The Future of Instream Water in Washington State

A Brief for Policy Makers
August 2022

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Dear Conservation Partners,

Long-term protection of Washington state's fish and wildlife habitat is essential to maintaining our quality of life, economic prosperity, and identity. However, climate change and increasing human population pressures will challenge the ability of streams to continue supporting native fish and wildlife. Managing water for fish and wildlife requires a thorough understanding of interactions between the changing climate, Washington's freshwaters, and the needs of fish, wildlife, and people. I am proud to provide you with this cross discipline[1] scientific brief intended to synthesize the best available science on effects of climate change and human population growth on instream water in Washington now and in the future. It includes an important section on Pacific salmon, whose conservation confers protection to many native co-occurring species.

This brief is a synthesis of knowledge from two interdisciplinary groups of experts: a policy advisory group that developed a comprehensive list of questions that could inform water management for the protection of instream water and a panel of scientists to answer those questions. Both groups represented a broad range of management and science expertise on climate change, ground water, domestic water use, and salmon ecology. We have distilled their knowledge into a description of the best available and policy-relevant science.

Although our intent is to inform water management for fish and wildlife, we do not recommend policy or specific processes to deal with the current and future challenges of conserving instream water for fish and wildlife. Instead, we attempt to synthesize a lot of information in order to raise awareness, foster common understanding, and focus attention in ways that can ultimately lead to wise decisions.

We remain committed to collaborating on research and policies that improve Washington's ability to manage water for fish, wildlife, and people into the future.

Sincerely,

Kelly Susewind
Director

[1] Climate Impacts Group, Puget Sound Institute, Northwest Climate Action Center, US Geological Survey, National Oceanic and Atmospheric Associations, US Forest Service. Pacific NW National Laboratory, Northwest Indian Fisheries Commission, Swinomish Tribe, Muckleshoot Tribe, King County, Washington State Depts of Ecology, and Fish and Wildlife, Washington State University, University of Washington.

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Urgency for Action

Urgency for Action

Climate change and increasing demand for water threaten our rivers and streams and the species they support, including humans. Wise management requires a deeper understanding of interactions between the changing climate, Washington's waters, and the needs of fish, wildlife, and people. This brief is the product of a multi-year effort by two interdisciplinary groups of experts representing a broad range of management and science expertise on climate change, ground water, domestic water use, and salmon ecology. We have distilled their knowledge into a description of the best available and policy-relevant science.

This brief was created to provide the technical information that policymakers need to make informed decisions to prepare for future water-supply challenges in Washington state. The urgency to minimize expected impacts of climate change and increases in municipal and agricultural demands of instream water has never been greater and will continue to increase throughout the 21st century and beyond. While there will always be gaps in knowledge, one thing is quite clear: Actions taken now will give us the greatest chance of meeting the needs of fish, wildlife, and people in the future.

Existing water laws and policies were designed to meet statewide goals that often did not account for future challenges that have only recently become clear. This brief does not recommend new policy or comment on existing policy. Our intent is to summarize scientific advances that should illuminate future challenges, and inform the process of designing new laws and policies to meet them. The goal is to meet water needs not only of humans, which are largely out-of-stream, but also of non-human species, which are largely instream. Native salmonids are highlighted because their needs are shared by many other species, they are widely distributed, and our wellbeing would be greatly diminished without them.

Executive Summary

Executive Summary

Maintaining instream water for fish, wildlife, and people is a 21st century challenge. Losses of instream water have been largely due to increasing human demands for out-of-stream uses, and climate warming due to global anthropogenic greenhouse gas emissions. For many areas of the state, climate models project further increases in winter streamflow, consequent declines in summer streamflow, and increasing stream temperatures. These impacts will, in places, be made worse by changes in land cover, and by new demands for water. The warming climate will cause changes in seasonal irrigation demands that are likely to further reduce summer low flows, and increase summer stream temperatures. Some new municipal water demands will be met from deep groundwater sources, but others will tap shallow groundwater or surface water, increasing evaporation losses. Instream water reductions will be greatest where both urban and rural losses accrue, especially during summer. These pressures will further degrade habitat quantity and quality for many native aquatic species, and particularly cold water-adapted fish like salmon[1]. Water conservation and storage measures may relieve some increases in demand, but the manifold environmental impacts associated with climate change are likely to exceed the capacity of native fish and wildlife to adapt, and will not be easily mitigated.

This brief does not specify solutions, but it is worth emphasizing that the current framework for managing water availability (both regulatory and non-regulatory) does not always meet existing fish and wildlife needs or proactively address future challenges. We need a holistic approach deploying a suite of existing and potentially new tools to ensure adequate water for fish and wildlife given the challenges of climate change that we have outlined here.

Here we characterize the principal bio-physical challenges, intending that shared understanding of these challenges will contribute to effective and enduring solutions. These will require coordinated planning among local, state, federal, and other partners, creation of a science-policy forum to guide the process, identification of regional knowledge gaps, crafting of effective measures, and prioritization of areas for protection and restoration of streamflows.

[1]Isaak, D. J., C. H. Luce, D. L. Horan, G. L. Chandler, S. P. Wollrab, and D. E. Nagel. 2018. Global Warming of Salmon and Trout Rivers in the Northwestern U.S.: Road to Ruin or Path Through Purgatory? *Transactions of the American Fisheries Society* 147:566-587.

Throughout this brief, the needs of native salmonids are highlighted for the same reasons that justify growing investment in their recovery: their needs are shared by many other species, they are widely distributed, and our wellbeing would be greatly diminished without them.

Figure 1. Climate change will modify aquatic habitat conditions in our streams and rivers to the benefit of certain fish species over other species*. Habitat generalists including invasive species, will be better adapted to projected future stream conditions than many native species, including salmon, and thus will increase in abundance relative to native species. The risk scale refers to the set of life history traits that will be favored or disfavored under future conditions. Note that some runs of salmon such as Spring Chinook are more at risk than others such as Fall Chinook by virtue of when they enter the river system.*

The brief lists proactive actions intended to reduce uncertainty, in support of informed and deliberate choices about our future. One includes the creation of a science-policy planning framework that addresses land-use and water management on a regional scale. The state recently passed legislation to “include climate resiliency” into Growth Management Planning. This should be expanded to other forms of land-use planning. Further important actions include:

- Better predict future shifts in precipitation and their effects on streamflow.
- Better estimate groundwater/surface-water interactions and the formation of cool-water refugia.
- Better estimate how the distribution of aquatic plants and animals will shift in time and space.
- Better estimate how climate change and other stressors will affect salmon survival.
- Maximize realized benefits of restoration projects that enhance flows with monitoring and adaptive management.
- Better understand human water use in a changing climate.
- Determine best approaches to meet future human water needs that minimize instream impacts.

Science Findings

Science Findings: Climate and Human Population Effects on Streamflow, Fish, and Wildlife

With input from the management group, the science group synthesized peer-reviewed research and identified important scientific considerations for decision makers intending to manage water supply while also protecting instream water. Highlights from this synthesis are listed below.

Projected Hydrology and Temperature Changes—Changing Flows and Warming Streams

Climate change models project increases in winter streamflow, declines in summer streamflow, and increasing stream temperatures. These will alter the timing, quantity, and quality of instream water.

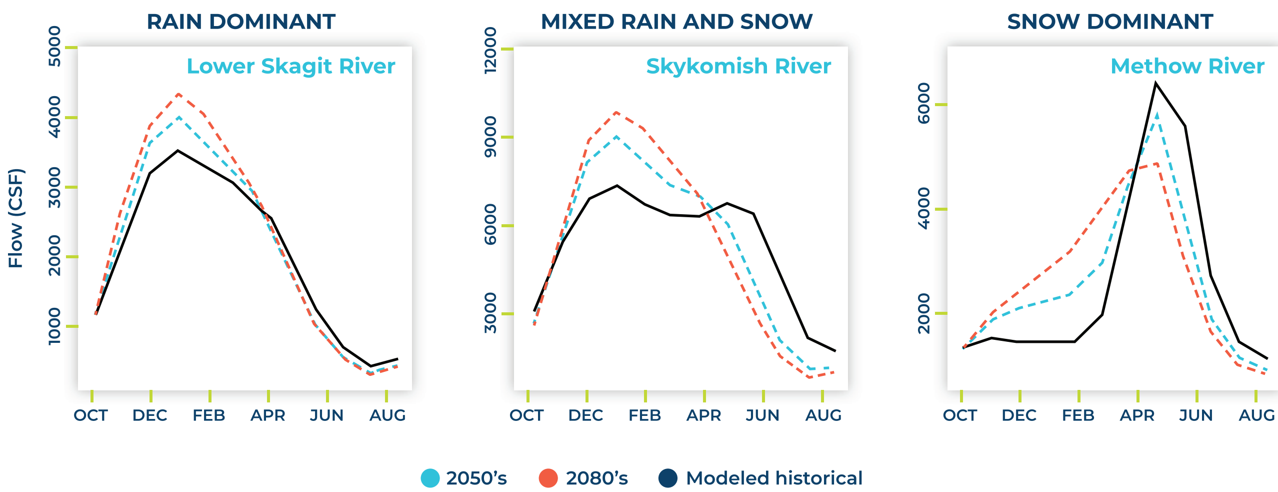

Figure 2. Streamflow is projected to increase in winter and decrease in spring and summer across rain dominant, mixed-rain-and-snow, and snow-dominant basins. *Rain dominant watersheds (left panel) are projected to experience higher winter streamflow as winter precipitation increases, with little to no change in streamflow timing. Mixed-rain-and-snow basins (center panel), which sit near the freezing level, are the most sensitive to warming temperatures. These basins are projected to shift towards rain-dominant conditions. Snow dominant watersheds (right panel) are projected to experience earlier peak spring streamflow and declines in summer streamflow. The three panels show projected changes in monthly average streamflow (cubic feet/second) for the 2050s (2040-2069; dashed blue line) and the 2080s (2070-2099; dashed red line), under a high greenhouse gas scenario (RCP 8.5; model average). Modeled historical (1970-1999) streamflow is represented by the solid black line (Data Source: RMJOC-II)*[2] .

These projected changes will have widespread implications for fish, wildlife, and people:

- ***Winter streamflow is projected to increase.*** This will be most pronounced in basins that straddle the freezing level, and historically received a mix of rain and snow during winter. In these basins, increasing temperatures will increase the proportion of winter precipitation falling

[2] Chegwidden, O. S., et al. 2019. How do modeling decisions affect the spread among hydrologic climate change projections? Exploring a large ensemble of simulations across a diversity of hydroclimates. *Earth's Future* 7:623-637.

as rain instead of snow, and reduce snowpack. This in turn will increase winter streamflow as well as flood[3] and landside risk.

- ***Summer streamflow is projected to decrease*** due to diminished snowpack, reduced summer rainfall, and increased evapotranspiration. Compared to historical patterns, summer flows will be lower for longer.
- ***Heavy rainfall events are projected to become more intense.*** A warmer atmosphere holds more water vapor, which can increase precipitation intensity during storm events. Increases in heavy rainfall events could further increase winter streamflow as well as flood and landslide risk.
- ***Stream temperatures are projected to increase*** driven by warming air temperatures, decreasing snowpack, falling glacier contributions, and declines in summer streamflow.
- ***Population demands for water are projected to increase.*** A warming climate will lead to changes in seasonal irrigation demands, which may exacerbate declines in summer low flows and increases in summer water temperatures, particularly in eastern and central Washington. Municipal and domestic water demands, while much smaller than agricultural demands, are also expected to increase substantially with human population growth over coming decades, especially in the Puget Sound region and south-central Washington. Some new municipal demands will be met from deep groundwater supplies, but others will likely tap shallow groundwater or surface-water sources, with a higher likelihood of reducing instream water levels.

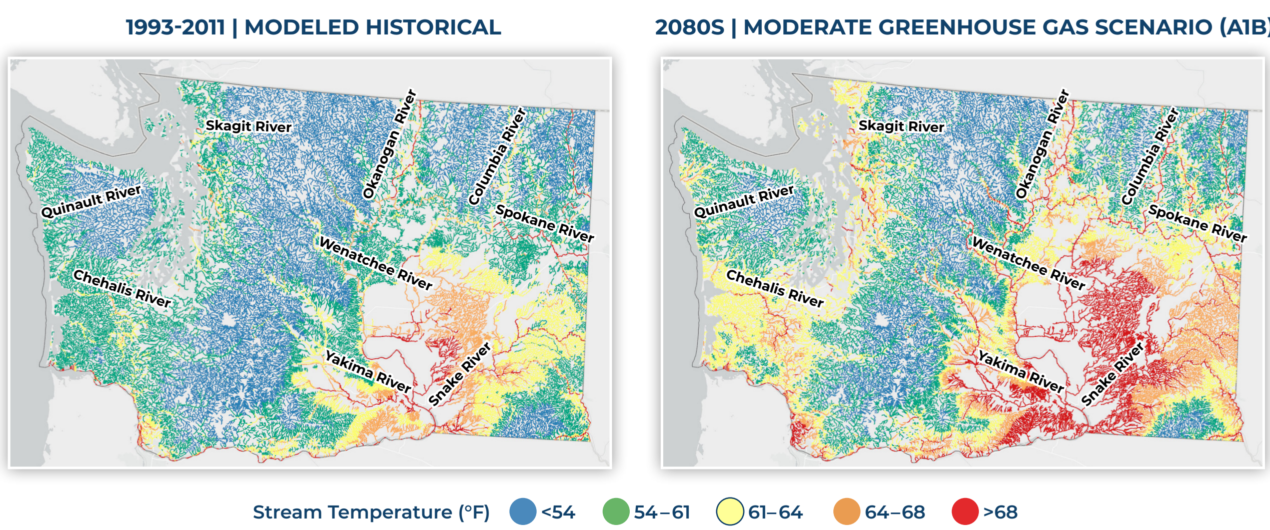

Figure 3. Water temperatures are projected to increase in low- and mid-elevation streams across much of Washington state. *These maps show modeled historical temperatures (1993-2011; left map) and projected average August stream temperatures in the 2080s (2070-2099; right map) under a moderate greenhouse gas scenario (A1B)[4]. In some areas, these temperature changes will exceed thermal tolerances of aquatic species including salmonids.*

[3] Queen, L. E., P. W. Mote, D. E. Rupp, O. Chegwidden, and B. Nijssen. 2021. Ubiquitous increases in flood magnitude in the Columbia River basin under climate change. *Hydrology and Earth System Sciences* 25(1):257-272.

[4] Isaak, D., et al. 2017. The NorWeST summer stream temperature model and scenarios for the western U.S.: A crowd-sourced database and new geospatial tools foster a user community and predict broad climate warming of rivers and streams. *Water Resources Research* 53:9181-9205.

Projected Effects on Fish & Wildlife — Widespread Changes

Climate projections indicate that many fish and wildlife populations will be negatively affected by increasing winter flooding, decreasing summer streamflow, and increasing stream temperatures. Human population pressures will increase land-use change and habitat loss with unintended negative consequences for fish and wildlife. These environmental changes may exceed the capacity for some species to adapt, especially fish species with the longest freshwater residence times that are most susceptible to changes in water quantity and quality (e.g., spring Chinook salmon, summer steelhead, coho salmon). Other expected outcomes are:

- ***Pre-spawning mortality will increase in summer- and fall-spawning salmon due to warmer water and lower low flows.*** Projected stream temperatures will stress adult salmon. Declining summer streamflow will decrease the quantity and quality of juvenile rearing habitat, and in some cases delay and in others accelerate downstream smolt migration, creating mismatches in timing of adequate food and/or the absence of predators.
- ***Fewer fish will survive beyond the fry stage due to increased winter flooding.*** Early life-history stages of salmon may experience higher mortality as a result of higher flows that scour eggs and reduce the availability of slow-water habitat for rearing juvenile fish. Scour events will also increase sediment loads that can reduce primary productivity (photosynthesis) and, thus, the production of food for juvenile salmon.
- ***Riparian habitat, stream shading, bank stability, and organic inputs will likely be negatively impacted by increased wildfire frequency and intensity.*** Over time, riparian vegetation is more likely to resemble adjacent upland vegetation, reducing its ability to provide riparian functions and increasing its susceptibility to wildfire. This may be especially significant in arid and semi-arid basins. Specific impacts of increased wildfires on riparian areas are complex, depending on local conditions and historic management, but these changes may have profound effects on riparian habitat availability and function. While riparian habitat makes up only a small proportion of the landscape, approximately 85% of wildlife species in Washington use or are associated with streams and rivers, with approximately 170 species requiring riparian habitat for some portion of their lives.

Projected Changes in Human Water Demand — Some Parts of the State More Impacted

How changing water demand and use affect instream water levels depend on many factors, including groundwater and surface-water interactions, and year-to-year variability in precipitation and air temperature. Additional factors will apply locally. For example, where the soil remains wet during summer months (typically, western Washington and irrigated parts of eastern Washington), higher air temperatures are expected to increase evapotranspiration rates, and reduce summer low flows accordingly. In contrast, where the soil is dry during summers (mostly in non-irrigated parts of central and eastern Washington), higher temperatures will increase potential but not actual evapotranspiration, and summer low flows will be reduced by direct evaporation alone. Other impacts are outlined below.

- ***Municipal and domestic water demands are expected to increase over the next 20 years, with the greatest increase coincidental with the largest population increases (Spokane and some Puget Sound Counties)*** Within Puget Sound, municipal water demands will continue to be met from groundwater and surface-water sources, with King, Pierce, and Snohomish Counties being the largest surface-water users, and Pierce, King, Thurston, and Kitsap Counties being the largest groundwater users[5]. Water use in the city of Spokane includes the only surface-water municipal supplies in eastern Washington and water use in the counties of Spokane, Yakima, and Benton include the largest groundwater uses for municipal supplies in the state.

- ***Areas with the largest surface-water diversions and groundwater withdrawals will likely impact instream water the most, especially during the summer.*** Surface-water diversions and groundwater withdrawals will affect instream water differently. Surface-water diversions, most commonly from reservoirs, directly reduce instream water at a specific location, but the timing of the impact can be mitigated through reservoir management. In contrast, ground water withdrawals generally reduce instream water in a dispersed manner over a larger area, and the timing and magnitude of the impact is difficult to predict and mitigate. In most Washington streams, lower groundwater levels will reduce water levels in nearby streams, and such reductions will be most acute during the summer low flow period, when streamflow is largely sustained by groundwater. Small streams are more sensitive to changes in surrounding groundwater levels than large streams because low flows in larger streams are more often sustained by larger aquifer systems that are less sensitive to groundwater withdrawals. As a result, the upper reaches of streams will be directly affected soonest by groundwater use, with streams becoming dry intermittently or permanently. We can predict the location and magnitude of declining flows in the future, but such predictions require detailed information on future population growth and per capita water use along with detailed aquifer and stream characteristics.

[5] Lane, R. C. and W. B. Welch. 2015. Estimated freshwater withdrawals in Washington, 2010: *U.S. Geological Survey Scientific Investigations Report 2015-5037*, 48 p. http://dx.doi.org/10.3133/sir20155037.

- ***Changes in irrigation practices, caused by changes in the timing and form of precipitation, will impact water demand and require careful planning.*** Total freshwater withdrawals in eastern and central Washington were 2.8 times higher than freshwater withdrawals from western Washington, with most (84% as of 2010) water going towards irrigation and sourced from surface water (76% as of 2010). In the majority of Washington's river basins there is a mismatch between seasonal supply and demand, with some receiving inter-basin water transfers to meet demand. Models are required to understand how evaporation and plant transpiration rates will respond to climate change, how irrigation demands change with different crops, and how cropping strategies may be adapted to a warmer climate when allowable with existing water rights. For example, warmer temperatures may cause some crops to be planted earlier, which could change the seasonality of demand, moving irrigation earlier in the year when precipitation is more plentiful. Arid and semi-arid settings that are heavily reliant on snowmelt runoff for irrigation supply, for example, most of the eastern front of the Cascades, are most at risk for pumping-related groundwater storage losses. This issue is an active topic of research.

Opportunities for Action

Opportunities for Action

Addressing key information needs about future conditions will help inform decisions about water management for people, fish, and wildlife. These needs include the ability to:

- ***Better predict future shifts in precipitation and their effects on streamflow.*** Few climate projections can accurately estimate future changes in precipitation, and those that do lack the resolution to capture microclimate and other weather phenomena (e.g., thunderstorms). Improved projections of future precipitation are the most important element needed to accurately estimate future streamflow. A clearer understanding of how streamflow may shift throughout the year, especially within mid-elevation basins that straddle the freezing level, will come from estimates of future precipitation and temperature. In turn, these estimates can be used to project the volume of precipitation likely to fall as snow, and the parts of the basin most dependent on that snow. This information is needed to estimate biological impacts, potential for species to adapt, and possible mitigation.
- ***Better estimate groundwater/surface-water interactions and the formation of refugia.*** Locations with significant springs where groundwater meets the surface are often local nodes of biodiversity that support rare species, maintain highly diverse communities of plants and animals, and can serve as temperature refugia and holding areas for salmon and other cold water adapted species during the summer[6]. Identifying geomorphologic and hydrologic settings that tend to yield upwelling or downwelling (i.e., gaining or losing) reaches and producing an inventory of large permanent springs is consistent with the idea of protecting the last, best places before taking other, often more expensive, conservation or restoration measures.
- ***Better estimate how aquatic plants and animals will shift in time and space.*** Distributions of native fish species are expected to shift northward (higher latitudes) and into higher elevations as stream temperatures rise. The rate at which different species or life stages can move is largely unknown. At the same time, invasive species will become more abundant and in many cases be better adapted to the new hydrogeological conditions. Major knowledge gaps include how inter-species interactions will change due to changes in distribution and how life-stage transitions (e.g., egg incubation timing, spawning initiation) will be affected by changes to thermal and hydrological cues. This work is essential to the management of risk on species persistence.
- ***Better estimate how climate change and other stressors will affect salmon survival.*** Life cycle modeling should be used to assess multiple stressors at each life stage of the life cycle and to estimate how cumulative effects at each life stage may affect population viability. Information on climate change impacts to species is most useful when it can be linked to growth and mortality at each stage of the species' life history. Species currently believed to be at greatest risk should be given priority.

[6] Ebersole, J. L., R. M. Quinones, S. Clements, and B. H. Letcher. 2020. Managing climate refugia for freshwater fishes under an expanding human footprint. *Frontiers in Ecology and the Environment* 18:271-280.

- ***Maximize realized benefits of restoration projects that enhance flows with monitoring and adaptive management***. Decreases in instream water will not be easily undone and caution is needed in developing restoration strategies using our current set of tools. Flow restoration projects, especially those with uncertain outcomes, need to consider future pressures (climate change and human population increase) and include monitoring and adaptive management to maximize realized benefits. Existing research also strongly suggests that projects are more likely to be effective when they are planned, implemented, monitored, and managed at large spatial scales — such as a Water Resource Inventory Area — to incorporate characteristic scales of watershed hydrology[7].

- ***Understand human water use in a changing climate.*** The systems by which we extract, use, and return unused water are complex, including surface-water diversions and groundwater withdrawals. Accurate monitoring of these systems is vital for managing the state's water resources. Monitoring should include timing, flow rates, locations, and interconnections of multiple components, many of which will change as human needs change. Monitoring the economics of water use — how water is conveyed and sold to users — would improve forecasts of impacts to instream water from human consumption, and highlight potential management levers such as incentives for water conservation. This could include more widespread metering of withdrawals and diversions and/or quantification of consumptive use by sharing water use data through existing assistance programs[8].

- ***Determine best approaches to meet human population water needs that minimize instream impacts.*** Estimates of how different approaches for supplying water to a growing population will impact instream water could be improved by exploring conjunctive use strategies through scenario planning. Future population growth and per capita water use are reasonably well predicted for the largest water systems. We do not know how different combinations of surface-water diversions, community groundwater withdrawals (Group A water systems), and dispersed smaller groundwater withdrawals (permit exempt wells) could be used to avoid or minimize unintended effects to instream water.

[7] Katz, S. and B. Luff. Review of Evidence for Management Action Effectiveness of Streamflow Restoration. Report prepared for WDFW by Washington State University. 101 (2020).

[8] USGS Water-Use Data and Research Program

Case Studies: Snoqualmie and Walla Walla

Washington state is diverse – geologically, topographically, hydrologically, in degree of development and land use – all of which influence how climate change affects watershed processes. This means there are few 'universal' solutions, rather, solutions should be tailored to local conditions and trends. Two case studies are given below, featuring the Snoqualmie and Walla Walla watersheds, to demonstrate how sub-basins differ in the type and scale of interventions that may be required to manage water sustainably. Sub-basins that are more intrinsically resilient to climate change may be better candidates for protection than less resilient sub-basins, which may benefit more from restoration. Additional case studies could and should be developed for other watersheds that are representative of larger areas across the state.

Snoqualmie River Watershed

The Snoqualmie River basin drains 695 mi^2 on the west side of the Cascade Mountains, with an elevation ranging from 23 to 7,010 ft. Its three main forks, the South, Middle and North Forks, converge near North Bend before flowing over Snoqualmie Falls, where the river is joined by the Raging and Tolt Rivers. The Snoqualmie River ends at its convergence with the Skykomish River, which flows into the Snohomish River and estuary before entering Puget Sound.

Precipitation occurs predominantly from October to March across an elevational temperature gradient controlling what falls as rain and what falls as snow. The watershed provides habitat for Chinook, coho, chum, and pink salmon, and winter steelhead which are constrained to reaches below Snoqualmie Falls. Above the Falls there are several species of genetically unique native trout and introduced stocks.

The South Fork Tolt River is part of Seattle Public Utilities' (SPU) freshwater supply system providing about 30% of the drinking water for 1.4 million people in and around Seattle. SPU is an active member of the Water Supply Forum, a regional organization of public water systems and local governments from King, Pierce, and Snohomish counties that addresses current and future water supply issues, including supply planning, environmental stewardship, and other water supply related issues facing the region. The Forum's 2009 Regional Water Supply Outlook found that the current water supply is likely to meet the regions' anticipated demands through 2050, including the projected effects of climate change. This Forum may serve as an example of a regional-scale framework for water planning that could be used in other parts of the state.

Climate change has already had significant impacts on the Snoqualmie River and those changes will accelerate over the next 50 years:

- There will be significantly lower streamflow from late spring through fall[9]. Projected declines in low flow magnitude range from 10-13%. Reductions in August flows range from 15-18% in snowmelt dominated tributaries and 4% in the rainfall dominated Raging River.
- Mean August stream temperature is projected to increase 4.3 °F (1993-2011 compared to 2080s)[10].
- Sixty-five percent of stream reaches are already above state water quality standards for temperature during summer, a figure that is projected to increase to over 90% by 2100[9].
- Declines in snowpack will lead to reductions in low-flows over an extended period in summer. Additionally, a decrease in summer precipitation (up to 70%) will further reduce summer low flows. Land cover changes that can result from wildfire or logging will also influence groundwater recharge and evaporation rates, further impacting low flows.
- Precipitation is projected to increase up to 58% during the winter and early spring[10] potentially increasing flood and landslide risk.

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[9] Yan, H., N. Sun, A. Fullerton, and M. Baerwalde. 2021. Greater vulnerability of snowmelt-fed river thermal regimes to a warming climate. *Environmental Research Letters 16*, 054006. **https://doi.org/10.1088/1748-9326/abf393**.

[10] Isaak, D. J., et al. 2017. The NorWeST Summer Stream Temperature Model and Scenarios for the Western U.S.: A Crowd-Sourced Database and New Geospatial Tools Foster a User Community and Predict Broad Climate Warming of Rivers and Streams. *Water Resources Research* 53:9181–9205. **https://doi.org/10.1002/**

- This watershed will likely experience smaller increases in air temperature compared to eastside watersheds due to its proximity to Puget Sound and the Pacific Ocean.

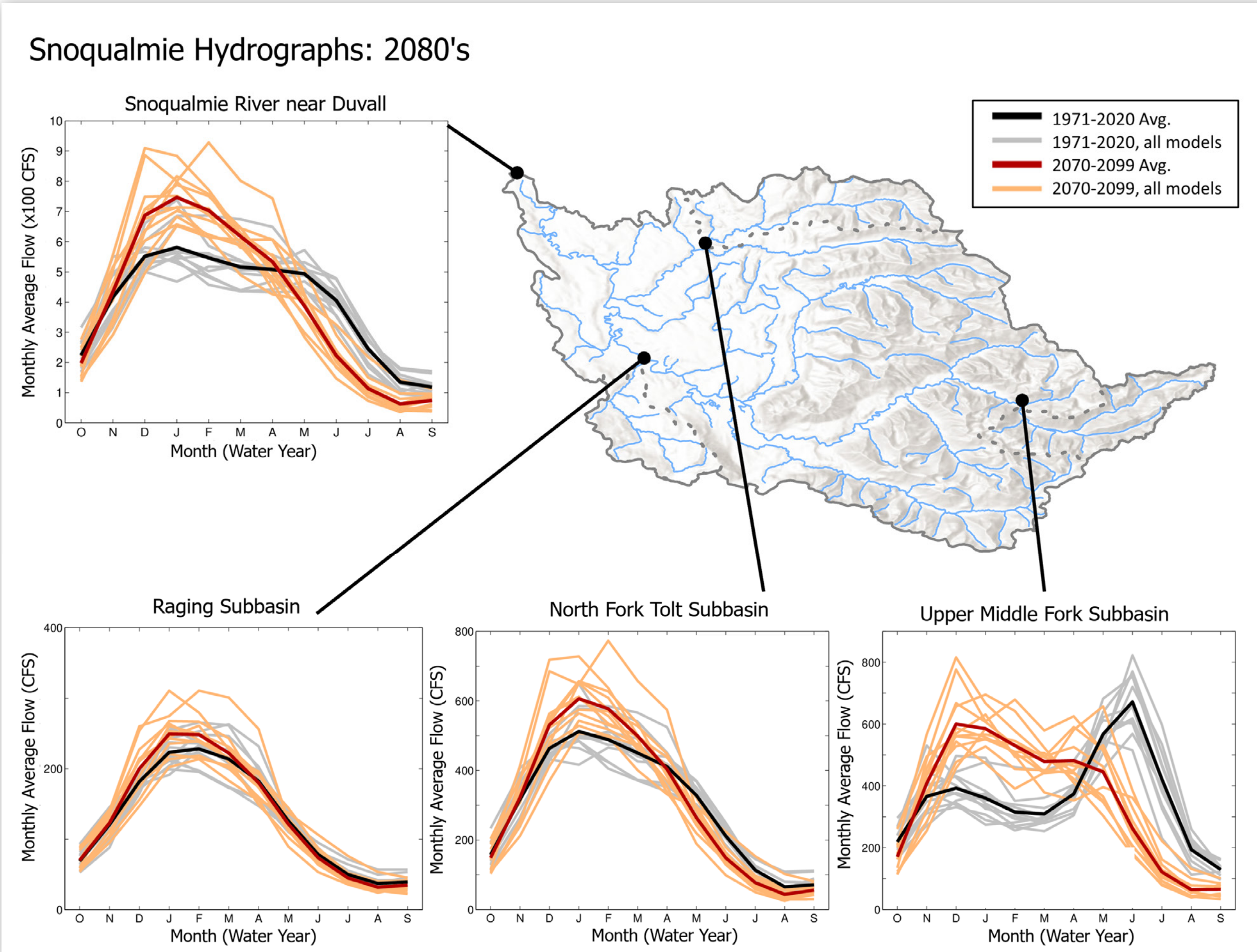

Figure 4. Changes in climate will alter annual streamflow patterns differently *within subbasins of a single watershed (e.g., the Snoqualmie[11]) based on geography, elevation, and land use. The four inset panels show modeled historical and projected future river flow in the rain-dominated Raging River, rain-snow transient North Fork Tolt, snow-dominated Upper Middle Fork and the mainstem Snoqualmie River near Duvall. Black lines are the modeled average historical flows from 1971-2020 (all models denoted by the gray lines), red lines represent projected average flows for 2070-2099 (all models denoted by the orange lines). Twelve global climate models (GCMs) were used as input to the regional model based on the high-end RCP 8.5 greenhouse gas scenario[12] to reflect different assumptions about future green-house gas emissions.*

The predicted impacts of these changes on fish are:

- Higher mortality for all life stages of salmon in the summer months due to flow reductions that can increase water temperature and reduce pool and riffle habitat area, thereby increasing competition, and reducing reproductive success.

[11] Lines and watershed boundaries were sourced from the National Hydrography Dataset (USGS) and the hill shade /background from an ESRI Basemap.

[12] Mauger, G.S., et al. 2021. New Culvert Projections for Washington State: Improved Modeling, Probabilistic Projections, and an Updated Web Tool. Report prepared for the Northwest Climate Adaptation Science Center. Climate Impacts Group, University of Washington.

- Increases in direct mortality of juvenile salmon during winter due to increased severity of floods.
- The possibility of significant increases in salmon egg and fry mortality from higher flows during spawning months.

Change in Hydrologic/ Thermal Event	Mortality	Reproductive Success	Competition	Predation	Habitat Area	GPP & Food Production
Low flow extent only	↑	↓ (SSH) ? (others)	↑	↑	↓	↓
Habitat forming flow events	↑	↓	?	?	↑ ↓	?
Sediment mobilizing flow events	↑	↓	?	?	↓	?
August average streamflow	↑	↓	↑	↑	↓	↓
Peak flow timing (earlier or later) and increases in scouring events	↑	↓ (SSH) ? (others)	?	↑	↓	?
Average historical to projected 2080's water temperature	↑	↓ (SSH) ? (others)	↑	↑	↓	↑

**Chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), winter steelhead (O. mykiss), chum salmon (O. keta), and pink salmon (O. gorbuscha) and multiple species of genetically unique native trout (Oncorhynchus spp.).*

Table A (Snoqualmie). *Projected climate related changes to the hydrologic and thermal environment (rows) in the Snoqualmie River and biological responses of salmonids* (columns). Up arrows denote an increase in the biological response, down arrows a decrease, and a question mark indicates an unknown response. Up and down arrows are different colors to improve table readability. Food production was assessed as change in gross primary production (GPP). Responses specific to Summer steelhead are denoted SSH.*

Walla Walla River Watershed

The Walla Walla River Basin drains 1,730 mi^2 of the Blue Mountains, flowing westward into the Columbia River above McNary Dam. The river originates as the North and South Forks, and major tributaries include the Touchet River, Mill Creek, and Dry Creek. Elevation ranges from 230 to 6,070 feet.

The Walla Walla has an arid continental climate with hot dry summers and cold wet winters. It is primarily a rain-dominated watershed with precipitation mainly falling from October to March. The watershed provides habitat for spring and fall Chinook salmon, summer steelhead, bull trout, and mountain whitefish.

River water levels in this arid basin are already lower, and water temperatures higher, in part due to extensive abstraction of water for human uses. The watershed is primarily in private ownership, except for the headwaters in the Blue Mountains. Land is used primarily for crop and livestock production, which has increased nonnative grasses, reduced riparian zones, and led to stream incision. River water is over-allocated for agricultural uses, which in places has reduced streamflow to zero during the irrigation season. Increasing urban development in the Walla Walla and Touchet valleys also increases the demand on the aquifer. Major challenges in the basin include increasing instream flows and determining where to restore habitat to the greatest benefit of aquatic species.

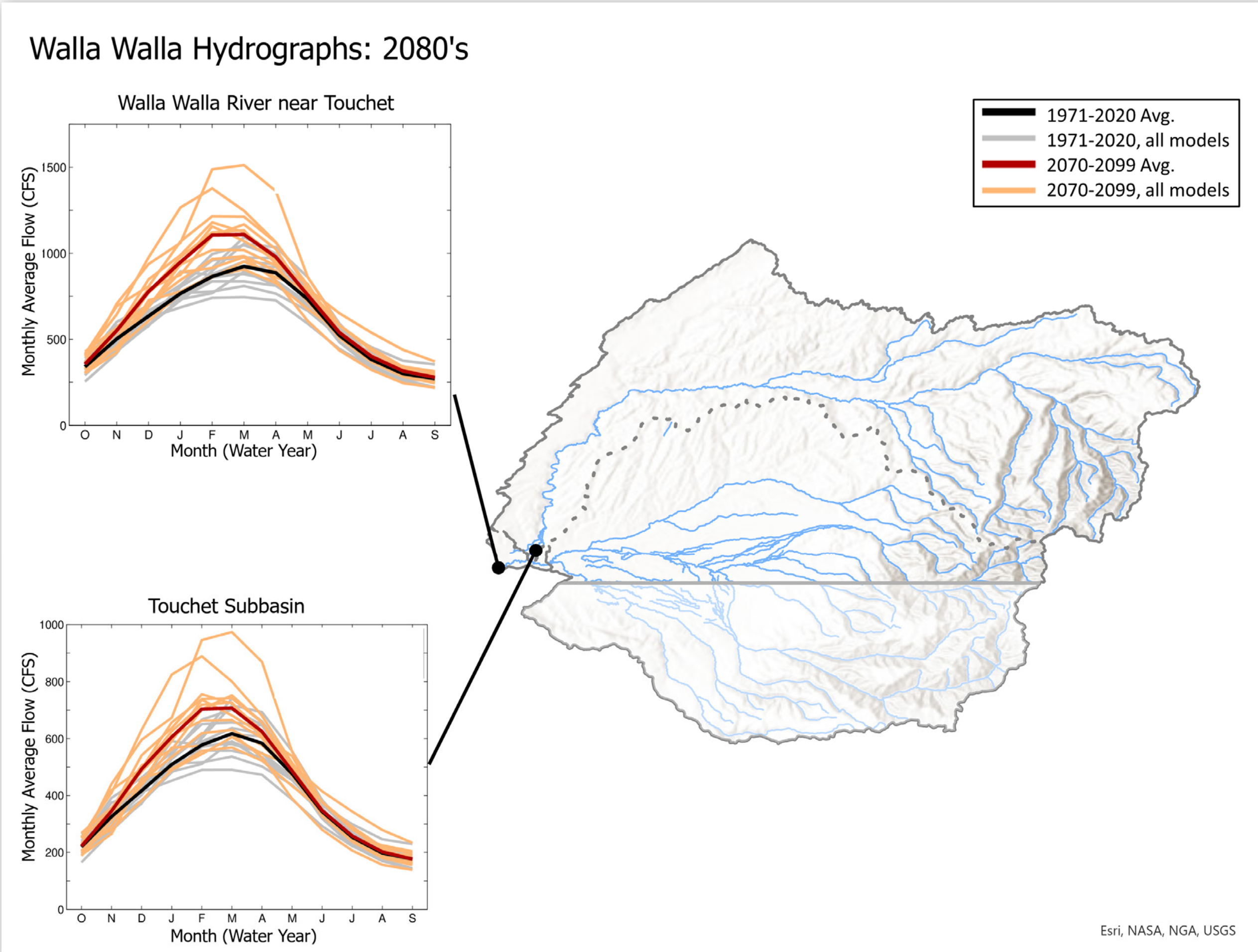

***Figure 5. Map of the Walla Walla watershed[11] with hydrographs of monthly mean flow from two locations**, the Touchet subbasin and the Walla Walla mainstem near Touchet. Black lines are the modeled average historical flows from 1971-2020 (all models denoted by the gray lines), red lines represent projected average flows for 2070-2099 (all models denoted by the orange lines). The primary impact from climate change is earlier snowmelt in both the Touchet subbasin and the Walla Walla River near Touchet that may negatively affect groundwater recharge. This can be readily seen by the upward and left shift of the red line relative to the black line suggesting higher and slightly earlier flows in winter and less flow in late summer. Twelve global climate models (GCMs) were used as input to the regional model based on the high-end RCP 8.5 greenhouse gas scenario[12] to reflect different assumptions about Earth's responses to future green-house gas emissions.*

The Walla Walla is a trans-boundary basin in Washington and Oregon, complicating the supply and management of water. Over the past decade, the Walla Walla Management Partnership developed local water plans and water banking agreements, working with stakeholders across the border to examine shared water resource issues, including the persistence of streamflow at crucial times of the year. However, streamflow goals have not been met, and groundwater levels continue to decline. In response, the Washington State legislature authorized the *Walla Walla Water 2050 Initiative* to improve streamflow and water supplies in the basin over the next 30 years. This Initiative may serve as an example of a bi-state, WRIA-scale framework for water planning that could be used in other parts of the state. Oregon is also working with the U.S. Geological Survey to better estimate water use from irrigated lands to minimize instream impacts[13].

[13] https://www.usgs.gov/programs/water-availability-and-use-science-program/water-use-grants

Climate change is predicted to have the following significant impacts on the Walla Walla River:

- Summer low flows will continue to decline due to declines in groundwater levels and changes in land cover. Land cover changes have had a substantial impact on low flows already[14]. Shallow groundwater levels have already declined from historical levels and are projected to continue declining, with approximately 50% less water from historical levels by 2040[15]. Although some snow does accumulate in winter, it is not enough to dramatically influence low flows. It is also already an arid watershed, so evaporation is not likely to change substantially in the future.
- Stream temperature will likely increase across much of the basin. Upstream reaches have less water, which warms more readily than water in lower reaches. While water is more plentiful in lower reaches, it is exposed to higher air temperatures.
- Wildfires are projected to increase substantially. Based on comparisons with similar locations, the likely effects on water quality and quantity will be an increase in flow during spring, increased water temperature, and increased sediment load.
- Demand for water from large agricultural users is likely to continue increasing, which will decrease summer low flows and further increase water temperatures.

Predictions of biological impacts for summer steelhead, spring Chinook, and bull trout[16] are:

- Higher water temperatures in summer will likely increase adult mortality for all three species, especially for spring Chinook that reside in the river during summer for extended periods.
- Juvenile mortality will likely increase due to reduced habitat area that increases competition among rearing juveniles, increases susceptibility to predators, and increases water temperatures in low-flow habitat areas.
- Egg-fry mortality could be significantly increased in all three species due to increases in the frequency of winter high flow events large enough to mobilize streambed gravel and scour salmon redds.
- Direct mortality of fish and other biota could increase due to increased severity of high flows.

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[14] 2021 Columbia River Basin Long-Term Water Supply & Demand Forecast

[15] Walla Walla Water 2050

[16] Predictions of biological impacts to other fish species are unknown due to inadequate population data.

Change in Hydrologic/ Thermal Event	Mortality	Reproductive Success	Competition	Predation	Habitat Area	GPP & Food Production
Low flow extent only	↑	↓ SPCH / ? others	↑	?	↓	- - or ↓
Habitat forming flow events	?	↓	?	?	↑ / ↓	?
Sediment mobilizing flow events	↑ SSH, BT / ? SPCH	↓	- - or ↓	?	↓	?
August average streamflow	↑ SPCH / ? others	↓ SPCH / ? others	?	?	?	↓
Peak flow timing (earlier or later) and increases in scouring events	↑ SSH, BT / ? SPCH	↓	- - or ↓	?	↓	?
Average historical to projected 2080's water temperature	↑	? SSH, SPCH, BT	↑	↑	↓	?

**Summer steelhead (Oncorhynchus mykiss), Spring Chinook salmon (Oncorhynchus tshawytscha), and bull trout (Salvelinus confluentus).*

Table B (Walla Walla). *Projected climate related changes to the hydrologic and thermal environment (rows) in the Snoqualmie River and biological responses of salmonids* (columns). Up arrows denote an increase in the biological response, down arrows a decrease, a dash means no change, and a question mark indicates an unknown response. Up and down arrows are different colors to improve table readability. Food production was assessed as change in gross primary production (GPP). Species specific responses are denoted Summer steelhead (SSH), Spring Chinook salmon (SPCH), and bull trout (BT).*

Conclusion

Conclusion: Urgent Need for Action

Climate change is currently altering the air temperature and the hydrologic cycle and thus the quality, quantity, and timing of instream waters in Washington state — a pattern that will intensify over the course of the 21st century.

Increasing needs for water in Washington, coupled with a warming climate, create severe challenges to supplying out-of-stream water for humans, while maintaining instream water for fish and wildlife in coming decades. While changes to the climate and hydrologic cycle are slow to develop and hard to detect over the short term, the Walla Walla serves as an example of failing to plan at sufficiently large scales, with complete information. Further, key knowledge gaps will take time to fill but enough is known to begin taking appropriate action. Coordinated water conservation planning among local, state, federal, and other partners should help to establish a science-policy forum to address instream water issues, prioritize regional knowledge gaps, and identify key areas for protection and restoration of water resources.

The time to act is now.

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