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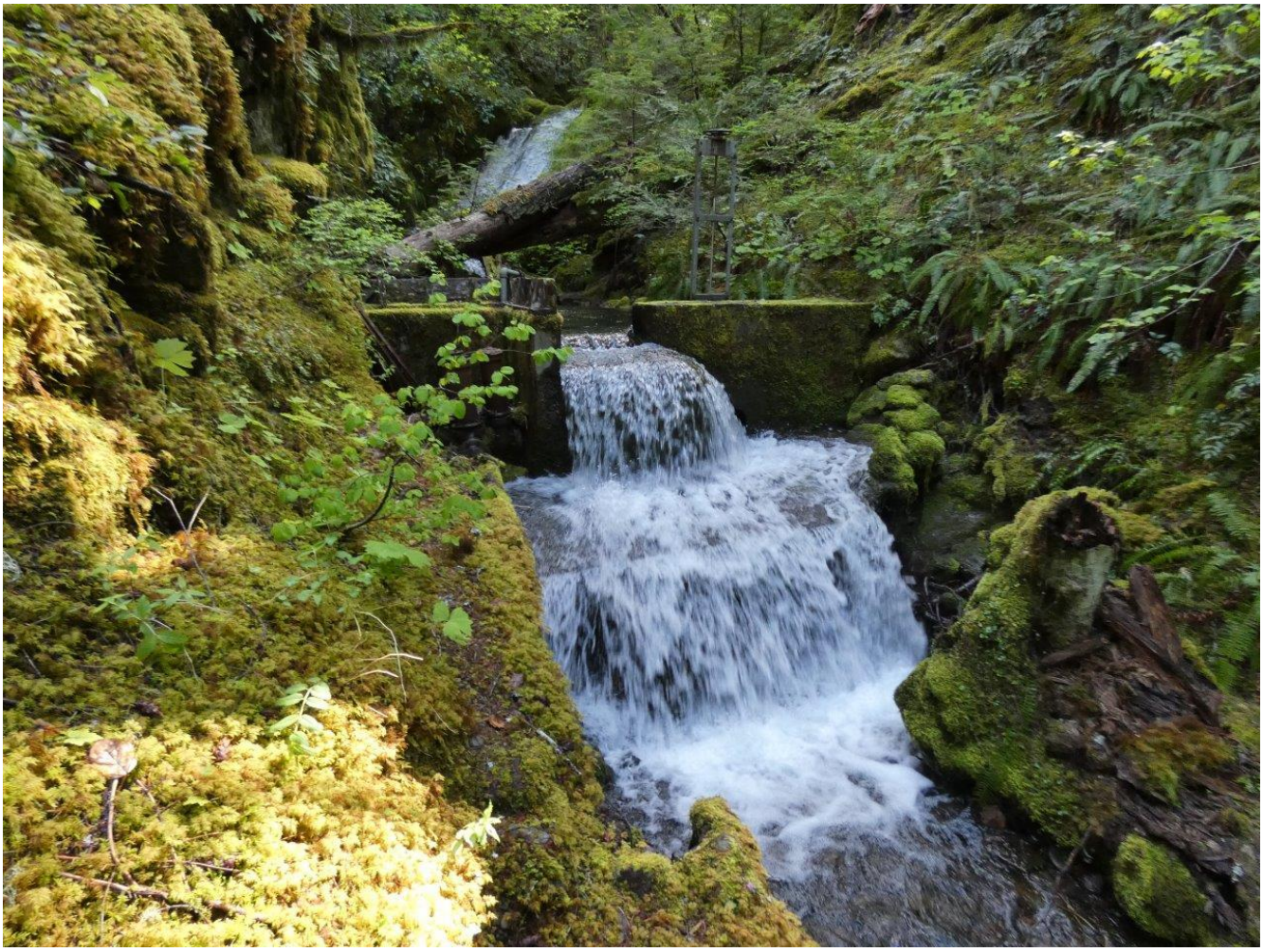
Predicting Impacts of Climate Change on Water Supply

Mount Rainier National Park

Natural Resource Report NPS/MORA/NRR—2022/2400



ON THE COVER
Photo of the Ohanapecosh water intake on No-Name Creek, May 2019
Photograph by: NPS

Predicting Impacts of Climate Change on Water Supply

Mount Rainier National Park

Natural Resource Report NPS/MORA/NRR—2022/2400

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Contents

Figures

Page

Figures (continued)

Page

Tables

Page

Appendices

Page

Abstract

Mount Rainier National Park's (MORA) water supply primarily depends on streams and lakes fed by snowmelt and perennial snowfields. The loss of perennial snowfields during the past thirty years, combined with the potential for lower annual snowpack and increased air temperatures, could have profound implications for Park water supplies. Warming temperatures correspond with shifts from solid to liquid precipitation resulting in earlier snowmelt. In response to increasing Park visitation, multiple stressors on sensitive aquatic organisms, and projected climate changes, MORA is taking steps to develop a range of water supply options and park management strategies to adapt to climate change.

As a case study, warm winter temperatures during water year 2015 had a profound effect on snowpack in MORA. During the months when most snow is deposited in our mountains (December to March), temperatures typically averaged more than 3° C above normal. Although precipitation was near normal, warmer temperatures caused much of this precipitation to fall as rain, resulting in an unusually low snowpack. These conditions stressed water supplies that are critical to Park operations, and likely stressed sensitive aquatic species (e.g., cold-water fishes and insects) downstream of water supply intakes as a consequence of elevated stream temperatures and low stream flow. Conditions resembling historical droughts, including the recent 2015 event, are projected to be more likely within this century as the climate warms across the region. These changes are likely to coincide with increased Park visitation and greater stresses on sensitive aquatic ecosystems.

In order to provide sufficient context for our analysis, we have summarized MORA's current water supply demands, history of development, issues, changes over time, and potential impacts to aquatic organisms. Focusing on key water supply systems within the Park, we estimated the potential maximum use and storage capacity of existing water. We then scaled region-wide streamflow projections under multiple emission scenarios to water supply intake drainage basins to evaluate future water supply scenarios within the Park. Our findings suggest the most viable immediate options for securing water supplies long-term include increasing system storage capacity and adding groundwater sources. These results can be used to directly inform current Park planning efforts and potential management actions to adapt to changing visitation demands, infrastructure needs, and climate change.

Acknowledgments

Data, figures, or summary information were downloaded from the Columbia Basin Climate Change Scenarios Project website at http://warm.atmos.washington.edu/2860/ (Accessed August 2019). These materials were produced by the Climate Impacts Group at the University of Washington in collaboration with the WA State Department of Ecology, Bonneville Power Administration, Northwest Power and Conservation Council, Oregon Water Resources Department, and the B.C. Ministry of the Environment.

This work is a result of a collaborative effort between multiple staff from Mount Rainier National Park and the National Park Service, Water Resources Division. We thank Peter Fahmy, Tyler Gilkerson, and Steve Rice for their technical expertise. We also thank Scott Beason, Taylor Kenyon, and Robert Jost for their data collection, analysis, planning, and field support. Lastly, we thank Jim Fuller for providing critical water use data and institutional knowledge.

Background

Mount Rainier National Park's most drought-sensitive water supply systems rely entirely on intakes located above permanent or temporary barriers on snowmelt-fed perennial streams. Systems located in the drier east side of the Park are particularly susceptible to drought. Throughout the Pacific Northwest, climate change is expected to increase year-round temperatures and cause declines in snowpack due to shifts from solid to liquid precipitation in winter, resulting in earlier snowmelt and peak runoff which may limit water availability in late summer and early autumn (Mote et al. 2018, Musselman et al. 2021). Park managers saw a preview of what future conditions may look like during water year 2015. Following a historically low snowpack and warm temperatures, by August stream flow had ceased into some intake reservoirs. These observations, coupled with projected continued increases in park visitation (Fisichelli et al. 2015, Bergstrom et al. 2020), have prompted an assessment of the Park's future water supplies with a focus on the four most susceptible systems in the eastern half of the Park – Stevens Canyon Entrance, Ohanapecosh, Sunrise and White River Entrance (Figure 1). Each of these systems is supported by an in-stream pipe intake and storage tank, except for Sunrise which sources its water from a reservoir. For stream-fed systems, we calculated their respective drainage basin areas in acres (Table 1).

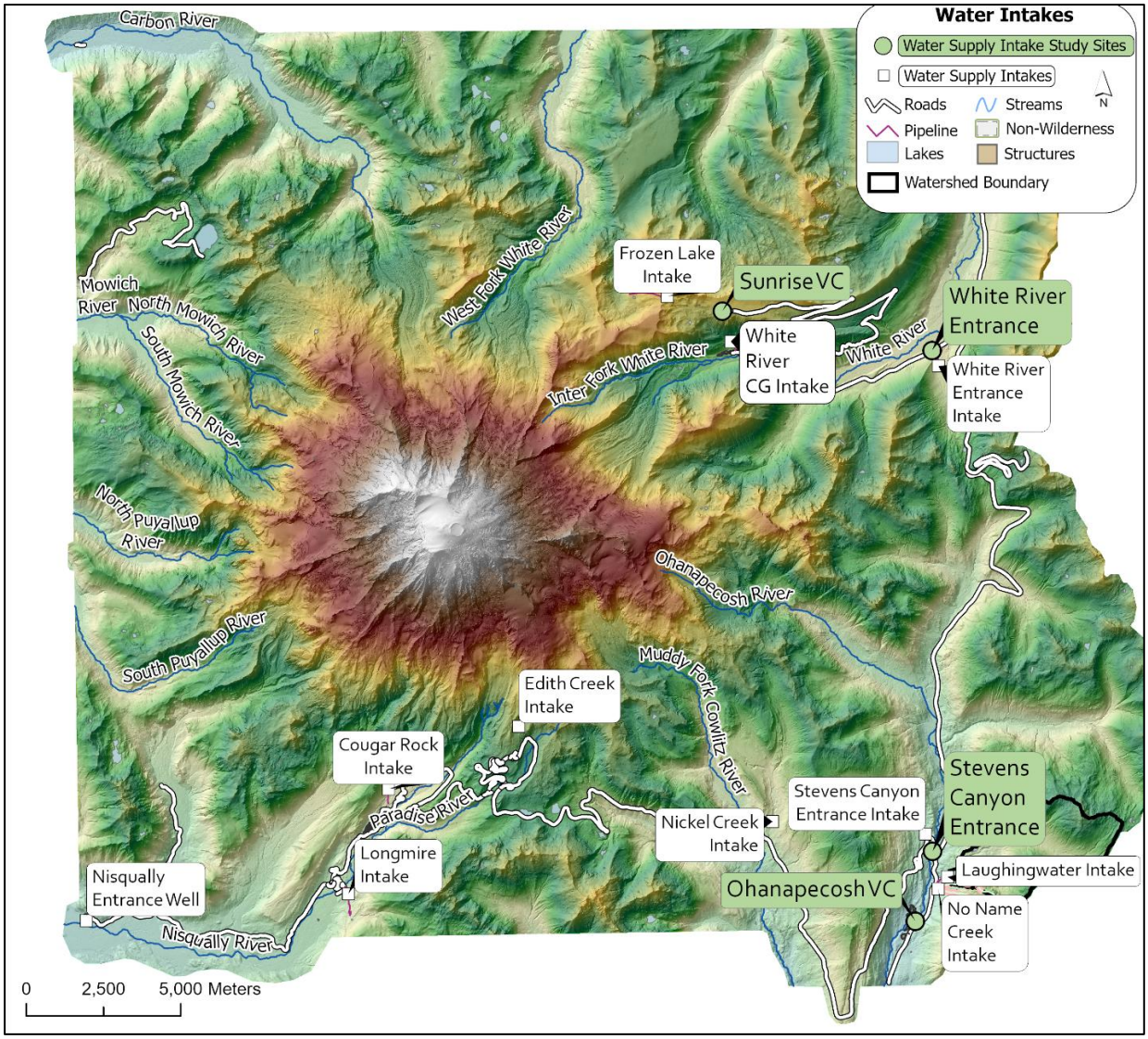

Figure 1. Map of MORA water supply intake locations. The four east-side water intakes considered most vulnerable to climate change and the focus of this study are labeled in green.

Table 1. Surface drainage area (acres) and water tank storage capacity (ft^3) of drought-sensitive MORA surface water intakes.

System	Water Source	Drainage area (acres)	Storage capacity (ft^3)
Stevens Canyon Entrance	Falls Creek	570	1,070
Ohanapecosh	No-Name Creek	325	13,360
Abandoned Ohanapecosh	Laughingwater Creek	2,644*	N/A
White River Entrance	Klickitat Creek	2,150	2,670
Sunrise	Frozen Lake	22	2,767,575

*Laughingwater Creek drainage area is based on former abandoned intake location.

Stevens Canyon Entrance

The Stevens Canyon Entrance water intake on Falls Creek serves bathroom facilities at the Grove of the Patriarchs trailhead and the Stevens Canyon Entrance station (Figure 2). This system has the smallest storage tank of all the priority systems assessed (Table 1), and the tank is also designated as a historic structure. The Grove of the Patriarchs is a particularly popular day use trail system in the Park that has seen increasing visitation in recent years. Furthermore, the bathroom facilities are the only ones in the Park without low-flow toilets. The installation of low-flow toilets can reduce water use by 20 to 60%, from up to six down to 1.28 gallons per flush (EPA 2013). The site of the storage tank and intake pipe is not excluded from wilderness (Appendix A). Coastal giant salamander (*Dicamptodon tenebrosus*) and coastal tailed frog (*Ascaphus. truei*) have been documented in Falls Creek (Samora et al. 2013a).

Figure 2. Photo of Stevens Canyon Entrance water intake on Falls Creek, May 2019.

Ohanapecosh

Supplied by a surface intake on No-Name Creek, Ohanapecosh's water system serves the Ohanapecosh campground, a visitor center, and employee housing (Figures 1 and 3). This system has the largest storage capacity but is supplied by an intake within the smallest drainage area of the systems assessed (Table 1). Previously, a second intake located on Laughingwater Creek, which has a significantly larger drainage area, also provided water for Ohanapecosh (Table 1, Figures 4 and 5). However, due to the dynamic nature of Laughingwater Canyon, the intake was abandoned during the 1980s after recurring washouts and the loss of access to the intake site as a result of landslides. Cutthroat trout (*Oncorhynchus clarkia*) and four species of amphibians have been documented in Laughingwater Creek including northwest salamander (*Ambystoma gracile*) coastal tailed frog (*A.*

truei), western red-backed salamander (*Plethodon vehiculum*), and Cascades frog (*Rana cascadae)* (Samora et al. 2013a, 2013b, WADOE 2021).

Figure 3. Photo of Ohanapecosh water intake on No-Name Creek, August 2019.

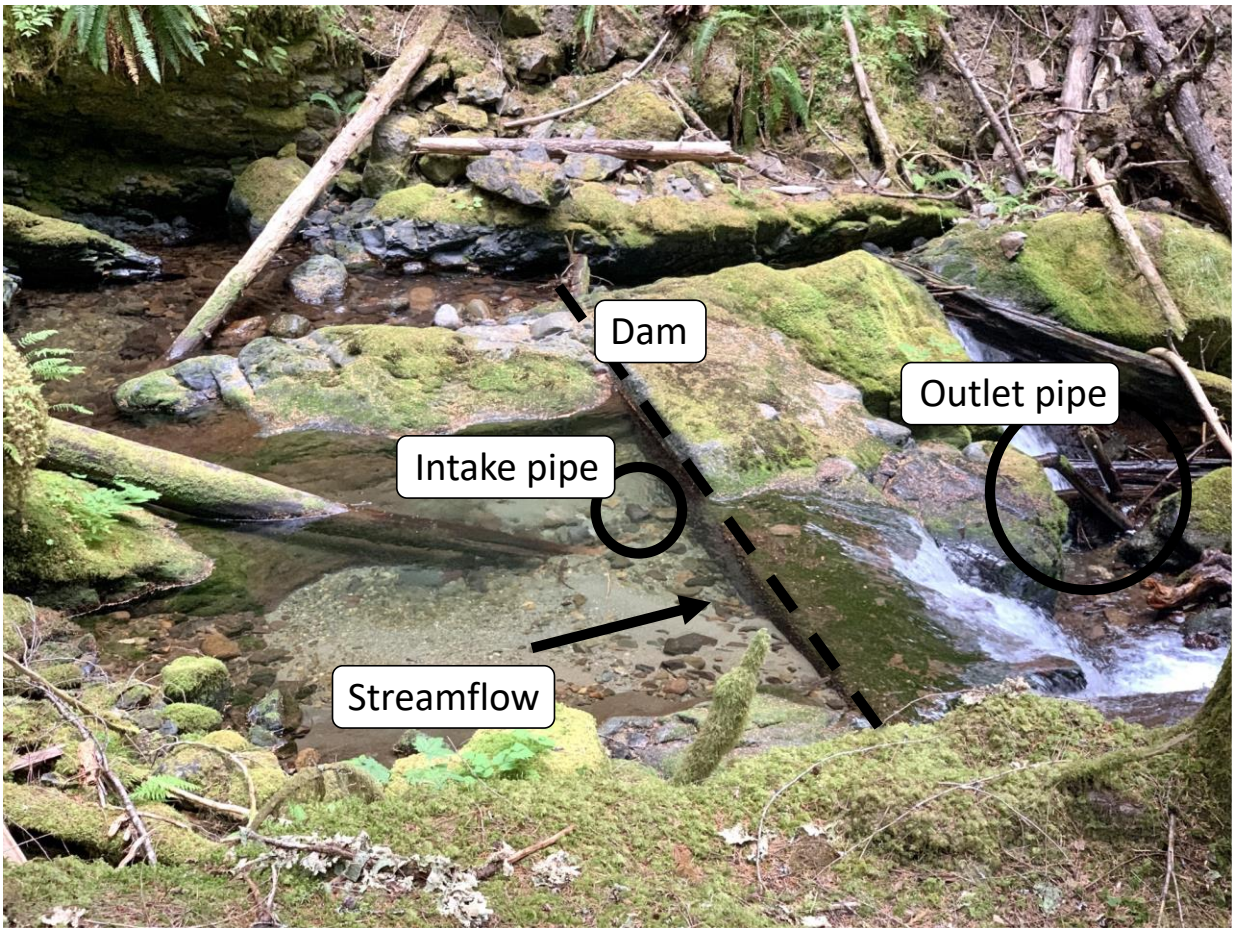

Figure 4. Photo of abandoned Ohanapecosh water intake on Laughingwater Creek, August 2021. Note the concrete dam in the center of photo, partially covered intake pipe to the left of the dam, and damaged outlet pipe to the right of the dam. Streamflow is toward the right.

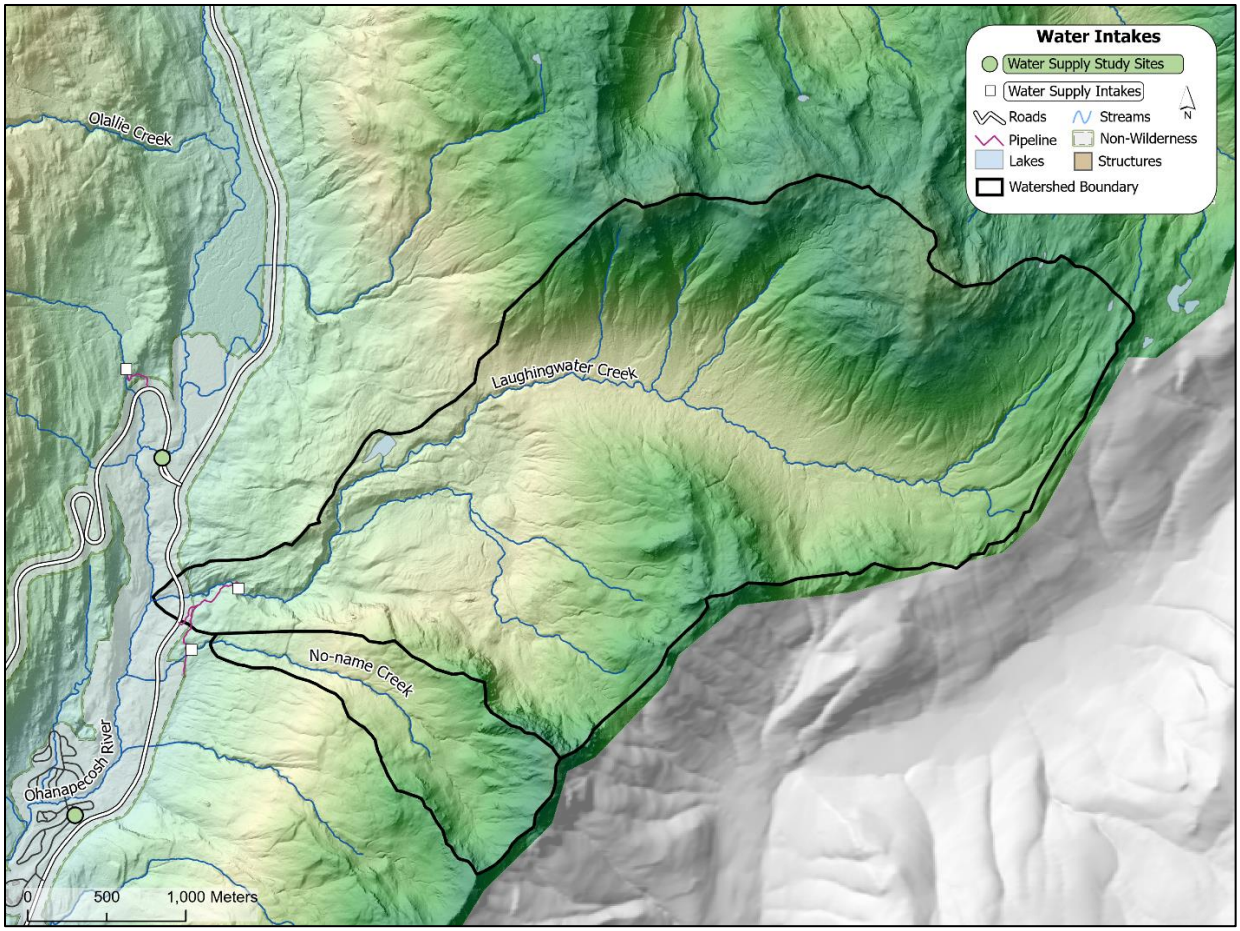

Figure 5. Map of current and historical Ohanapecosh water intakes.

White River Entrance

Located in the northeast corner of the Park, the White River Entrance water system on Klickitat Creek serves the White River Entrance Station, visitor restroom facilities, a maintenance garage, and employee bunkhouses (Figure 1). Unlike the other systems assessed, the White River Entrance water system does not have a permanent intake. The intake pipe in Klickitat Creek is re-installed and removed annually by Park maintenance at the start and end of the summer season. As streamflow recedes later in the summer, a temporary impoundment reservoir is constructed at the intake site using a fallen tree, a board, and sandbags. This system requires frequent maintenance throughout the season to capture sufficient flow.

White River's storage tank has a relatively low capacity (Table 1). Upon its initial construction, the water system was intended to support a maximum of eleven permanent residents in employee housing. Currently, there are fourteen employees housed at White River each summer. Additionally, the intake pipe and supply line on Klickitat Creek and storage tank are not excluded from wilderness (Appendix B).

Klickitat Creek also supports bull trout (*Salvelinus confluentus*), a species listed as threatened under the Endangered Species Act (1998) (USFWS 2014, Samora et al. 2013b). The creek serves as

important spawning habitat for the species, and redds (spawning nests) have been observed in Klickitat Creek consistently since 2000 (Appendix C). Cutthroat trout (*O. clarkia*), brook trout (*S. fontinalis*), and coastal tailed frog *(A. truei*) have also been documented (Samora et al. 2013a, 2013b). Park staff measure Klickitat Creek discharge weekly at sites upstream and downstream from the temporary intake for the duration of the summer season. These measurements indicate that stream flow peaks in early June, then declines steadily and reaches baseflow conditions by late July/early August (Figure 6). Currently a maximum of 4 gallons per minute (gpm) of water is diverted from Klickitat Creek. Such water usage is less than 0.5% of Klickitat Creek's low August 2019 flow of approximately 2 cubic feet per second (ft^3/s). It was previously thought that bull trout only used Klickitat Creek for spawning and rearing below a natural fish barrier located approximately 0.7 miles downstream of the intake, but recently bull trout have been observed upstream of the intake in the late summer. The extent to which the species inhabits the upper reaches of Klickitat Creek for the duration of the summer remains unknown.

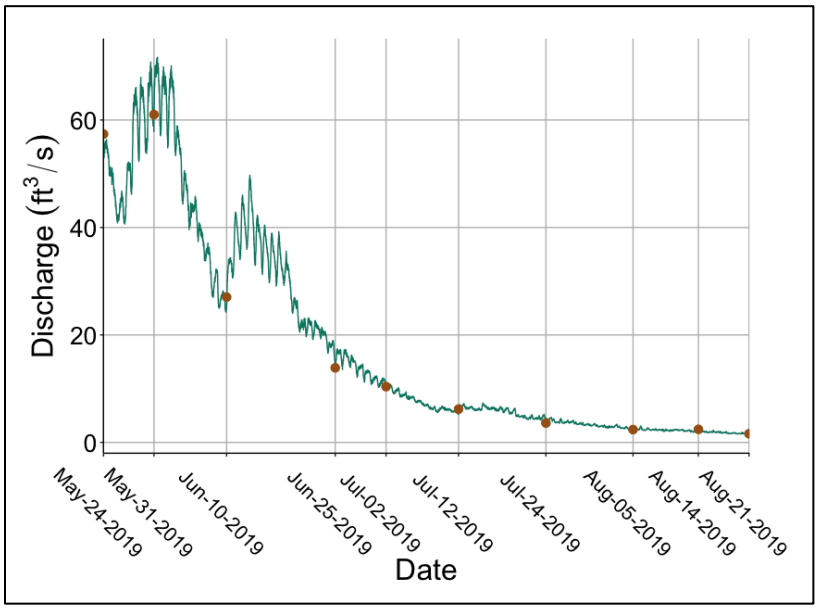

Figure 6. Klickitat Creek calculated discharge (blue line) supplying White River Entrance water system, 2019. Dates of manual discharge measurements (brown dots) are denoted by x-axis labels.

Sunrise

Located in the northeast corner of MORA, Sunrise's water supply comes from Frozen Lake, a high elevation snowmelt-fed reservoir (6,719 ft. above mean sea level) that sits in a small drainage basin (Table 1) a few hundred feet above the visitor center, bathrooms, cafeteria, employee housing, and guest services housing that it supports (Figures 1 and 7). The intake pipe sits above the bottom of the lake, and a concrete dam increases the retention capacity of the lake basin. Construction of the dam was completed in 1930 (Figure 8). Over time, the reservoir's capacity has declined due to the runoff of fine sediment from the surrounding terrain. Additionally, due to the reservoir's limited capacity, during spring runoff some snowmelt water typically spills over the top of the dam. In the past, water from Lodi Springs was pumped uphill via a pipeline into the basin to supplement Frozen Lake

(Figure 9). However, the pipeline was removed more than thirty years ago and there is no surficial evidence of a spring at the pumphouse's previous location. Projected declines in snowpack, combined with a shorter duration of runoff, could seriously impair the quantity and reliability of Sunrise's water supplies, potentially resulting in more water flowing over the top of the dam during the spring instead of being retained as snowpack and gradually replenishing Frozen Lake during the summer. Higher temperatures resulting in more rain and less snow may also increase erosion of the surrounding basin and sedimentation of Frozen Lake over time. Cascades frog and Pacific chorus frog (*Pseudacris regilla*) have been documented at Frozen Lake (Samora et al. 2013a).

Figure 7. Photo of Frozen Lake reservoir, water supply for Sunrise, June 2015.

Figure 8. Photo of Frozen Lake dam construction, 1930.

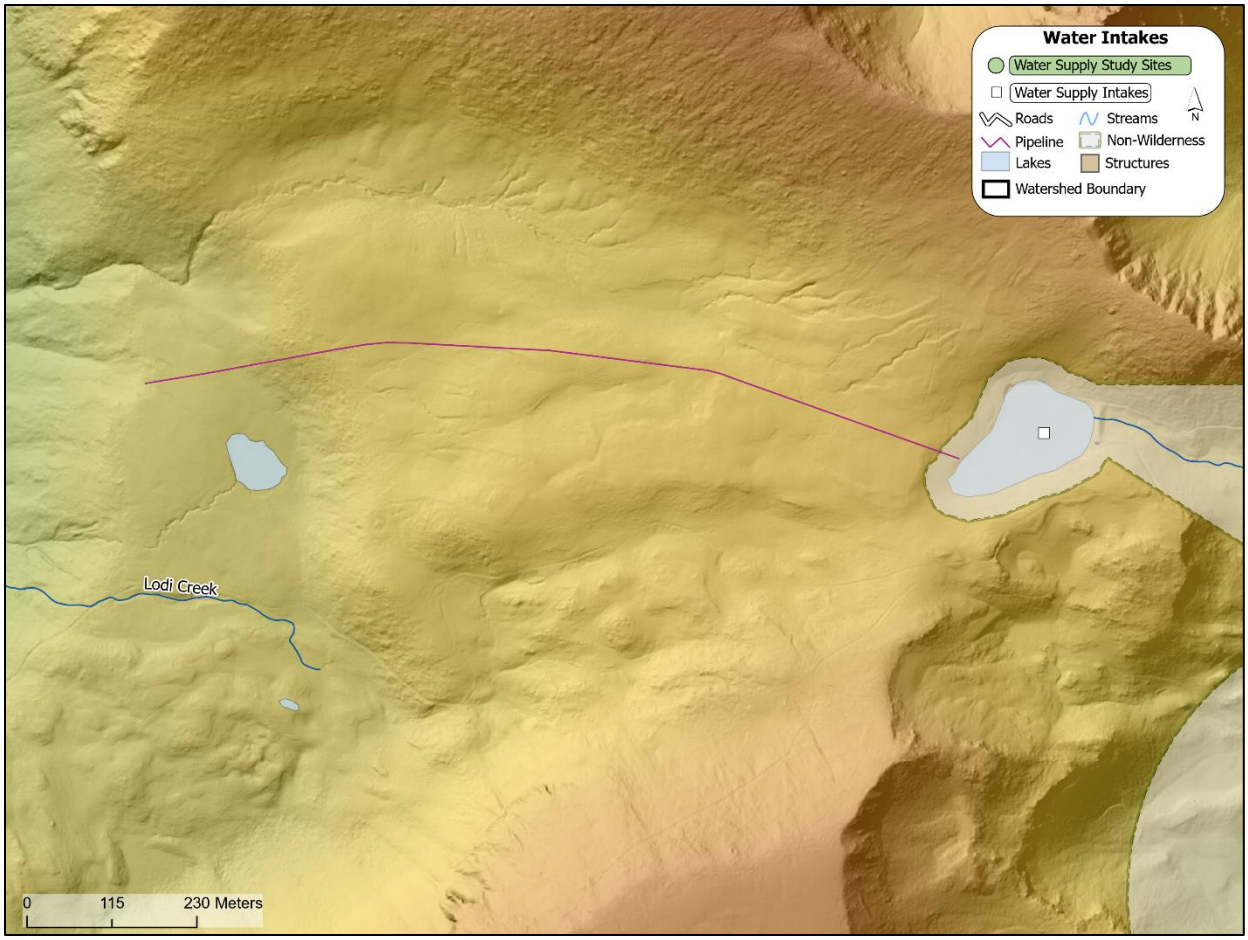

Figure 9. Map of abandoned Lodi Springs intake and pipe which used to supplement Frozen Lake.

Water Year 2015

During the winter of water year 2015, October through March temperatures in Washington state averaged more than 3° F above the 1981-2010 normal, substantially increasing the amount of precipitation that occurred as rain and resulting in a significantly lower snowpack (OWSC 2015; Marlier et al. 2017). By August and September, MORA was experiencing drought-like conditions in its predominantly snowmelt-fed watersheds due to the reduction in snowmelt runoff. Flow into the in-stream water impoundment at Ohanapecosh's No-Name Creek intake had ceased entirely and in-stream flows at the Stevens Canyon Entrance and White River Entrance intakes were visually estimated to be a fraction of the normal discharge (Figure 10). The perennial snowfield in the Frozen Lake watershed was almost gone and the lake water level notably low.

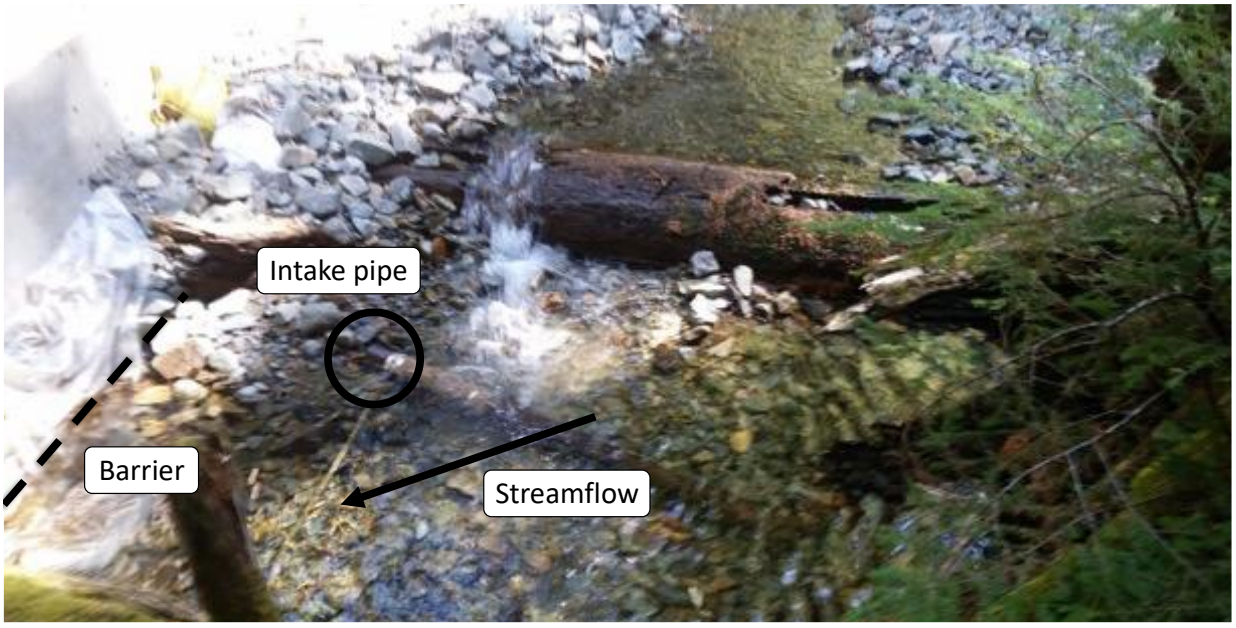

Figure 10. Photo of White River water intake positioned above water level on Klickitat Creek, August 28, 2015. Note the plastic barrier serving as the lower end of the impoundment on the left and arrow denoting the direction of streamflow.

Water year 2015 differed from most historical droughts in the state, which have typically been the result of low winter precipitation, as total winter precipitation was near the 1981-2010 normal (Figure 11). Analyses of this year's drought severity relative to historical climate data and future climate projections suggest that conditions in 2015 reflect conditions that are predicted to exist throughout the Pacific Northwest by the 2050s (Marlier et al. 2017). Transitional (mixed rain and snow) watersheds at intermediate elevations, such as those we describe here, demonstrate the greatest change in runoff timing as a result of winter warming (Vano et al. 2015). Furthermore, while sea surface temperature (SST) anomalies contributed strongly to the observed 2015 drought in Washington state, anthropogenic influences on temperature intensified the snow drought (Mote et al. 2016). Given the preview of anticipated future conditions that water year 2015 provides, it is clear

that MORA's east-side surface water supplies are particularly susceptible to reduced summer flows following periods of below-normal winter precipitation and earlier snowmelt runoff.

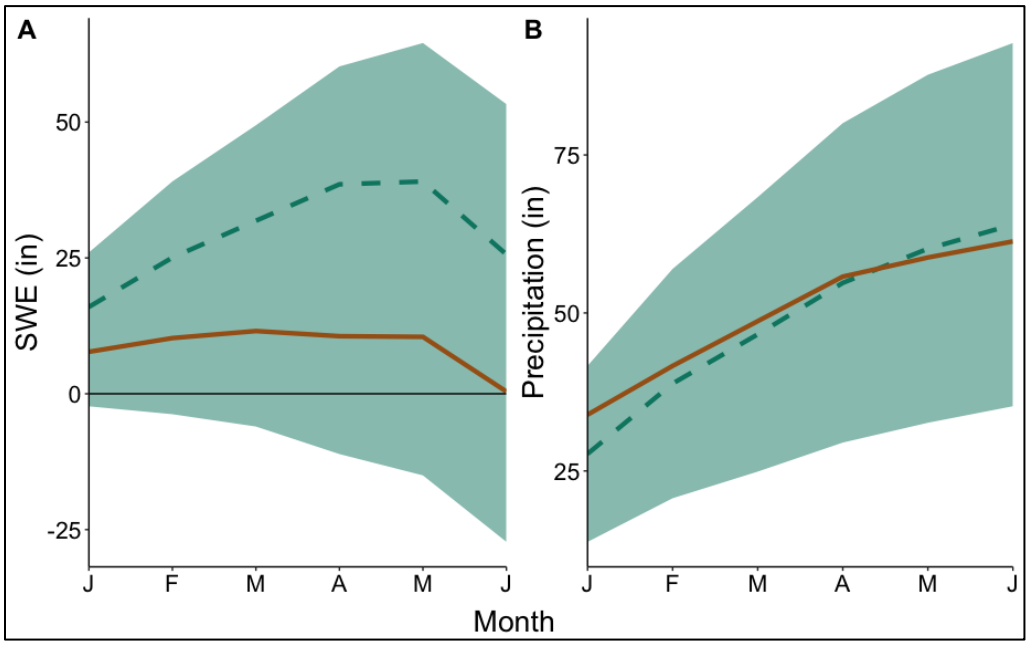

Figure 11. Mount Rainier National Park average monthly snow water equivalent (in., A) and average accumulated precipitation (in., B) for 2015 (brown, solid) compared to averages for January-June of 1985-2014 (blue, dashed). Solid background represents standard deviation. Values calculated from four closest SNOTEL locations to MORA (IDs: 375, 418, 679, 863) with continuous data for time period. Data obtained from National Resources Conservation Service National Water and Climate Center.

Current water demand in Mount Rainier National Park

Total annual water use across most eastern MORA systems has declined significantly between 2006 and 2018 (Figure 12), largely due to efforts to upgrade water supply utilities. However, water use at Stevens Canyon Entrance has increased nearly threefold during this same timeframe (Figure 13). Water use at Ohanapecosh has steadily declined, while use at White River Entrance fluctuates significantly from year to year (Figure 13). Sunrise had the sharpest decline in use, primarily during water years 2012-2014, which Park maintenance has attributed to the installation of higher efficiency hot water heaters in employee housing (Figure 13). On a month-to-month basis, water use peaks across all systems in July and August (Figure 14). White River also uses a significant amount of water in May for opening and maintenance procedures (Figure 14).

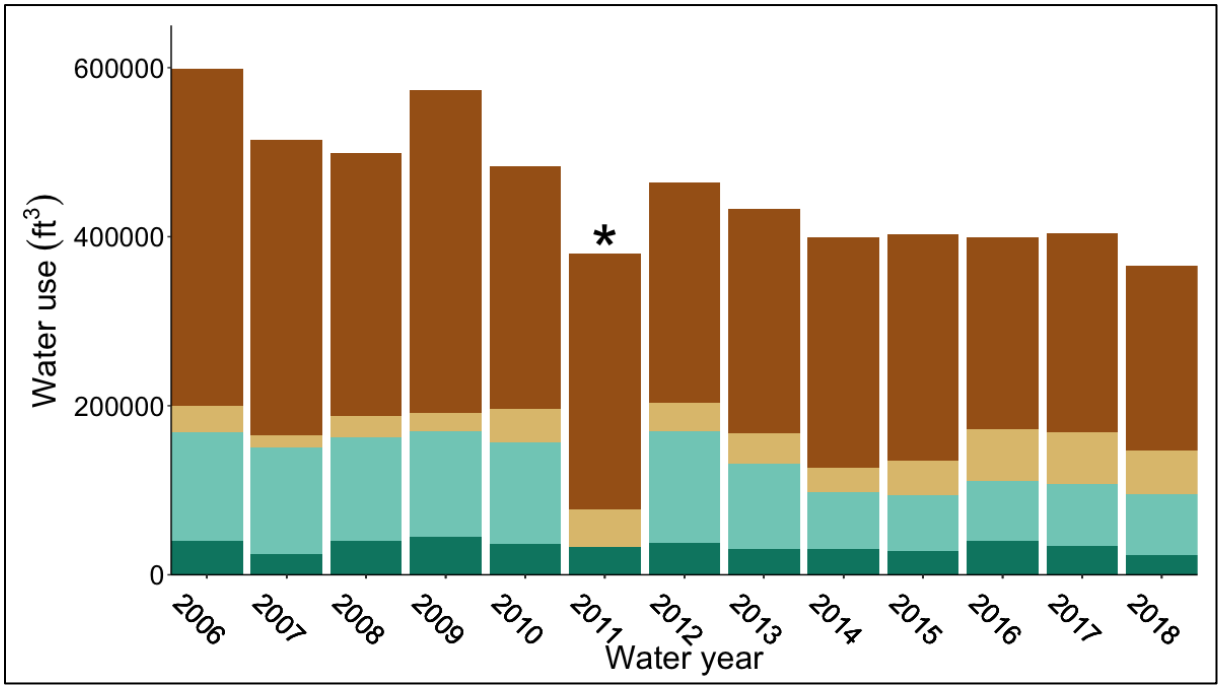

Figure 12. Annual water use (ft^3) for 2006-2018 at Ohanapecosh (dark brown), Stevens Canyon Entrance (light brown), Sunrise (light blue), and White River Entrance (dark blue) water supply systems. *2011 water use for Sunrise unavailable.

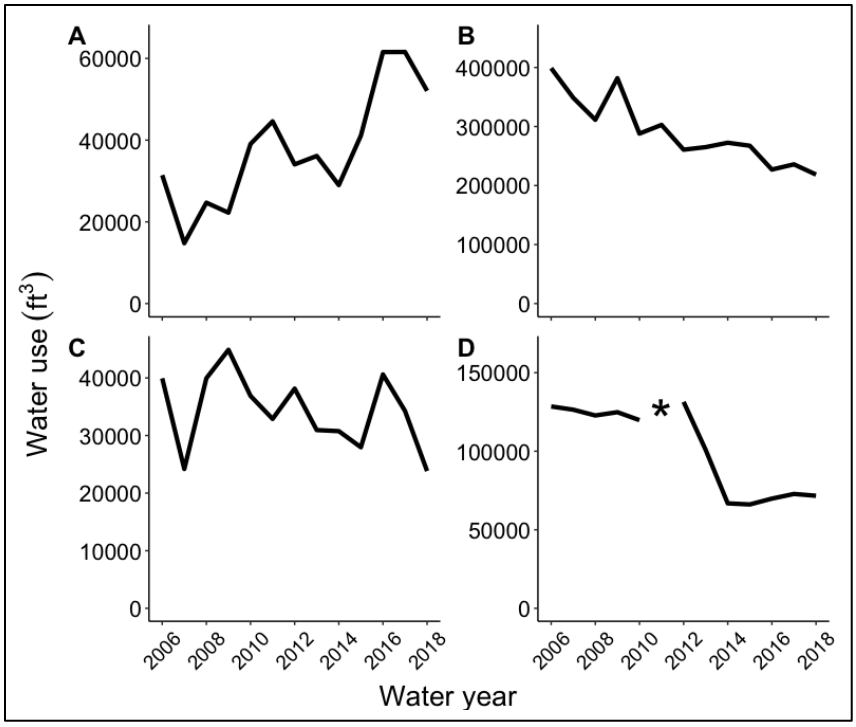

Figure 13. Annual water use (ft³) from 2006-2018 at **(A)** Stevens Canyon Entrance, **(B)** Ohanapecosh, **(C)** White River Entrance, and **(D)** Sunrise. *2011 water use for Sunrise unavailable.

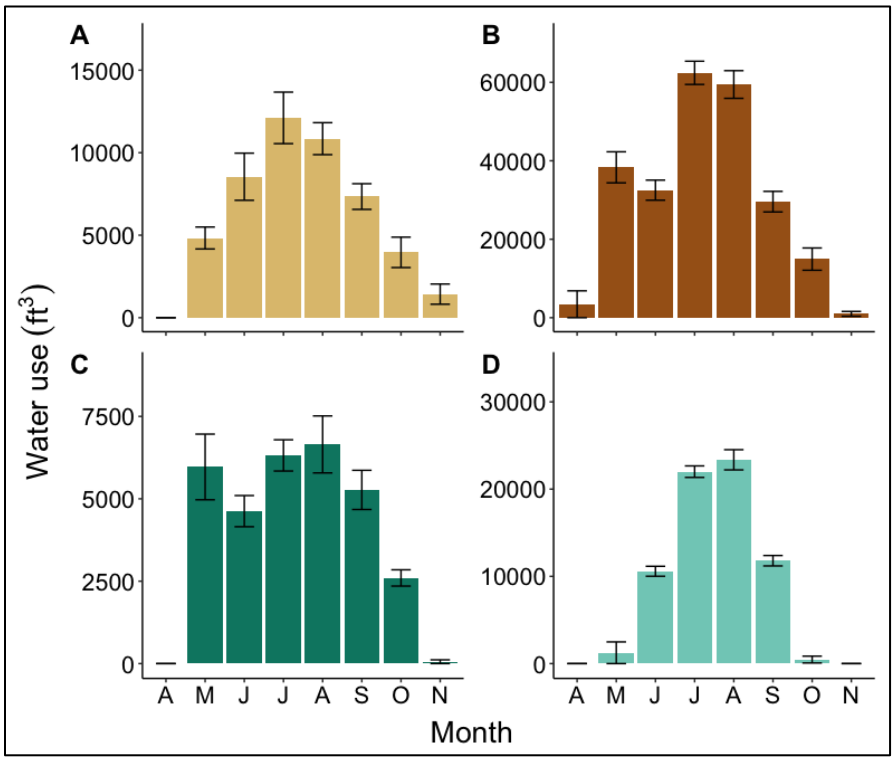

Figure 14. Mean monthly water use (ft³) from April to November over 2014-2018 at **(A)** Stevens Canyon Entrance, **(B)** Ohanapecosh, **(C)** White River Entrance, and **(D)** Sunrise. Error bars represent standard deviation.

Future streamflow and water availability projections for Mount Rainier National Park

We estimated monthly discharge in the 2040s and 2080s under emissions scenarios representing very rapid economic growth and an increase in carbon emissions relative to present day (A1B) versus rapid introduction of resource-efficient technologies and a decrease in carbon emissions relative to present day (B1) using existing basin-wide streamflow projections for the Cowlitz (Stevens Canyon and Ohanapecosh intakes) and White River (White River intake) watersheds from the Columbia Basin Climate Change Scenarios Project (CBCCSP) (Miles et al. 2000). CBCCSP projections were developed using the 5 best-ranked global climate models (GCMs) based on their ability to simulate 20th century climate in the Pacific Northwest from a suite of 20 models considered in the Fourth International Panel on Climate Change Assessment Report.

Basin streamflow projections for the aforementioned watersheds were downscaled to the White River, Stevens Canyon, and Ohanapecosh water supply intake sub-basins according to their relative drainage area proportion. Specifically, we multiplied historical monthly discharge and projected future monthly discharge for each climate scenario by the fraction of each water intake sub-basin drainage area divided by the larger basin (White or Cowlitz) drainage area for which these discharge estimates were originally calculated by Miles et al. (2000). In addition, we also scaled streamflow projections for the previously abandoned Laughingwater Creek intake, which was used to supplement Ohanapecosh's water supply.

The scaled streamflow projections for water intake locations only account for upgradient drainage basin area and basin-wide projected future precipitation and temperature, and fail to consider additional sub-basin factors determining the timing and magnitude of flow regimes such as groundwater contributions, average drainage area elevations, and differences in precipitation type and snowpack. Historic streamflow data are lacking for all water intake locations, and thus as described previously the historic discharge curves shown here are downscaled from gauges on the Cowlitz and White Rivers by relative drainage area proportion.

By the 2080s, all four current and former intake basins are projected to shift from annual snowmelt-dominated flow regimes to rainfall driven regimes in which peak runoff generally coincides with winter storms in December and January (Figures 15-18). The disparity between historical and future flows is most evident in the major water use months of June and July under the A1B emissions scenario in the 2080s, where mean monthly discharge is projected at 50% or less compared to historical data across all intake locations (Figures 15-18).

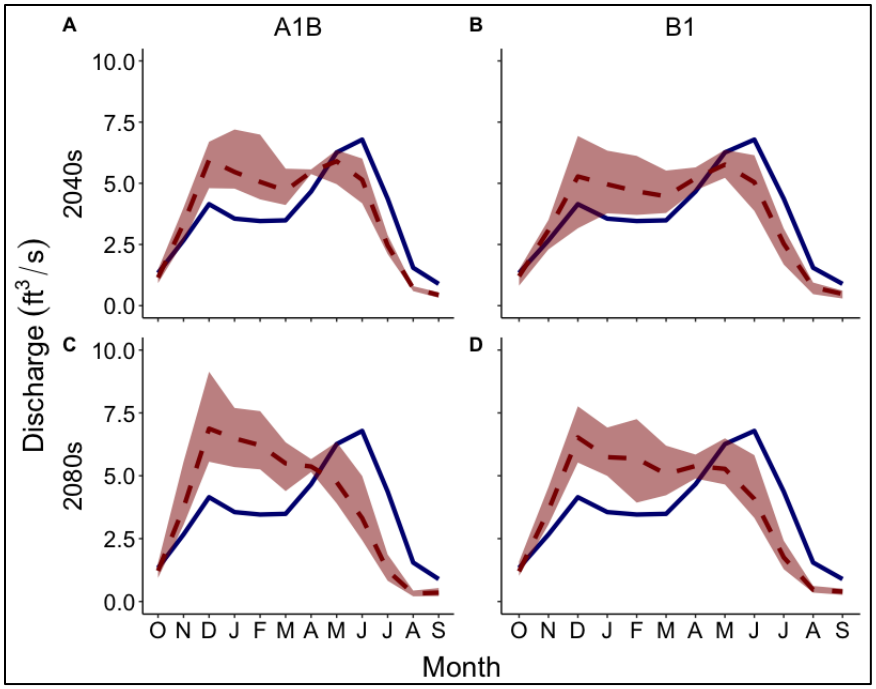

Figure 15. Monthly mean (blue) historic and (red) projected discharge at Stevens Canyon Entrance intake in 2040 and 2080 under **(A,C)** A1B and **(B,D)** B1 climate scenarios. Error ribbons on projection curves indicate maximum and minimum predicted flows from among the five best-fit basin-scale models.

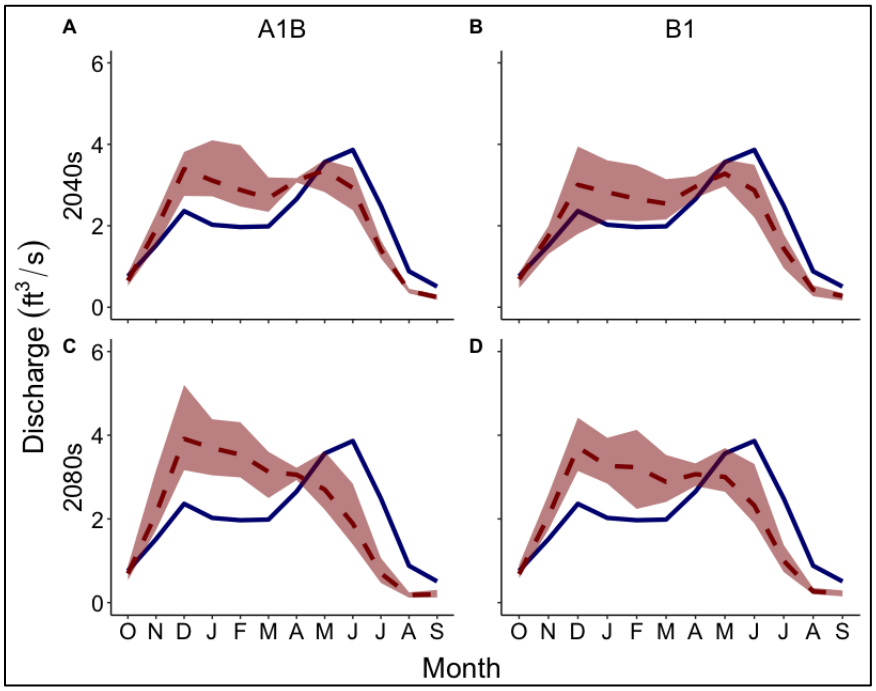

Figure 16. Monthly mean (blue) historic and (red) projected discharge at No-Name Creek (Ohanapecosh) intake in 2040 and 2080 under **(A,C)** A1B and **(B,D)** B1 climate scenarios. Error ribbons on projection curves indicate maximum and minimum predicted flows from among the five best-fit basin-scale models.

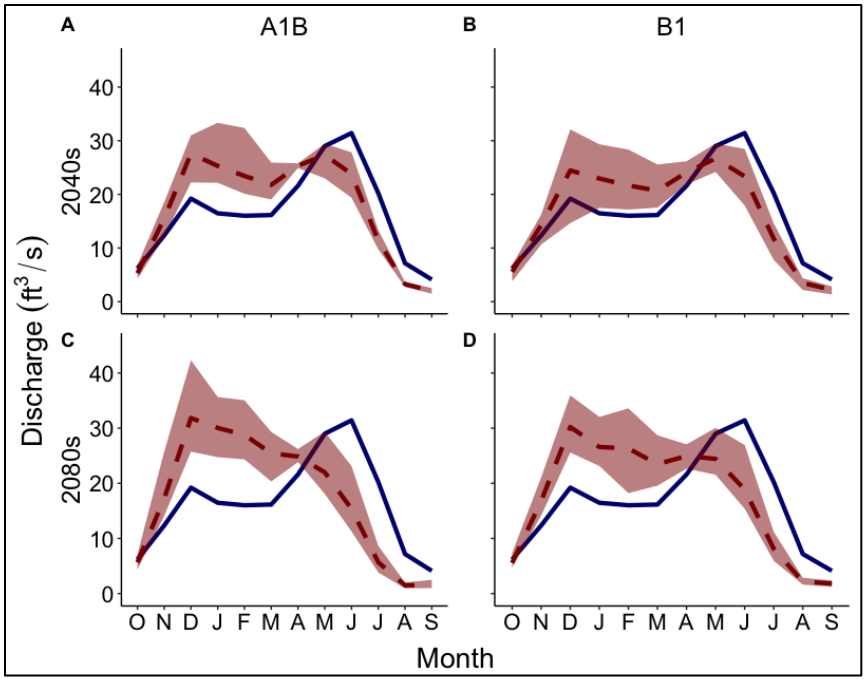

Figure 17. Monthly mean (blue) historic and (red) projected discharge at Laughingwater Creek (Ohanapecosh, abandoned) intake in 2040 and 2080 under **(A,C)** A1B and **(B,D)** B1 climate scenarios. Error ribbons on projection curves indicate maximum and minimum predicted flows from among the five best-fit basin-scale models. Notably, the abandoned Laughingwater Creek intake receives significantly more discharge than the current No-Name Creek intake for Ohanapecosh.

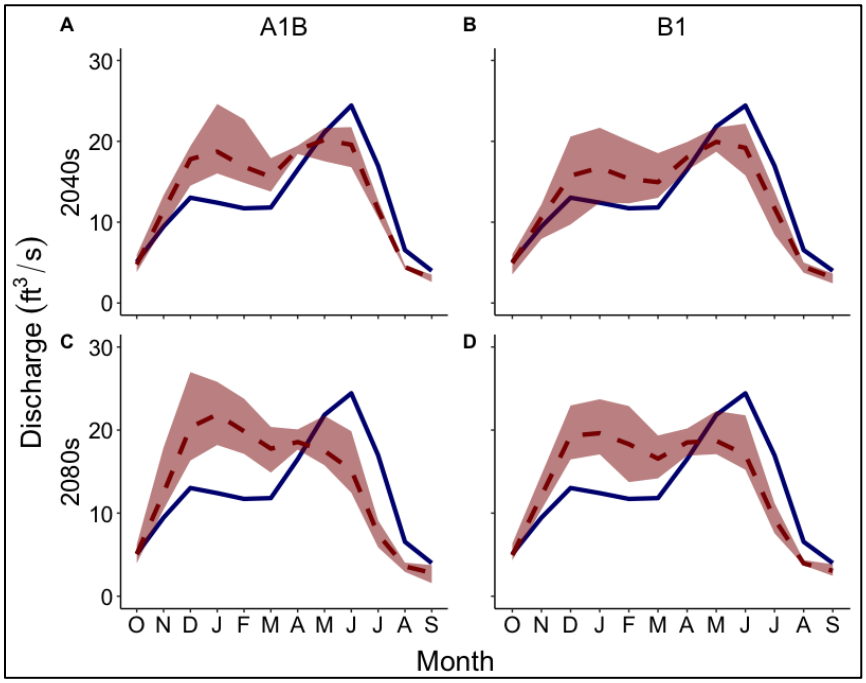

Figure 18. Monthly mean (blue) historic and (red) projected discharge at White River Entrance intake in 2040 and 2080 under **(A,C)** A1B and **(B,D)** B1 climate scenarios. Error ribbons on projection curves indicate maximum and minimum predicted flows from among the five best-fit basin-scale models.

In addition, we calculated the total capacity of Frozen Lake using bathymetric maps prepared in 2020 (Appendix D). We found that the lake's maximum current total volume is approximately 1,315,139 ft^3, compared to its volume upon construction in 1930 of 2,787,810 ft^3 (Brandt et al. 2011), indicating a considerable decrease in Frozen Lake's storage capacity.

Supporting Research

The Water Resources Division (WRD) of the National Park Service is leading a groundwater investigation to evaluate the feasibility of supplementing existing surface water wells in the Ohanapecosh, White River Entrance, and Stevens Canyon Entrance areas (Gilkerson 2020). Proposed test well locations have been identified utilizing results of previous water supply studies and a preliminary scoping trip conducted in 2019 (USGS 1971, Martin, 1999, Rice, 2019). Additional geophysical surveys including electrical resistivity and (or) seismic refraction surveys are planned to further evaluate potential test well locations (Gilkerson 2020). While this study focused on vulnerable east side water supply systems at Mount Rainer, an evaluation of all surface water systems in the Park should be completed.

To support the potential development of groundwater resources in the White River watershed, United States Geologic Survey (USGS) staff are developing a Soil-Water Balance (SWB) model to estimate groundwater recharge utilizing field data collected in 2020. Results will be used to evaluate the proportional impact of estimated Park groundwater use on groundwater resources in the White River watershed.

Results from a 2019-2021 USGS- MORA streamflow permanence project will provide Park-wide information of the extent of streams that have surface flow year-round (perennial) and to understand if and how perennial and non-perennial streams are sensitive to changes in climate and physical conditions that could affect timing of surface flow. These results will further define areas that are sensitive to stresses of low water surface availability (USGS, 2021).

Conclusions

Given the projected declines in snowpack and resulting mid to late summer flow reductions that MORA is projected to experience as the regional climate warms, a prudent first step in adapting the Park's water supplies is expanding the storage capacity of the water supply systems assessed here. In addition, alternative water sources (e.g., groundwater) could serve as secondary water sources to supplement water supplies during drought-like conditions and therefore should be thoroughly investigated. Here, we suggest management priorities for each system and discuss additional information needed to ensure long-term, sustainable water supplies across MORA facilities.

All surface-fed water systems in MORA lack local-scale data on the timing and magnitude of discharge at in-stream reservoirs. Park employees began measuring and calculating discharge weekly above and below the White River Entrance (Klickitat) intake in 2019, but additional monitoring efforts are needed to understand seasonal and interannual trends in discharge across all intake locations, as well as the impact of discharge on flow rates into intake pipes and subsequent rates of water retention in storage tanks.

Stevens Canyon Entrance

Because the Stevens Canyon Entrance is the only intake of interest where water use is steadily increasing over time, this pattern suggests that water use here is largely dependent on increasing visitor use of the bathrooms at Grove of the Patriarchs. Priorities for adapting this system include the installation of low-flow toilets and expansion of the historic storage tank capacity. In addition, groundwater options will continue to be explored. Any available groundwater would serve as a secondary water supply rather than a replacement supply.

Ohanapecosh

Ohanapecosh's existing intake at No-Name Creek relies on a relatively small watershed area that may be insufficient to supply water use demands if the timing of peak runoff shifts to earlier in the year. Therefore, additional water sources in the area should be explored, starting with the abandoned Laughingwater Creek intake though the long-term viability of this site is unknown based on the dynamic nature of Laughingwater Canyon. Based on a WRD Scoping Report, groundwater options in the Ohanapeosh area appear to be the most promising of any of the east side water supply locations (Gilkerson, 2020).

Gilkerson (2020) states, "The Ohanapecosh area is mostly underlain by the ≥2,600-foot-thick Ohanapecosh Formation. Drillers logs for three geothermal exploration wells indicate that significant amounts of groundwater were encountered in the Ohanapecosh Formation at depths less than 350 feet (Barnett and Korosec, 1989; unpublished records retrieved from the National Geothermal Data System on February 28, 2020). According to the drillers log for a well located approximately 1.2 miles southwest of the Ohanapecosh Ranger Station groundwater was encountered at 195 to 201, 248, 277, and 304 feet."

White River Entrance

White River Entrance's storage tank is relatively small for a system supplying Park housing, and an initial priority is expanding its capacity. Furthermore, the number of permanent residents and operations at White River should not be increased at this time without considering water supply limitations as the system is already being stretched beyond its intended maximum residency. Similar to Ohanapecosh and Stevens Canyon, groundwater options will be explored as a secondary supply; however, Park managers will need to obtain a groundwater drilling exemption for White River basin from Washington State Department of Ecology prior to pursuing this course of action. The USGS is currently developing a SWB model to estimate groundwater recharge in the White River watershed upstream from the White River Entrance. Additionally, bull trout use of Klickitat Creek upstream from the intake must be further explored, and alternative methods for ensuring sufficient flow into the intake at low discharge without impeding fish passage should be implemented.

Sunrise

The major issues facing Sunrise are limitations on Frozen Lake's capacity imposed by changes in the timing and peak volume of spring runoff, sedimentation of the reservoir, and inability to pull from the reservoir once lake levels fall below the height of intake. Expanding the lake's storage capacity directly would require increasing the height of the dam, dredging the lake bottom, and/or pumping water from below the intake pipe which sits well above the lake bottom. Groundwater options will also be explored at Sunrise.

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Appendix A: Map of Stevens Canyon Entrance Water Supply System

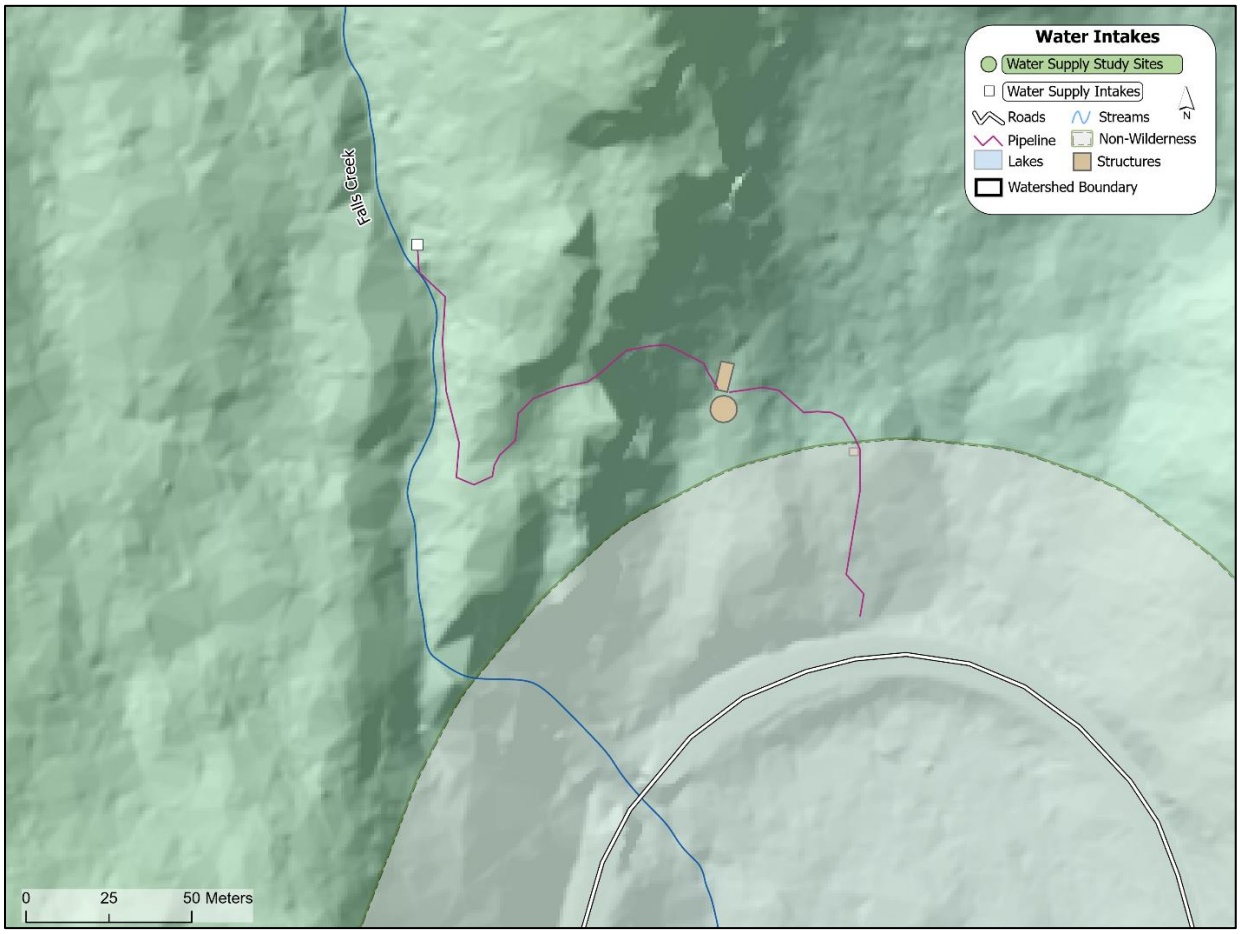

Figure A-1. Map of Stevens Canyon Entrance water supply system on Falls Creek relative to wilderness boundary.

Appendix B: Map of White River Entrance Water Supply System

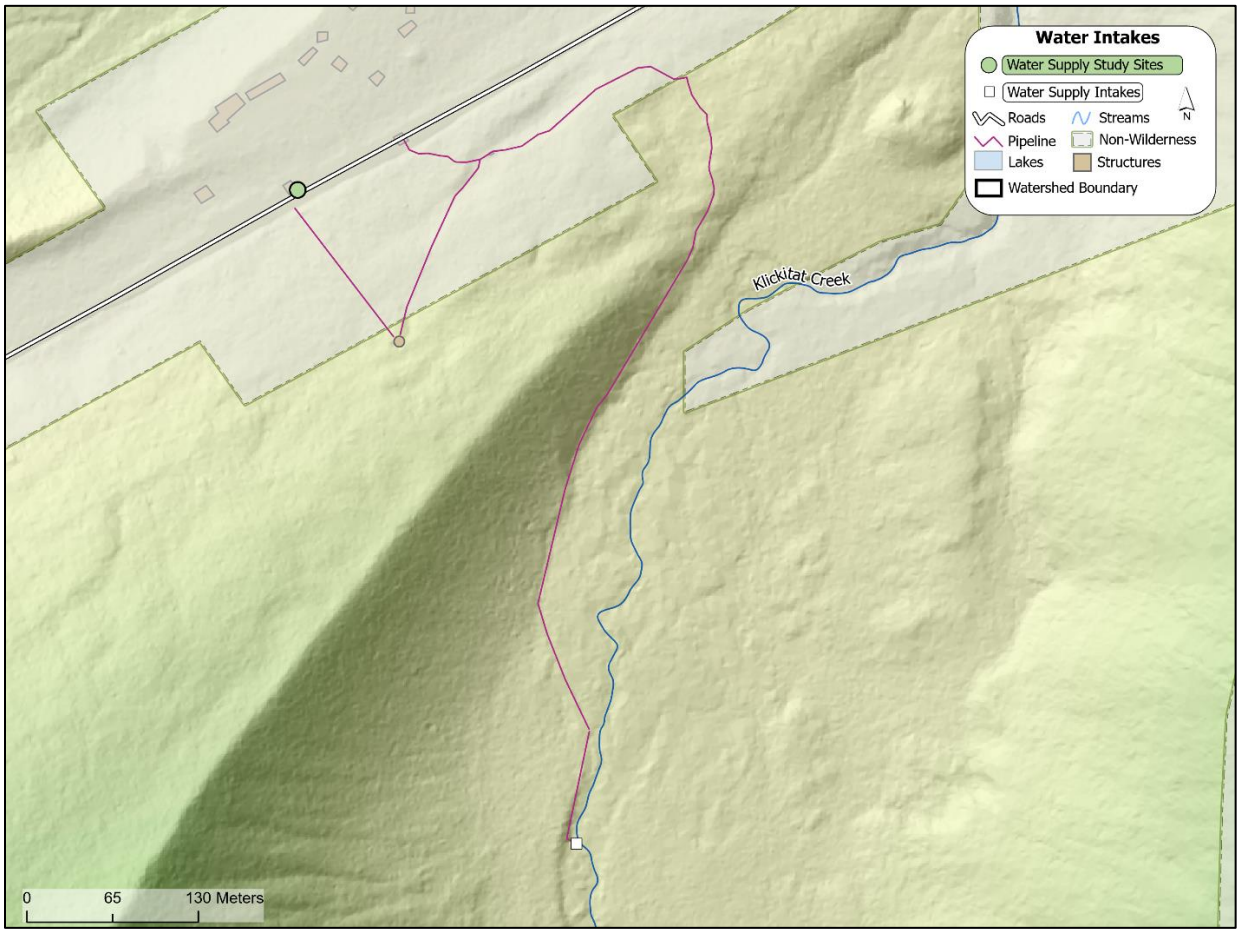

Figure B-1. Map of White River Entrance water supply system on Klickitat Creek relative to wilderness boundary.

Appendix C: Annual Bull Trout Redd Counts for Selected Streams in the White River Watershed

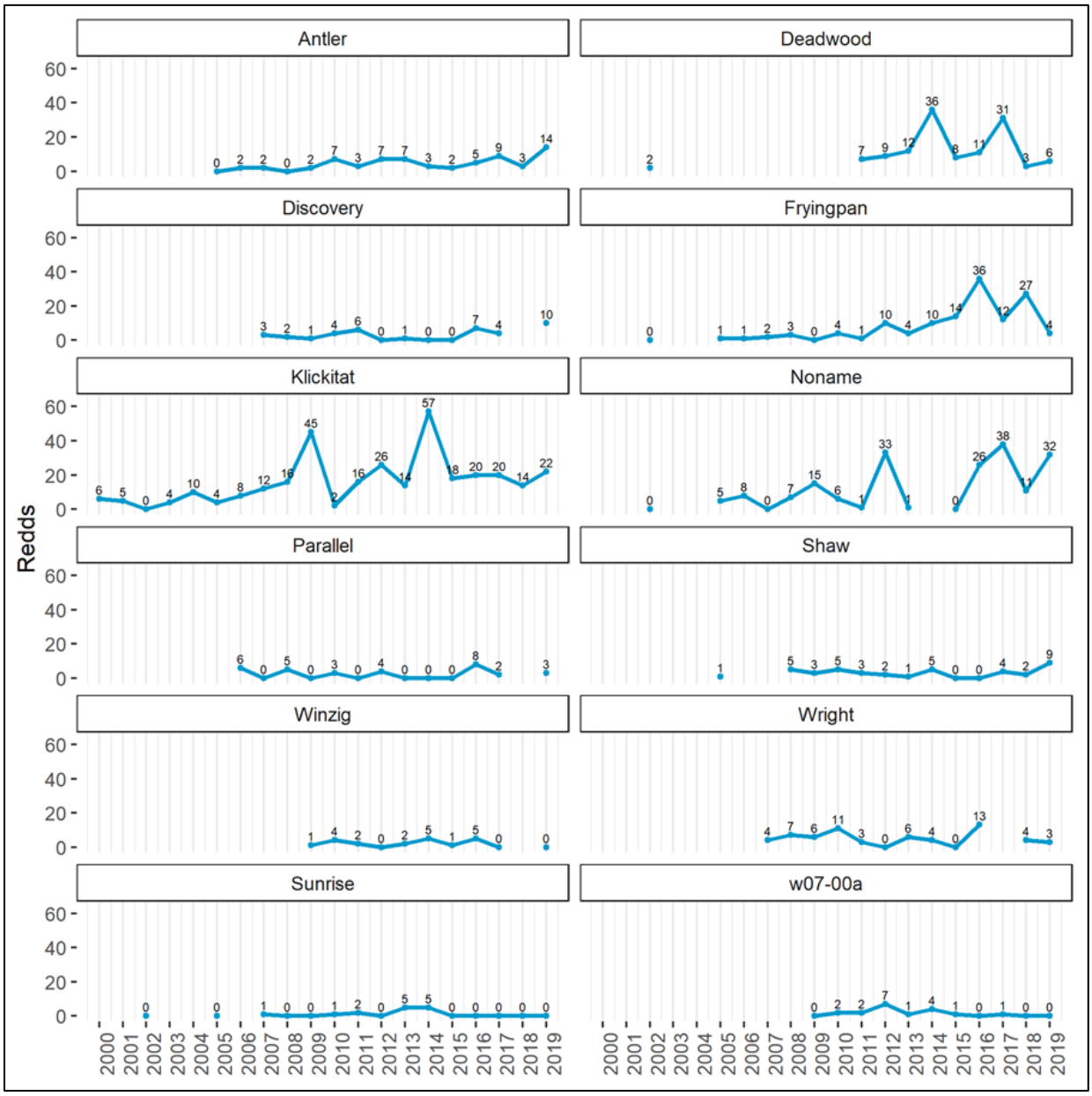

Figure C-1. Annual bull trout redd counts (2000-2019) for selected streams in the White River watershed.

Appendix D: Frozen Lake Bathymetry

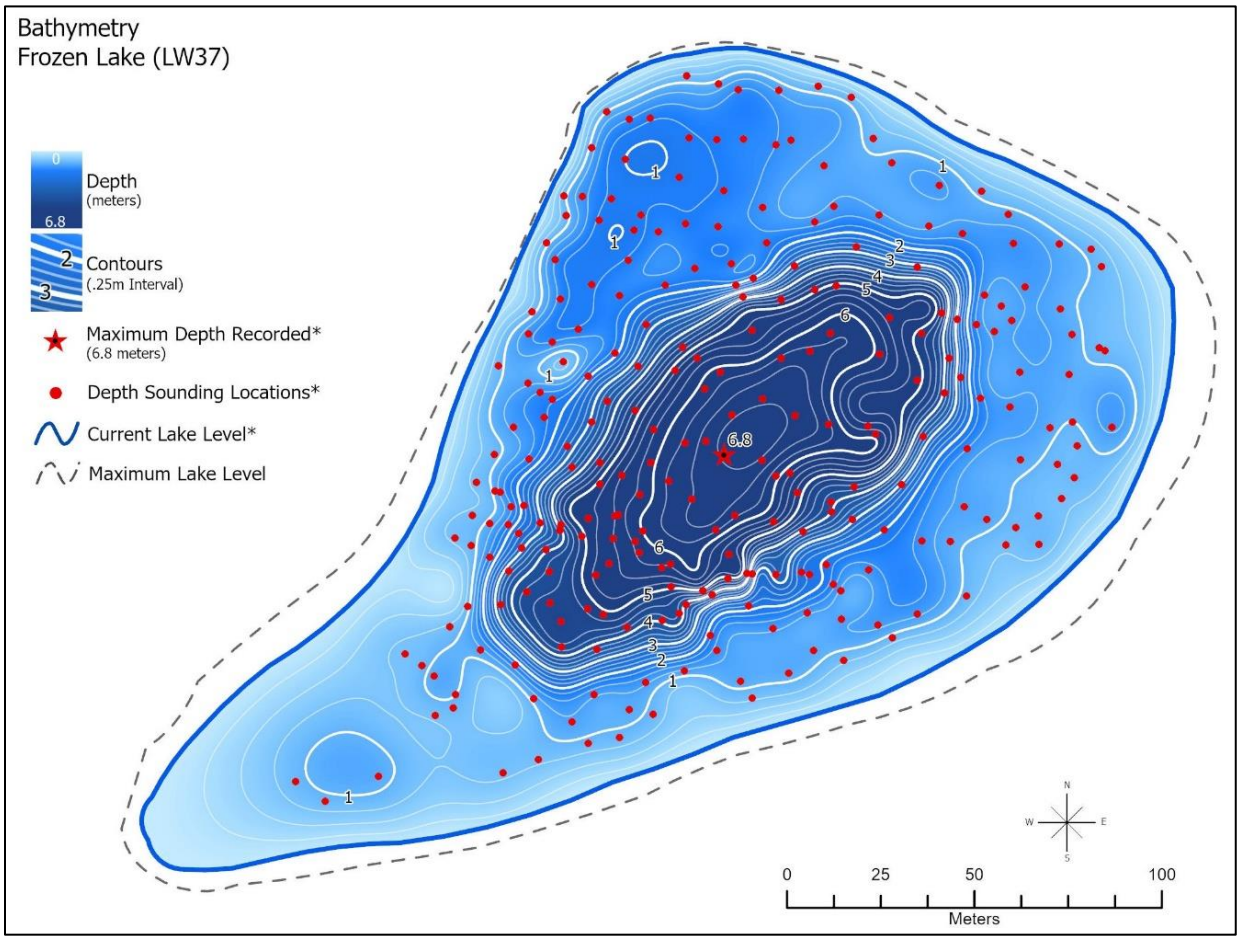

Figure D-1. Frozen Lake bathymetry measured in 2020. At maximum lake level, modeled volume is approximately 37,240 cubic meters (1,315,139 cubic feet).

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