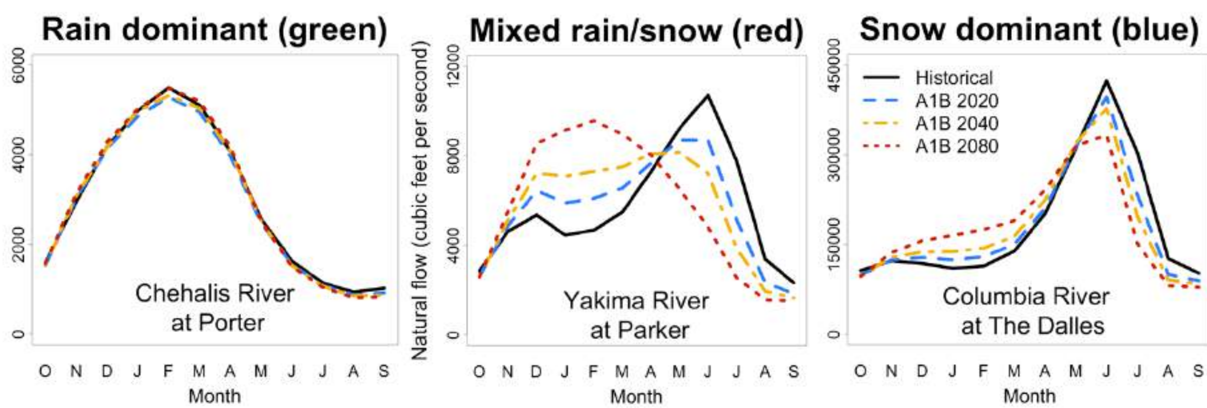


Figure 1. Changing hydrology with warming. Maps above indicate current and future watershed classifications, based on the proportion of winter precipitation stored in peak annual snowpack. Graphs below indicate current and future average monthly streamflow for these watershed types. Both compare average historical conditions (1916-2006) and projected future conditions for two time periods, the 2040s (2030-2059) and the 2080s (2070-2099), under a medium greenhouse gas scenario (A1B). Green shading in the maps indicates warm ("rain-dominant") watersheds, which receive little winter precipitation in the form of snow. In these basins, streamflow peaks during winter months and warming is projected to have little effect (below, left). Blue indicates cold ("snow-dominant") watersheds, that is, cold basins that receive more than 40% of their winter precipitation as snow. Depending on elevation, these basins are likely to experience increasing winter precipitation as rain and increased winter flows (below, right). The most sensitive basins to warming are the watersheds that are near the current snowline ("mixed rain and snow"), shown in red. These are middle elevation basins that receive a mixture of rain and snow in the winter, and are projected to experience significant increases in winter flows and decreases in spring flows as a result of warming (below, center). Source: Hamlet et al., 2013.



Forests

Forests in northwest Washington are projected to **experience a continued shift in the** geographic distribution of species, changes in forest growth and productivity, increasing fire activity, and changing risks from insects, diseases, and invasive species. These changes have significant implications for ecosystem composition and species interactions. Changes are projected to be most pronounced at higher elevations, where increasing air temperatures and decreasing snowpack can reduce habitat quality for some species but benefit others via a longer snow-free season and increased biological productivity. Many of the changes expected for Northwest forests are likely to be driven by increases in the frequency and intensity of disturbances such as fire, insect outbreaks, and disease.

Climate change is expected to increase fire activity in northwest Washington, even though the area is not thought to have been fire prone historically. Warming air temperatures and drier conditions are the primary mechanism leading to projected increases in area burned for Washington State.

Sea Level Rise

Sea level is projected to continue rising through the 21st century. By 2100, sea level rise along Washington's central and southern coast and in Puget Sound is projected to increase by +4 to +56 inches by 2100, relative to 2000.

Vertical land movement is a process which plays an important role in determining local and regional sea level rise. Washington State is a tectonically active area which causes the land surface to rise and fall over time. For example, the land surface of Neah Bay along the Northwest Olympic Peninsula is currently experiencing uplift. Conversely, Seattle and surrounding areas are subsiding, which exacerbates the local effects of sea level as the land surface is sinking.

Projected Changes in the Climate of Northwest Washington

Temperature	
Annual Temperature – Projected	Projected increase in average annual temperature for the **2050s** (2040-2069), relative to 1970-1999, for northwest Washington: Low emissions (RCP 4.5): +4.3°F (range: +3.0 to +5.6°F) High emissions (RCP 8.5): +5.6°F (range: +4.5 to +7.3°F) Projected increase in average annual temperature for the **2080s** (2070-2099), relative to 1970-1999, for Washington state: Low emissions (RCP 4.5): +5.6°F (range: +4.2 to +7.5°F) High emissions (RCP 8.5): +9.4°F (range: +7.5 to +11.9°F)
Temperature – Seasonal	Projected increase in seasonal temperatures for the **2050s** (2040-2069), relative to 1970-1999, for northwest Washington: *Winter* Low emissions (RCP 4.5): +4.0°F (range: +2.9 to +5.1°F) High emissions (RCP 8.5): +5.0°F (range: +3.2 to +6.7°F) *Spring* Low emissions (RCP 4.5): +4.0°F (range: +2.4 to +5.4°F) High emissions (RCP 8.5): +4.9°F (range: +3.1 to +7.8°F) *Summer* Low emissions (RCP 4.5): +5.2°F (range: +3.4 to +7.7°F)

	High emissions (RCP 8.5): +7.6°F (range: +5 to +9.9°F) *Fall* Low emissions (RCP 4.5): +4.1°F (range: +2.6 to +5.7°F) High emissions (RCP 8.5): +5.6°F (range: +3.9 to +7.3°F) Projected increase in seasonal temperatures for the **2080s** (2060-2099), relative to 1970-1999, for northwest Washington: *Winter* Low emissions (RCP 4.5): +5.0°F (range: +4.4 to +6.4°F) High emissions (RCP 8.5): +8.5°F (range: +6.1 to +10.4°F) *Spring* Low emissions (RCP 4.5): +5.4°F (range: +3.9 to +8.4°F) High emissions (RCP 8.5): +8.1°F (range: +5.3 to +11.6°F) *Summer* Low emissions (RCP 4.5): +6.5°F (range: +4.7 to +9.3°F) High emissions (RCP 8.5): +11.3°F (range: +9.1 to +15.4°F) *Fall* Low emissions (RCP 4.5): +5.2°F (range: +3.8 to +7.2°F) High emissions (RCP 8.5): +9.2°F (range: +6.6 to +11.3°F)
Number of Days Above Warm Thresholds	Projected increase in the number of days above various thresholds (80°F, 90°F, 100°F) for the historical period (1970-1999), 2050s, and the 2080s. **2050s** 80°F: Historical (1970-1999): 10 days RCP 4.5: +18 days (range: +12 to +28 days) RCP 8.5: +27 days (range: +19 to +38 days) 90°F: Historical (1970-1999): 1 day RCP 4.5: +4 days (range: +2 to +6 days) RCP 8.5: +6 days (range: +3 to +11 days) 100°F: Historical (1970-1999): 0 days RCP 4.5: +0 days (range: +0 to +0 days) RCP 8.5: +0 days (range: +0 to +1 days) **2080s** 80°F: Historical (1970-1999): 10 days RCP 4.5: +24 days (range: +16 to +36 days) RCP 8.5: +50 days (range: +35 to +68 days) 90°F: Historical (1970-1999): 1 day RCP 4.5: +5 days (range: +3 to +8 days) RCP 8.5: +17 days (range: +8 to +29 days) 100°F: Historical (1970-1999): 0 days RCP 4.5: +0 days (range: +0 to +1 days) RCP 8.5: +2 days (range: +0 to +4 days)
Precipitation	
Annual Precipitation – Projected	Projected change in average annual precipitation for the **2050s** (2040-2069), relative to 1970-1999, for northwest Washington: Low emissions (RCP 4.5): +3.9% (range: +0.4 to +11.4%) High emissions (RCP 8.5): +4.7% (range: −2.4 to +13.1%)

	Projected increase in average annual precipitation for the **2080s** (2070-2099), relative to 1970-1999, for Washington state: Low emissions (RCP 4.5): +6.1% (range: −0.2 to +9.9%) High emissions (RCP 8.5): +6.6% (range: +0.7 to +8.8%)
Seasonal Precipitation – Projected	Projected change in seasonal precipitation for the **2050s** (2040-2069), relative to 1970-1999, for northwest Washington: *Winter* Low emissions (RCP 4.5): +9.8% (range: −1.8 to +21.4%) High emissions (RCP 8.5): +10.5% (range: +1.8 to +19.6%) *Spring* Low emissions (RCP 4.5): +2.5% (range: −9.0 to +13.3%) High emissions (RCP 8.5): +4.1% (range: −6.8 to +13.3%) *Summer* Low emissions (RCP 4.5): −22.4% (range: −44.5 to −6.4%) High emissions (RCP 8.5): −22.5% (range: −50.1 to −1.2%) *Fall* Low emissions (RCP 4.5): +5.4% (range: −5.9 to +12.8%) High emissions (RCP 8.5): +6.1% (range: −2.5 to +18.7%) Projected increase in seasonal precipitation for the **2080s** (2060-2099), relative to 1970-1999, for northwest Washington: *Winter* Low emissions (RCP 4.5): +11.0% (range: +1.1 to +15.9%) High emissions (RCP 8.5): +14.5% (range: +5.9 to +22.5%) *Spring* Low emissions (RCP 4.5): +1.9 % (range: −2.8 to +10.3%) High emissions (RCP 8.5): +2.9% (range: −6.6 to +11.2%) *Summer* Low emissions (RCP 4.5): −19.9 % (range: −36.9 to −10.2%) High emissions (RCP 8.5): −27.4% (range: −52.7 to +10.1%) *Fall* Low emissions (RCP 4.5): +11.4% (range: +1.8 to +20.9%) High emissions (RCP 8.5): +9.8% (range: +1.4 to +15.2 %)
Heavy Precipitation – Projected	Projected changes in **western Oregon and Washington** precipitation extremes for the **2080s** (2070-2099, relative to 1970-1999) for a high (RCP 8.5) greenhouse gas scenario: Annual 99th percentile of 24-hour precipitation: +22% (range: +5 to +34%) Frequency of exceeding the historical 99th percentile of 24-hour precipitation: Historical (1970-1999): 2 days / year Future (2070-2099): 7 days / year (range: 4 to 9 days / year)
Snow *April 1st Snowpack*	Projected changes in northwest Washington average April 1st snowpack[62]; for the **2050s** (2040-2069) and the **2080s** (2070-2099), relative to 1970-1999: **2050s** Low emissions (RCP 4.5): −43.2% (range: −51.4 to −28.2%)

[62] These numbers show projected changes in April 1st Snow Water Equivalent (SWE). 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.

	High emissions (RCP 8.5): −50.8% (range: −64.6 to −47.6%) **2080s** Low emissions (RCP 4.5): −54.7% (range: −64.6 to −34.4%) High emissions (RCP 8.5): −73.2% (range: −84.6 to −57.2%)
Snow Season Length	Increasing air temperatures are projected to result in a shortening of the length of the snow season.[63] Projected change in snow season length for the **2050s** (2040-2069) and **2080s** (2070-2099), relative to 1970-1999, for northwest Washington: **2050s** Low emissions (RCP 4.5): −35.8 days (range: −43.7 to −25.9 days) High emissions (RCP 8.5): −47.2 days (range: −64.4 to −28 days) **2080s** Low emissions (RCP 4.5): −50 days (range: −62.8 to −38.6 days) High emissions (RCP 8.5): −82.6 days (range: −99 to −58.2 days)

Streamflow	***Projected Long-term Change***

Streamflow timing	Peak streamflows are projected to occur earlier in many snowmelt-influenced rivers in the Northwest.
	• Change in the timing of peak streamflow for the Skagit River and the Green River for the 2080s (2070-2099, relative to 1970-1999). Average and range for a moderate (A1B) greenhouse gas scenario[64]:
	  ○ Skagit R: -22 days (-36 to -13 days)
	  ○ Green R: -38 days (-50 to -31 days)

Stream temperatures	Water temperatures are projected to increase.
	• Northwest Washington rivers are projected to increasingly experience average August stream temperatures stressful to salmon (in excess of 64°F) and char (in excess of 54°F).
	• Increase in the number of river miles in excess of thermal tolerances, on average for the 2080s (2070-2099, relative to 1970-1999) and a moderate (A1B) greenhouse gas scenario, for the Skagit River and the Green River:
	  ○ Skagit R: +566 mi. (>54 °F; char), +121 mi. (>64 °F; salmon)
	  ○ Green R: +173 mi. (>54 °F; char), +73 mi. (>64 °F; salmon)

[63] Snow season length is defined as the number of days between the date of 10% accumulation and 90% melt, relative to annual maximum snow water equivalent.

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

Flooding	Most scenarios project an increase in peak flows.
	
	• Projected change in streamflow associated with the 100-year (1% annual probability) flood event for the Skagit River and the Green River, on average for the 2080s (2070-2099m relative to 1970-1999):
	  o Skagit R: +42% (+4 to 86%)
	  o Green R: +32% (+15 to 73%)
	• Increase in the area flooded due to the combined effects of high river flows and sea level rise, for the 2080s (2070-2099, relative to 1970-1999):[65]
	
	  o Skagit R (100-yr event, average change): +74%

Minimum Flows	Streamflow is projected to decline for summer minimum flows.
	
	• Projected changed in summer minimum streamflow (7Q10)[66] for the Skagit River and the Green River, on average for the 2080s (2070-2099, relative to 1970-1999). Average and range for a moderate (A1B) greenhouse gas scenario:[64]
	  o Skagit R: -51% (-65 to -38%)
	  o Green R: -16% (-21 to -7%)
	
	• Rain dominant and mixed rain and snow basins show the greatest and most consistent decreases in minimum flows, while changes for snow dominant basins are smaller.
	
	• The above projections do not account for contributions from melting glaciers. Projections indicate that glaciers may augment minimum flows in the near term due to the increased rate of melt, but nearly all scenarios show a sharp decline in meltwater in the late 21st century as glaciers diminish in size.

Runoff	Projected change in summer and winter runoff for the **2050s** (2040-2069) and **2080s** (2070-2099), relative to 1970-1999, for northwest Washington: **2050s** *Winter (Oct-March)* Low emissions (RCP 4.5): +26.7 cm (range: +18.1 to +38.45 cm) High emissions (RCP 8.5): +34.5 cm (range: +20.5 to +57.4 cm) *Summer (April-Sept)* Low emissions (RCP 4.5): −15.2 cm (range: −19.1 to −6.9 cm) High emissions (RCP 8.5): −17.7cm (range: −24.5 to −7.6 cm) **2080s** *Winter (Oct-March)* Low emissions (RCP 4.5): +41.2 cm (range: +21.8 to +56.3 cm) High emissions (RCP 8.5): +62.0 cm (range: +44.4 to +77.4 cm) *Summer (April-Sept)* Low emissions (RCP 4.5): −19.0 cm (range: −24.2 to −8.4 cm) High emissions (RCP 8.5): −28.4 cm (range: −39.5 to −19.6 cm)

[65] Sea level rise projections were obtained from the 2007 IPCC report; streamflow projections were based on 10 global climate model projections and a moderate (A1B) greenhouse gas scenario. Flood simulations assume all levees would remain intact, although they could be overtopped. When levee failure scenarios are included, the increase in flooded area is much less pronounced. With levee failure, much of the floodplain would be inundated even in the absence of climate change – increased flows and higher sea levels do increase water depths, but do not significantly change the area flooded.

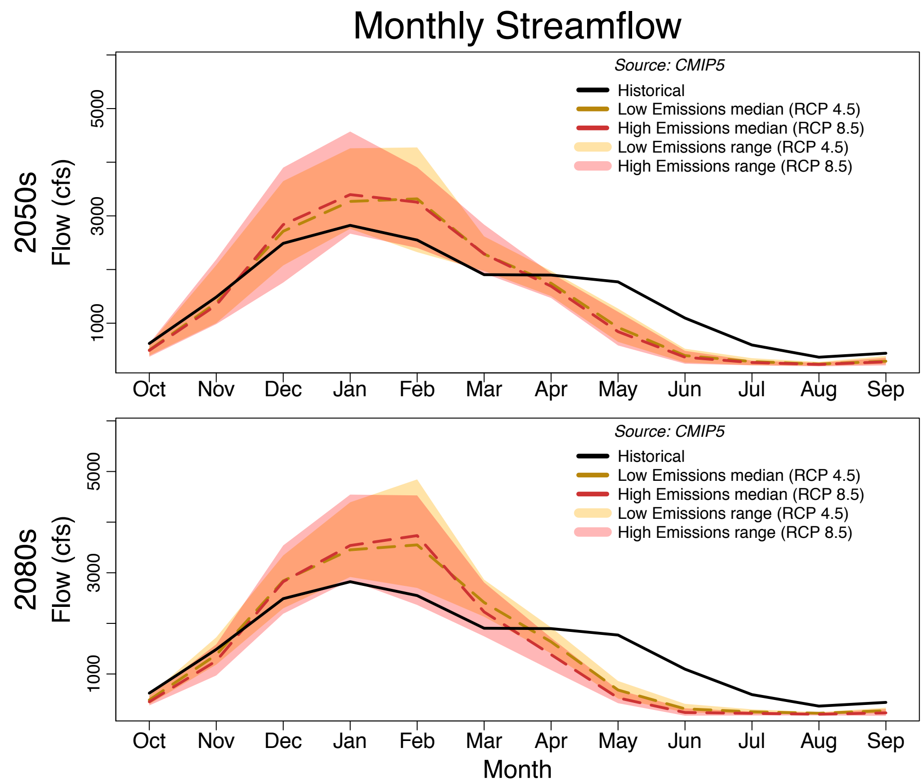
[66] The 7Q10 flow is the lowest 7-day average flow that occurs on average once every 10 years. 7Q10 flows are a common standard for defining low flow for the purpose of setting permit discharge limits.

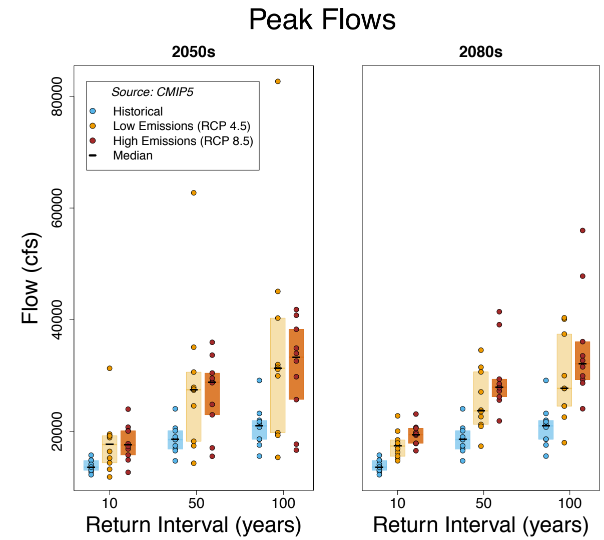
Oceans	
Sea Level – Projected	Rising for all scenarios (2100, relative to 2000) Seattle, WA: +24 inches (+4 to +56 inches)
Ocean Acidification – Projected	Global Increase by 2100 for all scenarios (relative to 1986-2005). Low emissions (RCP 4.5): +38 to +41% High emissions (RCP 8.5): +100 to +109%

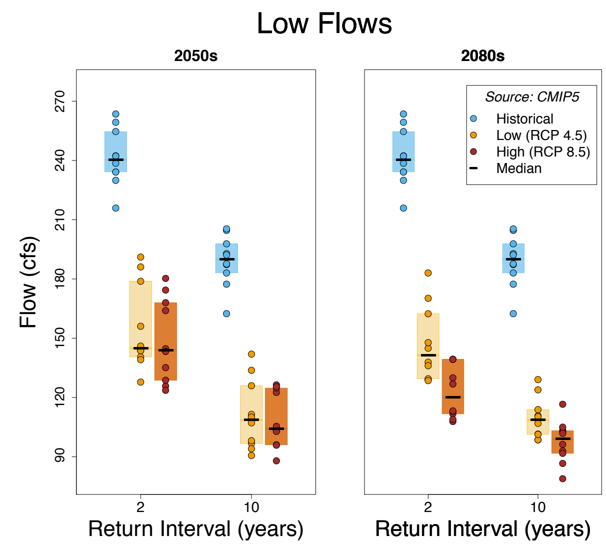
For more information on climate change impacts in Northwest Washington, see *State of Knowledge: Climate Change in Puget Sound* (2015), available at https://cig.uw.edu/resources/special-reports/ps-sok/.

Green River Watershed

CMIP5 projections



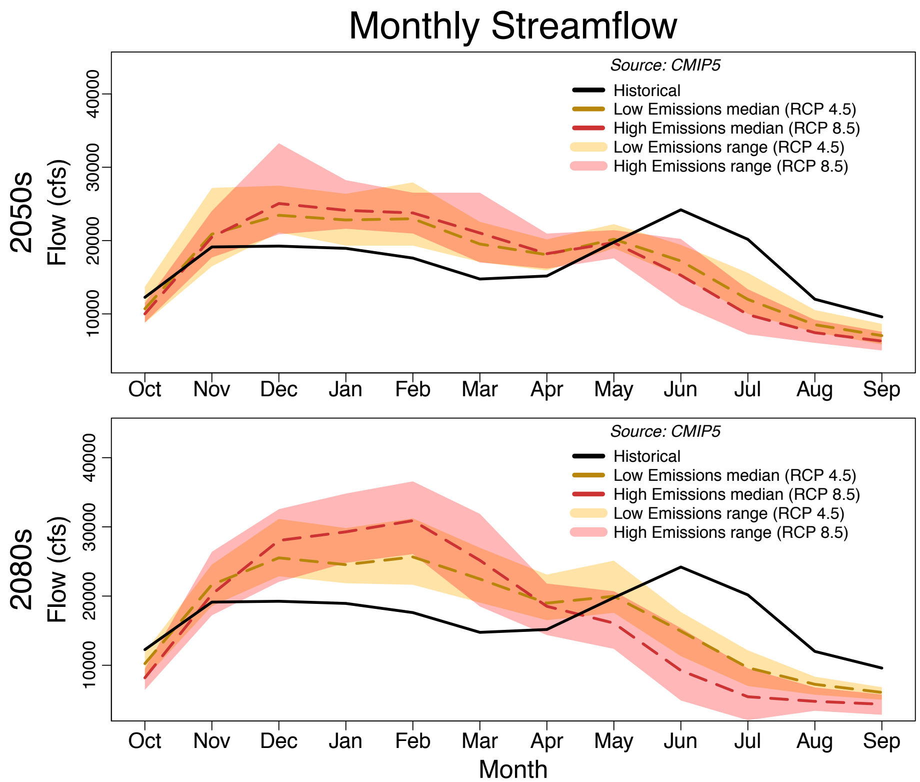


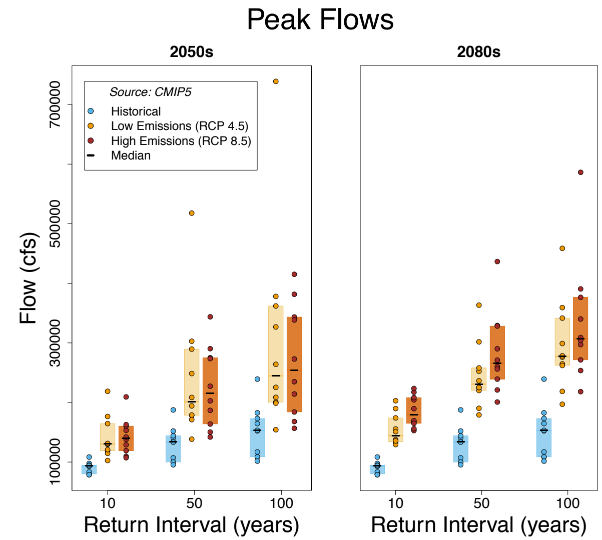


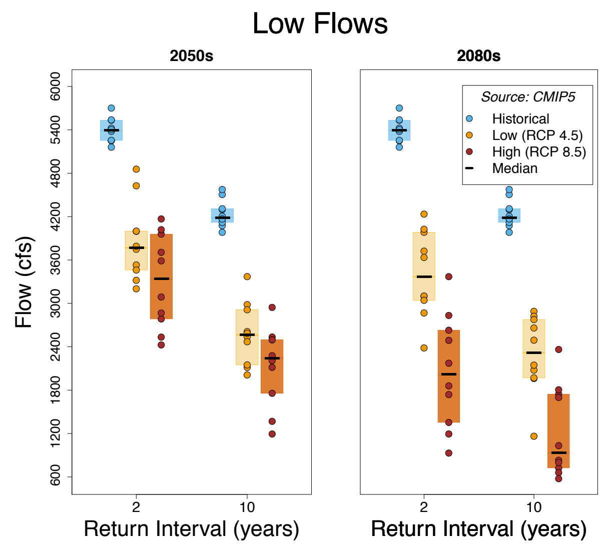
Figures D-7b. As described on Page D-2, for the Green River watershed, based on the CMIP5-based hydrologic projections.[1,2]

Skagit River Watershed

CMIP5 projections







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Snowpack. As air temperatures warm, snowpack is projected to decline in winter and melt more rapidly during spring and summer. Average spring snowpack (April 1 SWE) in Southwest Washington is projected to decline between –75% and –88% by the 2080s (2070-2099, relative to 1970-1999), on average, for a low (RCP 4.5) and a high (RCP 8.5) greenhouse gas scenario.

Warming air temperatures will drive the freezing level to higher elevations, which will result in a greater proportion of winter precipitation falling as rain rather than snow (Figure 1). This increase in winter rainfall will increase winter flood risk in mid-elevation, transient basins.

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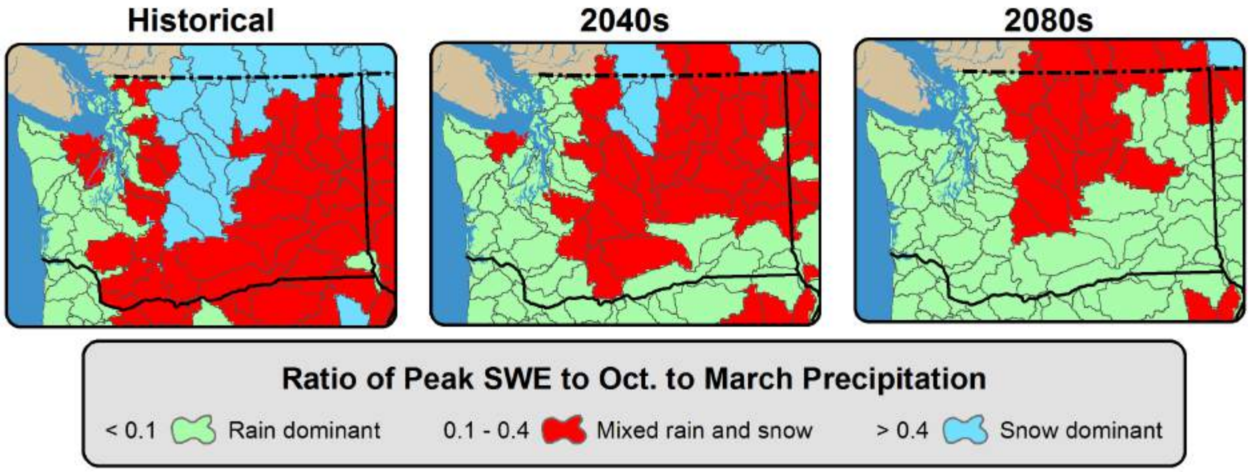

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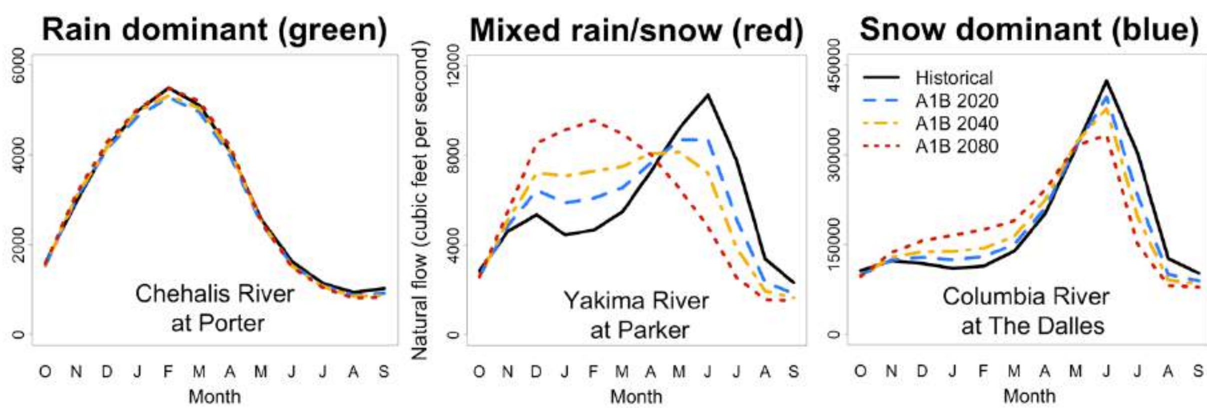

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Temperature – Seasonal	Projected increase in seasonal temperatures for the **2050s** (2040-2069), relative to 1970-1999, for southwest Washington: *Winter* Low emissions (RCP 4.5): +3.6°F (range: +2.9 to +5.1°F) High emissions (RCP 8.5): +4.5°F (range: +3.2 to +6.7°F) *Spring* Low emissions (RCP 4.5): +3.4°F (range: +2.1 to +4.4°F) High emissions (RCP 8.5): +4.1°F (range: +2.5 to +6.3°F) *Summer* Low emissions (RCP 4.5): +4.5°F (range: +2.8 to +6.5°F)

	High emissions (RCP 8.5): +5.9°F (range: +4.1 to +8.7°F) *Fall* Low emissions (RCP 4.5): +3.8°F (range: +2.4 to +5.1°F) High emissions (RCP 8.5): +5.2°F (range: +3.6 to +6.9°F) Projected increase in seasonal temperatures for the **2080s** (2060-2099), relative to 1970-1999, for southwest Washington: *Winter* Low emissions (RCP 4.5): +4.7°F (range: +3.8 to +6.5°F) High emissions (RCP 8.5): +7.7°F (range: +5.5 to +9.9°F) *Spring* Low emissions (RCP 4.5): +4.7°F (range: +3.5 to +6.7°F) High emissions (RCP 8.5): +7.0°F (range: +5.1 to +9.7°F) *Summer* Low emissions (RCP 4.5): +5.8°F (range: +4.1 to +8.1°F) High emissions (RCP 8.5): +9.9°F (range: +7.9 to +13.7°F) *Fall* Low emissions (RCP 4.5): +4.9°F (range: +3.4 to +6.7°F) High emissions (RCP 8.5): +8.6°F (range: +6.2 to +10.5°F)
Number of Days Above Warm Thresholds	Projected increase in the number of days above various thresholds (80°F, 90°F, 100°F) for the historical period (1970-1999), 2050s, and the 2080s. **2050s** 80°F: Historical (1970-1999): 17 days RCP 4.5: +17 days (range: +12 to +25 days) RCP 8.5: +24 days (range: +18 to +34 days) 90°F: Historical (1970-1999): 2 days RCP 4.5: +5 days (range: +3 to +7 days) RCP 8.5: +8 days (range: +5 to +13 days) 100°F: Historical (1970-1999): 0 days RCP 4.5: +1 day (range: +0 to +1 days) RCP 8.5: +1 day (range: +1 to +2 days) **2080s** 80°F: Historical (1970-1999): 17 days RCP 4.5: +22 days (range: +16 to +32 days) RCP 8.5: +44 days (range: +33 to +64 days) 90°F: Historical (1970-1999): 2 day RCP 4.5: +7 days (range: +4 to +11 days) RCP 8.5: +17 days (range: +10 to +29 days) 100°F: Historical (1970-1999): 0 days RCP 4.5: +1 days (range: +0 to +2 days) RCP 8.5: +3 days (range: +1 to +6 days)
Precipitation	
Annual Precipitation – Projected	Projected increase in average annual precipitation for the **2050s** (2040-2069), relative to 1970-1999, for southwest Washington: Low emissions (RCP 4.5): +3.9% (range: +0.6 to +11.3%) High emissions (RCP 8.5): +4.8% (range: −3.0 to +11.8%)

	Projected increase in average annual precipitation for the **2080s** (2070-2099), relative to 1970-1999, for southwest Washington: Low emissions (RCP 4.5): +5.9% (range: −1.2 to +9.2%) High emissions (RCP 8.5): +6.4% (range: −0.1 to +10.4%)
Seasonal Precipitation – Projected	Projected changes in seasonal precipitation for the **2050s** (2040-2069), relative to 1970-1999, for southwest Washington: *Winter* Low emissions (RCP 4.5): +9.7% (range: −0.5 to +19.3%) High emissions (RCP 8.5): +10.7% (range: +1.9 to +16.6%) *Spring* Low emissions (RCP 4.5): +0.6% (range: −12.5 to +7.8%) High emissions (RCP 8.5): +1.6% (range: −12.6 to +11.3%) *Summer* Low emissions (RCP 4.5): −20.4% (range: −49.6 to −6.0%) High emissions (RCP 8.5): −19.8% (range: −51.7 to −1.9%) *Fall* Low emissions (RCP 4.5): +4.1% (range: −6.8 to +12.9%) High emissions (RCP 8.5): +5.0% (range: −4.0 to +17.9%) Projected changes in seasonal precipitation for the **2080s** (2060-2099), relative to 1970-1999, for southwest Washington: *Winter* Low emissions (RCP 4.5): +10.6% (range: +1.3 to +15.7%) High emissions (RCP 8.5): +13.9% (range: +6.0 to +22.4%) *Spring* Low emissions (RCP 4.5): −1.1% (range: −7.2 to +5.4%) High emissions (RCP 8.5): −0.1% (range: −13.5 to +8.2%) *Summer* Low emissions (RCP 4.5): −18.2% (range: −40.9 to −6.9%) High emissions (RCP 8.5): −21.8% (range: −53.5 to +9.8%) *Fall* Low emissions (RCP 4.5): +10.6% (range: −0.2 to +20.3%) High emissions (RCP 8.5): +7.7% (range: −1.0 to +14.3%)
Heavy Precipitation – Projected	Projected increase in **western Oregon and Washington** precipitation extremes for the **2080s** (2070-2099, relative to 1970-1999) for a high (RCP 8.5) greenhouse gas scenario: Annual 99th percentile of 24-hour precipitation: +22% (range: +5 to +34%) Frequency of exceeding the historical 99th percentile of 24-hour precipitation: Historical (1970-1999): 2 days / year Future (2070-2099): 7 days / year (range: 4 to 9 days / year)

Snow *April 1st Snowpack*	Projected decrease in southwest Washington average April 1 snowpack[69] for the **2050s** (2040-2069) and the **2080s** (2070-2099), relative to 1970-1999: **2050s** Low emissions (RCP 4.5): −63.3% (range: −71.8 to −45.0%) High emissions (RCP 8.5): −69.4% (range: −85.5 to −51.4%) **2080s** Low emissions (RCP 4.5): −74.7% (range: −87.5 to −64.4%) High emissions (RCP 8.5): −87.6% (range: −96.5 to −75.2%)
Snow Season Length	Increasing air temperatures are projected to result in a shortening of the length of the snow season.[70] Projected decline in snow season length for the **2050s** (2040-2069) and **2080s** (2070-2099), relative to 1970-1999, for southwest Washington: **2050s** Low emissions (RCP 4.5): −40 days (range: −52 to −28 days) High emissions (RCP 8.5): −49 days (range: −68 to −28 days) **2080s** Low emissions (RCP 4.5): −53 days (range: −71 to −39 days) High emissions (RCP 8.5): −77 days (range: −93 to −55 days)

Streamflow	***Projected Long-term Change***
Streamflow timing	Peak streamflows are projected to occur earlier in many snowmelt-influenced rivers in the Southwest. **2080s** • Change in the timing of peak streamflow for the Dungeness River and the Elwha River for the **2080s** (2070-2099, relative to 1970-1999). Average and range for a moderate (A1B) greenhouse gas scenario[71]: ○ Dungeness R: -15 days (-35 to -6 days) ○ Elwha R: -28 days (-41 to -20 days)
Stream temperatures	Water temperatures are projected to increase. • Southwest Washington rivers are projected to increasingly experience average August stream temperatures stressful to salmon (in excess of 64°F) and char (in excess of 54°F). • Increase in the number of river miles in excess of thermal tolerances, on average for the **2080s** (2070-2099, relative to 1970-1999) and a moderate (A1B) greenhouse gas scenario, for the Dungeness River and the Elwha River: ○ Dungeness R: +32 mi. (>54 °F), +0 mi. (>64 °F) ○ Elwha R: +64 mi. (>54 °F), +0 mi. (>64 °F)

69 These numbers show projected changes in April 1 Snow Water Equivalent (SWE). SWE is a measure of the total amount of water contained in the snowpack. April 1 is the approximate current timing of peak annual snowpack in the mountains of the Northwest.

70 Snow season length is defined as the number of days between the date of 10% accumulation and 90% melt, relative to annual maximum snow water equivalent.

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

Flooding	Most scenarios project an increase in peak flows. **2040s** • Projected change in streamflow associated with the 100-year (1% annual probability) flood event for the Satsop River, Columbia River (at Bonneville), Chehalis River, Dungeness River, and Elwha River on average for the **2040s** (2030-2059, relative to 1970-1999): ○ Satsop R: +14% (+1 to 27%) ○ Chehalis R: +10% (-13 to 35%) ○ Columbia R[72]: -6% (-22 to 5%) ○ Dungeness R: +60% (+29 to 112%) ○ Elwha R: +24% (+14 to 52%) **2080s** • Projected change in streamflow associated with the 100-year (1% annual probability) flood event for the Satsop River, Columbia River (at Bonneville), Chehalis River, Dungeness River, and Elwha River, on average for the **2080s** (2070-2099, relative to 1970-1999): ○ Satsop R: +26% (+1 to 55%) ○ Chehalis R: +22% (+3 to 52%) ○ Columbia R:[72] +1% (-17 to +38%) ○ Dungeness R: +55 (+20 to 116%) ○ Elwha R: +29 (+5 to 50%)
Minimum Flows	Summer minimum flows are projected to decrease. **2040s** • Projected changed in summer minimum streamflow (7Q10)[74] for the Satsop River, Columbia River (at Bonneville), Chehalis River, Dungeness River, and Elwha River, on average for the **2040s** (2030-2059, relative to 1970-1999). Average and range for a moderate (A1B) greenhouse gas scenario:[64] ○ Satsop R: -13% (-22 to -1%) ○ Chehalis R: -3% (-7 to +2%) ○ Columbia R:[72] -5% (-15 to +5%) ○ Dungeness R: -21% (-31 to -12%) ○ Elwha R: -27% (-40 to -16%) **2080s** • Projected changed in summer minimum streamflow (7Q10; see footnote 7) for the Satsop River, Columbia River (at Bonneville), Chehalis River, Dungeness River, and Elwha River, on average for the **2080s** (2070-2099, relative to 1970-1999). Average and range for a moderate (A1B) greenhouse gas scenario:[64] ○ Satsop R: -18% (-24 to -10%) ○ Chehalis R: -5% (-9 to -1%) ○ Columbia R:[72] -9% (-18 to +6%) ○ Dungeness R: -35% (-45 to -27%) ○ Elwha R: -39% (-49 to -27%) • Rain dominant and mixed rain and snow basins show the greatest and most

[72] At Bonneville

[74] The 7Q10 flow is the lowest 7-day average flow that occurs on average once every 10 years. 7Q10 flows are a common standard for defining low flow for the purpose of setting permit discharge limits.

Runoff[73]	consistent decreases in minimum flows, while changes for snow dominant basins are smaller. • The above projections do not account for contributions from melting glaciers. Projections indicate that glaciers may augment minimum flows in the near term due to the increased rate of melt, but nearly all scenarios show a sharp decline in meltwater in the late 21st century as glaciers diminish in size. Projected change in summer and winter runoff for the **2050s** (2040-2069) and **2080s** (2070-2099), relative to 1970-1999, for southwest Washington: **2050s** *Winter (Oct-March)* Low emissions (RCP 4.5): +18.4 cm (range: +12.1 to +30.0 cm) High emissions (RCP 8.5): +22.2 cm (range: +10.6 to +35.5 cm) *Summer (April-Sept)* Low emissions (RCP 4.5): −15.1 cm (range: −22.2 to −8.3 cm) High emissions (RCP 8.5): −16.3 cm (range: −26.1 to −7.2 cm) **2080s** *Winter (Oct-March)* Low emissions (RCP 4.5): +27.0 cm (range: +8.4 to +37.7 cm) High emissions (RCP 8.5): +34.2 cm (range: +25.3 to +43.1 cm) *Summer (April-Sept)* Low emissions (RCP 4.5): −18.8 cm (range: −25.7 to −8.8 cm) High emissions (RCP 8.5): −28.4 cm (range: −37.7 to −15.5 cm)

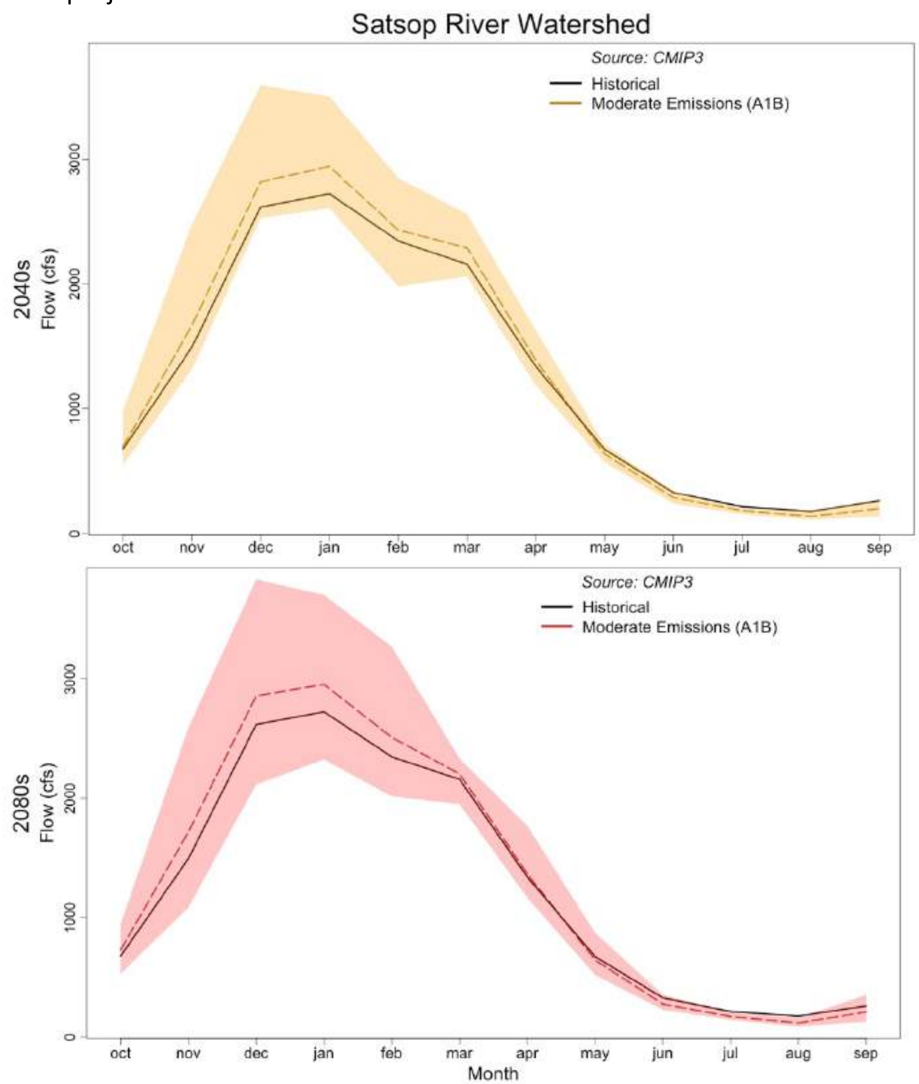
Oceans	
Sea Level – Projected	Rising for all scenarios (2050 and 2100, relative to 2000) Seattle, WA: • **2050:** +6 inches (-1 to +19 inches) • **2100:** +24 inches (+4 to +56 inches)
Ocean Acidification – Projected	Global Increase by 2100 for all scenarios (relative to 1986-2005). Low emissions (RCP 4.5): +38 to +41% High emissions (RCP 8.5): +100 to +109%

For more information on climate change impacts in Southwest and Northwest Washington, see *State of Knowledge: Climate Change in Puget Sound* (2015), available at https://cig.uw.edu/resources/special-reports/ps-sok/.

73 This includes any overland water flows in addition to subsurface runoff in shallow groundwater.

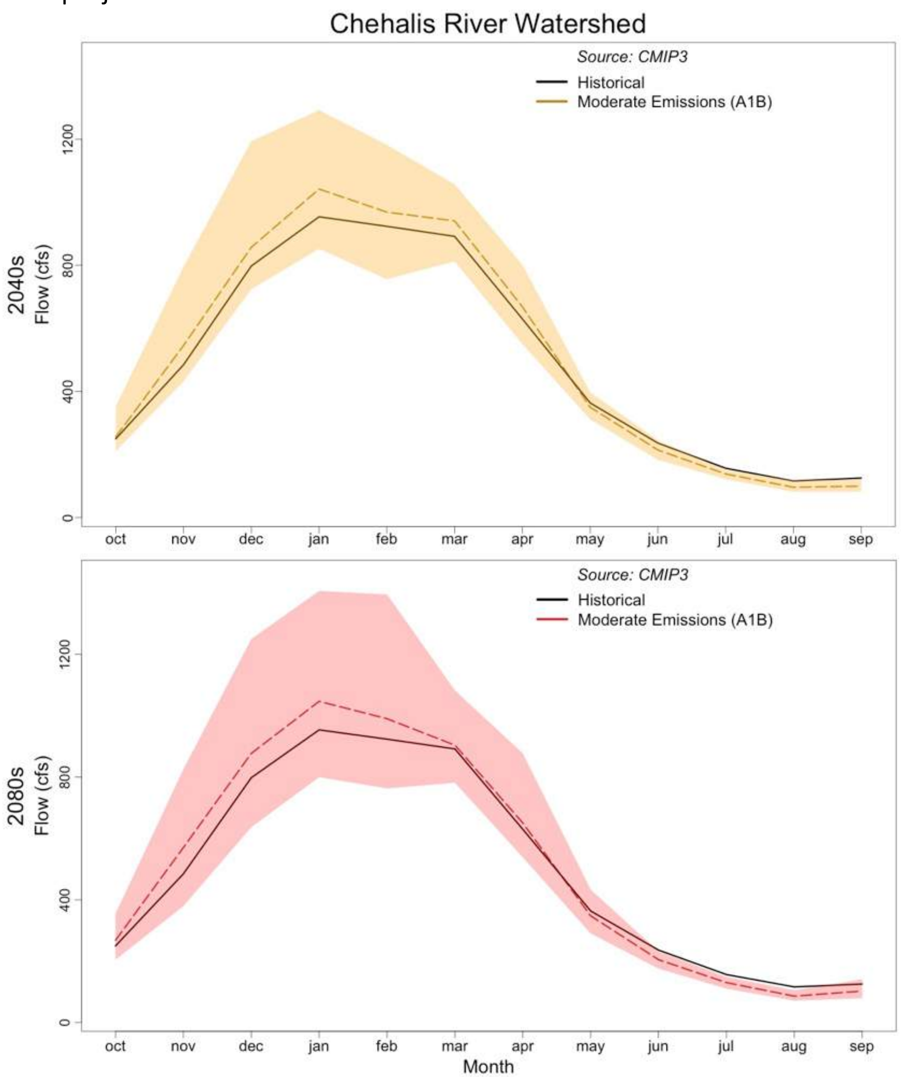
Satsop River Watershed

CMIP3 projections



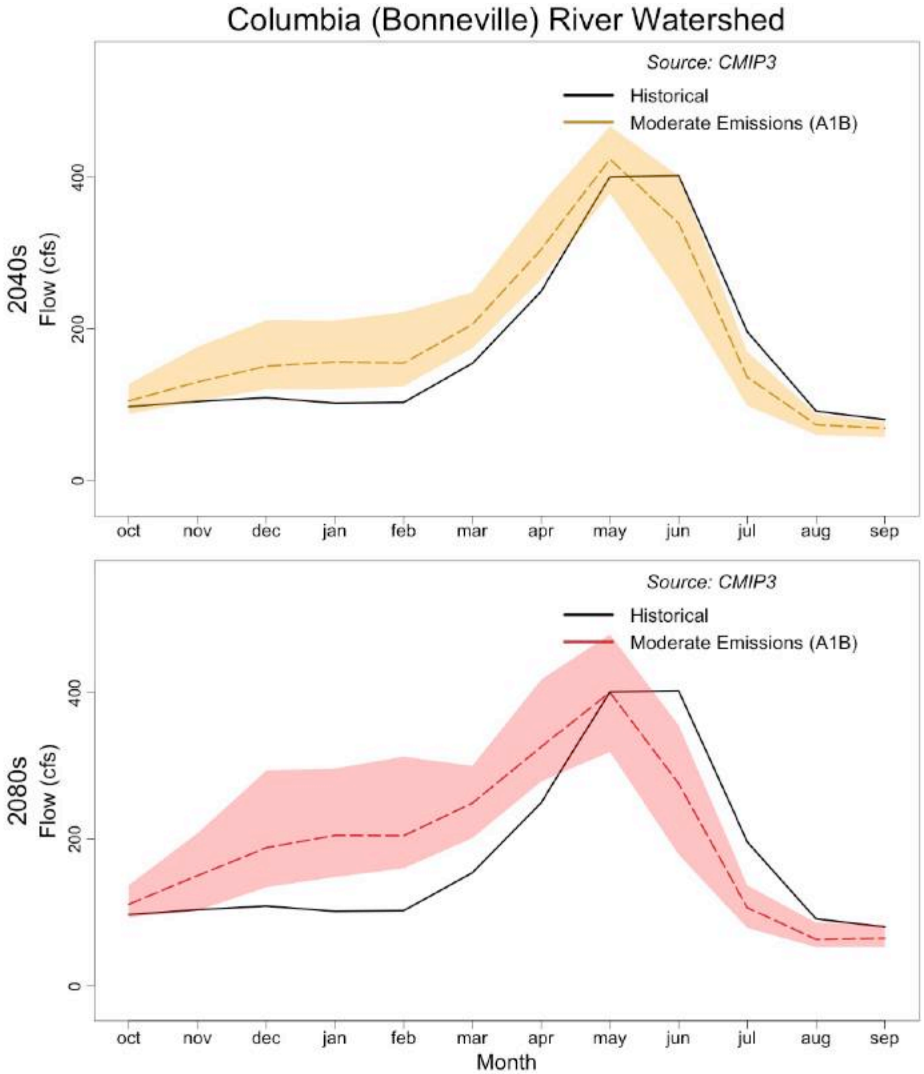
Chehalis River Watershed

CMIP3 projections



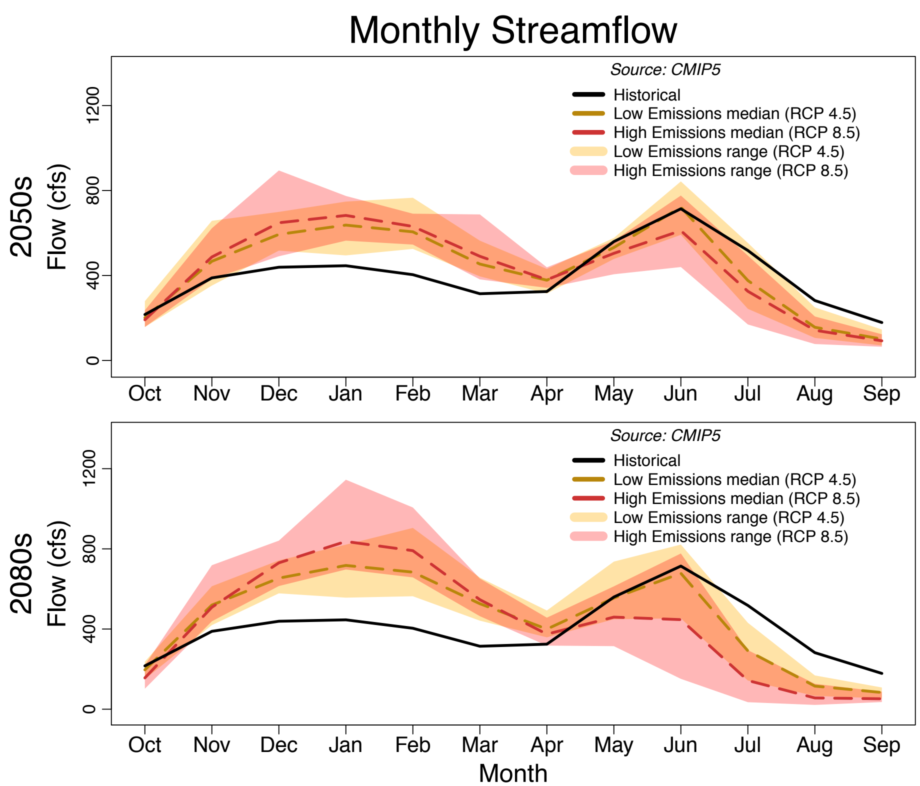
Columbia (Bonneville) River Watershed

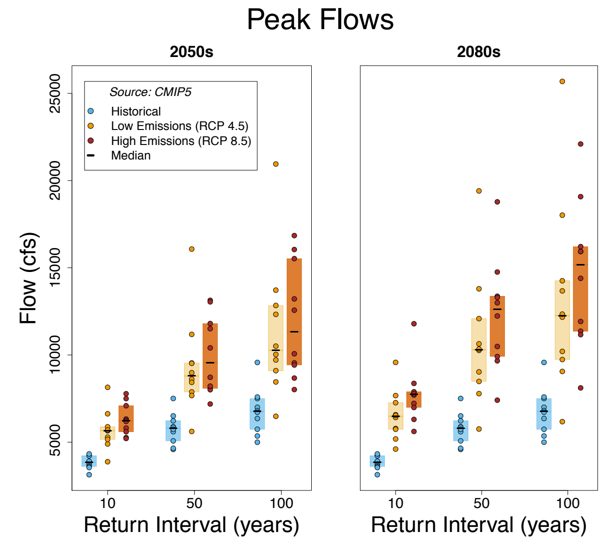
CMIP3 Projections

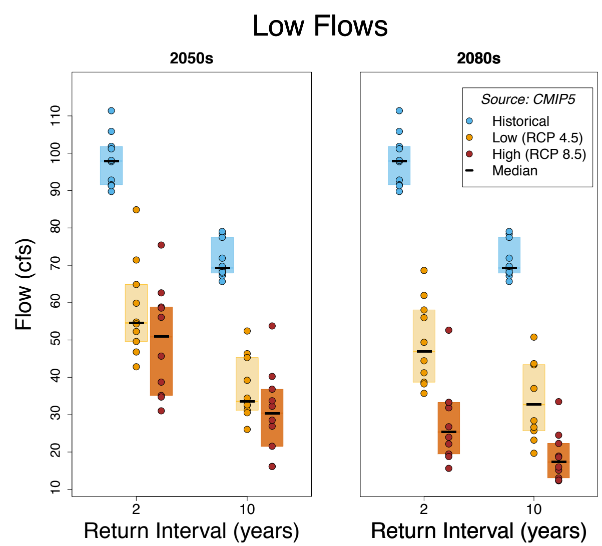


Dungeness River Watershed

CMIP5 projections

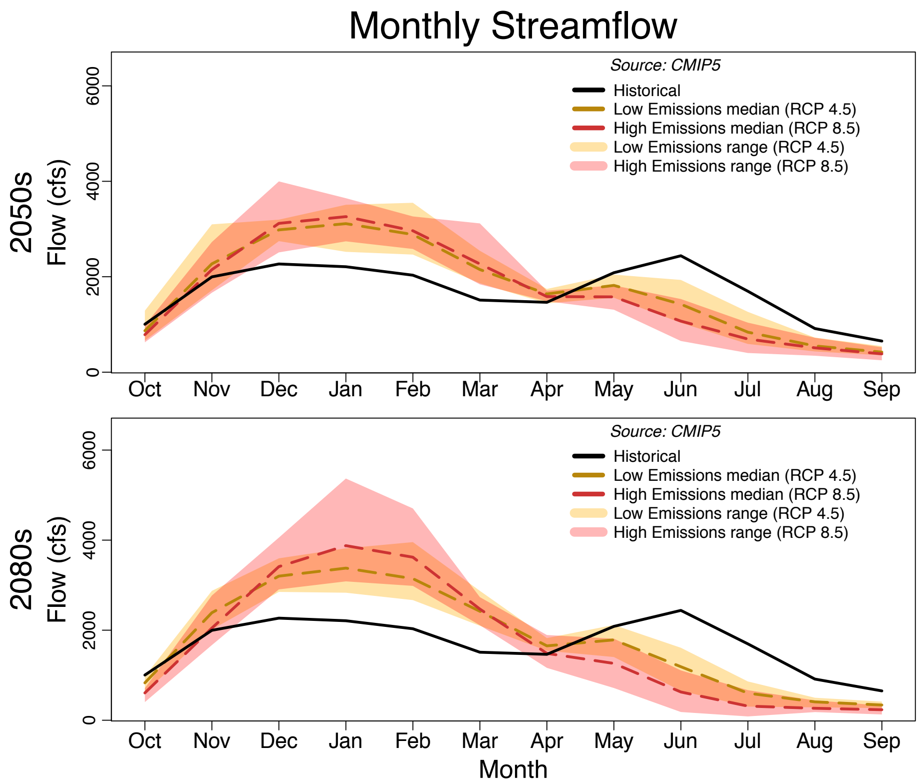


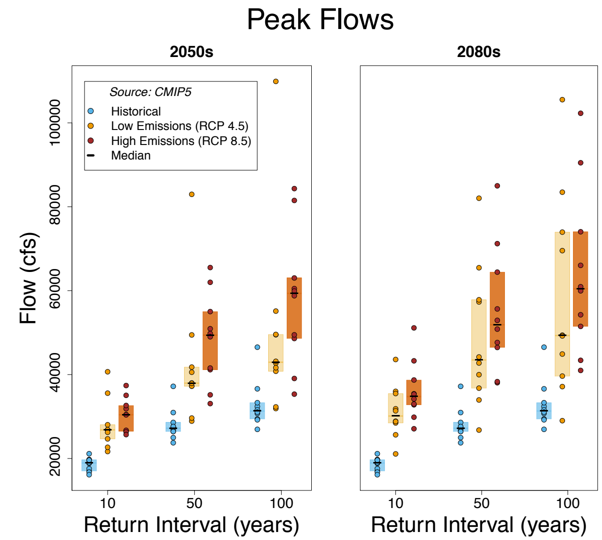


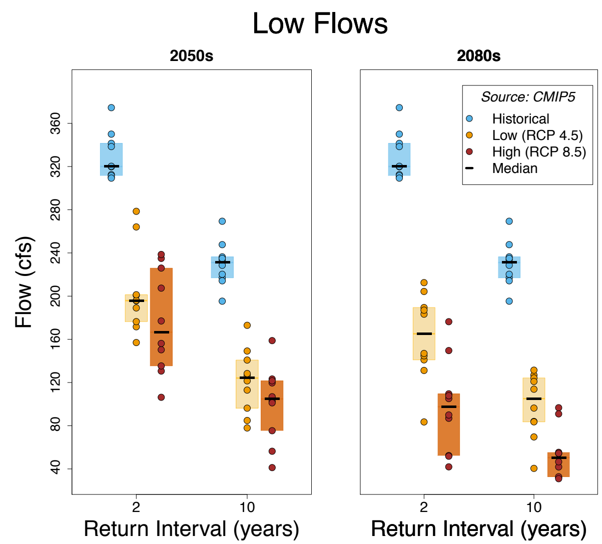


Elwha River Watershed

CMIP5 projections







Appendix B:
Eastern Region Climate Summary

Prepared by

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Climate

Temperature. The eastern region of Washington State is projected to warm rapidly throughout the 21st century, as a result of greenhouse gases associated with human activities. This warming is projected to occur across all seasons, with the most warming occurring during summer. Average annual temperature in the Eastern region of Washington is likely to increase +5.9 to +9.8°F by the 2080s[75], with extreme heat events becoming more frequent and extreme cold events less frequent.

Precipitation. Changes in annual and seasonal precipitation will continue to be primarily driven by year-to-year variations rather than long-term trends, but heavy rainfall events are projected to become more frequent and severe throughout the 21st century.

Water Resources

Eastern Washington is projected to experience a declining snowpack, a shifting balance between snow and rain, changes in streamflow timing, increasing flood risk, and lower summer minimum flows as a result of warming air temperatures. The largest changes are projected for mid-elevation basins with significant snow accumulation (today's so-called "mixed rain and snow" watersheds; Figure 1).

Snowpack. As air temperatures warm, snowpack is projected to decline in winter and melt more rapidly during spring and summer. Average spring snowpack (April 1 SWE) in eastern Washington is projected to decline between –58% and –73% by the 2080s (2070-2099, relative to 1970-1999), on average, for a low (RCP 4.5) and a high (RCP 8.5) greenhouse gas scenario.

Flooding. Warming air temperatures will drive the freezing level to higher elevations, which will result in a greater proportion of winter precipitation falling as rain rather than snow (Figure 1). This increase in winter rainfall will increase winter flood risk in mid-elevation, transient basins.

Forests

Overview | Forests in eastern Washington are projected to experience a continued shift in the geographic distribution of species, changes in forest growth and productivity, increasing fire activity, and changing risks from insects, diseases, and invasive species. These changes have significant implications for ecosystem composition and species interactions. Changes are projected to be most pronounced at higher elevations, where increasing air temperatures and decreasing snowpack can reduce habitat quality for some species but benefit others via a longer snow-free season and increased biological productivity. Many of the changes expected for eastern forests are likely to be driven by increases in the frequency and intensity of disturbances such as fire, insect outbreaks, and disease.

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75 Under RCP 4.5 and RCP 8.5, respectively.

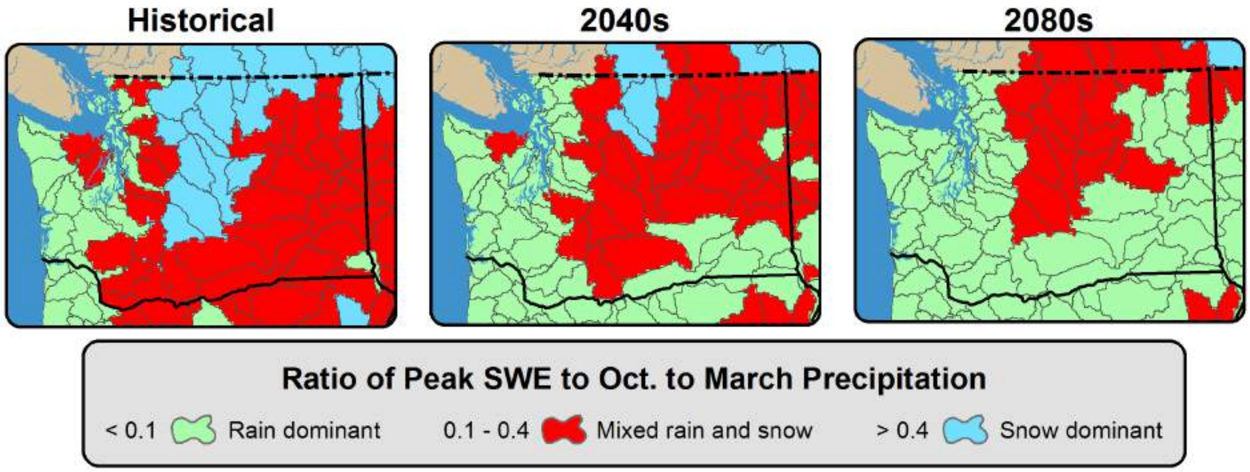
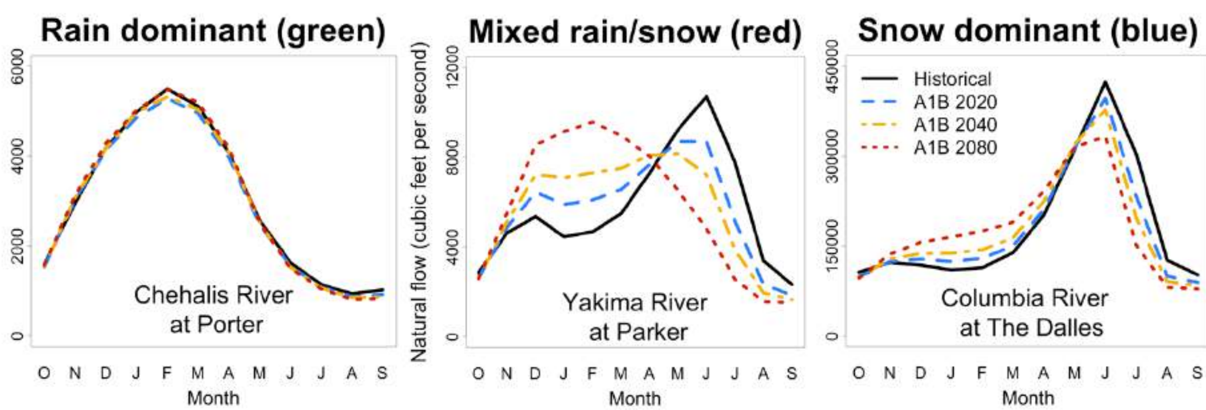


Figure 1. Changing hydrology with warming. Maps above indicate current and future watershed classifications, based on the proportion of winter precipitation stored in peak annual snowpack. Graphs below indicate current and future average monthly streamflow for these watershed types. Both compare average historical conditions (1916-2006) and projected future conditions for two time periods, the 2040s (2030-2059) and the 2080s (2070-2099), under a medium greenhouse gas scenario (A1B). Green shading in the maps indicates warm ("rain-dominant") watersheds, which receive little winter precipitation in the form of snow. In these basins, streamflow peaks during winter months and warming is projected to have little effect (below, left). Blue indicates cold ("snow-dominant") watersheds, that is, cold basins that receive more than 40% of their winter precipitation as snow. Depending on elevation, these basins are likely to experience increasing winter precipitation as rain and increased winter flows (below, right). The most sensitive basins to warming are the watersheds that are near the current snowline ("mixed rain and snow"), shown in red. These are middle elevation basins that receive a mixture of rain and snow in the winter, and are projected to experience significant increases in winter flows and decreases in spring flows as a result of warming (below, center). Source: Hamlet et al., 2013.



Water-Limited Forests & Species Biogeography | Warming temperatures and declining summer precipitation are likely to increase the extent of water-limited forests in eastern Washington, with episodes of drought increasing in both frequency and duration. By the 2080s, forests within the Okanogan Highlands and the foothills of the northeastern Cascade Mountains are projected to transition to severely water-limited forest. These climatic changes (increasing temperatures and declining growing season water availability) are also projected to shift the spatial distribution of suitable climate for many ecologically and economically important tree species in Washington state. For example, by the 2060s models project that Douglas-fir at the margins of its current distribution in the state. Within eastern Washington, areas of climatic suitability for Douglas-fir are projected to decline most noticeably at lower elevations, especially in the Okanagan Highlands. These increases in temperature and decreases in growing season water availability are also projected to increasingly stress pine forests in Washington state by the 2060s. The stress on pine species is expected to be most pronounced in the Columbia Basin and the eastern Cascades, particularly in northeastern Washington.

Wildfire | Climate change is expected to increase the annual area burned by fire in eastern Washington. Warming temperatures and increasing summer water deficit are the primary mechanism leading to projected increases in area burned for the region. By the 2040s, the area burned in *non-forest ecosystems* in eastern Washington, specifically the Columbia Basin and Palouse Prairie, are expected to increase on average by a factor of 2.2 (relative to 1980-2006). Projected change in area burned in *forested ecosystems* are not available exclusively for eastern Washington, however, the mean area burned within a region including western Washington, eastern Washington, the Okanogan highlands, and the Palouse Prairie, is projected to increase by a factor of 3.8 (relative to 1980-2006).

Mountain Pine Beetle | The area of forest susceptible to mountain pine beetle outbreaks is projected to first increase then decrease. In Washington state under a medium greenhouse gas scenario, the area susceptible to mountain pine beetle outbreak is projected to first increase (+27% higher in 2001-2030 compared to 1961-1990) as warming exposes higher elevation forests to the pine beetle, but then decrease (−49 to −58% lower by 2071-2100) as temperatures exceed the beetle's thermal optimum. Further research is needed into how other insects may respond to climate change. Anticipating future impacts will require better understanding the role of climate in other insects' (e.g., spruce and fir beetles or defoliators) life cycles and host vulnerabilities.

Projected Changes in the Climate of Eastern Washington

Temperature	
Annual Temperature – Projected	Projected increase in average annual temperature for the **2050s** (2040-2069), relative to 1970-1999, for eastern Washington: Low emissions (RCP 4.5): +4.6°F (range: +3.1 to +5.9°F) High emissions (RCP 8.5): +6.0°F (range: +4.7 to +7.6°F) Projected increase in average annual temperature for the **2080s** (2070-2099), relative to 1970-1999, for eastern Washington: Low emissions (RCP 4.5): +5.9°F (range: +4.4 to +7.5°F) High emissions (RCP 8.5): +9.8°F (range: +7.9 to +12.2°F)
Temperature – Seasonal	Projected increase in seasonal temperatures for the **2050s** (2040-2069), relative to 1970-1999, for eastern Washington: *Winter* Low emissions (RCP 4.5): +4.5°F (range: +3.1 to +5.6°F) High emissions (RCP 8.5): +5.5°F (range: +3.7 to +7.2°F) *Spring* Low emissions (RCP 4.5): +4.0°F (range: +2.5 to +4.9°F) High emissions (RCP 8.5): +4.9°F (range: +3.6 to +6.6°F) *Summer* Low emissions (RCP 4.5): +5.6°F (range: +3.9 to +8.3°F) High emissions (RCP 8.5): +7.5°F (range: +5.5 to +10.5°F) *Fall* Low emissions (RCP 4.5): +4.3°F (range: +2.6 to +5.6°F) High emissions (RCP 8.5): +5.9°F (range: +4.0 to +7.9°F) Projected increase in seasonal temperatures for the **2080s** (2060-2099), relative to 1970-1999, for eastern Washington: *Winter* Low emissions (RCP 4.5): +4.5°F (range: +3.1 to +5.6°F) High emissions (RCP 8.5): +5.5°F (range: +3.7 to +7.2°F) *Spring* Low emissions (RCP 4.5): +5.4°F (range: +3.8 to +7.1°F) High emissions (RCP 8.5): +8.0°F (range: +5.1 to +10.1°F) *Summer* Low emissions (RCP 4.5): +7.0°F (range: +4.8 to +10.1°F) High emissions (RCP 8.5): +12.3°F (range: +9.7 to +16.7°F) *Fall* Low emissions (RCP 4.5): +5.5°F (range: +3.9 to +7.1°F) High emissions (RCP 8.5): +9.5°F (range: +6.6 to +11.7°F)
Number of Days Above Warm Thresholds	Projected increase in the number of days above various thresholds (80°F, 90°F, 100°F) for the historical period (1970-1999), 2050s, and the 2080s. **2050s** 80°F: Historical (1970-1999): 55 days RCP 4.5: +29 days (range: +20 to +38 days) RCP 8.5: +37 days (range: +26 to +46 days)

	90°F: Historical (1970-1999): 16 days RCP 4.5: +22 days (range: +14 to +31 days) RCP 8.5: +30 days (range: +20 to +39 days) 100°F: Historical (1970-1999): 1 day RCP 4.5: +8 days (range: +4 to +11 days) RCP 8.5: +12 days (range: +6 to +19 days) **2080s** 80°F: Historical (1970-1999): 55 days RCP 4.5: +35 days (range: +23 to +44 days) RCP 8.5: +55 days (range: +46 to +67 days) 90°F: Historical (1970-1999): 16 days RCP 4.5: +28 days (range: +20 to +38 days) RCP 8.5: +51 days (range: +36 to +66 days) 100°F: Historical (1970-1999): 1 day RCP 4.5: +11 days (range: +7 to +17 days) RCP 8.5: +27 days (range: +15 to +41 days)
Precipitation	
Annual Precipitation – Projected	Projected increase in average annual precipitation for the **2050s** (2040-2069), relative to 1970-1999, for eastern Washington: **2050s** Low emissions (RCP 4.5): +4.4% (range: +0.6 to +8.8%) High emissions (RCP 8.5): +5.8% (range: −3.0 to +12.5%) Projected increase in average annual precipitation for the **2080s** (2070-2099), relative to 1970-1999, for eastern Washington: **2080s** Low emissions (RCP 4.5): +6.7% (range: +1.1 to +11.1%) High emissions (RCP 8.5): +8.4% (range: +4.1 to +11.0%)
Seasonal Precipitation – Projected	Projected changes in seasonal precipitation for the **2050s** (2040-2069), relative to 1970-1999, for eastern Washington: **2050s** *Winter* Low emissions (RCP 4.5): +11.0% (range: +2.3 to +21.8%) High emissions (RCP 8.5): +12.6% (range: +6.0 to +20.6%) *Spring* Low emissions (RCP 4.5): +4.1% (range: −3.8 to +16.0%) High emissions (RCP 8.5): +6.9% (range: −0.2 to +20.5%) *Summer* Low emissions (RCP 4.5): −14.3% (range: −30.4 to +2.9%) High emissions (RCP 8.5): −16.0% (range: −39.3 to +4.6%) *Fall* Low emissions (RCP 4.5): +5.1% (range: −1.8 to +11.0%) High emissions (RCP 8.5): +6.8% (range: −3.1 to +19.0%)

	Projected changes in seasonal precipitation for the **2080s** (2060-2099), relative to 1970-1999, for eastern Washington: **2080s** *Winter* Low emissions (RCP 4.5): +11.7% (range: +2.8 to +19.1%) High emissions (RCP 8.5): +18.0% (range: +7.6 to +27.3%) *Spring* Low emissions (RCP 4.5): +4.6% (range: −2.5 to +14.6%) High emissions (RCP 8.5): +7.2% (range: −0.2 to +15.5%) *Summer* Low emissions (RCP 4.5): −9.3% (range: −22.4 to +10.9%) High emissions (RCP 8.5): −19.1% (range: −45.9 to +7.3%) *Fall* Low emissions (RCP 4.5): +10.1% (range: +1 to +22.8%) High emissions (RCP 8.5): +10.5% (range: +3.9 to +22.4%)
Snow *April 1st Snowpack*	Projected decrease in eastern Washington average April 1 snowpack[76] for the **2050s** (2040-2069) and the **2080s** (2070-2099), relative to 1970-1999: **2050s** Low emissions (RCP 4.5): −45.6% (range: −56.8 to −28.7%) High emissions (RCP 8.5): −53.1% (range: −69.3 to −38.9%) **2080s** Low emissions (RCP 4.5): −57.8% (range: −69.2 to −47.6%) High emissions (RCP 8.5): −73.1% (range: −85.8 to −58.2%)
Snow Season Length	Increasing air temperatures are projected to result in a shortening of the length of the snow season.[77] Projected decline in snow season length for the **2050s** (2040-2069) and **2080s** (2070-2099), relative to 1970-1999, for eastern Washington: **2050s** Low emissions (RCP 4.5): −16 days (range: −22 to −10 days) High emissions (RCP 8.5): −22 days (range: −31 to −16 days) **2080s** Low emissions (RCP 4.5): −23 days (range: −31 to −14 days) High emissions (RCP 8.5): −38 days (range: −49 to −27 days)

[76] These numbers show projected changes in April 1 Snow Water Equivalent (SWE). SWE is a measure of the total amount of water contained in the snowpack. April 1 is the approximate current timing of peak annual snowpack in the mountains of the Northwest.

[77] Snow season length is defined as the number of days between the date of 10% accumulation and 90% melt, relative to annual maximum snow water equivalent.

Streamflow	Projected Long-term Change
Stream temperatures	Water temperatures are projected to increase. **2080s** By the 2080s (2070-2099, relative to 1970-1999), more stream locations are projected to experience weekly summer stream temperatures stressful to adjust salmon (in excess of 67°F): ○ Eastern Washington: 19% more sites
Flooding	Most scenarios project an increase in peak flows. **2040s** Projected change in streamflow associated with the 100-year (1% annual probability) flood event for the Methow River (at Twisp), Spokane River (at Spokane), Yakima River (at Parker), and Columbia River (at the Dalles), on average for the **2040s** (2030-2059, relative to 1970-1999): ○ Methow R: -1% (-14.2 to +23.3%) ○ Spokane R: +34.1% (-6.9 to +94.1%) ○ Yakima R: +28.1% (+5.6 to +65.7%) ○ Columbia R: –6.7% (–22.1 to +5.0%) **2080s** Projected change in streamflow associated with the 100-year (1% annual probability) flood event for the Methow River (at Twisp), Spokane River (at Spokane), Yakima River (at Parker), and Columbia River (at the Dalles), on average for the **2080s** (2070-2099, relative to 1970-1999): ○ Methow R: +22.7% (-11.5 to +81.4%) ○ Spokane R: +61.4% (+32.1 to +140.8%) ○ Yakima R: +46.9% (+3.6 to +96.7%) ○ Columbia R: +1% (–17.7% to +37.5%)
Minimum Flows	Summer minimum flows are projected to decrease. **2040s** Projected changed in summer minimum streamflow (7Q10)[79] for the Methow River (at Twisp), Spokane River (at Spokane), Yakima River (at Parker), and Columbia River (at the Dalles), on average for the **2040s** (2030-2059, relative to 1970-1999). Average and range for a moderate (A1B) greenhouse gas scenario[80]: ○ Methow R: –2.4% (–8.6% to +2.0%) ○ Spokane R: –1.7% (–4.2% to +3.4%) ○ Yakima R: –14.2% (–18.8% to –10.3%) ○ Columbia R: –4.3% (–14.2% to +5.2%) **2080s** Projected changed in summer minimum streamflow (7Q10; see footnote 7) for

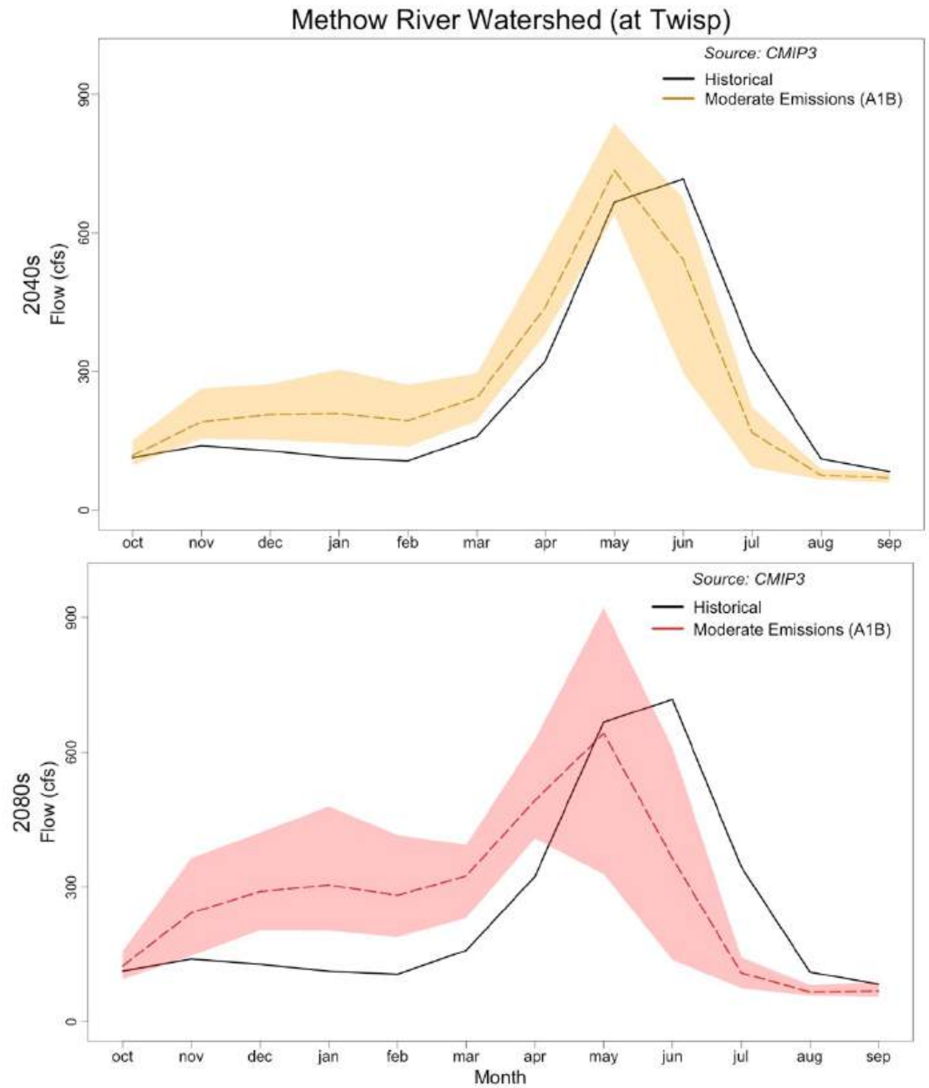
[80] The 7Q10 flow is the lowest 7-day average flow that occurs on average once every 10 years. 7Q10 flows are a common standard for defining low flow for the purpose of setting permit discharge limits.

	the Methow River (at Twisp), Spokane River (at Spokane), Yakima River (at Parker), and Columbia River (at the Dalles), on average for the **2080s** (2070-2099, relative to 1970-1999). Average and range for a moderate (A1B) greenhouse gas scenario (see footnote 7): ○ Methow R: –5.1% (–10.8 to +0.3%) ○ Spokane R: –2.8% (–4.9 to +3.1%) ○ Yakima R: –16.8% (–20.3 to –13.5%) ○ Columbia R: –8.1% (–17.8% to +6.5%) Rain dominant and mixed rain and snow basins show the greatest and most consistent decreases in minimum flows, while changes for snow dominant basins are smaller. The above projections do not account for contributions from melting glaciers. Projections indicate that glaciers may augment minimum flows in the near term due to the increased rate of melt, but nearly all scenarios show a sharp decline in meltwater in the late 21st century as glaciers diminish in size.
Runoff [78]	Projected change in summer and winter runoff for the **2050s** (2040-2069) and **2080s** (2070-2099), relative to 1970-1999, for eastern Washington: **2050s** *Winter (Oct-March)* Low emissions (RCP 4.5): +24.2 cm (range: +19.5 to +30.2 cm) High emissions (RCP 8.5): +29.7 cm (range: +16.4 to +43.2 cm) *Summer (April-Sept)* Low emissions (RCP 4.5): +5.3 cm (range: −1.3 to +14.4 cm) High emissions (RCP 8.5): +5.8 cm (range: −6.4 to +18 cm) **2080s** *Winter (Oct-March)* Low emissions (RCP 4.5): +31.6 cm (range: +13.1 to +46.2 cm) High emissions (RCP 8.5): +45.6 cm (range: +37.5 to +56.5 cm) *Summer (April-Sept)* Low emissions (RCP 4.5): +5 cm (range: −8.8 to −25.2 cm) High emissions (RCP 8.5): +5.3 cm (range: −4.6 to +14.7 cm)
Irrigation Water Supply	Increase in water short years in the Yakima River basin, in which water delivery is curtailed to junior water rights growers. Likelihood of shortfalls: ○ Historical (1975-2004): 14% ○ 2020s (2010-2039): 24 to 27% ○ 2040s (2030-2059): 31 to 33% ○ 2080s (2070-2099): 43 to 68%

78 This includes any overland water flows in addition to subsurface runoff in shallow groundwater.

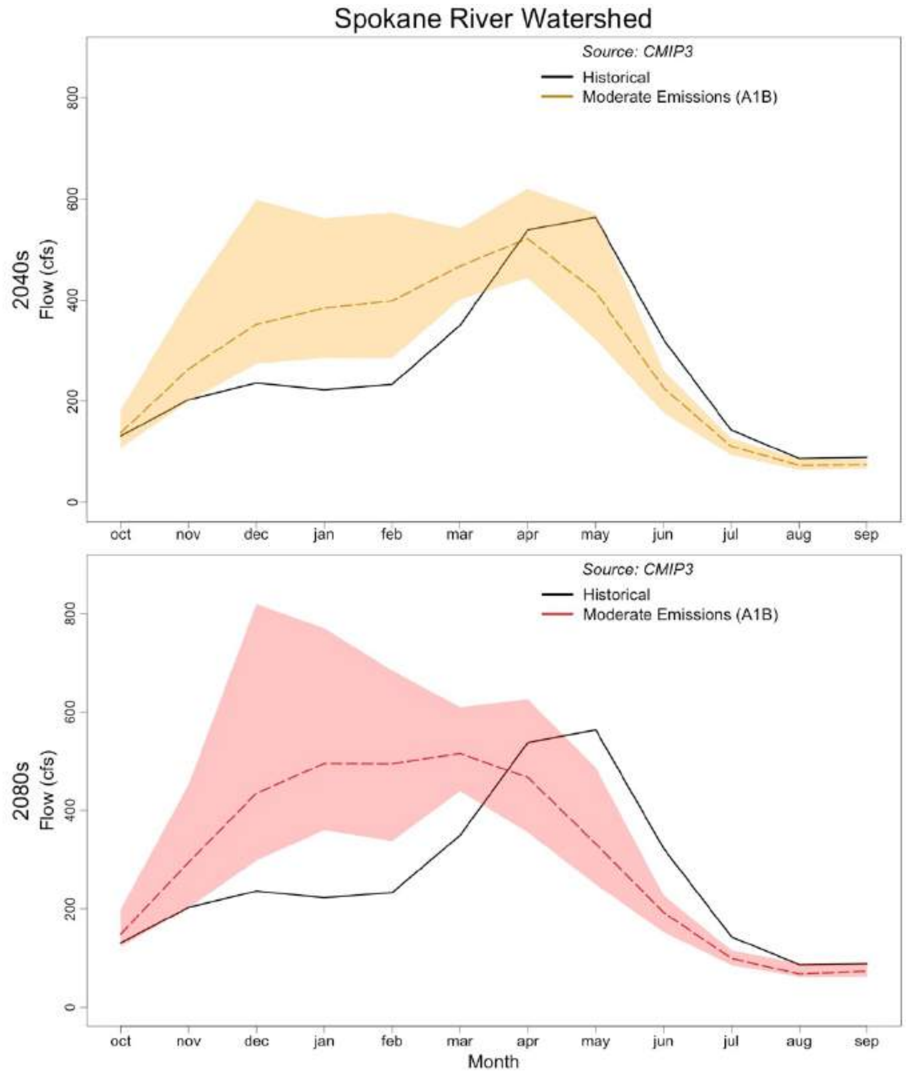
Methow River (at Twisp)

CMIP3 projections



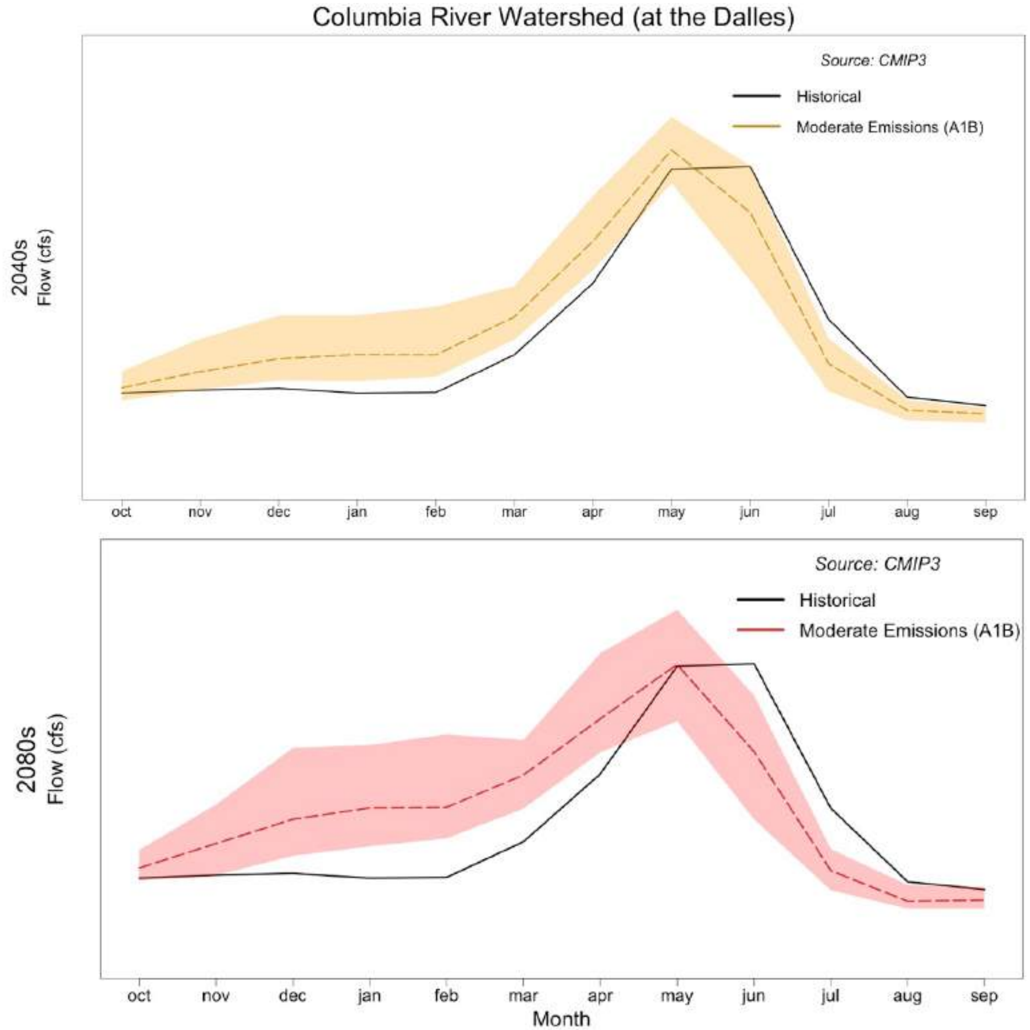
Spokane River (at Spokane)

CMIP3 projections



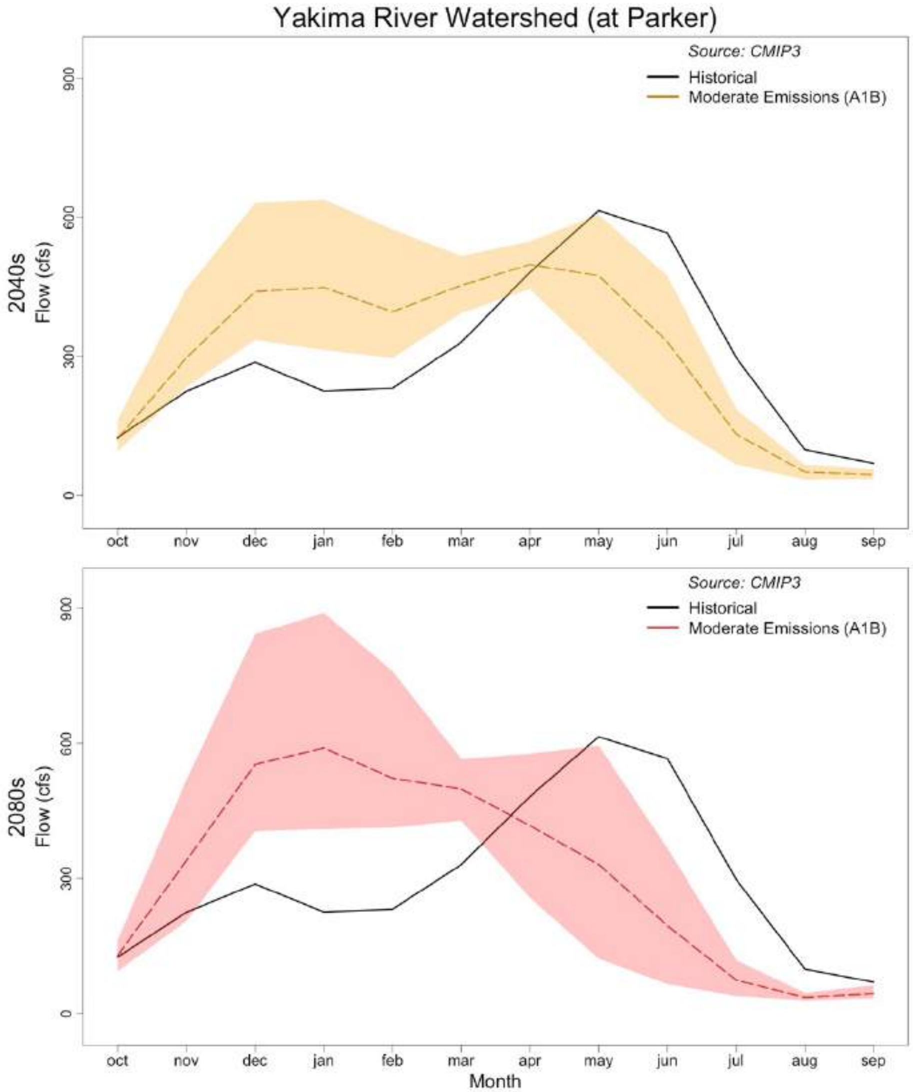
Columbia River (at the Dalles)

CMIP3 Projections



Yakima River (at Parker)

CMIP3 projections



Appendix B:
Statewide Climate Summary

Prepared by

Harriet Morgan, Lara Whitely Binder, and Dan Siemann
University of Washington Climate Impacts Group

Climate[81]

Temperature. Washington State is projected to warm rapidly throughout the 21st century, as a result of greenhouse gases associated with human activities. This warming is projected to occur across all seasons, with the most warming occurring during summer. Average annual temperature is likely to increase +5.6 to +9.4°F by the 2080s[82], with extreme heat events becoming more frequent and extreme cold events less frequent.

Precipitation. Changes in annual and seasonal precipitation will continue to be primarily driven by year-to-year variations rather than long-term trends, but heavy rainfall events are projected to become more frequent and severe throughout the 21st century.

Water Resources

Washington State is projected to experience a declining snowpack, a shifting balance between snow and rain, changes in streamflow timing, increasing flood risk, and lower summer minimum flows as a result of warming temperatures. The largest changes are projected for mid-elevation basins with significant snow accumulation (today's so-called "mixed rain and snow" watersheds; Figure 1).

Snowpack. As air temperatures warm, snowpack is projected to decline in winter and melt more rapidly during spring and summer. Average spring snowpack (April 1 SWE) across Washington State is projected to decline between –61% to –76% by the 2080s (2070-2099, relative to 1970-1999), on average, for a low (RCP 4.5) and a high (RCP 8.5) greenhouse gas scenario.

Warming air temperatures will drive the freezing level to higher elevations, which will result in a greater proportion of winter precipitation falling as rain rather than snow (Figure 1). This increase in winter rainfall will increase winter flood risk in mid-elevation, transient basins.

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81 Information in this summary sheet is from: Snover, A.K, G.S. Mauger, L.C. Whitely Binder, M. Krosby, and I. Tohver. 2013. Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers. State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle.

82 Under RCP 4.5 and RCP 8.5, respectively.

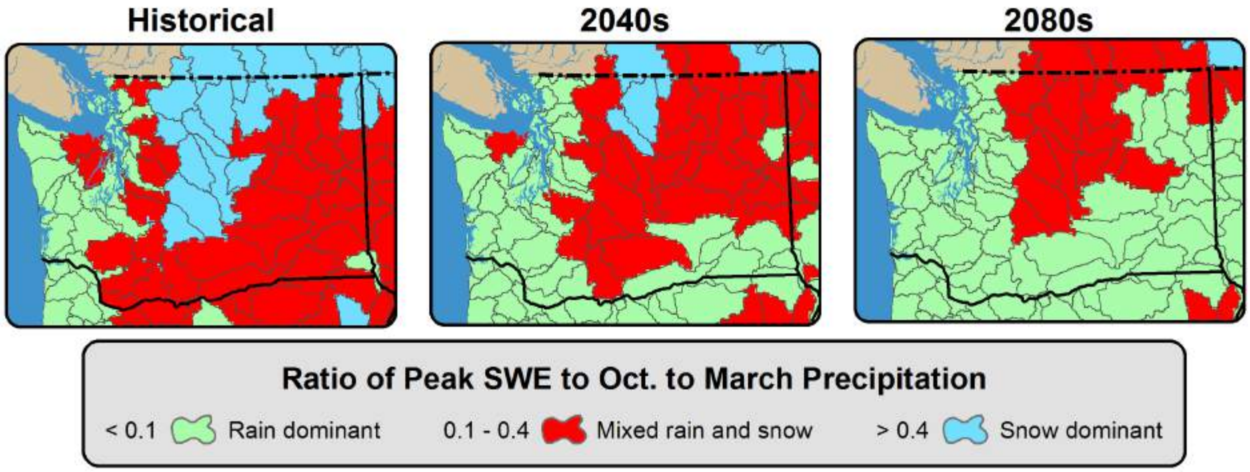
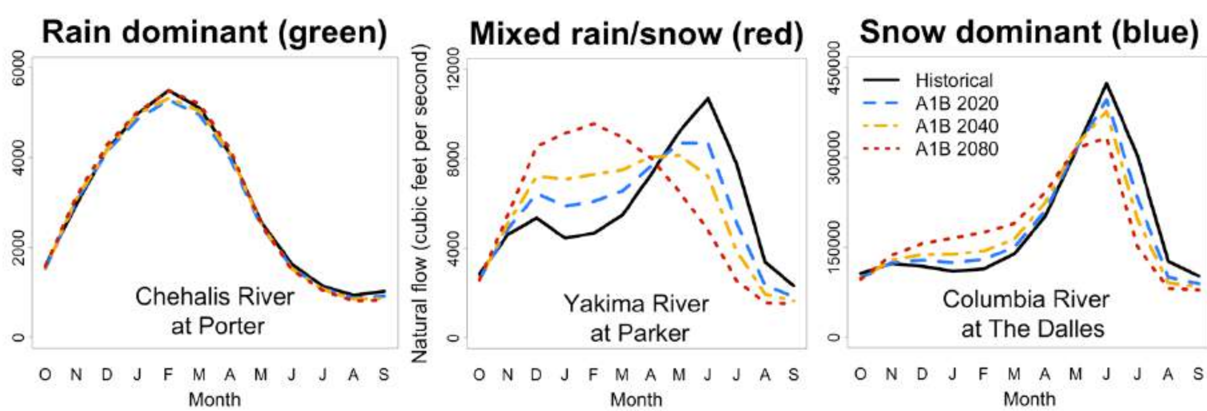


Figure 1. Changing hydrology with warming. Maps above indicate current and future watershed classifications, based on the proportion of winter precipitation stored in peak annual snowpack. Graphs below indicate current and future average monthly streamflow for these watershed types. Both compare average historical conditions (1916-2006) and projected future conditions for two time periods, the 2040s (2030-2059) and the 2080s (2070-2099), under a medium greenhouse gas scenario (A1B). Green shading in the maps indicates warm ("rain-dominant") watersheds, which receive little winter precipitation in the form of snow. In these basins, streamflow peaks during winter months and warming is projected to have little effect (below, left). Blue indicates cold ("snow-dominant") watersheds, that is, cold basins that receive more than 40% of their winter precipitation as snow. Depending on elevation, these basins are likely to experience increasing winter precipitation as rain and increased winter flows (below, right). The most sensitive basins to warming are the watersheds that are near the current snowline ("mixed rain and snow"), shown in red. These are middle elevation basins that receive a mixture of rain and snow in the winter, and are projected to experience significant increases in winter flows and decreases in spring flows as a result of warming (below, center). Source: Hamlet et al., 2013.



Forests

Washington forests are likely to become increasingly water-limited, with episodes of drought increasing in area and intensity. This is likely to lower forest productivity in some areas, while also increasing vulnerability to disturbance, such as fire and insect damage.
Drier, warmer conditions are likely to increase forest fire risk in Washington State. This is because projected decreases in summer precipitation and increases in summer temperatures would reduce moisture of existing fuels, facilitating fire, while earlier snowmelt could lead to earlier onset of the fire season.

Sea Level Rise

Sea level rise is expected to affect most coastal areas in Washington State. By 2100, sea level rise along Washington's central and southern coast and in Puget Sound is projected to increase by +4 to +56 inches by 2100, relative to 2000. It is possible that sea level may actually fall along the northwest Olympic Peninsula over the next few decades, because the rate of vertical land movement is currently outpacing the rate of sea level rise.

Vertical land movement is a process which plays an important role in determining local and regional sea level rise. Washington State is a tectonically active area which causes the land surface to rise and fall over time. As discussed above, the land surface of Neah Bay along the Northwest Olympic Peninsula is currently experiencing uplift. Conversely, Seattle and surrounding areas are subsiding, which exacerbates the local effects of sea level as the land surface is sinking.

Projected Changes in the Climate of Washington State

Temperature	
Annual Temperature – Projected	Projected increase in average annual temperature for the **2050s** (2040-2069), relative to 1970-1999, for Washington State: Low emissions (RCP 4.5): +4.4°F (range: +3.0 to +5.6°F) High emissions (RCP 8.5): +5.7°F (range: +4.5 to +7.3°F) Projected increase in average annual temperature for the **2080s** (2070-2099), relative to 1970-1999, for Washington state: Low emissions (RCP 4.5): +5.6°F (range: +4.2 to +7.3°F) High emissions (RCP 8.5): +9.4°F (range: +7.6 to +11.7°F)
Temperature – Seasonal	Projected increase in seasonal temperatures for the **2050s** (2040-2069), relative to 1970-1999, for Washington State: *Winter* Low emissions (RCP 4.5): +4.2°F (range: +2.9 to +5.6°F) High emissions (RCP 8.5): +5.3°F (range: +3.5 to +6.9°F) *Spring* Low emissions (RCP 4.5): +3.8°F (range: +2.4 to +4.7°F) High emissions (RCP 8.5): +4.8°F (range: +3.4 to +6.6°F) *Summer* Low emissions (RCP 4.5): +5.3°F (range: +3.6 to +7.8°F) High emissions (RCP 8.5): +7.1°F (range: +5.1 to +10.1°F) *Fall* Low emissions (RCP 4.5): +4.2°F (range: +2.6 to +5.5°F)

Temperature	
	High emissions (RCP 8.5): +5.7°F (range: +3.9 to +7.6°F) Projected increase in seasonal temperatures for the **2080s** (2060-2099), relative to 1970-1999, for Washington State: *Winter* Low emissions (RCP 4.5): +5.4°F (range: +4.4 to +6.7°F) High emissions (RCP 8.5): +8.8°F (range: +6.6 to +10.6°F) *Spring* Low emissions (RCP 4.5): +5.2°F (range: +3.8 to +7.3°F) High emissions (RCP 8.5): +7.8°F (range: +5.1 to +10.3°F) *Summer* Low emissions (RCP 4.5): +6.6°F (range: +4.7 to +9.5°F) High emissions (RCP 8.5): +11.7°F (range: +9.3 to +15.9°F) *Fall* Low emissions (RCP 4.5): +5.4°F (range: +3.8 to +7.0°F) High emissions (RCP 8.5): +9.3°F (range: +6.5 to +11.3°F)
Number of Days Above Warm Thresholds	Projected increase in the number of days above various thresholds (80°F, 90°F, 100°F) for the historical period (1970-1999), 2050s, and the 2080s. **2050s** 80°F: Historical (1970-1999): 40 days RCP 4.5: +25 days (range: +18 to +34 days) RCP 8.5: +33 days (range: +23 to +41 days) 90°F: Historical (1970-1999): 11 days RCP 4.5: +16 days (range: +10 to +22 days) RCP 8.5: +22 days (range: +14 to +29 days) 100°F: Historical (1970-1999): 1 day RCP 4.5: +5 days (range: +3 to +7 days) RCP 8.5: +8 days (range: +4 to +13 days) **2080s** 80°F: Historical (1970-1999): 40 days RCP 4.5: +30 days (range: +22 to +40 days) RCP 8.5: +52 days (range: +41 to +66 days) 90°F: Historical (1970-1999): 11 days RCP 4.5: +20 days (range: +14 to +28 days) RCP 8.5: +38 days (range: +27 to +53 days) 100°F: Historical (1970-1999): 1 day RCP 4.5: +7 days (range: +4 to +11 days) RCP 8.5: +18 days (range: +10 to +27 days)

Precipitation	
Seasonal Precipitation – Projected	Projected change in seasonal precipitation for the **2050s** (2040-2069), relative to 1970-1999, for Washington State: *Winter* Low emissions (RCP 4.5): +10.5% (range: +1.1 to +21.2%)

	High emissions (RCP 8.5): +11.9% (range: +5.2 to +19.5%) *Spring* Low emissions (RCP 4.5): +3.1% (range: −5.8 to +13.9%) High emissions (RCP 8.5): +5.4% (range: −3.1 to +17.1%) *Summer* Low emissions (RCP 4.5): −16.8% (range: −36.6 to −0.4%) High emissions (RCP 8.5): −17.8% (range: −43.5 to −2.2%) *Fall* Low emissions (RCP 4.5): +4.9% (range: −1.9 to +11.2%) High emissions (RCP 8.5): +6.3% (range: −2.6 to +18.3%) Projected increase in seasonal precipitation for the **2080s** (2060-2099), relative to 1970-1999, for Washington State: *Winter* Low emissions (RCP 4.5): +11.4% (range: +2.2 to +17.4%) High emissions (RCP 8.5): +16.6% (range: +7.6 to +24.0%) *Spring* Low emissions (RCP 4.5): +3.0% (range: −2.9 to +12.0%) High emissions (RCP 8.5): +5.0% (range: −2.6 to +12.1%) *Summer* Low emissions (RCP 4.5): − 12.8% (range: −28.5 to +3.7%) High emissions (RCP 8.5): −20.9% (range: −44.6 to +8.3%) *Fall* Low emissions (RCP 4.5): +10.4% (range: +0.9 to +21.8%) High emissions (RCP 8.5): +9.8% (range: +2.8 to +19.4%)
Heavy Precipitation – Projected	Projected changes in **western Oregon and Washington** precipitation extremes for the **2080s** (2070-2099, relative to 1970-1999) for a high (RCP 8.5) greenhouse gas scenario: Annual 99th percentile of 24-hour precipitation: +22% (range: +5 to +34%) Frequency of exceeding the historical 99th percentile of 24-hour precipitation: Historical (1970-1999): 2 days / year Future (2070-2099): 7 days / year (range: 4 to 9 days / year)
Snow *April 1st Snowpack*	Projected changes in Washington State average April 1st snowpack[83]; for the **2050s** (2040-2069) and the **2080s** (2070-2099), relative to 1970-1999: **2050s** Low emissions (RCP 4.5): −48.7% (range: −58.4 to −31.9%) High emissions (RCP 8.5): −55.9% (range: −71 to −40.5%) **2080s** Low emissions (RCP 4.5): −60.6% (range: −71.9 to −51.7%) High emissions (RCP 8.5): −76.1% (range: −87.7 to −61.4%)
Ski Season *Snow Season Length*	Increasing air temperatures are projected to result in a shortening of the length of the

[83] These numbers show projected changes in April 1st Snow Water Equivalent (SWE). 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.

	snow season.[84] Projected change in snow season length for the **2050s** (2040-2069) and **2080s** (2070-2099), relative to 1970-1999, for Washington State: **2050s** Low emissions (RCP 4.5): −25 days (range: −32 to −18 days) High emissions (RCP 8.5): −33 days (range: −45 to −21 days) **2080s** Low emissions (RCP 4.5): −35 days (range: −46 to −24 days) High emissions (RCP 8.5): −55 days (range: −68 to −39 days)
More Warm Winters	Probability of a warm winter (average Dec-Feb temperature above freezing) for Washington State ski resorts: Historic (1971-2000): 0 to 33%, depending on location With +3.6°F[85] of warming: 33 to 77%

Streamflow	***Projected Long-term Change***
Annual	Mixed, but most models project a small increase in annual streamflow, on average for Washington State. • Total annual streamflow is projected to increase slightly. 2040s (2030-2059, relative to 1917-2006): +2.1 to +2.5% 2080s (2070-2099, relative to 1917-2006): +4.0 to +6.2%[86] ▪ Changes are small relative to year-to-year variability in streamflow, and models disagree on the direction of change.
Winter	Mixed, but most models project an increase in winter streamflow, on average for Washington State. • Winter (Oct-Mar) streamflow change: 2040s (2030-2059, relative to 1917-2006): +20 to +16% 2080s (2070-2099, relative to 1917-2006): +25 to +34%[86] • Changes are small relative to year-to-year variability in winter streamflow, and models disagree on the direction of change.
Summer	Mixed, but most models project a decrease in summer streamflow, on average for Washington State. • Summer (Apr-Sep) streamflow change: 2040s (2030-2059, relative to 1917-2006): −30 to −23%

[84] Snow season length is defined as the number of days between the date of 10% accumulation and 90% melt, relative to annual maximum snow water equivalent.

[85] +3.6°F relative to 1971-2000 is near the low end of warming projected for mid-century.

[86] 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.

	2080s (2070-2099, relative to 1917-2006): −44 to −34%[86] • Changes are small relative to year-to-year variability in summer streamflow, and models disagree on the direction of change.
Streamflow timing	Peak streamflows are projected to occur earlier in many snowmelt-influenced rivers in the Northwest. • Peak streamflow is projected to occur 4 to 9 weeks earlier by the 2080s (2070-2099, relative to 1917-2006) in four Puget Sound watersheds (Sultan, Cedar, Green, Tolt) and the Yakima basin.[86]
Stream temperatures	Warming • By the **2080s** (2070-2099, relative to 1970-1999)[87], more stream locations are projected to experience weekly summer stream temperatures stressful to adjust salmon (in excess of 67°F): Eastern Washington: 19% more sites Western Washington: 16% more sites • Many stream locations projected to exceed 70°F for the entire summer season by 2080 – resulting in waters that are warm enough to impede migration and increase the risk of fish kills.
Flooding	Increases in most watersheds • Projected changes in streamflow volume associated with the 100 year (1% annual probability) flood event, by basin type, in Washington State for the **2080s** (2070-2099, relative to 1916-2006): Rain dominant watersheds: +18% (range: +11 to +26%) Mixed rain-snow watersheds: +32% (range: −33 to +132%) Snow dominant watersheds: −2% (range: −15 to +22%)[88][89] • Projected changes in heavy rainfall are not included in the above projections. Preliminary research indicates an increase in the proportion of heavy rain events occurring in early fall. Both changes will likely increase flood risk in rain dominant and mixed rain and snow watersheds, especially west of the Cascade crest.

87 Average projected change for 124 stream locations across Washington State. Projections are made using ten global climate models and a medium greenhouse gas scenario (A1B).

88 Results for a low (B1) and medium (A1B) greenhouse gas scenario for 112 medium sized watersheds in Washington.

89 Watersheds were defined as rain dominant if the average winter temperature (Dec-Feb) was greater than 35.6°F (+2°C), mixed rain and snow if the average winter temperature (Dec-Feb) was between 21.2 and 35.6°F (-6 to +2°C), and snow dominant if the average winter temperature (Dec-Feb) was below 21.2°F (-6°C).

Minimum flows	Decreased flow in most watersheds • Projected changes for changes in 7Q10 flows,[90] by basin type, in Washington State for the 2080s (2070-2099, relative to 1916-2006): Rain dominant watersheds: −14% (−44 to −3%) Mixed rain-snow watersheds: −15% (−60 to +14%) Snow dominant watersheds: −6% (−12 to +4%)[88][89]
Runoff	Projected change in summer and winter runoff for the **2050s** (2040-2069) and **2080s** (2070-2099), relative to 1970-1999, for Washington state: **2050s** *Winter (Oct-March)* Low emissions (RCP 4.5): +23.3 cm (range: +18.3 to +31.4 cm) High emissions (RCP 8.5): +28.8 cm (range: +16.5 to +43.7 cm) *Summer (April-Sept)* Low emissions (RCP 4.5): −2.1 cm (range: −6.5 to +6.4 cm) High emissions (RCP 8.5): −2.4 cm (range: −12.5 to +8.6 cm) **2080s** *Winter (Oct-March)* Low emissions (RCP 4.5): +32.0 cm (range: +13.4 to +43.1 cm) High emissions (RCP 8.5): +45.6 cm (range: +37.6 to +55.2 cm) *Summer (April-Sept)* Low emissions (RCP 4.5): −3.7 cm (range: −13.8 to +12.9 cm) High emissions (RCP 8.5): −6.1 cm (range: −16.35 to +1.5 cm)

Oceans	
Sea Level – Projected	Rising for all scenarios Seattle, WA: +4 to +56 inches (2100, relative to 2000)
Ocean Acidification – Projected	Global Increase by 2100 for all scenarios (relative to 1986-2005). Low emissions (RCP 4.5): +38 to +41% High emissions (RCP 8.5): +100 to +109%

For more information on climate change impacts in Washington, see *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers* (2013), available at https://cig.uw.edu/resources/special-reports/wa-sok/.

[90] The 7Q10 flow is the lowest 7-day average flow that occurs on average once every 10 years. 7Q10 flows are a common standard for defining low flow for the purpose of setting permit discharge limits.