Streamflow

Chapter 4—Streamflow Impact Study for Spokane, Washington

Chapter Summary: Examines the impact that projected hydrological changes to the Spokane River will have on river recreation, Redband trout habitat, and the Spokane Valley-Rathdrum Prairie Aquifer.

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Key Findings:

1. In the coming decades, the shift of precipitation from snow to rain coupled with earlier snow melts is expected to alter the timing of streamflow on the Spokane River even while the total annual volume of streamflow in the river is expected to remain similar to historical levels.
2. Impacts from low summer flows are likely to intensify over time, particularly if greenhouse gas emissions are allowed to continue increasing at their current rate.
3. By the end of the century, flows conducive to optimum whitewater rafting and kayaking on the Spokane River may cease as early as June.
4. The expected changes to the unregulated flow of the Spokane River is expected to have several detrimental impacts, including for native Redband trout, summer recreational opportunities, and the general aesthetic value that the Spokane River provides to the community.

Resilience Actions

- **Reduce Emissions**—Take all possible actions to reduce greenhouse gas emissions and avoid the high emissions scenario (RCP 8.5).
- **Prioritize Trout Habitat**—Reconsider regulations at Post Falls to help prioritize Redband trout habitat.
- **Future Research**—Conduct more research to fully understand the long-term impacts of climate change on the Spokane Valley-Rathdrum Prairie Aquifer.
- **Future Research**—Investigate well depth and pump technology.

Climate Data Story—Recreation on the Spokane River

The Spokane River is arguably Spokane's top natural attraction, especially during the spring and summer months when outdoor enthusiasts and visitors spend more time along or on the river. As the Spokane area's primary source of visitor information, the organization Visit Spokane encourages visitors to float down the river, paddleboard, fish, or simply take in the scenery from along the shoreline (**Visit Spokane 2019**). It is no surprise that summertime recreation activities associated with the river have a significant economic impact for our region. According to a 2015 report from Washington's Recreation & Conservation Office, the total annual economic contribution of all types of outdoor recreation in Spokane County amounted to nearly $1.2 billion and 12,500 jobs annually (**Washington State Recreation & Conservation Office 2015**). Although not broken down at a county level, annual state expenditures on non-motorized boating and rafting activities have been estimated to exceed $640 million (**Briceno and Schundler 2015**).

Several individuals representing local paddling organizations and commercial rafting enterprises were interviewed in an effort to determine potential ramifications to recreational users and businesses from an earlier high streamflow and extended summer low-flow on the Spokane River. Although qualitative information from the individuals was mixed, a few common themes came out of the discussions. The first is that the lower portion of the river between Spokane Falls and Nine Mile Reservoir—which includes the Spokane River Gorge, the Bowl & Pitcher rock formation, and the Devil's Toenail whitewater rapids—relies on a minimum flow of approximately 2,500 cubic feet per second (cfs) for the commercial rafting companies and most kayakers to safely navigate the section.

Once flow drops below 2,000 cfs, all but the most extreme kayakers are limited to milder "float" trips that include longer sections of calmer water. Historical trends in streamflow typically allowed rafting companies to market whitewater trips through this section of the Spokane River during the month of June, when school is out and many Americans begin their summer vacations. With earlier spring high flows and an earlier and extended summer low-flow period, future whitewater conditions may cease as early as June, according to our analysis. This means that optimum whitewater conditions could shift from June to May, resulting in a reduced consumer base. (**Rains 2019**).This would limit local rafting companies from capitalizing on summer tourism.

Although representatives of the commercial rafting companies contacted for this report recognized existing and potential financial impacts from an earlier whitewater season on the Spokane River, they also reported that they already mitigate for seasonal variations through a variety of methods, including operating on multiple regional rivers, highlighting scenic float trips on the Spokane River versus whitewater trips, and/or by offering other types of river activities, such as tubing. Representatives also indicated that while the instream flow rule (***See Analysis—Assumptions & Limitations***) is not as favorable to recreational use as they would prefer, the rule does mitigate against potential extreme low flow conditions occurring in mid to late summer. Rafting company representatives also noted that during the last several years, smoke from seasonal wildfires has had an even greater detrimental effect on river use than streamflow.

Larger Context—Streamflows are Changing Across the Pacific Northwest United States

As the ***Precipitation*** chapter noted, projected future precipitation for Spokane under both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5) is not expected to deviate significantly from historical levels in terms of both total annual volume and seasonal timing. Spokane and the Pacific Northwest United States generally are projected to see a slight increase in precipitation during the fall, winter, and spring months, and a slight decrease in precipitation over the summer months. However, as the ***Precipitation*** chapter notes, precipitation projections should not be considered alone. As noted in the ***Temperature*** chapter, throughout this century Spokane is projected to see an increase in annual and monthly temperatures under both RCP 4.5 and RCP 8.5. As temperatures rise throughout this century, the Pacific Northwest is expected to see more rain and less snow in many of its watersheds during the cool months. This shift in the form of precipitation is anticipated to greatly alter the flow of water in the Pacific Northwest's rivers and streams even while precipitation generally is projected to remain similar to (or become slightly wetter than) current conditions during the fall, winter, and spring months. In general across the Pacific Northwest, projected future warming is expected to lead to higher river and stream flows during the winter months and lower river and stream flows during the summer months (**Chegwidden et al., 2019**).

When precipitation falls as snow it can contribute to *snowpack,* a critical natural water storage system for our region. Snowpack, especially mountain snowpack, delays the timing of the water entering a stream system. Conversely, when winter precipitation falls as rain, that water enters the stream system immediately. This leads to a decrease in the amount of water stored in the mountains as snow that would otherwise enter the stream system later during the spring and summer months. As a result, more water flows out of the watershed earlier in the year, leading to earlier and longer summer-low flows in rivers and streams.

Local Context—Lower Summer Flows on the Spokane River

"From Lake Coeur d'Alene to its confluence with the Columbia, the Spokane River travels 111 miles of varied and often spectacular terrain-rural, urban, in places wild. The river has been a trading and gathering place for Indigenous peoples for thousands of years. With bountiful trout, accessible swimming holes, and challenging rapids, it is a recreational magnet for residents and tourists alike. The Spokane also bears the legacy of industrial growth and remains caught amid interests competing over natural resources."

– Paul Lindholdt, "The Spokane River"

It is with Paul Lindholdt's eloquent words that we investigated projected future trends to the flow of the Spokane River resulting from a warming climate. Setting aside the influence of regulated flows from Post Falls Dam at Coeur d'Alene Lake, publicly available climate and hydrologic models together suggest that human-caused climate change will have a dramatic effect on the seasonal flow of the Spokane River compared to historic levels.

The impacts on streamflow of the transition from rain to snow has already been seen in the Spokane River watershed in individual years (**Abatzoglou 2016**) and multi-year/decadal time frames (**Porcello et al., 2017**). Our analysis indicates that due to decreased snowpack and increased rainfall, the river's summertime flow rates will continue to decrease throughout the 21st century. The timing and severity of changes to the flow of the Spokane River are likely to have a detrimental impact on habitat for native Redband trout, summer recreational opportunities for boaters and anglers, and the general aesthetic value that the Spokane River provides to our community and its visitors. These climate impacts, our analysis suggests, are likely to have financial impacts to Spokane's regional economy. Our analysis further estimates that impacts to the Spokane Valley–Rathdrum Prairie Aquifer will be less significant than impacts to Redband trout and impacts to river-based recreation. However, a more in-depth analysis is needed to fully understand the potential impacts that future climate scenarios might have on the aquifer.

It is clear that impacts to the Spokane River are likely to intensify over time, particularly if greenhouse gas emissions are allowed to continue increasing at their current rate. Impacts are projected to be more intense under the high emissions scenario (RCP 8.5), which closely resembles humanity's current emissions rates, when compared to the lower emissions scenario (RCP 4.5).

Methods—Geography, Data Tools, Assumptions & Limitations, Multi-model Means, Emissions Scenarios, Variables, and Climate Data Stories

Geography: Historical and projected future streamflow rates and volumes for the Spokane River were simulated for the U.S. Geological Survey stream gauge below Post Falls Dam, which is located in Idaho at the upstream end of the Spokane River, just below Coeur d'Alene Lake. The Post Falls gauge (USGS stream gauge station number 12419000) was used to evaluate how climate change may affect the Spokane River in terms of habitat, recreation, and aquifer recharge. Projected mountain snowpack (as snow water equivalent) was evaluated for the two highest elevation Snow Telemetry (SNOTEL) stations in the local watershed: the Sunset and Lost Lake stations.

Data Tools:
Data and visualizations were reviewed from the climate web tools available online in The Climate Toolbox (https://climatetoolbox.org/), a product of The Pacific Northwest Climate Impacts Research Consortium (CIRC), A NOAA Regional Integrated Sciences and Assessments Team (**"Climate Tools" CIRC 2019**). The Toolbox provides projections from multiple global climate models (GCMs) and two emission scenarios (RCP 4.5 and RCP 8.5) downscaled to a 2.5-mile resolution. This analysis primarily used 10 GCMs downscaled using Multivariate Adaptive Constructed Analogs (MACA) statistical downscaling method. Downscaled GCM data were then run through the Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model (**Climate Toolbox 2019**). Downscaling data from multiple GCM runs adds localized data to make the models more useful at a local scale. For this analysis, our team downloaded data and figures from the following Toolbox tools:

- Future Streamflows Tool (https://climatetoolbox.org/tool/Future-Streamflows)
- Climate Mapper Tool (https://climatetoolbox.org/tool/Climate-Mapper)
- Future Climate Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots)

Assumptions & Limitations: Our analysis of projected impacts to the Spokane River began with an analysis of projected declines in mountain snowpack and the increased likelihood of rain during the fall, winter, and spring months. We then analyzed how more rain and less snow is likely to manifest as changes to flows in the Spokane River. From there we analyzed how projected low flows might impact water-based recreation on the Spokane River (***Climate Data Story—Recreation on the Spokane River)***, Redband Trout (***Climate Data Story—Redband Trout Habitat***), and the local aquifer (***Climate Data Story—Spokane Valley-Rathdrum Prairie Aquifer***). The primary limitations and uncertainties in this initial exploration of future trends to the flow of the Spokane River resulting from climate change arises from the uncertainties inherent in the following:

(1) The many different global climate models that are available.
(2) The processes of downscaling rainfall, snowmelt, and temperature information from those models to local watersheds.
(3) Additional uncertainties that arise when translating the downscaled climate information into estimates of flow rates in the Spokane River using a hydrologic modeling process.
(4) Uncertainty regarding future rates of greenhouse gas emissions expressed as the two emissions scenarios used in the Toolbox, the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5).

Another limitation our team confronted concerned the two highest elevation Snow Telemetry (SNOTEL) stations in the local watershed: the Sunset and Lost Lake stations. Our team hoped to determine how snowpack at the two stations might change under projected future climate change. To determine this, our team used the variable snow water equivalent (SWE) as a proxy for projected future snow on the ground at the two stations. SWE is a measure of how much liquid water is available in a given amount of snow on the ground. We were limited in our analysis by the resolution of downscaled data available from the Toolbox. As noted above, the Toolbox uses GCM data that has been downscaled to a 2.5-mile grid cell resolution. This meant that while we were interested in projected future SWE at the exact point locations for the Sunset and Lost Lake stations, what we were able to determine using Toolbox data was projected future SWE for the two 2.5-mile grid cells containing the stations. Because the grid cells assume a set average elevation for the entire cell, this meant that the elevations of the two stations in reality might have been either above or below the average elevation for the two cells containing the two stations.

Additionally, there are two other assumptions and limitations that warrant consideration in discussions of flow rates in the Spokane River, but which are not possible to directly evaluate in this analysis:

1. The streamflow data from the Toolbox are projections of *unregulated* flow and do not account for the *regulated* flow on the Spokane River that is largely controlled by the Post Falls Dam in Idaho. The Post Falls Dam is operated

by the Avista power utility. The 50-year license from the Federal Energy Regulatory Commission (FERC) issued to Avista in 2009 includes regulatory thresholds of minimum flows to address aesthetic, recreation, and fish habitat concerns. At the Post Falls Dam, consideration is also given to property owners and recreation opportunities on Coeur d'Alene Lake from June 5th until Labor Day. Further downstream, the Upriver, Monroe Street, and Nine Mile dams are operated as "run-of-the-river" facilities that unlike Post Falls Dam are not used to regulate the river's flow.

2. The State of Washington's instream flow rule for the Spokane River (**Chapter 173-557 Washington Administrative Code**) took effect on February 27th, 2015 and was developed primarily to identify and establish instream flow levels necessary to protect wildlife, fish, scenic, aesthetic, recreation, water quality, and other environmental values, navigational values, stock watering requirements, and existing water rights (**Washington State Legislature 2019**). Because these instream flow levels are target flow rates for the river, like other regulated flows on the river they are not accounted for in the Toolbox's streamflow data sets. Specific details regarding the flow rates established under the instream flow rule for the Spokane River are as follows:
    a. Seasonally variable flow rates are identified throughout the year in this instream flow rule at the location on the river of the Monroe Street stream gauge (the U.S. Geological Survey gauge formally known as the "Spokane River at Spokane" gauge, which is USGS stream gauge station number 12422500) (**Washington State Legislature, "Stream management units" 2019**). The minimum instream flow standards at this gauge are 850 cubic feet per second (cfs) for the period of June 16 through September 30; 1,700 cfs from October 1 through March 31; and 6,500 cfs from April 1 through June 15.

    b. The rule also identifies a set of streamflow standards at the Greenacres gauge number 12420500 at Barker Road, but only for the period of June 16 through September 30, when the standard is set at 500 cfs.

Multi-model Means: Many of the data and figures that make up this analysis employ the mean resulting from multiple global climate models (GCMs). In general, the Toolbox uses 20 global climate models (GCMs) to create its climate projections (temperature, precipitation, etc.) and 10 GCMs to create its hydrology projections (snow water equivalent, streamflow, etc.). As noted above, this analysis primarily used data from 10 GCMs downscaled using the MACA method and that were then run through the VIC hydrologic model. Using a multi-model mean, as opposed to the results of a single model, is accepted as best practice by the climate science community. However, the multi-model mean does not show the full spread of results from all the GCMs used to create a future projection, but rather the average of that multi-model spread. In other words, actual future climate conditions—when we get to them in the decades ahead—might lie either above or below the multi-model mean.

Emissions Scenarios: For this analysis, we utilized both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5) from phase 5 of the Coupled Model Intercomparison Project (**Climate Toolbox 2019**). The RCP 8.5 scenario simulates what is likely to happen if greenhouse gases continue to be released into the atmosphere at their current rate, and, as result, warming is allowed to continue at its current upward trajectory throughout this century and beyond. RCP 4.5 simulates a dramatic reduction in greenhouse gas emissions, so that while warming continues throughout this century, warming starts to level off after 2100. In general, the two emissions scenarios start to diverge around the middle decades of this century (2040–2069). At mid-century, warming under RCP 4.5 slows while warming under RCP 8.5 continues at its current rate (**CIRC 2019**). The two scenarios were used side by side in this analysis to evaluate whether the climate impacts to the Spokane River differed significantly from RCP 4.5 to RCP 8.5. **In general, while we found impacts to flows on the river under both scenarios, RCP 8.5 produced far greater impacts when compared to RCP 4.5.**

(Note: RCP 4.5 isn't the *lowest* emissions scenario used by climate researchers. RCP 2.6 is the lowest emissions scenario considered in climate models. However, because the collective global emissions pathway has very likely veered off course from that modeled under RCP 2.6, RCP 2.6 is no longer used as the low emissions scenario pathway. Since RCP 4.5 is lower than RCP 8.5, this report has adopted the standard used by many in the climate research community: *lower* to describe RCP 4.5 and *high* to describe RCP 8.5, rather than *lower* and *higher* to describe the two scenarios.)

Variables: Future projections of snow accumulation and melt were calculated *as snow water equivalent* (SWE), the amount of liquid water contained in a given amount of snow. Projected SWE was evaluated at the Sunset and Lost Lake SNOTEL stations using the variable *April 1st snow water equivalent* (SWE). (As noted above and below, this analysis entailed a large limitation.) The date April 1st is a commonly used date to measure SWE because this date historically has often marked the point of peak snow accumulation across much of the Pacific Northwest United States. Historical and projected future streamflow rates and volumes for the Spokane River were calculated in cubic feet per second (cfs). We used the following variables and Climate Toolbox tools to guide our analysis:

- *Streamflow as measured in cubic feet per second* (Future Streamflows Tool)

- *April 1st Snow Water Equivalent* (Future Climate Boxplots Tool)

Climate Data Stories: For our analysis we chose to investigate three climate data stories covering the potential effects of changing streamflows on Redband Trout habitat (***Climate Data Story— Redband Trout Habitat***), the Spokane Valley–Rathdrum Prairie Aquifer (***Climate Data Story—Spokane Valley-Rathdrum Prairie Aquifer***), and recreation on the Spokane River (***Climate Data Story—Recreation on the Spokane River***). A *climate data story* is defined by CIRC as "a narrative outlining climate facts and impacts specific to your community" (**Mooney et al., 2019**).

Projected Future Climate—Decrease in Snow Water Equivalent for Grid Cells Containing Sunset and Lost Lake

Variable: *April 1st Snow Water Equivalent*

Finding: The grid cells containing Sunset and Lost Lake SNOTEL Stations are projected to see declines in April 1st snow water equivalent (SWE) under both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5).

Finding: Declines in SWE at both stations will be greater under RCP 8.5 when compared to RCP 4.5.

Finding: Of the two stations, Sunset station, which is 570 feet lower in elevation than Lost Lake, is projected to see the largest declines in SWE.

Justification*:* For this analysis we examined future snow projections at two snow monitoring sites: the Sunset SNOTEL Station (Elevation: 5,540 feet) (47.55545 ºN, 115.82422 ºW) and the Lost Lake SNOTEL Station (Elevation 6,110) (47.0809 ºN, 115.9604 ºW). As noted above, this analysis entailed a large limitation. To determine how snowpack at the two stations might change under projected future climate change, our team used the variable snow water equivalent (SWE) as a proxy for projected future snow on the ground at the two stations. (SWE is a measure of how much liquid water is available in a given amount of snow on the ground.) The date April 1st was chosen to examination SWE at the two stations because the date marks the point of peak snow accumulation across much of the Pacific Northwest. However, our analysis was limited due to downscaled data available through the Toolbox. The Toolbox downscales data to a 2.5-mile grid cell resolution. This meant that while we were interested in projected future SWE at the exact point locations of the Sunset and Lost Lake stations, what we were able to determine using the Toolbox was projected future SWE for the entire 2.5-mile grid cells that contained the two stations. Because the grid cells each used a set average elevation across the entire cells, this meant that the elevations of the two stations in reality might have been either above or below the average elevation for the two cells containing the two stations. This made our results more general than we would have liked. That said, our analysis was able to give us a general picture of how SWE at the two grid cells containing the two station is projected to decline under future climate change.

Sunset and Lost Lake are the two highest elevation upstream SNOTEL sites in our local watershed. Snow measured at the two stations ultimately feeds the Spokane River and Coeur d'Alene Lake (***Figure 1***). *SNOTEL*—short for "Snow Telemetry"—are fixed stations in the mountains of the Western United States that measure snow depth and SWE. SNOTEL stations are operated by the Natural Resources Conservation Service (**NRCS 2019**). ***Table 1*** and ***Figure 2*** summarize the SWE that is projected to be lost at each grid cell containing each site under both RCP 4.5 and RCP 8.5. SWE is measured in inches. The grid cells containing both the Sunset and Lost Lake stations are projected to see significant decreases in snow water equivalent (SWE) under both RCP 4.5 and RCP 8.5. The grid cell containing the Sunset station is projected to see a greater degree of SWE loss compared to the grid cell containing the Lost Lake station. This is likely due to the difference in elevation between these two stations. The Sunset station is 570 feet *lower* in elevation than the Lost Lake station. Being at a lower elevation makes the Sunset more likely to experience less snowpack under projected warming as that warming will be more intense at the lower elevations.

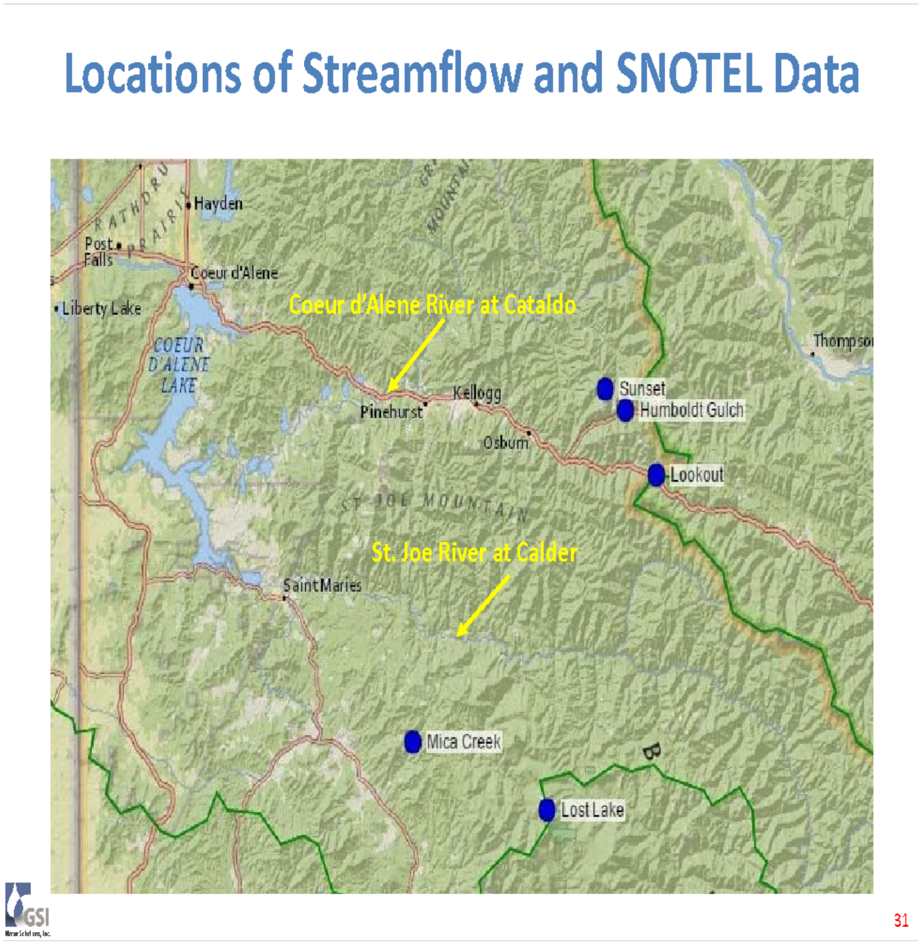

Figure 1: Map of Spokane-area SNOTEL sites, including the Sunset and Lost Lake stations. Source: John Porcello and Jake Gorski, GSI Water Solutions, 2016 (http://gsiwatersolutions.com/).

Table 1: April 1 Snow Water Equivalent (SWE) (in inches) for the grid cells containing the Sunset SNOTEL and Lost Lake SNOTEL monitoring stations for the simulated historical period 1971–2000 and the projected future period 2010–2039, 2040–2069, and 2070–2099 under both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5). The numbers used in this table represent the multi-model mean from 10 downscaled GCMs. Source: Future Climate Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), The Climate Toolbox.

SNOTEL Station	**Historical (1971–2000) April 1st SWE in inches**	**RCP 4.5 Mid-Century (2040–2069) April 1st SWE in inches**	**RCP 8.5 Mid-Century (2040–2069) April 1st SWE in inches**	**RCP 4.5 Late-Century (2070–2099) April 1st SWE in inches**	**RCP 8.5 Late-Century (2070-2099) April 1st SWE in**
Sunset **(Elevation: 5,540 feet)**	32.72 ″	25.62 ″	21.69 ″	20.88 ″	10.77 ″
Lost Lake **(Elevation: 6,110)**	47.54 ″	46.32 ″	44.03 ″	44.13 ″	33.71″

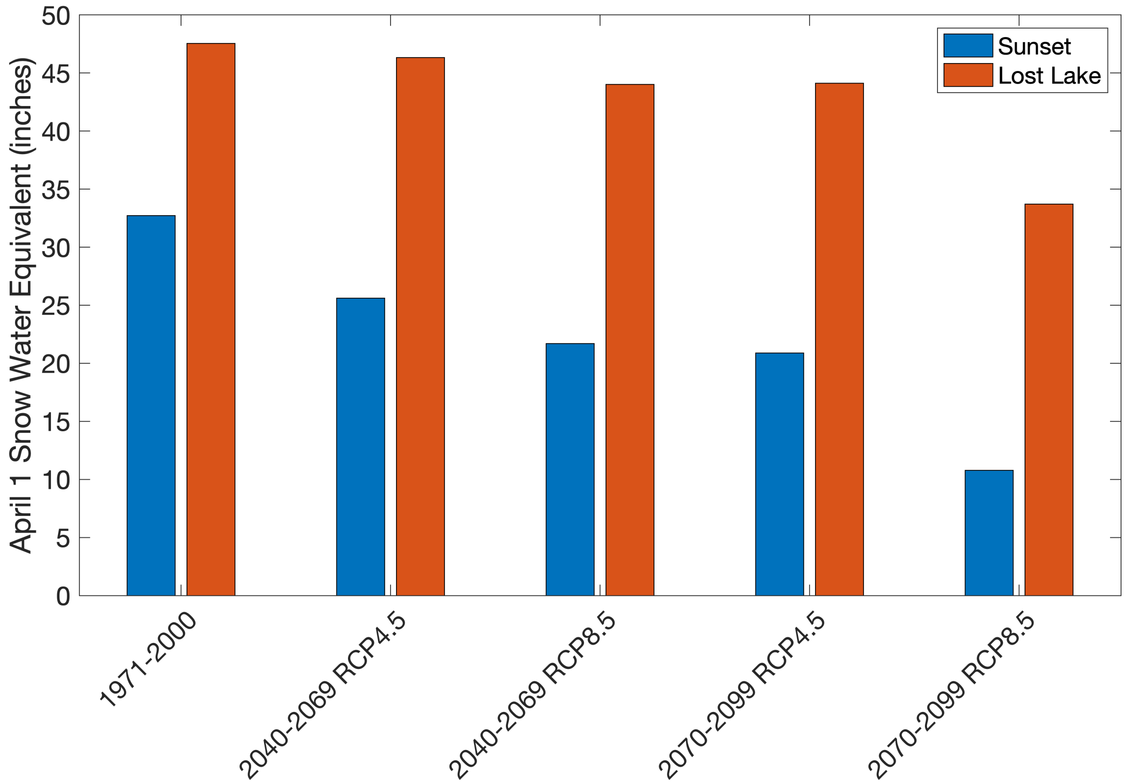

Figure 2: April 1 snow water equivalent (in inches) for the grid cells containing the Sunset SNOTEL and Lost Lake SNOTEL monitoring stations for the simulated historical period 1971–2000 and the projected future periods 2010–2039, 2040–2069, and 2070–2099 under both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5). The numbers used in this figure represent the multi-model mean from 10 downscaled GCMs. Source: Future Climate Boxplots Tool (https://climatetoolbox.org/tool/Future-Boxplots), The Climate Toolbox.

Projected Future Climate—Change in Timing and Intensity of High and Low Flow Rates on the Spokane River

Variable: *Streamflow*

Finding: In the coming decades, the shift of precipitation to more rain and less snow during the fall, winter, and spring months coupled with earlier snow melts is expected to alter the timing of streamflow on the Spokane River.

Finding: From 1971–2000, flows peaked on the Spokane River during the month of May. By the mid-century (2040–2069) under both the lower emissions scenario (RCP 4.5) and the high emissions scenario (RCP 8.5), the Spokane River will see two peaks: first in February and then again in April. These represent high flow events that result from more precipitation falling as rain in the cool season and immediately running off as well as earlier snow melt.

Finding: Under both the lower emissions scenario (RCP 4.5) and high emissions scenario (RCP 8.5), summertime low flow rates (historically seen in August and September) are projected to begin one month earlier (July) by mid-century (2040–2069) and as much as two months earlier (June) by late century (2070–2099).

Justification: The projected declines in snow water equivalent (SWE) in the local watershed (discussed above) are expected to lead to higher flows in the Spokane River during the winter months and lower flows during the summer months. By examining the non-regulated streamflow projections for the Spokane River at Post Falls Dam, a changing pattern in spring flows was identified. Historically, the timing of peak river flow has been in May, as depicted in the hydrographs in ***Figures 4*** and ***5***. Historical flows for the years 1971–2000 are depicted in black. Data are displayed across *the water year*, which runs from October 1st of a given calendar year through September 30th of the following calendar year. By the mid-century (2040–2069) under both the lower emissions scenario (RCP 4.5) (shown in blue) and the high emissions scenario (RCP 8.5) (shown in orange), models project two smaller peaks in river flow: first in February and then again in April (***Figure 4***).

Similarly, by late century (2070–2099) under both RCP 4.5 (blue) and RCP 8.5 (orange) two peaks representing high river flow events once again occur in February and April (***Figure 5***). It is also important to note that under both RCP 4.5 and RCP 8.5, summertime low flow rates (historically seen in August and September) are projected to begin one month earlier (July) by mid-21st century (***Figure 4***) and as much as two months earlier (June) by the end of the 21st century (***Figure 5***).

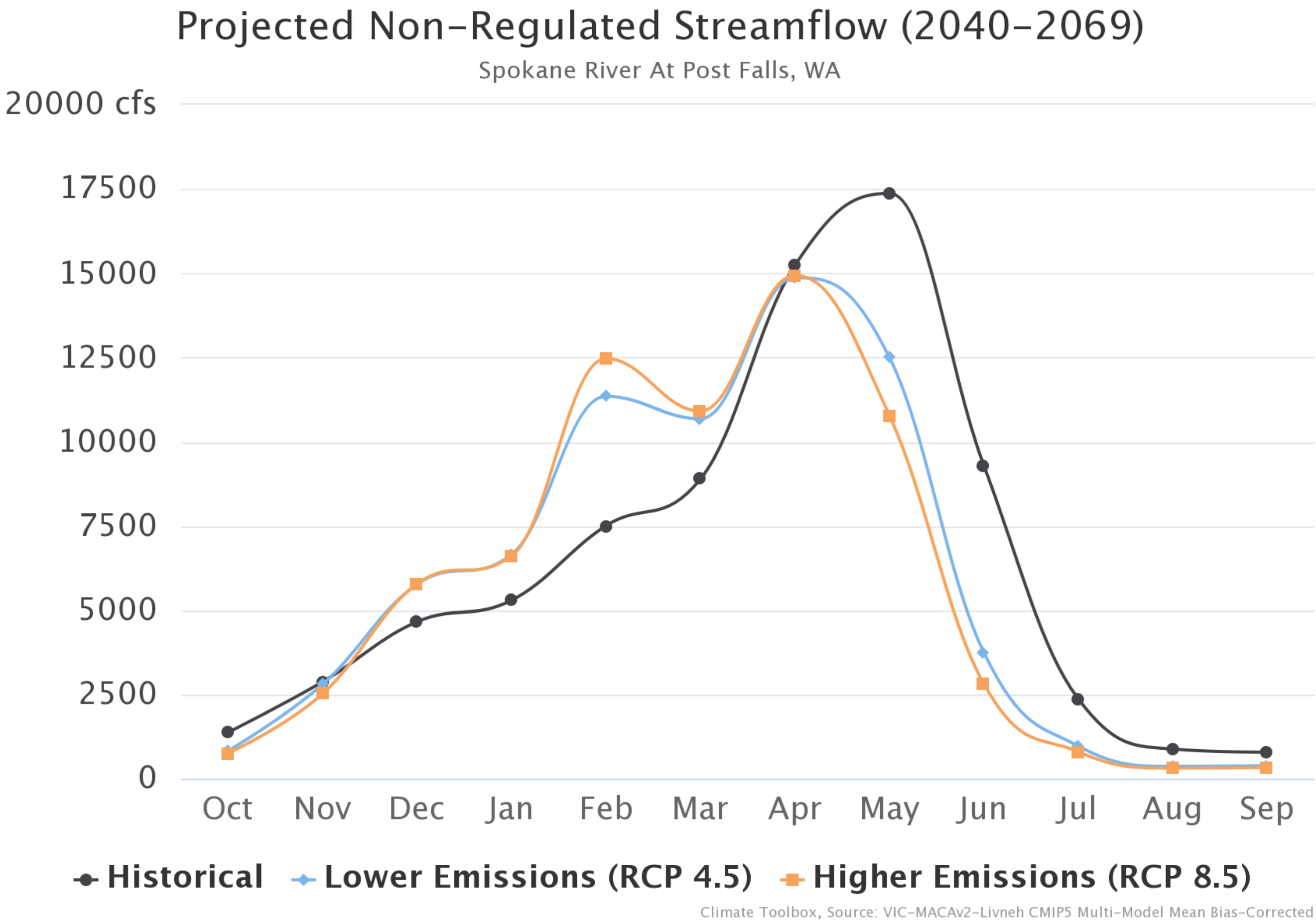

Figure 4: Non-regulated streamflow on the Spokane River at Post Falls, Washington, for the historical period 1971–2000 (black) and projected future period 2040–2069 (mid-century) for both the lower emissions scenario (RCP 4.5) (blue) and the high emissions scenario (RCP 8.5) (orange). Data is displayed for the water year, which runs from October 1st of a calendar year through September 30 of the following calendar year. The data presented here represents the multi-model mean of 10 downscaled global climate models run through the Variable Infiltration Capacity (VIC) Hydrologic Model. Source: Future Streamflows Tool (https://climatetoolbox.org/tool/Future-Streamflows), The Climate Toolbox.

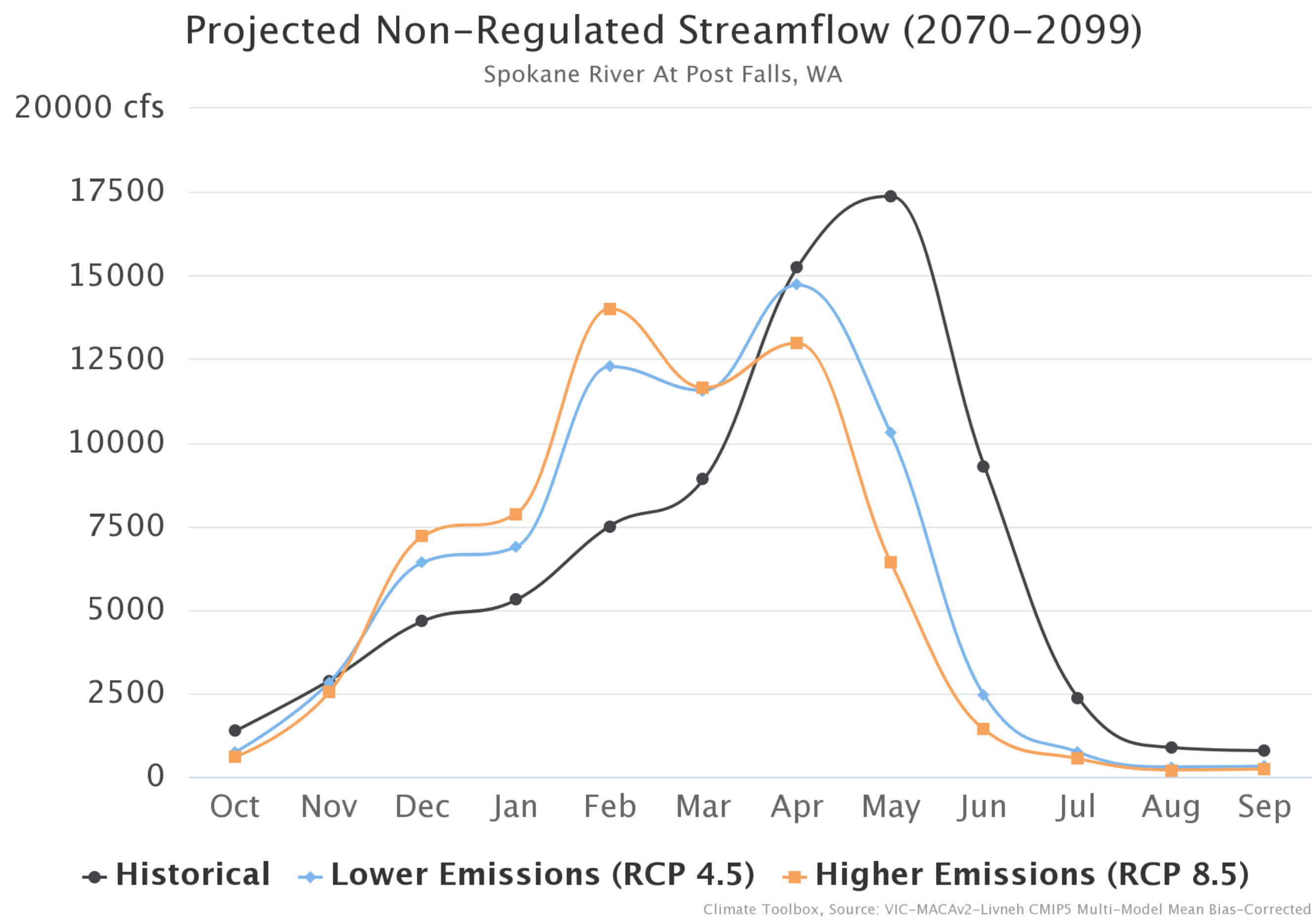

Figure 5: Non-regulated streamflow on the Spokane River at Post Falls, Washington, for the historical period 1971–2000 (black) and projected future period 2070–2099 (late century) for both the lower emissions scenario (RCP 4.5) (blue) and the high emissions scenario (RCP 8.5) (orange). Data is displayed for the water year, which runs from October 1st of a calendar year through September 30 of the following calendar year. The data presented here represents the multi-model mean of 10 downscaled global climate models run through the Variable Infiltration Capacity (VIC) Hydrologic Model. Source: Future Streamflows Tool (https://climatetoolbox.org/tool/Future-Streamflows), The Climate Toolbox.

Climate Data Story— Redband Trout Habitat

"Interior Redband trout are considered a species of special concern by the American Fisheries Society and the U.S. Fish and Wildlife Service (FWS) in most states where the subspecies historically existed and are classified as a sensitive species by the U.S. Forest Service and Bureau of Land Management." – Western Native Trout Status Report

"The Redband population has been severely reduced due to habitat destruction, warm water temperatures and the negative effects of sediment loading on riverbeds." – Spokane Riverkeeper

The Redband trout is a subspecies of Rainbow trout and is the primary native Salmonid species of the Spokane River. The Washington Department of Fish and Wildlife considers Redband trout a *sentinel species*, meaning the health and abundance of the species are indicating factors of the overall health of a river ecosystem (**Gerber 2017**). Over the past century, many factors have contributed to a decline in the population of Redband trout. Projected changes in-stream flow rates would exacerbate the problem, according to our analysis. It is estimated that Redband trout once occupied 37,465 miles of streams and 152 natural (un-impounded) lakes throughout Washington, Oregon, Idaho, Nevada, Montana, and northern California. Currently Redband trout occupy approximately 42% of their historical stream habitat (**Western Native Trout 2018; Muhlfeld et al., 2014**).

Locally, substantial impacts to the species will likely occur in the upper Spokane River, where populations are already depressed (**Lee 2019**). Projected reduced flows below Post Falls Dam could result in warmer water temperatures that benefit smallmouth bass (a non-native species) and approach the upper lethal temperature range for Redband trout. Redband trout generally prefer stream temperatures less than 70 degrees Fahrenheit (**Wydoski and Whitney 2003**) and experience stress at 71.6 °F and above (**Behnke 1992**). The effects of climate change on rising temperatures and their effects on salmonids has already been overserved (**Isaak et al., 2012**). Earlier peak-flow and reduced summer flows projected under climate change could decrease viable rearing habitat for Redband trout. While reduced flows in late May/early June could dewater and desiccate trout eggs, reducing trout populations

During a survey conducted by Michael Taylor McCroskey in the summer of 2015, very few Redband trout were present in the upper reaches near the spawning areas. The study was conducted during an extreme drought year (in historical context), during which river flows were lower than usual and water temperatures were warmer than normal, which likely influenced species distribution, but may have also impacted spawning success and survival. Additionally, a large population of smallmouth bass was documented, which likely impacted the survival of juvenile Redband trout from predation; to what extent is unknown (**McCroskey 2015**).

The Spokane River (below Sullivan Road) is heavily influenced by groundwater recharge, which moderates summer stream temperatures with an influx of cooler water. However, projections of reduced surface flows would result in reduced carrying capacity for Redband trout and an anticipated increase in predation from species that thrive in warmer water temperatures. Of particular concern to the viability of Redband trout is the projected earlier low-flow period beginning as early as May, rather than later in the summer. According to the Parametrix 2003 spawning report, spawning generally commences at the beginning of April when water temperature reaches 45 ° F (**Parametrix 2003**). Emergence occurs near the end of May and into the beginning of June. Future projections indicate that a decrease in streamflow will occur during the Redband trout incubation period that could result in water levels falling below the level of fish nests, a process called *redd dewatering*.

Climate Data Story—Spokane Valley – Rathdrum Prairie Aquifer

The Spokane Valley-Rathdrum Prairie (SVRP) Aquifer is the sole-source drinking water for over 500,000 people (**MacInnis et al., 2009**). According to our analysis, the aquifer appears to be less sensitive to climate change impacts than aquifers in other regions. Aquifer levels are primarily affected by recharge from the Spokane River and from several lakes in the region that bound and recharge the aquifer (**Hsieh et al., 2007; Kahle et al., 2007**). Seasonal changes in streamflow under future climate conditions are anticipated, according to our analysis. Specifically, peak streamflows may occur earlier in the winter and/or spring months, while the summer-season low streamflows could begin earlier in the summer. However, future climate projections indicate that only small percentage changes in annual total precipitation and streamflows are likely to occur, which suggests—assuming no net change in annual water extraction due to human factors—that there might be just a limited overall change in annual volumes of aquifer recharge on a long-term multi-decadal basis. However, within these long multi-decadal time periods, aquifer recharge periodically could be below historically observed conditions if multi-year droughts were to occur more frequently than in the past or be more intense than in the past.

The primary mid-term vulnerability of the Spokane region's sole source of potable water may have less to do with climate change and more to do with the fact that historically some of the region's water supply wells have been drilled only into the very uppermost portion of the aquifer. The oldest wells in the region were excavated and/or hand-dug within the city of Spokane during the early 1900s. Accordingly, these wells were constructed no further than necessary into the water table, which means they obtain water by essentially "skimming" off of the top of this thick aquifer (**CH2M HILL, 1998; GSI, 2012**). The operational efficiencies of some of these shallow wells may be sensitive to small climate-driven changes in summer-season water levels in the aquifer (**GSI et al., 2019**). Newer wells in the region were constructed using more conventional drilling methods, achieving greater penetration depths into the water table. However, even these wells were not typically drilled any deeper than necessary, in order to minimize drilling and pumping costs.

Due to the particularly low water levels observed in the aquifer during the past few summers, the City of Spokane is now actively working to understand the resiliency of several of its water supply wells and to evaluate what types of modifications (if any) to certain wells and/or pumping systems might be warranted for future implementation (**GSI et al., 2019**). The City is conducting this work as part of its planning for capital improvement projects. Although other municipal water providers own conventional drilled wells that penetrate deeper into this aquifer, it is possible that some of those providers could eventually identify that one or more of their wells would warrant resilience evaluations in the future, and potentially adjustments to their construction and/or their pumping systems to optimize or improve well operations.

More research is needed before we can fully understand the longer-term impacts of climate change on the Spokane Valley-Rathdrum Prairie Aquifer. In addition to further climate analysis, it is also necessary for local policy makers to understand the non-climate related impacts, such as increased demand on the aquifer due to (1) population growth and (2) increased evapotranspiration as temperatures rise in our region. Individual choices, business practices, and government policy are all necessary components of an effective strategy to prevent adverse climate-induced impacts on water availability.

Conclusion

Future climate projections suggest that as temperatures rise in the Inland Pacific Northwest, snow from the mountains will thaw faster and earlier in the season. This coupled with the increased likelihood that precipitation will fall as rain rather than as snow will create earlier seasonal high flows during the spring months and more noticeable low flow rates in the river during the summer months.

Changes in timing and intensity of peak streamflow will likely create some challenges in our region in terms of Redband trout habitat, recreation on the river, and possibly (though maybe not) refresh rates for the Spokane Valley-Rathdrum Prairie Aquifer. (As noted above, the impact of climate change on the aquifer needs more research.) In recent years, researchers have already witnessed the effects of low summer flows on the Redband trout spawning and rearing grounds. As peak flows on the Spokane River occur earlier in the spring, local rafting companies will likely experience some loss in revenue as many families tend to wait for mid-June before taking their vacations. Our analysis clearly shows that impacts to flows in the Spokane River will be greater under the "business as usual," high emissions scenario (RCP 8.5) when compared to the lower emissions scenario (RCP 4.5), which assumes a reduction in greenhouse gas emissions. This leads us to the conclusion that absent an immediate and significant reduction in greenhouse gas emissions, climate-related impacts to the Spokane River are likely to continue throughout the 21st century. We therefore recommend the following resilience actions.

Recommended Resilience Actions

It is with the above findings in mind that we recommend the following resilience actions:

- **Reduce Emissions**—Take all possible actions to reduce greenhouse gas emissions and avoid the high emissions scenario (RCP 8.5).
- **Prioritize Trout Habitat**—Reconsider regulations at Post Falls to help prioritize Redband trout habitat.
- **Future Research**—Conduct more research to fully understand the longer-term impacts of climate change on the Spokane Valley-Rathdrum Prairie Aquifer.
- **Future Research**—Investigate well depth and pump technology.

Future Work

The findings of this report indicate the need for more research to be conducted on the future vulnerability of the Spokane Valley-Rathdrum Prairie Aquifer, which is the Spokane metropolitan region's sole source of potable water to its residents. In addition to further climate analysis, it is also necessary for local policy makers to understand the non-climate related impacts, such as increased demand on the aquifer due to (1) population growth and (2) increased evapotranspiration as temperatures rise in our region. Individual choices, business practices, and government policy are all necessary components of an effective strategy to prevent adverse climate-induced impacts on water availability.

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