Climate Change and Stream flow: Barriers and Opportunities

Preliminary project report to the Washington State Department of Ecology

By

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For the

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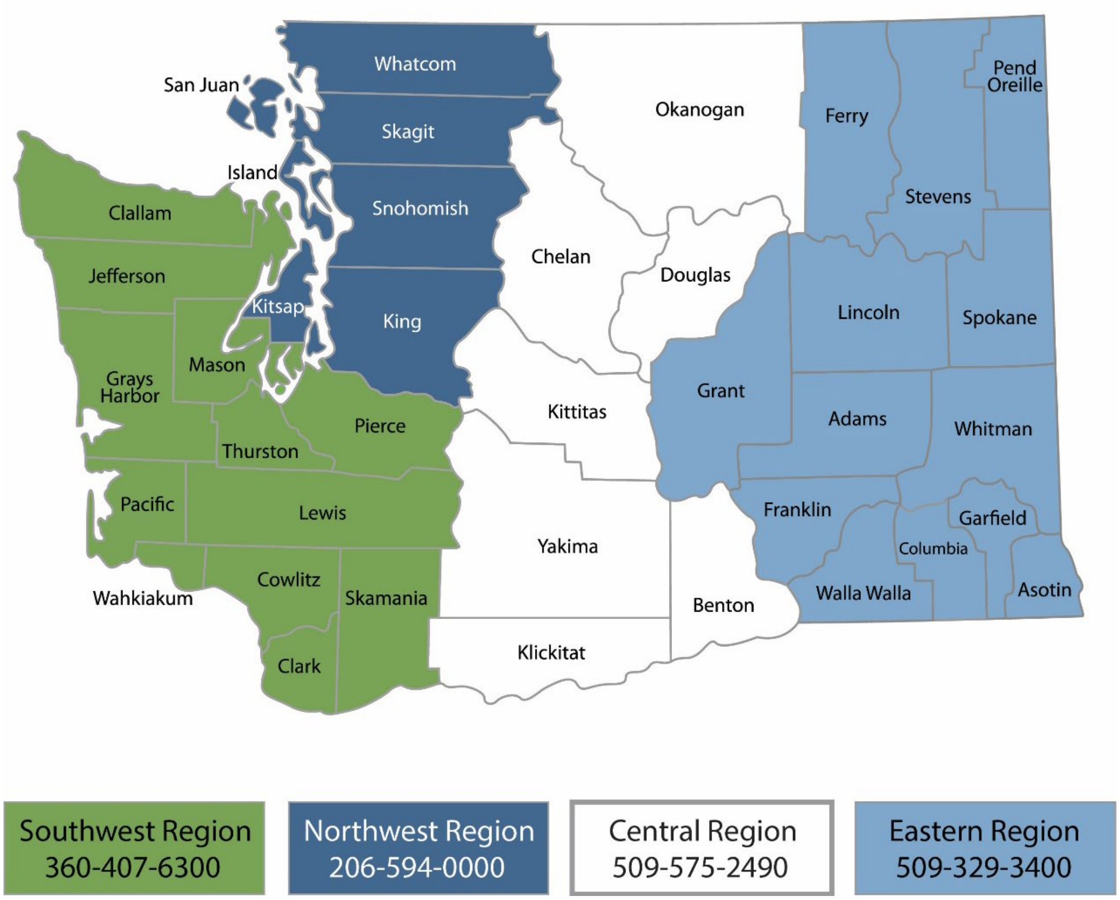

Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	P.O. Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	P.O. Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 West Alder Street Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 North Monroe Spokane, WA 99205	509-329-3400
Headquarters	Statewide	P.O. Box 46700 Olympia, WA 98504	360-407-6000

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1. Introduction

The purpose of the proposed work is to improve understanding of localized climate change impacts on streamflow, water temperature, and associated ecosystem services, and to identify water code and case law barriers and opportunities for climate change adaptation.

This report is organized around four main topics: (1) summary of projected climate effects on streamflow and water temperature by focusing on low flow conditions in regions with distinct hydrology, climate, and other significant factors; (2) an analysis of projected climate impacts on salmonids by characterizing critical flow conditions and other limiting factors for salmon restoration related to habit requirements and legal framework for water resource management; (3) a summary of Washington State law and policy barriers to streamflow management in response to climate, and (4) a synthesis of Western States' policy responses to climate-induced stream flow change.

2. Projected Climate Effects on Streamflow and Water Temperature

Numerous reports and tools have synthesized existing science on changes in water for Washington State ((Snover et al., 2013), https://climatetoolbox.org/) as a result of climate change. These reports and existing resources provide useful trends and a general pattern of the expected changes in streamflow and snowpack, but a new dataset has recently become available to assess changes in streamflow across the Pacific Northwest that improves upon existing data in two key respects: They are based on a newer generation of models and approaches, and they provide comprehensive coverage of changes across the major rivers in Washington State.

This new comprehensive dataset, the River Management Joint Operating Committee's version 2 hydrologic projections (RMJOC-II, https://www.hydro.washington.edu/CRCC, (Chegwidden et al., 2019)), provides projections of future "naturalized" streamflow (i.e.: not accounting for dams or withdrawals) for all of the Columbia River and coastal drainage basins in Oregon and Washington based on 10 global climate models and two scenarios of future greenhouse gas concentrations (see Appendix A1 for additional information on this dataset). The RMJOC-II dataset does not include projections of future water temperatures in these basins. Future water temperature data are provided by the NorWeST modeling project and similarly cover all major basins in Washington state (Isaak et al., 2017).

Snowpack

Streamflow in many Washington State watersheds is influenced by snowpack (Li et al., 2017), which stores precipitation in winter, releasing it during the melt season in spring and early summer. The region receives relatively little precipitation in summer, making snowmelt a critical contribution to water availability during this season. This means that changes in snowpack, which have already been observed (Mote et al., 2018), will have a major impact on streamflow in Washington State.

Past research has identified critical thresholds differentiating watersheds where streamflow patterns are dominated by precipitation falling as rain, a mix of rain and snow, and snow (Hamlet et al., 2013). Figure 1 shows how rain and snow dominance play out across Washington State, showing a dramatic shrinking of the areas influenced by snowpack (full-page figures follow the full text of this section).

Peak Streamflows

As the snowline rises, more precipitation falls as rain, resulting in bigger floods in the future. Figure 2 shows the projected change in the 2-year peak flow event ("Q2", the 2-year event which occurs on average every other year), for major river reaches throughout Washington State. The biggest changes are projected for rivers that draw from mountainous areas on the western slopes of the Cascades and in the Olympics, where snowpack is expected to rapidly decline. In general, the changes are largest for areas that are transitioning from mixed to rain dominant with warming because winter temperatures are often near freezing. In these areas, only a small amount of warming is needed to shift precipitation from snow to rain.

As an indicator of the uncertainty in the projections, we have included the median among all 20 model projections, as well as the minimum and maximum model projection for each location. These show that the direction of change (increase or decrease), as well as the overall spatial distribution of changes, are generally similar among all 20 model projections. Specifically, snow-influenced areas show the greatest changes, particularly for rivers that are nearer the transition between rain and snow dominance. The primary model uncertainty is in the exact magnitude of the change, which can differ substantially between the minimum and maximum model projection.

An important limitation of these projections, which is not captured in the minimum and maximum projections illustrated here, is that these projections do not accurately capture potential changes in the intensity of precipitation extremes. Recent research projects that heavy rain events will become more intense in the future (Warner et al., 2015), and that better methods are needed to adequately capture this effect in hydrologic modeling (so-called "dynamical downscaling", as opposed to "statistical downscaling";(Salathé et al., 2014)). The current dataset makes use of a method (statistical downscaling), which does not accurately capture changes in heavy rain events. This means that the results shown in Figure 2 may underestimate potential changes in peak flows and therefore flood risk, particularly for rain-dominated watersheds where changes in snowpack are minimal.

Low Streamflows

Declining snowpack results in decreased snowmelt and an earlier end to the melt season. For snow-influenced basins, this is expected to result in a more prolonged low flow season and lower low flows in the future. Figure 3 shows the projected change in the 7Q2, the 7-day average low flow that is likely to occur every two years on average. Again, results are shown for the median, minimum, and maximum among all 10 models. In this case the results are more mixed, showing the largest and most spatially consistent decreases in the Olympic mountains, on the western slopes of the Cascades, and in the Blue Mountains in southeastern Washington – particularly in watersheds that draw from high-elevation areas. Increases in low flows for the northeast Cascades reflect a transition from lowest flows in wintertime – a common phenomenon in cold basins where winter precipitation falls predominantly as snow – to lowest flows occurring in summer, associated with a shorter and less pronounced contribution from snowmelt. Even in these locations, it is likely that summer low flows are declining in response to a decrease in snowmelt.

Low flows are more difficult to model accurately, compared to peak flows, because they depend more on assumptions about soil and vegetation properties (e.g., porosity, transpiration rates). This is another modelling uncertainty that is not captured in the median, minimum, and maximum projections included in Figure 3. Peak flows, in contrast, often occur during the cool season when soils are already saturated, and evaporation is minimal. Vegetation can still affect peak flows by temporarily storing precipitation in the canopy (so-called "interception"), but overall low flows are much more sensitive to modelling assumptions than Peak flows. This means that the low flow results must be treated with greater caution. In general, we find that it is most challenging to accurately model low flows in the drier parts of the state east of the Cascade Crest. This is particularly true for the Columbia Plateau for which the results show a spread among models that includes both increases and decreases. In spite of these caveats, we consider the results to be most reliable when they provide similar answers for watersheds that share common characteristics, and similar results for the median, minimum, and maximum projections. For instance, decreases in the Olympics, west of the Cascades, and in the Blue Mountains, and increases in the northeast Cascades and Okanagan mountains.

Water Temperature

Water temperatures are projected to increase in response to both lower streamflow and warmer air temperatures. Figure 4 shows how average August water temperatures are projected to change relative to specific temperature thresholds that approximately relate to thermal tolerances for char (12ºC) and salmon (18ºC and 21ºC). These show that the high mountain areas with temperatures suitable to char are projected to shrink substantially over the course of this century. Many mainstem river reaches – a key migratory pathway for reaching upstream spawning areas – are increasingly reach temperatures that exceed thermal tolerances for salmon. In particular, the 2080s results show that much of the Columbia and Snake Rivers in Washington are projected to exceed thermal tolerances for salmon. Since these are focused on the average stream temperature for the month of August, maximum annual stream temperatures likely exceed those shown in the figure.

The stream temperature results are based on a simplified model of climate change impacts on water temperatures, in which statistical relationships are used to estimate future water temperatures. This means that the results are likely most reliable closer to long-term stream temperature sites, and where conditions in the future can be readily extrapolated from past relationships between flow, air temperature, and water temperature. This may not be the case, for example, in areas that are projected to shift from snow to rain dominance, or for streams with significant glacier melt contributions (given the likely loss of many glaciers over the course of this century).

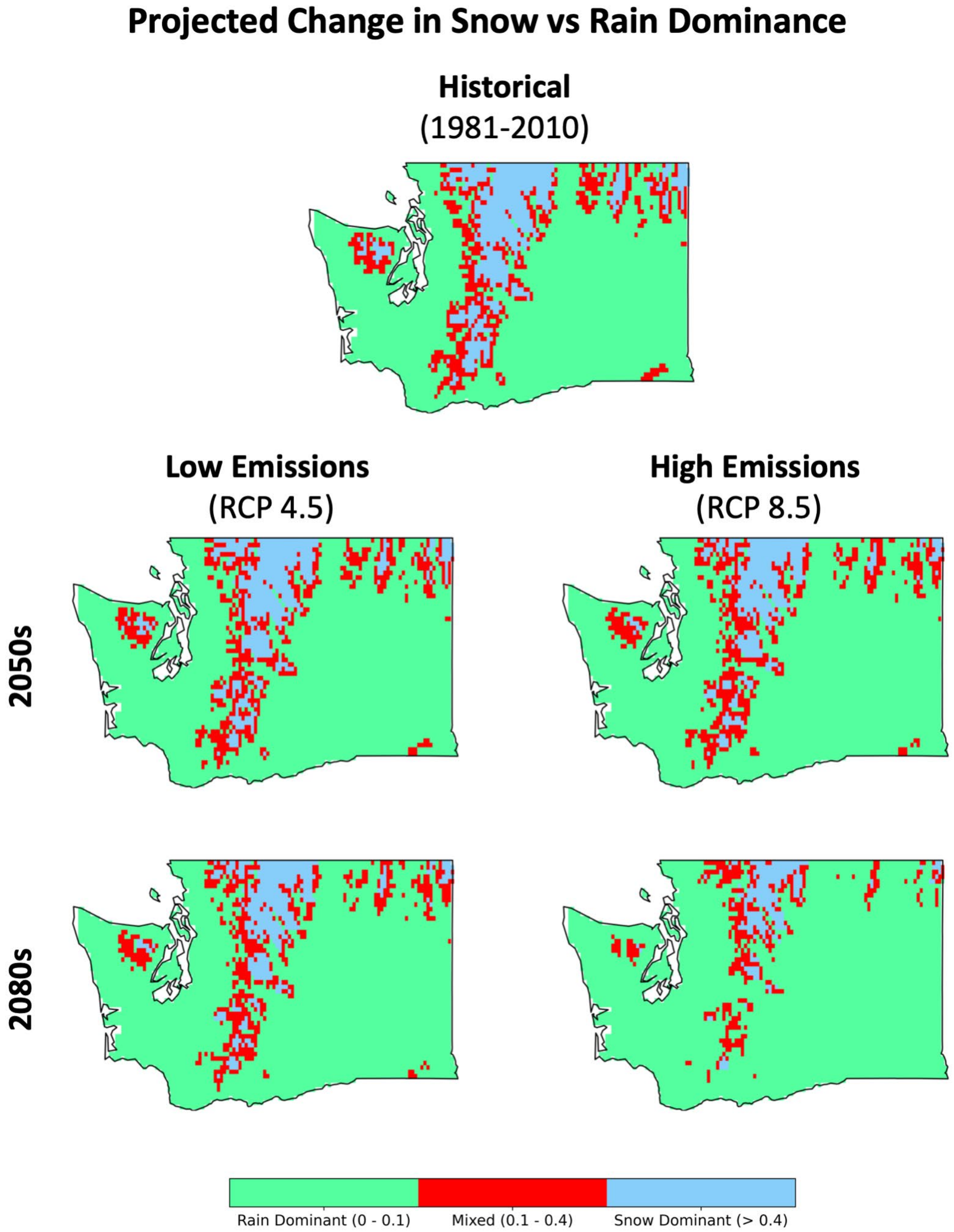

Figure 1. By the end of the century, snow-dominant areas are almost entirely confined to the upper elevations of the North Cascades, and very few areas outside of the high elevation Cascades exhibit any snow influence at all. All maps show the percent of winter precipitation stored as snowpack on April 1st, and classified as rain dominant (green), mixed rain-and-snow (red), and snow dominant (blue), according to the relative importance of each. The most change is expected for the Olympic mountains and west slopes of the Cascades. Results are shown for the recent past (1980-2009) as well as the 2050s (2040-2069) and 2080s (2070-2099), for both a low (RCP 4.5) and high (RCP 8.5) greenhouse gas scenario. All maps show the median result for all 10 model projections.

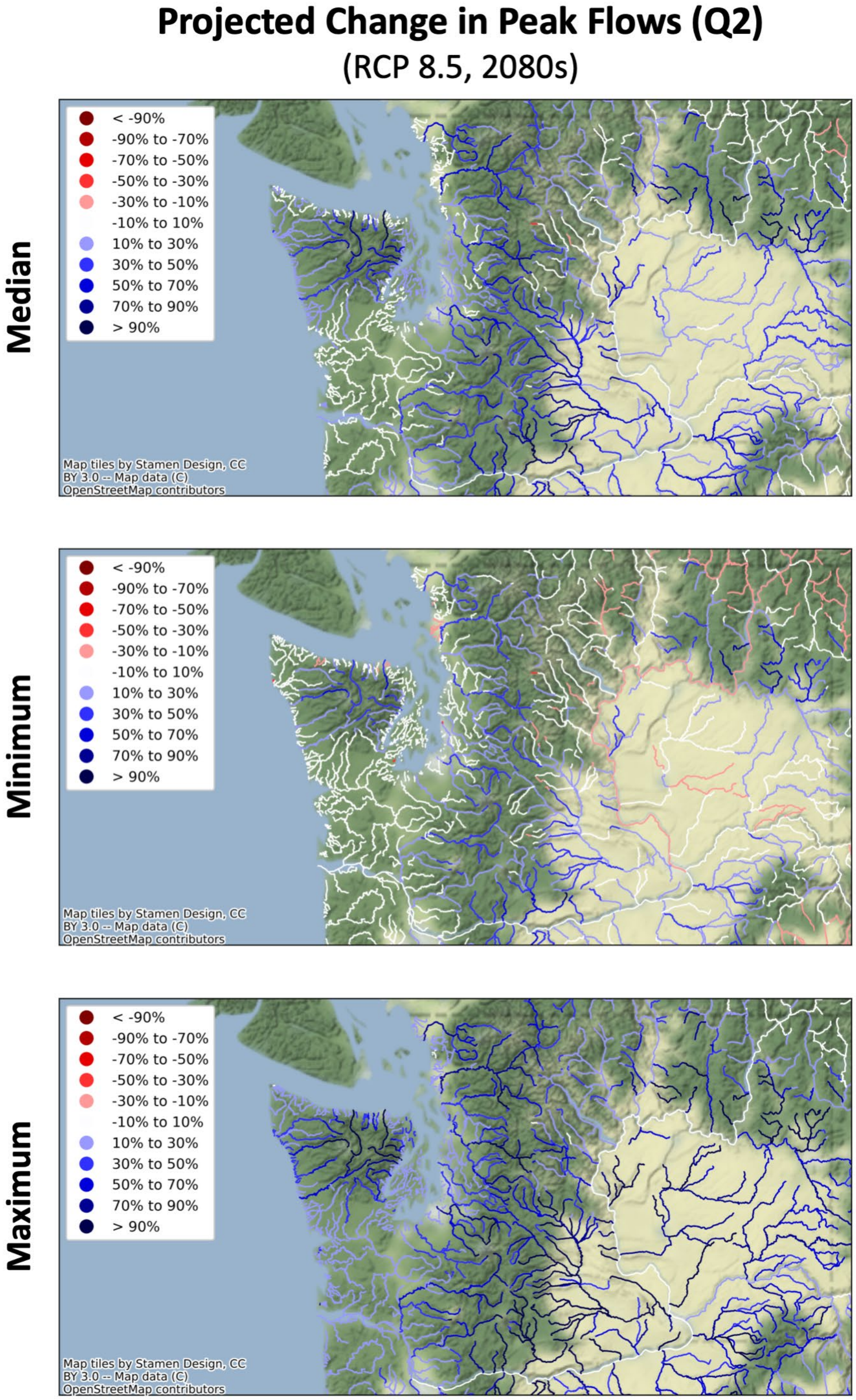

Figure 2. Peak flows are projected to increase everywhere, with the greatest increases in rivers on the western slopes of the Cascades and in the Olympic mountains, where snowpack is expected to rapidly decline. All maps show the percent change in the 2-year peak daily flow event for all major river reaches in Washington state, including the median (top), minimum (middle), and maximum (bottom) change among all 10 models. Projections are shown for the 2080s (2070-2099) relative to the 1990s (1980-2009), and for a high greenhouse gas scenario (RCP 8.5).

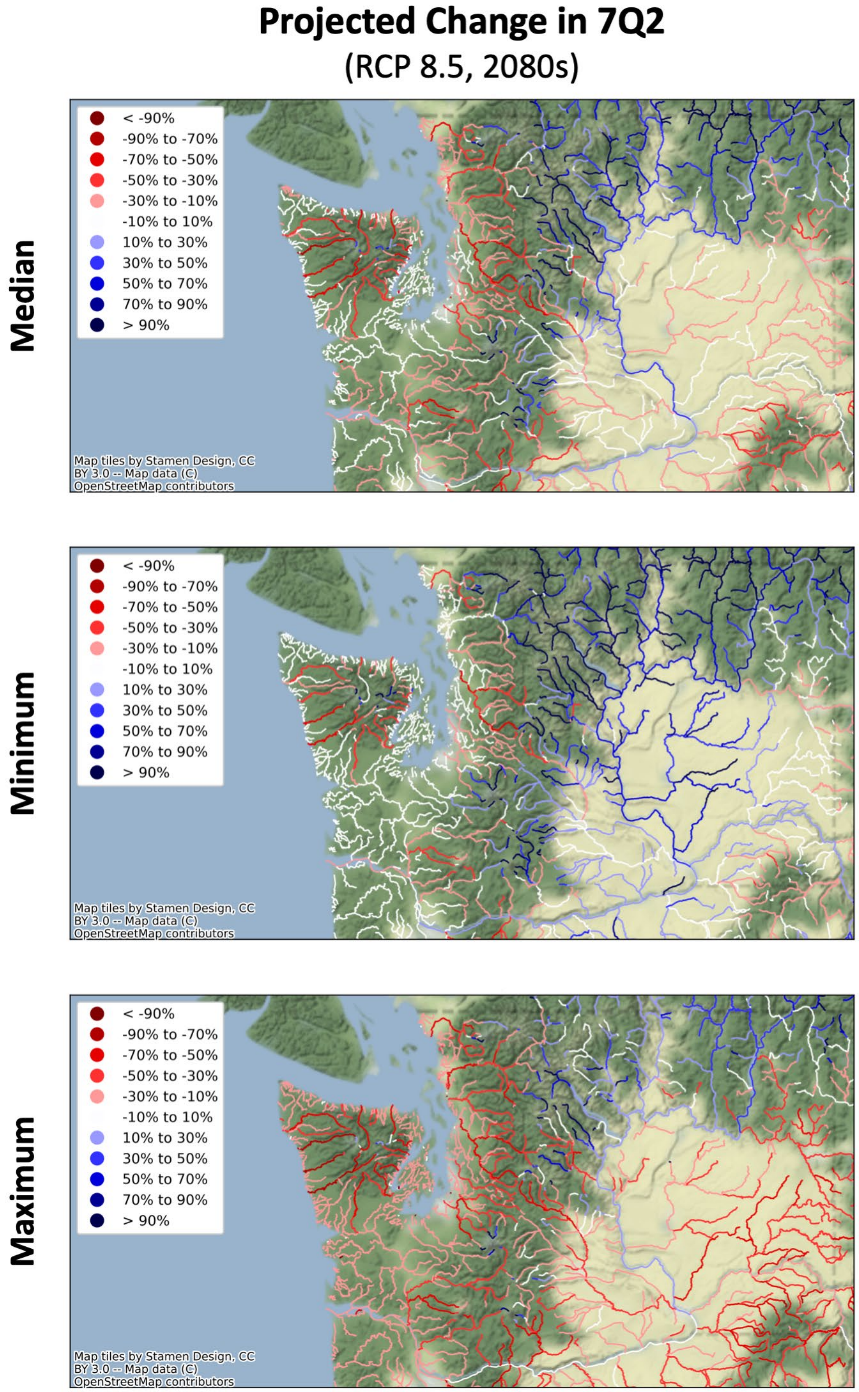

Figure 3. Results show a mix of increases and decreases in low flows as indicated by the 7Q2, the lowest 7-day average flow expected to occur every two years on average. The largest and most spatially consistent decreases are in the Olympic mountains, the western slopes of the Cascades, and the Blue Mountains in southeastern Washington. Maps show the percent change in 7Q2 low flows for major river reaches in Washington state, including the median (top), minimum (middle), and maximum (bottom) change among all 10 models. Projections are for the 2080s (2070-2099) relative to the 1990s (1980-2009) and for a high greenhouse gas scenario (RCP 8.5). Uncertainty in low flow projections is greater than high flows because they are more difficult to model.

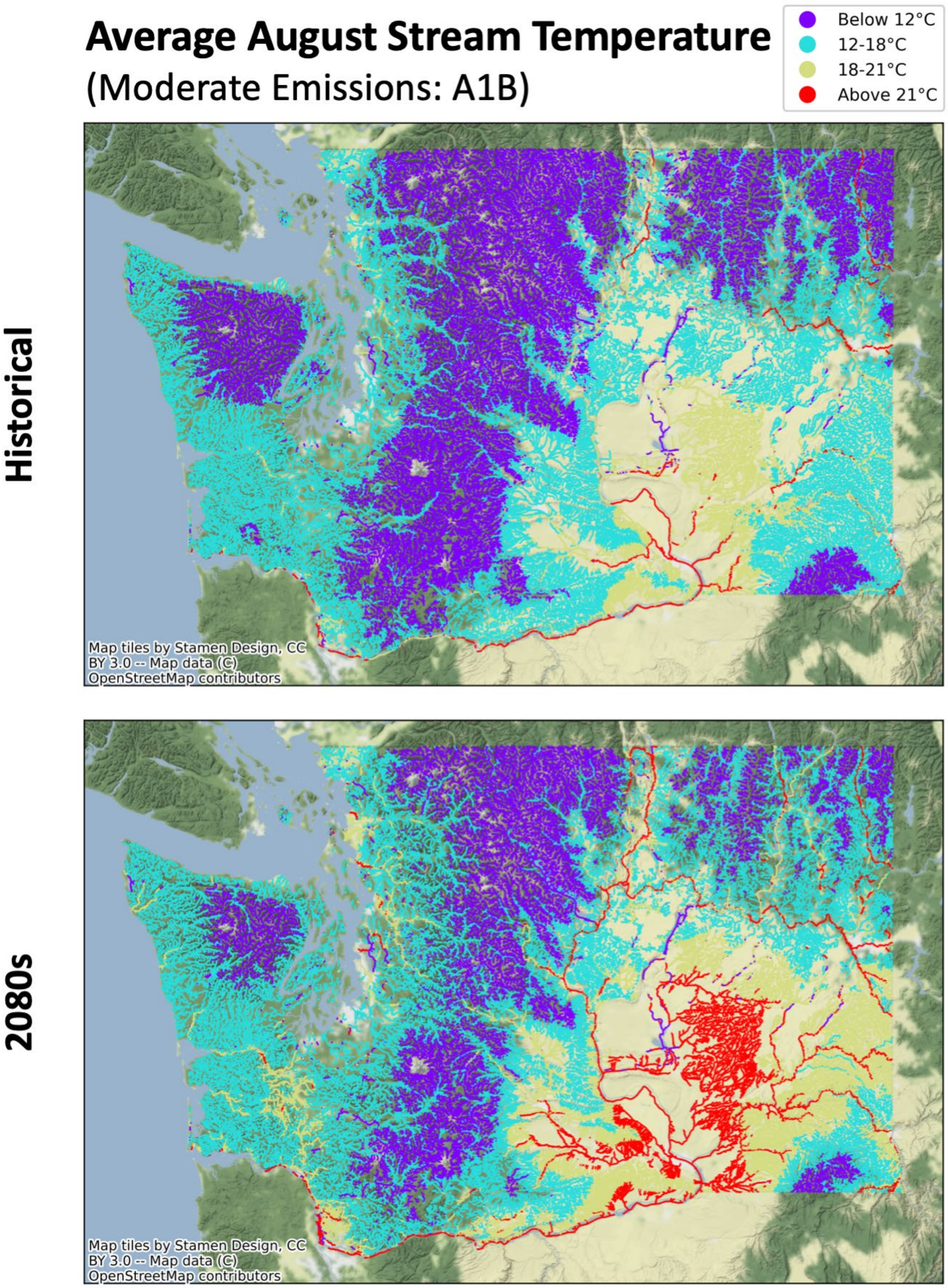

Figure 4. Stream temperatures are projected to more frequently exceed thermal tolerances for fish. Both maps show August average stream temperature, including historical (top, 1993-2011) and the 2080s (bottom, 2070-2099) for a moderate greenhouse gas scenario (SRES A1B). Colors indicate the temperature relative to specific thresholds that approximately relate to thermal tolerances for char (12ºC) and salmon (18ºC and 21ºC).

3. Projected Climate Impacts on Salmonids

Predicted climate impacts on Washington freshwater systems that affect salmon survival include increasing water temperature, increasing elevation of cold-water habitat, increasing peak flow magnitude, changes in timing of peak flows or low flows, and lower summer low flows (Section 2). Each of these predicted changes and their impacts on salmon will vary across the state. We divided the state into five regions based on predicted patterns of change in streamflow (high flow and low flow) and temperature using data described in Section 2 (Figures 2-4) and existing salmon population characteristics.

Using NOAA's 2015 West Coast Region Salmon & Steelhead Geodatabase (Dunn, 2015), we mapped current salmon life history diversity (i.e., number of Distinct Population Segments, DPS) by Hydrologic Unit Code (12-digit code) in Washington State (Figure 5, Top). We mapped listing status under the Endangered Species Act (ESA) for each population (Figure 5, Middle). We then combined the two parameters, life-history diversity and status, into groups (Figure 5, Bottom). We used these groupings to coarsely assess the current state of salmon across the state. For example, areas in south-western Washington have high life-history diversity (high DPS count) and a low percent of ESA-listed populations. North-eastern Washington has areas with low diversity (low DPS count) and high percent of populations listed.

To define five regions distinct in terms of predicted climate impacts on existing salmon populations, we intersected the maps of flow predictions presented in Section 2 with the map of salmon populations' distribution and status (Figure 5). The five regions are: (1) the Olympic Peninsula and Puget Sound, (2) southwestern Washington, (3) eastern slope of the North Cascades and the Okanogan Mountains, (4) Columbia Plateau), (5) Blue Mountains (Figure 6). These regions are useful for characterizing variation climate impacts on salmon.

Olympic Peninsula and the Puget Sound

Streamflow projections for the Olympic Peninsula and Puget Sound region show a consistent pattern of increasing peak flows and decreasing low flows. There are typically ≤3 salmon populations per sub-watershed and <50% of those populations are ESA-listed. These populations (particularly summer runs) are most likely to be impacted by the decrease in low flows, which reduces available habitat, limits upstream-downstream connectivity for fish migration, and magnifies the negative effects of warming water (because shallower water heats more quickly with increasing air temperatures). Impacts of warming include direct (mortality or thermal stress) and indirect (e.g., competition from warm water invasive species) stressors on salmon. Spring spawners or fall-run populations that have springtime egg incubation periods will also likely be negatively impacted by earlier, higher spring peak flows and increased scour during those events.

Southwestern Washington

Streamflow projections for southwestern Washington are more variable than for the Olympics/Puget Sound region, ranging from minor change (<10%) to substantial change (>70%) in flow magnitudes. This includes projections of no change to substantial increases in peak flows and either increases or decreases in low flows. In the majority of sub-watersheds, there are >3 salmon populations and none are ESA-listed. The diversity here may imply salmon resilience to change through the capacity to adapt. Finer resolution model downscaling will be needed to more clearly characterize climate impacts for this region.

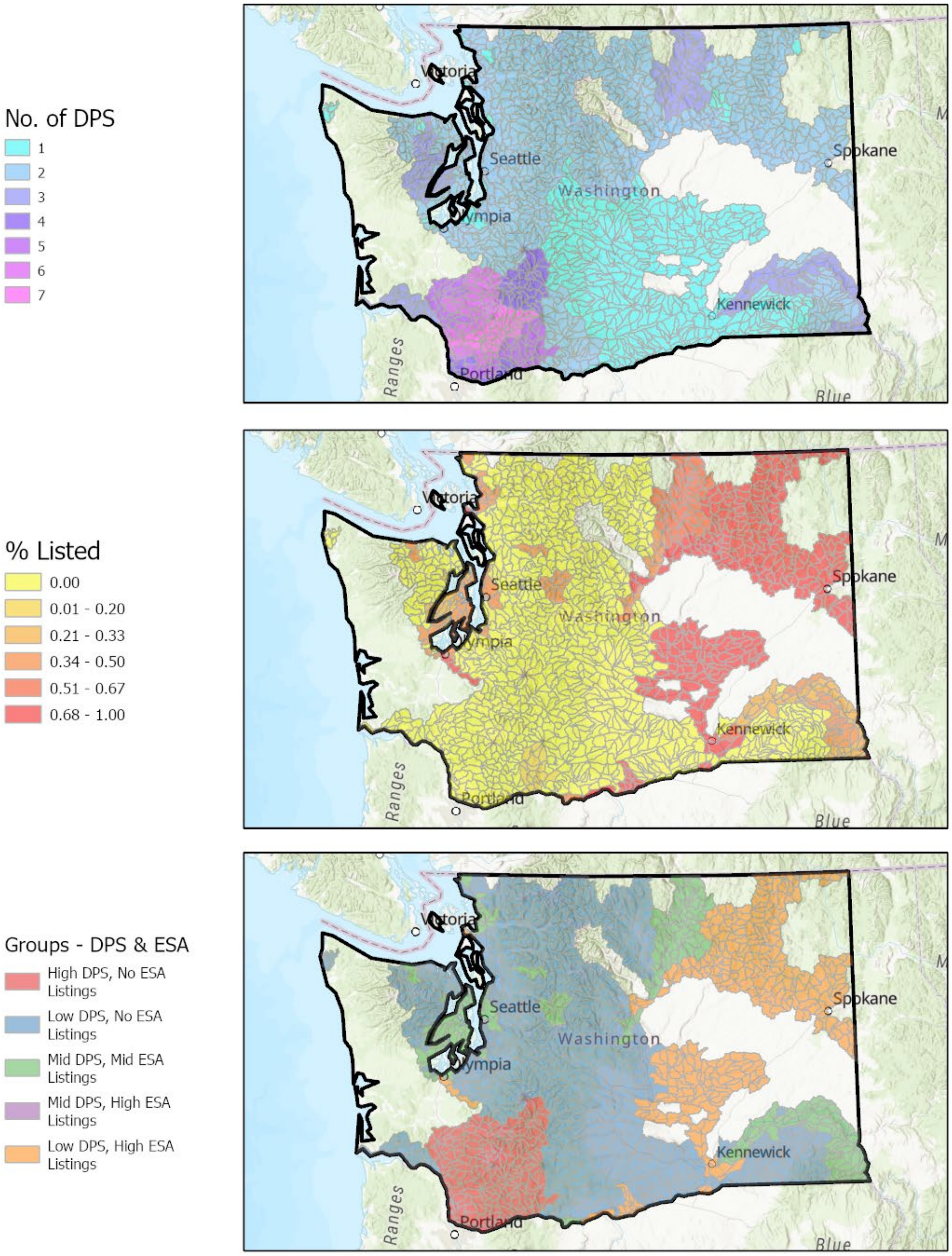

Figure 5. Salmon population characteristics of Washington State. (Top) the number of Distinct Population Segments (a description of life-history diversity in salmon), (Middle) The percentage of salmon populations ESA listed, (Bottom) A grouping based on DPS and ESA listing to show areas of both diversity and ESA listing. Much of the state has 1-2 distinct populations and no ESA listings (blue and green) with the SW having high diversity and low ESA, and NW having low diversity with almost all populations having ESA status.

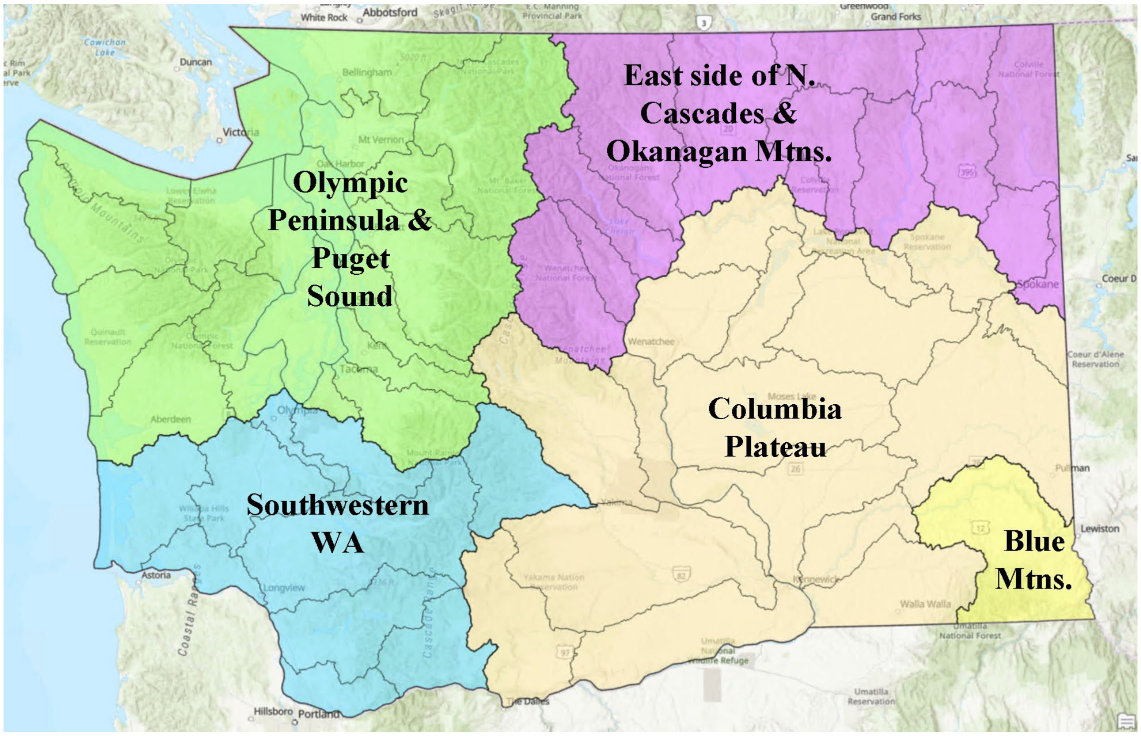

Figure 6. Regions in Washington State defined by climate driven changes to stream flow and temperature, and salmon population characteristics (migration distance and status).

Eastern slope of the North Cascades and the Okanagan Mountains

Streamflow projections for the streams draining the east side of the North Cascades and the Okanagan Mountains show variable increases in peak flows, with smaller increases in peak flows in streams draining the North Cascades, where snowpack is predicted to persist. Wintertime low flows were projected to increase in this region but this is due to the analysis (winter low flows are increasing and generally summer-time low flows are the biggest concern). There are ≤3 salmon populations per sub-watershed with at least one that is ESA-listed. For winter-run steelhead (ESA-listed, with Critical Habitat designated) that have springtime egg incubation periods, the main climate impact may be the earlier, higher spring peak flows and resulting streambed scour. Spring Chinook (ESA-listed, with Critical Habitat designated) will likely be negatively impacted by both higher spring flows in this region (directly affecting spawners swimming upstream) and the thermal exposure from higher water temperatures as they migrate up the Columbia River. Based on the available models, the cumulative thermal exposure while migrating up the Columbia River may be the most consequential climate impact for all migrating salmon in this region.

Columbia Plateau

Streamflow projections for the Columbia Plateau region show smaller increases in peak flows than most other regions of the state. Projected changes to low flows are highly variable, ranging from no change to substantial increases or decreases in low flows. In most sub-watersheds there is only 1 (or no) steelhead population. In many sub-watersheds the steelhead population is ESA-listed with designated critical habitat. The main climate impact for steelhead in this region will likely be the cumulative thermal exposure while migrating up the Columbia and/or Snake River and tributaries on the Plateau.

Blue Mountains

Streamflow projections for the Blue Mountains (southeastern Washington) show a consistent pattern of increasing peak flows and decreasing low flows. There are ≤3 salmon populations per sub-watershed with one or none of those populations ESA-listed. Although the patterns of projected streamflow change and current salmon status appear similar to the Olympics/Puget Sound region, climate impacts on salmon here will be different due to the migration distance. The cumulative thermal exposure during migration up the Columbia and/or Snake Rivers will likely be the main climate impact to salmon in this region.

Summary

We combined the spatial patterns of climate impacts on streams with the location, migration timing, and current status of salmon populations in an initial step toward mapping salmon vulnerability to climate change in Washington. For example, the few DPS of high conservation concern in eastern Washington (e.g., steelhead) may be more vulnerable to rising water temperatures in the Columbia River than to decreasing summer low flows in streams draining the east side of the North Cascades. For areas on the west side of the Cascades, decreasing low flows and increasing high flows may be of greatest concern, particularly for those watersheds in the Olympics and Puget Sound with low diversity (low DPS) or a substantial percent listed (mid ESA Listings). Future modelling efforts may be directed to focus on summer (rather than winter) low flows in snow-dominated watersheds, understanding more about predicted low flows (particularly in southwestern Washington), and including more detail to predict impacts on salmon by species and run timing for watersheds across Washington.

4. Washington Law and Policy Barriers to Streamflow Management in Response to Climate Change

Water resource use and management in the State of Washington is defined by a set of laws, judicial decisions, administrative rules, and other institutional context that affects how the state can address or adapt to climate-induced changes in streamflow. This section summarizes key laws, policy and other dimensions of water management that frame how Washington State can respond to climate change impacts on streamflow and stream ecosystems and identifies barriers and opportunities for their use in response to climate-induced streamflow changes.

Existing State authorities and programs and their relation to climate adaptation

Managing water resources and streamflow, in the face of climate change will rely on existing programs and use of existing authorities, as well as potentially making policy or statutory changes to improve the capacity to adapt to climate-induced impacts on streamflow.

Washington water law is based on the Prior Appropriations doctrine, as adopted in 1917. Prior Appropriation is described as "first in time, first in right," and is widely used to manage water resources in Washington State and the Western US in general. Water rights are allotted based on who puts the water to beneficial use first in time which determines the priority (Bruno & Sexton, 2017).

The Water Resources Act of 1971 was a landmark statute for the state of Washington. Under this act, Ecology was directed to establish minimum flows or levels in streams, rivers and lakes, known as "instream flows," to be protected from impairment from further water appropriation to protect fish, wildlife, and other environmental values.

The categories of authorities and programs highlighted below include the recognition of streamflow as a beneficial use under the Prior Appropriation doctrine as applied in Washington State, the legal basis and application of Instream Flow Rules for supporting streamflow, Washington's Trust Water Rights Program, water rights adjudication in support of climate change adaptation, the use of water storage for the benefit of streamflow, and water conservation.

Streamflow as a beneficial use

Washington State adopted the Prior Appropriations doctrine as a component of the Water Code of 1917. Historically, out-of-stream uses were formally considered a beneficial use to support a water right, but protection or maintenance of streamflow was not. Through a series of amendments to the Water Code, maintenance of streamflow for the benefit of fisheries and for other services become recognized as a basis of limiting water diversion rights issuance, establish minimum streamflows, and allowing water rights acquisition for the purpose of streamflow support (Barwin et al., 1988; Washington Department of Ecology, 2006).

Recognition of streamflow as a beneficial use has opened opportunities for voluntary and public support for streamflow through various mechanisms, including water markets and water trusts (King, 2004), with acquisition opportunities by both the private and public sector. Legal requirements for state management and regulatory authority over streamflow supports the establishment of Instream Flow Rules and the Washington Trust Water Program (discussed below), among other state programs and activities.

Instream Flow Rules

The Water Resource Act of 1971 (RCW 90.54) and Washington Revised Code § 90.22.010 allows and in some circumstances requires the State to establish minimum flow targets to protect and enhance steam flow for in-stream values. These Instream Flow Rules are a specific type of water right, with a specific

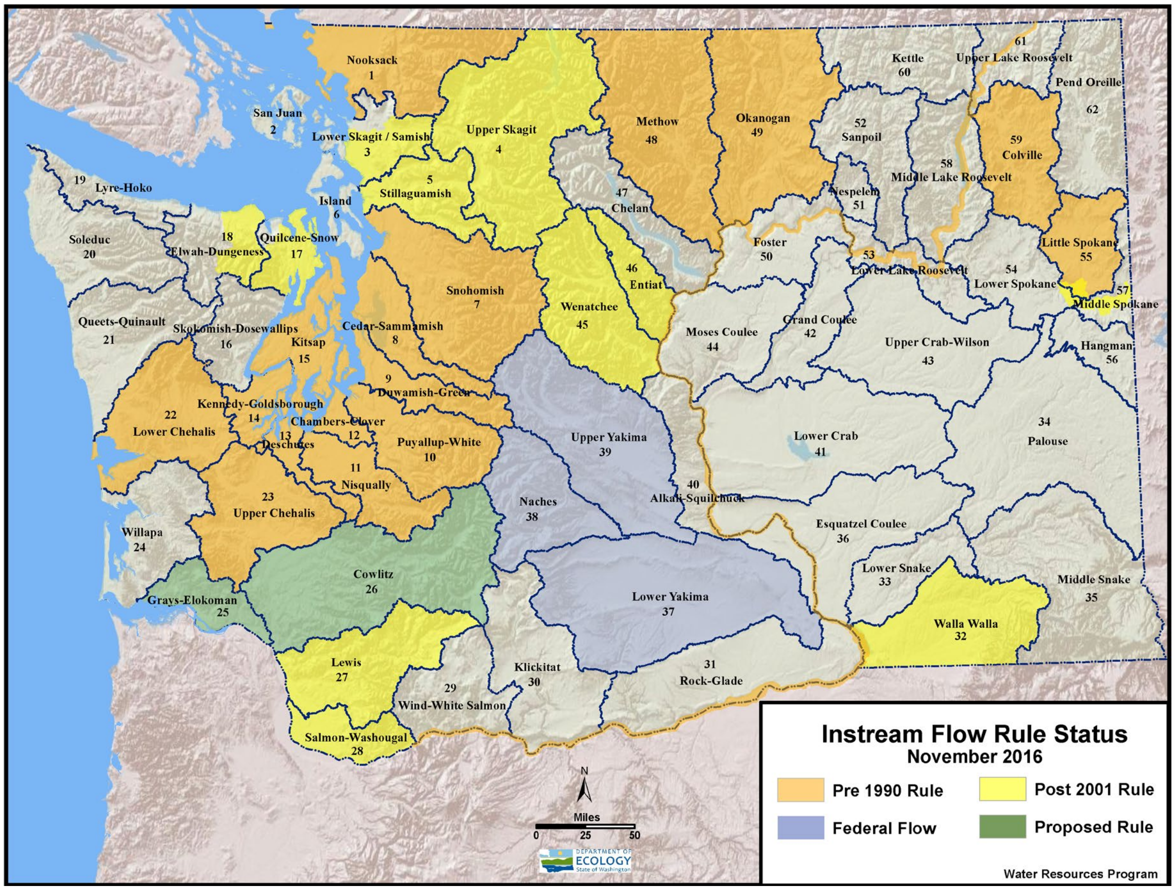

Figure 7. Water Resource Inventory Areas with Instream Flow Rules. Source: (Washington Department of Ecology, 2015)

priority date, that can be the basis for closure of a basin to issuance of additional water rights, and for limiting the use of more-junior water rights when the Instream Flow Rule is not being reached.

Figure 7 illustrates the basins that are subject to Instream Flow Rules as of 2016, and illustrates that the legislative mandate to adopt instream flow rules in all 62 WRIAs is not complete (Osborn & Mayer, 2020). Because the priority date of an instream flow rule depends on its date of issuance and its priority is the basis for part of its effectiveness, delay in establishing instream flow rules may limit their effectiveness.

Washington Trust Water Right Program

The legislature adopted a state-wide trust water right program in 1993 (Trust Water Rights Program Extended State-Wide, 1993). Water rights can be leased, acquired or donated by water right holders to Ecology to be held by the state to benefit instream flows or preserve groundwater levels. The rights held in trust hold their original priority date (Lovrich et al., 2004; Washington Department of Ecology, 2022b).

The Trust Water Right Program is an important mechanism for the support of streamflow and for adaptation to climate-induced streamflow changes, it has some shortcomings. Water Rights holders who would like to maintain their right without putting it to an off-stream use may withdraw their right from the Trust Water Program at their discretion, making these contributions to streamflow indefinite.

Water rights Adjudication

The 1917 water code created a process for general adjudication of water rights in which all existing water right holders in a watershed are brought into a court process to effectively decide on each of their legal water rights. In this process, valid rights are quantified, and invalid rights are eliminated. An important purpose and outcome of adjudication is reduction in uncertainties in the quantity and priority of water rights. Clarity and certainty over water rights reduces the barriers and costs of agreements and water transfers for the benefit of streamflow. Once a reliable supply is confirmed through adjudication, adaptive management strategies may likely be employed more effectively.

While Adjudication may reduce uncertainties for many classes of water rights, Tribal Treaty reserved rights to streamflow to support fisheries for customary and cultural use are a class of water rights with import for streamflow management and adaptation. This class of rights has a priority date of time immemorial, making them the most senior of water rights as recognized by the state. Pacific Northwest Tribes have a broad interest in maintaining streamflow to support fisheries as a central element of this type of right; and because the original treaties did not quantify the water right that the treaties imply. Adjudication of these rights may improve certainty about streamflow that these rights imply and may therefore in principle better support adaptation to climate-induced streamflow changes.

Despite the potential benefits of general water rights adjudication, much of the State of Washington is unadjudicated, and few tribal treaties reserved rights for streamflow are adjudicated, and this represents a barrier for adaptation to climate-induced streamflow change. Water rights adjudications are costly and slow (Ottem, 2006), and because the process of adjudication itself represents a source of uncertainty for individual water rights claimants, adjudications are sometimes viewed with concern. In relation to tribal treaty rights adjudication, federal law in relation to treaty rights generally complicates the state adjudication process. Further, because the purpose of reserved rights to streamflow are to support fisheries for the benefit of tribes, quantification may provide little adaptive benefit as climate changes because the needs of fish populations themselves will likely change with changing climate (Hedden-Nicely & Caldwell, 2020). These represent substantive barriers to adjudication of tribal treaty rights, which are an important class of rights in support of adaptation to climate-induced streamflow change.

Water Storage

The Federal Energy Regulatory Commission (FERC) oversees the regulation of hydropower projects, which must be relicensed on a periodic basis. Section 401 of the Clean Water Act provides authority delegated to Ecology to ensure that dam operations to not contribute to polluted waterways. Under the Elkhorn decision, this water quality authority includes ensuring minimum flow levels are maintained below hydropower projects. Through relicensing conditions, an effective climate change adaption strategy could include flow release patterns that benefit fish (Hanak & Lund, 2012).

Water storage infrastructure, such as dams, has a complicated relationship with streamflow and the benefits that streamflow provides. Existing dams may provide flexibility to retime streamflow to optimize for fish benefits as an adaptation to climate change. On the other hand, storage infrastructure such as dams and associated reservoirs can have negative impacts on fish populations by limiting upstream passage for migratory salmonids and decrease survival of out-migrating smolts. Further, water storage infrastructure that might be used to re-time streamflow for fisheries, while common, is not ubiquitous on most tributaries that support fisheries. And finally, water storage infrastructure is expensive to build and maintain.

Municipal Water Conservation

Municipal water purveyors must conserve water under the 2003 Municipal Water Law. Utilities must meter all customers, report on water loss through leakage to the Department of Health and meet maximum system leakage goals. Significant conservation has been realized by municipalities through programs to reduce residential and commercial water use that incentivize or mandate use of low water use fixtures, appliances, and landscaping.

Judicial case law affecting adaptation to climate-induced streamflow change

The existing authorities and programs summarized above are framed by both statutory and case law. Four key Washington State Supreme Court decisions protecting instream flows from impairment are summarized here:

1. *PUD No. 1 of Jefferson County v. Washington Department of Ecology (1994)* – In this case, also known as the *Elkhorn decision*, the US Supreme Court upheld Ecology's delegated authority under Section 401 of the Clean Water Act to impose minimum flow conditions during licensing of hydropower projects to protect waterbodies from water pollution.
2. *Postema v. Pollution Control Hearings Board (2000*) – The Supreme Court upheld Ecology's denial of proposed groundwater withdrawals that were hydraulically connected to surface water that would impair adopted instream flow levels or stream closures. The Court specified that impairment, including "*de minimus*" impairment, could not be authorized by Ecology in issuance of water rights. The Court determined that impairment would occur when a surface water is not meeting minimum flow levels, whenever there was any impact that could be determined, including impacts determined only using computer models.
3. *Swinomish Indian Tribal Community v. Skagit County (2013)* – The Supreme Court ruled that impairment to adopted instream flow levels could not be authorized by Ecology through a rulemaking process using the justification of "overriding consideration of public interest" (OCPI).
4. *Foster v. Ecology and City of Yelm (2015)* - Supreme Court ruled that Ecology cannot use OCPI to issue new water rights that impair instream flows, and that mitigation for impairment must address the legal (flow levels) impairment, despite the instream habitat benefits from "out-of-kind" mitigation.

These cases are highlighted here because they are generally supportive of the State's minimum flow requirements implemented via Instream Flow Rules. The *Elkhorn decision* supports the state's authority to set Instream Flow Rules as required by the Water Resource Act of 1971. The subsequent three cases recognize that water allocations or uses allowed or issued by Ecology after the adoption of an Instream Flow rule that impairs the flow of a river subject to an Instream Flow rule are not allowed. This holds in the last two cases (*Swinomish* and *Foster*) even if justified based on broad and overriding public benefit conferred by the activity leading to impairment. *Postema* implies that the magnitude of the impairment does not matter if the risk of minimal impairment is sufficiently likely. The *Foster* case effectively holds that there is no legal substitute for streamflow as set in an Instream Flow Rule, so compensating for a streamflow impairment with "out-of-kind" mitigation (e.g., fish habitat that at least compensates for the negative impacts of lower flows on fish) is not sufficient.

While these cases are generally supportive of maintaining streamflow by restricting subsequent water allocations that can impair streamflow, they do not address the problems associated with streamflow diminishment resulting from climate-induced change in flow conditions. Indeed, the *Foster* case may represent inflexibility for active fisheries management in the context of climate change impacts, by disallowing the retiming of flows that may diminish flows under an Instream Flow Rule (through reservoir management or other water allocation activities) even if the water provides equal or larger fisheries benefits elsewhere or at another time in the watershed.

5. Western States Management Responses to Streamflow Change

This section synthesizes other western states' management responses to climate-driven streamflow changes in relation to the barriers to streamflow management adaptation in the state of Washington that were identified in the previous section. We focus on the strategies of the six western states with ecosystems that are relatively like Washington: California, Colorado, Idaho, Montana, Oregon, and Utah.

Streamflow as a beneficial use

In the mid-1970s, western states began to establish mechanisms to recognize and protect non-consumptive use of water, at least some of which eventually returns to contribute to downstream flow and/or groundwater (Amos & Swensen, 2015). Until the late 1980s there were no established minimum water quantities for in-state rivers and streams. This led the proponents of increased streamflow to lobby for adequate legal protection for streamflow to support other uses for which the streams are designated (Kaufman, 1991). States generally accomplish the protection of instream flows by expanding the definition of beneficial use to include non-consumptive water uses, also referred to as instream flow (Amos, 2006). Table A1 in the Appendix summarizes beneficial use definitions in Western States. In short, all states examined for this report including Washington State recognize values provided by streamflow as a potential beneficial use.

The recognition of streamflow as a beneficial use in western state statutes provides a basis for the protection of streamflow. The same can be said of new laws on the transfer and retirement of diversion rights either temporarily or permanently for the purpose of augmenting streamflow. Importantly, these new laws provide flexibility for private and public investment in streamflow maintenance for the purposes of adapting to climate-induced streamflow.

Instream Flow Rights and the Role of State Agencies

Some states, like Washington, have adopted statutory provisions to address instream flow rights that include devising mechanisms involving state management resource authorities to manage water rights (Amos & Swensen, 2015). Table A2 in the Appendix gives a concise description of instream flow laws in select western states and a brief comparison to Washington States streamflow protection authority. The mechanisms by which states approach support of streamflow vary. Washington State's combination of Instream Flow Rules and the ways in which the Trust Water Rights Program supports streamflow span many or most of these approaches.

Individual Instream Flow Rights

A few states have created statutory mechanisms to allow individuals other than the state itself to hold and enforce an instream water right like the *Alaska Statute § 46.15.145(a) Reservation of Water* and *Arizona Revised Statute Annotated § 45-151(A) Right of Appropriation* (Amos & Swensen, 2015). *Oregon Revised Statute (ORS) 537.348* also allows any person to "purchase or lease all or a portion of an existing water right or accept a gift of all or a portion of an existing water right for conversion to an instream water right" retaining its priority date (*ORS 537.348*, 2022, p. 537). In contrast to Alaska, Arizona, and Oregon as described above, California has no comprehensive instream flow program at the state-level, but the "California Water Code *§* 1707 allows existing water right holders to transfer otherwise diverted water to instream flows up to the extent of the existing rights" (Amos & Swensen, 2015). This section also removes the requirement of actual diversion for the use of water right (Amos & Swensen, 2015).

Water leasing and acquisition for streamflow purposes

Legislation relating to streamflow leasing and acquisitions has become relatively common. Environmental water transaction programs (EWTPs) exist throughout the western US to aid instream flows and encourage innovative transactions to take place such as "temporary transfers, efficiency investments, retirement from urbanizing lands, and surface water rights transfers to environmental use to offset new groundwater uses" (Kendy et al., 2018). Water trusts work to create agreements with senior water rights holders to transfer their water rights temporarily or permanently to the trust or change their water use to protect or restore instream flows.

For instance, in 1996, the US Congress set up the Deschutes River Conservancy (DRC) to restore instream flow with a year-round goal of 33 cfs and improve water quality of the Deschutes River. Colorado passed HB 08-1346 that authorizes an annual appropriation of $1,000,000 from the Colorado Water Conservation Board (CWCB) Construction Fund to fund water rights leases or acquisitions for ISF covering the transaction costs subject to relevant criteria and guidelines. This Bill is motivated by CWCB's recognition that not all streamflow protection can be met through new streamflow appropriation, and most water rights owners would like to realize an economic benefit in exchange for their water rights (Benson, 2012). The Montana Code Annotated 85-2-436(3) similarly authorizes a lease for instream flow purposes. (*Montana Code Annotated 2021*, 2022). Utah allows the Division of Wildlife Resources and Division of Parks and Recreation the ability to change an existing water right permanently or temporarily for "the propagation of fish; public recreational or the reasonable preservation or enhancement of the natural stream environment" (Covell et al., 2017). The Division of Wildlife Resources may also purchase a water right for the purposes of instream flow or use of sovereign lands or accept a donated water right without legislative approval (*Utah Code Section 73-3-30*, 2022).

Oregon's instream leasing program allows water right holders to transfer a diversionary water right to instream flow for a period not exceeding 5 years, and the state's permanent instream transfer program allows a water right to be permanently moved instream held in trust by the Oregon Water Resources Department (Amos & Swensen, 2015). Once the 1987 law authorizes the transfer of water rights for instream purposes, a market began to emerge (Neuman et al., 2006). Several buyers with an intent to restore instream flows include the non-profit entities such as the Oregon Water Trust, the Deschutes River Conservancy, and regional land trusts; government agencies that include the Bonneville Power Administration, the Bureau of Reclamation and other state agencies; and private parties such as electric utilities, irrigation districts, and other large water users (Neuman et al., 2006).

Water Banking is an institutional arrangement to manage a system of water rights transactions among different users (Fazeli et al., 2021). Washington State has numerous water banks that were initiated largely for the purposes of mitigating the impacts of exempt well use on streamflows. In Utah, the state legislature approved the creation of the Utah Water Banking Strategy –a ten-year project that includes pilot studies on water rights and economic and hydrologic analyses to serve as a tool to facilitate the voluntary and temporary transfer of water rights (Utah Water Banking, 2022). The state of Idaho also has two water banking programs under the statewide water banking system called the Water Supply Bank administered by the Idaho Water Resource Board. The water banks provide an avenue to transfer surface and groundwater rights and local rental pools between users.

Acquisition and leasing of diversion rights is recognized in most or all western states, including Washington, as a mechanism for augmenting, protecting, or restoring streamflow. These approaches represent a relatively flexible opportunity to adapt to climate-induced streamflow change, and may be among a very limited set of opportunities in fully appropriated basins to reallocate water from out-of-stream to in-stream use. However, leases and purchases require funding either from the public sector or private entities with an interest in streamflow restoration. Matching diversion rights with streamflow needs is not always feasible, and administration of instream rights is also administratively burdensome.

Other State Initiatives that Aid Climate Change Adaptation

Comprehensive water plans and policies may facilitate a process to mitigate the impacts of climate change on streamflows. Principal elements of water resource plans developed by state or local agencies include: 1) water budgets based on climate change information, 2) flexible entitlements and focus on values of alternative uses, 3) risk sharing, and 4) tradability of water rights (Tarlock, 2018).

A drawback of climate change is that several of California's headwater streams are turning dry partly due to higher ecosystem use and loss in snowpack because of warming conditions. The projected decline in snowpack will impact water supply for downstream storage, reservoir operations, direct diversions, flood management and ecosystems as the snowpack from Sierra Nevada is a critical hydrologic resource that provides 60 percent of the water used by communities, agriculture and industry across the state (Hartman et al., 2021). Driven by these changes, the State Water Resources Control Board (WRCB) has taken various actions to respond to climate change such as the expansion of Recycled Water Policy Program through the amendment of the Recycled Water Policy in 2018, to help diversify the source of water supply in the localities and increase drought resilience. In addition, the State and Regional Water Boards have adopted regulations to increase the collection of urban storm water (Hartman et al., 2021) such as the implementation of stormwater permitting programs that includes Municipal Separate Storm Sewer System (MS4) Permits, Statewide Construction Storm Water General Permit, and Statewide Industrial Stormwater General Program (California State Water Resources Control Board, 2022).

Water Measurement and monitoring

Measurement and analysis of water and related resources play a role in adapting to climate change. First, it helps identify where climate-induced streamflow impacts are likely to occur and provides a basis for modelling it as depicted in Section 2. Second, it may be helpful in better understanding the value of streamflow and how this value varies over time and space. It also provides a basis for monitoring and enforcement of water usage, which may become increasingly important where summer water scarcity may increase.

In the face of climate change, determining optimal streamflow may help in achieving sustainable water management (Dobriyal et al., 2017). Identifying the instream need for a river requires extensive hydrological analyses, and water measurement tools play a key role. For example, the State of Washington requires water rights holders to keep metering records on site for the most current 5 years for certain uses such as new surface water uses, existing surface water uses greater than one cfs, and water uses in water-short areas (Washington Department of Ecology, 2022a). Similarly, SB 88 in California provides improved measurements and reporting requirements for water rights holders and diverters of more than 10 acre-feet of water per year to take effect on January 1, 2016 (Austin, 2015). Although Colorado has a state statute that authorizes water managers to require water measurements, the law is vague so the state is proposing a new rule on how farmers and ranchers in the Northwest of Colorado would measure their water use through certain types of measurement devices that will be installed and verified as well as rules on recording and reporting of water use to the state (Sakas, 2021).

Natural Approach to Infrastructure

"Natural Infrastructure is the strategic use of natural lands, such as forests and wetlands, and working lands, such as farms and ranches, to meet infrastructure needs" (Willamette Partnership Staff and Oregon Environmental Council, 2021). Several stakeholders including cities, utilities, landowners, and watershed partners in the state of Oregon practice the natural infrastructure approach to protect water resources. The Willamette Partnership Ecosystem Credit Accounting System is an incentive program that encourages and supports mechanisms targeting improved water quality, increased water quantity and habitat conservation. The program allows users to buy and sell credits for "ecosystem services, to a wide range of mechanisms designed to generate revenue from the functions performed by natural systems" (Willamette Partnership, 2018).

Water Storage

Demand management is a key component of the 2019 Drought Contingency Plan - a suite of agreements signed by the seven states (i.e., Arizona, California, Colorado, Nevada, New Mexico, Utah, Wyoming) surrounding the Colorado River Basin that primarily aims to provide additional security to the Basin (Ostdiek, 2022). Demand management is defined as the "temporary, voluntary, and compensated reduction of diversions in an effort to conserve water that would otherwise be consumed, or consumptively used" (Colorado Basin Roundtable, 2019). The plan is centred on creating a water storage account in Lake Powell and the Upper Colorado River Storage Project Act reservoirs (Aspinall, Flaming Gorge and Navajo) of up to 500,000-acre feet by paying water users to conserve water. The water conserved could later be used by the Upper Basin states to meet their delivery obligations (i.e., Colorado, New Mexico, Utah, and Wyoming) in the Colorado River Compact. However, in March 2022, the state of Colorado put a hard pause on the program to wait for the other three states in the Upper Basin to catch up with their concerns and the issues they see (Outcalt, 2022).

The Northern Integrated Supply Project based in Colorado is in the process of building two new reservoirs –the Glade Reservoir and the Galeton Reservoir- providing an additional 40,000 acre-feet of water supply to Northern Colorado with target completion in 2028. The Glade Reservoir, in the northwest of Fort Collins, will store water diverted from the Cache la Poudre River, and the Galeton Reservoir in the northeast of Greeley will store water diverted from the South Platte River. In addition to the additional storage, the project will also include five pump plants and several pipelines primarily to allow water exchanges between project participants (Northern Water, 2022). The state of Colorado also enacted *SB 18-170 ISF Protection of Water Releases from Reservoirs* in 2018 that allows water rights owners to work with the CWCB to dedicate water for release from a reservoir to "reasonably avoid, minimize, or mitigate impacts of the new reservoir capacity on fish and wildlife resources within an identified stream reach" (Reservoir Releases For Fish And Wildlife Mitigation, 2018).

The Central Oregon Irrigation District is in the process to remove the Cline Falls Dam to restore the fall to its natural condition and consequentially allow free downstream flow of sediment that previously was trapped, helping to improve both quality and quantity of habitat in the river (Upper Deschutes Watershed Council, 2017).

These and other programs around the western states highlight the broad ability and importance of storage as a mechanism for retiming water for the benefit of streamflow, perhaps adaptively compensating for detrimental climate-induced streamflow changes as they occur, but also some of the negative consequences of dams.

6. Conclusion

The intent of this report is to (1) summarize the projected changes in streamflow due to climate change in Washington State, (2) relate these changes to projected impacts on Salmonids in the state, (3) examine Washington State law, authorities, and programs that relate to, facilitate, or represent barriers to adaptation to climate-induce streamflow change, and (4) provide a summary of public policy and programs for adapting to climate-induced streamflow in a select set of other Western states.

Climate change impacts on streamflow vary significantly across the State. The biggest changes in peak flows are projected for rivers that draw from mountainous areas on the western slopes of the Cascades and in the Olympics, where snowpack is expected to rapidly decline. Projected impacts for low flows are mixed, with the largest decreases in the Olympic mountains, the western slopes of the Cascades, and in the Blue Mountains in southeastern Washington. Increases in low flows for the northeast Cascades, which reflect a transition from lowest flows in wintertime to lowest flows occurring in summer; even in these areas, summer low flows are expected to decrease. Water temperatures are projected to increase in response to both lower streamflow and warmer air temperatures.

Impacts on salmonids vary in complex ways with changes in streamflow characteristics. Salmon of the Olympic Peninsula are projected to be most impacted by decreases in low flows. Impacts on salmon in Southwestern Washington are varied and difficult to project due the variation in streamflow change in this region. In the Eastern slopes of the North Cascades, the Okanagan Mountains, the Columbia Plateau, and the Blue Mountains the most likely impact for summer-spawning salmon is heightened thermal exposure during migration up the Columbia River, though changes in other flow dimensions are likely to be important as well.

Water law, regulatory authorities, and management programs that have developed in the State of Washington frame the state’s capacity to adapt to climate-induced streamflow change. Historically, the recognition of streamflow and the values it provides as beneficial use under the Prior Appropriations Doctrine forms a foundation for several programs that support managing streamflow adaptively in response to climate change. The states Instream Flow Rule authority helps limit diversion appropriations and diversions for the sake of supporting streamflow, and case law over the last 30 years has bolstered the place of streamflow maintenance as a critical legal backstop for reallocation and alternative off-stream uses of water. The Trust Water Rights program facilitates the permanent or temporary retirement of diversion rights for the benefit of streamflow, and general water rights adjudications can act to reduce uncertainty over water rights and facilitate transactions for the benefit of streamflow adaptation. Water storage and water conservation may also be useful for supporting streamflow and the benefits it provides, but also come with drawbacks that may be counterproductive to the goals of adaptation to climate-induced streamflow change.

Most other western states are facing many of the same fundamental water challenges as the State of Washington, and likewise are facing the prospect of climate-induced streamflow change. Although there is great variation across the western states examined in this report, the similarities in the fundamentals of the various approaches are notable as well.

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8. Appendix

A1. Dataset Description

The RMJOC-II dataset (sometimes alternatively referred to as the “Columbia River Climate Change”, or CRCC, dataset) builds on previous hydrologic projections by updating to newer models and providing a much more systematic evaluation of the uncertainty space. Specifically, global climate model (GCM) projections were obtained from the newer Climate Model Inter-comparison Project, phase 5 (CMIP5; Taylor et al., 2012). Ten GCMs were selected based on Rupp et al. (2013), who evaluated and ranked global climate models based on their ability to reproduce the climate of the Pacific Northwest. For each GCM, two greenhouse gas scenarios were evaluated: RCP 4.5, a low-end scenario that has emissions peaking in mid-century and declining thereafter, and RCP 8.5, a high-end scenario that has emissions increasing through the end of the 21st century (Van Vuuren et al., 2011). The current analysis only includes results from the high-end RCP 8.5 scenario.

The GCM projections were statistically downscaled using two approaches: 1) the Multivariate Adaptive Constructed Analog technique (MACA) (Abatzoglou & Brown, 2012), and 2) the Bias-Correction, Spatial-Disaggregation technique (BCSD) (Wood et al., 2004). All projections provide daily maximum temperature, minimum temperature, precipitation, and wind speed, for the years 1950 through 2099.

The hydrologic modeling is further delineated by using two hydrologic models and three approaches to model calibration. The hydrologic models are the Variable Infiltration Capacity (VIC) model and a fourth was an implementation of the Precipitation Runoff Modeling System (PRMS). The VIC model includes a simple glacier model. Three different approaches to calibration were used as well. However, in the current analysis only one calibration method was used. Referred to as “P1” in the study, this approach makes use of the Pan & Wood (2013) approach to calibrate each grid cell independently across the domain.

VIC and PRMS produce gridded fields of surface and subsurface runoff. To obtain flows on rivers these then need to be aggregated, or “routed”, through the stream network to estimate flows at each location. The dataset we are using here has routed the VIC and PRMS flows to all major rivers and tributaries across the state. We used these reach-scale results to calculate flow statistics for each reach. Flow extremes were calculated using the approach described in (Tohver et al., 2014).

A2. Western States

Table A1. Definition of Beneficial Use of Water Rights in select western US states

State	Reference	Beneficial Use Definition
California	California Water Code 13050(f) (2019)	"include, but are not limited to, domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and preservation and enhancement of fish, wildlife, and other aquatic resources or preserves."
Colorado	Colorado Revised Statute 37-92-103 (4) (2019)	"includes (a) The impoundment of water for firefighting or storage for any purpose for which an appropriation is lawfully made, including recreational, fishery, or wildlife purposes; (b) The diversion of water by a county, municipality, city and county, water district, water and sanitation district, water conservation district, or water conservancy district for recreational in-channel diversion purposes; and (c) For the benefit and enjoyment of present and future generation, the appropriation by the state of Colorado in the manner prescribed by law of such minimum flows between specific points or levels for and on natural streams and lakes as are required to preserve the natural environment to a reasonable degree."
Idaho	Idaho Constitution Article XV Section 3; Idaho Code Annotated 42-233(1) (2021)	"The Idaho Constitution recognizes agriculture, mining, milling power, and domestic purposes as beneficial use, and statutorily excludes from the definition use of geothermal waters for any purpose other than heat."
Montana	Montana Code Annotated 85-2-102(5) (2021)	"Including but not limited to agricultural, stock water, domestic, fish and wildlife, industrial, irrigation, mining, municipal, power, and recreational uses"
Oregon	Oregon Revised Statute 536.300(1) (2021)	"Water for domestic, municipal, irrigation, power development, industrial, mining, recreation, wildlife, and fish life uses and pollution abatement"
Utah	Utah Code Annotated 73-3-21(1989 repl.); Utah Code Annotated 73-3-3 (Supp. 2006)	"Utah does not define beneficial use, but states that in times of scarcity, domestic and agricultural purposes have preference over other uses, and provides that instream flows may be appropriated for fish, recreation, and environmental preservation."
Washington	Washington Revised Code 90.54.020(1) (2020)	"Uses of water for domestic, stock watering, industrial, commercial, agricultural, irrigation, hydroelectric power production, mining, fish and wildlife maintenance and enhancement, recreational, and thermal power production purposes, and preservation of environmental and aesthetic values, and all other uses compatible with the enjoyment of the public waters of the state."

Source: Amos (2006). Note: Dates in parenthesis after the legislative reference are the latest date that the legislation is current based on various sources in literature.

Table A2. Instream Flow Laws in selected western US states

State	Legislation	Instream Flow Rules	Comparison to Washington
California	California Water Code § 1707	Any person or entity with existing water rights may dedicate them for instream flows for beneficial use of fish, wildlife, and recreation in perpetuity.	This may also be done in Washington by an individual donating senior water rights to the Washington Trust in perpetuity.
Colorado	N/A	N/A	The state has an agency and water court that could provide protection on instream flows in the future.
Idaho	1978 Idaho Code § 42-1501	"Public health, safety and welfare require that the streams of this state and their environments be protected against loss of water supply to preserve the minimum stream flows required for the protection of fish and wildlife habitat, aquatic life, recreation…"	None
Montana	Montana Code Ann. § 85-2-436(1)	"The department of fish, wildlife, and parks may change an appropriation right, which it either holds in fee simple or leases, to an instream flow purpose of use and a defined place of use to protect, maintain, or enhance stream flows to benefit the fishery resource."	In addition to the transfer of water rights for instream flows, Montana has a reservation system. Prior to 1973, it has also appropriated rights for stream flows under Murphy rights which are still held to date.

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Oregon	Oregon Revised Statute § 537.336	“(1) The State Department of Fish and Wildlife may request the Water Resources Commission to issue water right certificates for in-stream water rights on the waters of this state in which there are public uses relating to the conservation, maintenance and enhancement of aquatic and fish life, wildlife and fish and wildlife habitat. The request shall be for the quantity of water necessary to support those public uses as recommended by the State Department of Fish and Wildlife. (2) The Department of Environmental Quality may request the Water Resources Commission to issue water right certificates for in-stream water rights on the waters of this state to protect and maintain water quality standards established by the Environmental Quality Commission under ORS 468B.048 (Rules for standards of quality and purity). The request shall be for the quantity of water necessary for pollution abatement as recommended by the Department of Environmental Quality. (3) The State Parks and Recreation Department may request the Water Resources Commission to issue water right certificates for in-stream water rights on the waters of this state in which there are public uses relating to recreation and scenic attraction. The request shall be for the quantity of water necessary to support those public uses as recommended by the State Parks and Recreation Department.”	The state allows partially reduced flows.

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Utah	Utah Code 73-3-3(11)(a)	“[i]n accordance with the requirements of this section, the Division of Wildlife Resources or Division of Parks and Recreation may file applications for permanent or temporary changes for the purpose of providing water for instream flows, within a designated section of a natural *1189 stream channel or altered natural stream channel, necessary within the state of Utah for: (i) the propagation of fish; (ii) public recreation; or (iii) the reasonable preservation or enhancement of the natural stream environment.”	None
Washington	Washington Revised Code § 90.22.010.	The Department of Ecology may “establish minimum water flows or levels for streams, lakes or other public waters for the purposes of protecting fish, game, birds or other wildlife resources, or recreational or aesthetic values of said public waters whenever it appears to be in the public interest to establish the same.”	N/A

Overall Sources: (Freshwater Inflow, 2022; Jackson, 2009)

Oregon Source: (State Agencies Authorized to Request In-Stream Water Rights, 2021)