U.S. Fish and Wildlife Service

Columbia-Pacific Northwest Region

Warm Springs National Fish Hatchery
Climate Change Vulnerability Assessment
Final Report: August 2021

U.S. Fish and Wildlife Service

Columbia-Pacific Northwest Region

Climate Change Vulnerability Assessment Team

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The following individuals from the USFWS's Hatchery Evaluation Team (HET) for Warm Springs National Fish Hatchery (NFH) assisted with the preparation of this report: Michael Clark (Manager, Columbia River Gorge NFH Complex); Terry Freije (Manager, Warm Springs NFH); David Thompson and Katie Royer (USFWS Fish Health Program); David Hand, Doug Olson (ret.), and Jeremy Voeltz (Columbia River FWCO).

The following representatives from the Branch of Natural Resources of the Confederated Tribes of the Warm Springs Reservation of Oregon contributed to the adaptive capacity section of this report: Chris Brun, Alex Bybel, Ryan Gerstenberger, Lyman Jim, Mark Manion, and Ron Suppah.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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I. SUMMARY

Purpose and need

The U.S. Fish and Wildlife Service (USFWS) is assessing the vulnerability of its National Fish Hatcheries (NFHs) in Washington, Oregon, and Idaho in response to projected future climates. The Assessment Team has completed climate change vulnerability assessments (CCVAs) for Winthrop NFH (USFWS 2013), Quilcene NFH (USFWS 2016), and Makah NFH (USFWS 2018).[1] These assessments are focused on NFH vulnerabilities at the hatchery and local watershed levels and are motivated by long-term trends in climate and the increased likelihood of extreme weather events that could significantly affect USFWS programs and hatcheries in the Columbia-Pacific Northwest Region. Other agencies are evaluating climate change vulnerabilities of anadromous salmonid fishes in the marine environment and freshwater migration corridors.[2] The report presented here represents the USFWS's CCVA for Warm Springs NFH in central Oregon.

Definitions

A vulnerability assessment consists of four key components: sensitivity, exposure, impact, and adaptive capacity.

Sensitivity is the degree to which a system or species is likely to be affected by an environmental disturbance. ***Exposure*** is the magnitude or degree to which a system or species is expected to be subjected to an environmental disturbance. ***Impact*** is the combination of sensitivity and exposure of a system or species to an environmental disturbance. ***Adaptive capacity*** is the existing ability of a system or species to adjust to the impact of an environmental disturbance. ***Vulnerability*** of a system or species is an *impact* that cannot be adequately addressed by existing *adaptive capacity*.

Background and methods

Warm Springs NFH is located at river mile (RM) 10.0 of the Warm Springs River, a tributary to the Deschutes River near Madras, Oregon at RM 85 upstream from the Columbia River. The hatchery began operation in 1978 on reservation land leased from the Confederated Tribes of the Warm Springs Reservation in Oregon (CTWSRO).

The Warm Springs River is currently the only source of water for fish culture at Warm Springs NFH. Water is supplied to the hatchery via pumps. Water delivered to the hatchery building

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[1] Completed vulnerability assessment reports for National Fish Hatcheries in the Columbia-Pacific Northwest Region are available for download at: https://www.fws.gov/pacific/fisheries/CC%20Vulnerability%20Analyses/CCVulnerabilityIndex.cfm .

[2] Information regarding climate vulnerability assessments by NOAA Fisheries can be found at: https://www.fisheries.noaa.gov/feature-story/west-coast-salmon-vulnerable-climate-change-some-show-resilience-shifting-environment .

(egg incubation and fry nursery tanks) is filtered via sand filters, then chilled or heated - if needed - depending on river water temperature. Similarly, water supplied to adult holding ponds is filtered and chilled when adults are present in the late spring and summer. Water supplied to outside raceways is not filtered or chilled. The Warm Springs River can become very turbid and silt-laden during very high flows and can reach temperatures greater than 70 °F (21 °C) during summer.

Warm Springs NFH propagates a native population of Spring Chinook Salmon (*Oncorhynchus tshawytscha*) derived originally from adults trapped in the Warm Springs River. Adult salmon returning to Warm Springs NFH must migrate upstream from the Pacific Ocean approximately 300 miles and must pass over two Columbia River hydropower dams, Bonneville Dam and The Dalles Dam. The site elevation of the hatchery is 1,525 feet above sea level.

The vulnerability assessment described here was based on climate projections for the 2040s and information provided by the NFH staff and the USFWS's Hatchery Evaluation Team (HET).[3] We used baseline historical data for Warm Springs NFH to assess the *Sensitivity* of the hatchery and Spring Chinook Salmon to potential future changes in air temperature, precipitation, and surface and ground water temperature and availability. Climate projections for the 2040s were derived from downscaled temperature, precipitation, and hydrologic projections in the Warm Springs River basin based on an ensemble of 10 General Circulation Models (GCMs)[4], the A1B emission scenario (IPCC 2007; UW-CIG[5]), and the Variable Infiltration Capacity (VIC) hydrologic model of (Liang et al. 1994; as described by Mantua et al. 2010). The outputs of those models for the 2040s represent the *Exposure* of Warm Springs NFH to projected future climate.

We used the climate and hydrology projections, empirical data on recent fish culture conditions at Warm Springs NFH, and the fish growth model of Iwama and Tautz (1981) to predict future mean body size and total biomass of Chinook Salmon at the hatchery each month during the freshwater life history phase. We then derived future water *flow index* (FI) and fish *density index* (DI) values for the cultured fish based on in-hatchery environmental conditions projected for the 2040s. We used those indexes to assess the *Impacts* of future climate to Chinook Salmon propagated at Warm Springs NFH and to the infrastructure of the hatchery. We then used expert opinions from the HET, NFH staff, and biologist/managers from the CTWSRO to assess the

[3] The Hatchery Evaluation Team consists of the hatchery manager and other technical staff of the USFWS who coordinate activities at a hatchery including, but not limited to, (a) scheduling of major activities, (b) biosampling of fish and tissues for fish health and other assessments, and (c) marking and tagging of juvenile fish prior to release.

[4] GCMs are large, three-dimensional mathematical models that incorporate the latest understanding of the physics, fluid motion, chemistry and other physical processes of the atmosphere to simulate weather and climate globally.

[5] Climate projection data were obtained from the Climate Impacts Group, University of Washington, Seattle, Washington at the following website: http://warm.atmos.washington.edu/2860/ .

Adaptive Capacity and *Vulnerability* of Warm Springs NFH to the future climate projected for the 2040s.

Sensitivity of Warm Springs NFH: main points

- Warm Springs NFH is especially sensitive to high water temperatures and disease risks during the late spring and summer. Spring Chinook Salmon at Warm Springs NFH are particularly sensitive to Ich and Columnaris disease during the summer as subyearlings and Bacterial Kidney Disease (BKD) the following spring as yearlings prior to release into the Warm Springs River.
- Warm Springs NFH is sensitive to sustained low temperatures below freezing during winter when anchor ice forms on the water intake screen and surface ice forms in the outside raceways.
- Warm Springs NFH is sensitive to very low flows of the Warm Springs River during summer when water flows into the sump basin may be insufficient to meet the water demands of the hatchery.
- Warm Springs NFH, particularly the room housing the pumps and sump basin, is considered sensitive to very high surface flows and flood risks from the Warm Springs River.
- The physical facilities and infrastructure of Warm Springs NFH are sensitive to wildfire risks. These risks have increased in recent years because of droughts and generally warmer air temperatures along the east slope of the Cascade Mountains.

Exposure of Warm Springs NFH to future climate: main points

- Surface water temperatures of the Warm Springs River are expected to be higher in all months in the 2040s compared to the historic average. Mean annual water temperatures at the hatchery intake are projected to increase by 1.3 °C (2.3 °F) with (a) monthly increases of 1.0 – 1.7 °C (1.8 – 3.1 °F) and (b) mean temperatures during July and August in excess of 18.4 °C (65.1 °F).
- Total annual and mean monthly precipitations in the 2040s for the Warm Springs River basin are projected to be largely unchanged from historic values. However, substantially more precipitation will fall as rain and substantially less precipitation will fall as snow, with a projected 62% reduction in peak *snow water equivalent* (SWE) in March and a 65% reduction in mean monthly snowpack.
- Mean *annual* flows projected for Warm Springs River in the 2040s will be similar or slightly higher than the modeled historic values. However, the shape of the modeled hydrograph for the 2040s is projected to be quite different from the historic average with substantially higher mean flows in winter, a shift in peak mean flows from March to January, and substantially lower flows in May and June. The magnitude of the lowest flows during the summer and early fall are projected to decrease slightly from historic levels.

- The magnitude of 20-year, 50-year, and 100-year peak flows are expected to increase substantially with mean projected 50-year and 100-year peak flows exceeding 9,000 and 10,000 cfs, respectively. Three of 10 GCM models projected 100-year peak flows greater than 12,000 cfs.
- Overall, the Warm Springs River basin will most likely transition from primarily a snowmelt-driven watershed to a mixed snow-and-rain-driven watershed with substantial increases in peak flows in winter and lower base flows in summer.

Impact of future climate to Warm Springs NFH: main points

- Increasing water temperatures of the Warm Springs River through the 2040s will challenge Spring Chinook Salmon biologically and may lead to significant physiological stress at several life history stages.
- Higher water temperatures are expected to further increase disease risks in the future, particularly to juvenile salmon during the summer months (Columnaris, Ich), smolts prior to release (BKD), and adult broodstock held on station prior to spawning (parasitic infections of *Ceratonova shasta*).[6]
- Higher water temperatures are projected to increase growth rates of Spring Chinook Salmon such that smolts, on average, will be 36.6% heavier and 10.8% longer at release compared to historic sizes.
- While flow and density indexes projected for the 2040s are still within the fish health guidelines recommended for Spring Chinook Salmon at Warm Springs NFH (FI < 0.6; DI < 0.15), density index values during the summer months will exceed the more stringent guideline of DI < 0.1 recommended for those months at Warm Springs NFH.
- Transition of the Warm Springs River from primarily a snowmelt-driven watershed to a mixed snow-and-rain-driven watershed is expected to significantly increase flood risks to Warm Springs NFH by the 2040s.
- Higher mean air temperatures during the spring and summer, coupled with reduced snowpack and little change or slight decreases in mean monthly precipitation, are expected to increase fire risks to Warm Springs NFH through the 2040s and beyond.

Adaptive capacity of Warm Springs NFH: main points (options)

The Workgroup composed of the Assessment Team, the HET for Warm Springs NFH, and biologist/manager representatives of the CTWSRO identified the following adaptation strategies and options. Adaptations indicated by an asterisk (*) would require large monetary investments for which funding would need to be identified.

[6] The adult holding pond at Warm Springs NFH was recently rebuilt with the capability to chill water down to approximately 10 °C (50 °F). This recent modification reduces projected impacts to adult broodstock substantially.

- *Build a Partial Reuse-Water Aquaculture System (PRAS) equipped with chilling and UV disinfection at Warm Springs NFH so that juvenile Spring Chinook Salmon can be maintained on station from late spring through early fall.
- *Add mechanical filtration and UV sterilization (or ozonation) to the existing flow-through raceway system to reduce disease risks associated with warm water temperatures.
- Maintain Warm Springs NFH as an adult collection and smolt release facility for Spring Chinook Salmon, but rear the juveniles off station at another NFH with a year-round cool-water supply.
- *Same as the preceding bullet but rear the juveniles off-station at a new facility constructed at a location with a cool water source (a) in the upper Warm Springs River watershed or (b) on the mainstem Deschutes River.
- *Improve or replace the water intake structure to ensure an adequate water supply to the hatchery during the projected low-flow months of summer and early fall.[7]
- *Install an Obermeyer gate in the existing weir and/or construct an earthen berm around the hatchery to reduce flood risks to the hatchery during projected high flows of the Warm Springs River in winter.
- Implement one or more fire-safety measures in addition to those already in place.

Vulnerability of Warm Springs NFH: main points

Vulnerabilities were identified and assessed according to the ability and uncertainty to successfully implement the adaptive capacity measures identified by the Workgroup.

- Spring Chinook Salmon at Warm Springs NFH are highly vulnerable to the future impacts of climate change, due primarily to warmer water and lower flows of the Warm Springs River during summer when juveniles are reared in outside raceways. Those climate changes will also increase vulnerability to disease.
- The vulnerabilities of adult Spring Chinook Salmon in the migration corridor in the late spring and early summer, particularly in the Warm Springs River, are largely unknown and a major uncertainty.
- Warm Springs NFH may be highly vulnerable to future floods of the Warm Springs River if adaptive measures are not implemented.

Biological and environmental uncertainties

The vulnerability assessment presented here does not address two major uncertainties: (1) the effect of climate change on marine ecosystems and the *migration corridor* of the Columbia and Deschutes rivers, from the Pacific Ocean to the Warm Springs River, and (2) the future epidemiology of fish pathogens and disease under the climates projected for the 2040s. Both factors could greatly affect the ability of all hatcheries in the Columbia River Basin and other

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[7] Replacement of the water intake structure is already planned because the current water intake structure is prone to damage during high flows of the Warm Springs River.

regions of the Pacific Northwest to propagate Pacific salmon and Steelhead (*Oncorhynchus* spp.) through the 21st Century.

Conclusions

1. The projected effects of climate change will most likely preclude the future rearing of Spring Chinook Salmon at Warm Springs NFH unless adaptive measures are implemented that reduce those vulnerabilities.
2. Major new construction at Warm Springs NFH will likely be necessary to maintain juvenile Spring Chinook Salmon on station from late spring through early fall in the 2040s. Chilling with some form of water disinfection for the outside raceways will likely be necessary to prevent lethal temperatures and disease outbreaks.
3. Warm Springs NFH may be able to continue its current role as an adult collection and smolt-release facility for Spring Chinook Salmon in the 2040s if juveniles are reared elsewhere, either at another NFH with a cool water supply or at new facilities constructed in the upper Warm Springs River watershed or on the mainstem Deschutes River.
4. Warm Springs NFH appears to be highly vulnerable to future flood risks because of a major shift in hydrology from primarily a snowmelt-driven watershed to a mixed rain and snowmelt-driven watershed.
5. Wildfire risks from late spring through early fall are expected to increase through the 2040s and beyond.
6. Major uncertainties exist regarding the ability of adult Spring Chinook Salmon to ascend the Warm Springs River in the 2040s because of higher water temperatures and a temporal shift in peak flows from spring to winter. As a result, a mismatch exists between current return timing of Spring Chinook Salmon in the Warm Springs River and projected flows in the 2040s.

Recommendations

1. In the near term, develop a standard operating procedure (SOP) for rearing juvenile Spring Chinook Salmon at another hatchery with a cooler water supply. Transfers of fish for rearing at another hatchery would best occur at the eyed egg stage.
2. Implement proactive measures to reduce flood risks at Warm Springs NFH. Construction of an earthen berm around the hatchery and/or a flow gate in the existing weir structure may be desired.
3. The Assessment Team has no preferred recommendations for potential construction of new facilities for maintaining juvenile Spring Chinook Salmon within the Warm Springs or Deschutes River watersheds. Three alternative adaptation strategies are presented: (1) construction of a PRAS at Warm Springs NFH; (2) construction of new rearing facilities in

the upper Warm Springs River watershed; and (3) construction of new facilities on the Deschutes River.

4. Ensure that a wildfire-response protocol manual is developed and available to all staff at Warm Springs NFH. The manual should include procedures for emergency fish release, fire suppression, and emergency evacuation of personnel.

II. INTRODUCTION

The U.S. Fish and Wildlife Service (USFWS) in the Columbia-Pacific Northwest Region operates 13 National Fish Hatcheries (NFHs) that annually release more than 60 million juvenile Pacific salmon and Steelhead (*Oncorhynchus* spp.)[8] in the Columbia River basin and Olympic Peninsula (USFWS 2009). Collectively, more than 150 State, Tribal, Federal, and Provincial fish hatcheries in Oregon, Washington, and British Columbia annually release more than 100 million juvenile salmon and Steelhead (ODFW 2011). Fisheries supported by these hatcheries generate billions of dollars in economic activity annually (Lichatowich and McIntyre 1987; Caudill 2002).

Despite the biological, economic, and cultural significance of hatchery-origin fish, little attention has been spent, until recently, assessing how future trends in climate will affect hatchery operations in the Pacific Northwest (Hanson and Ostrand 2011). Higher stream temperatures, earlier timing of snowmelt runoff, and reduced snowpack have been observed in recent years in the western U.S. (Kaushal et al. 2010; Luce and Holden 2009; Mote et al. 2008). Continuing thermal and hydrologic changes are projected to accelerate in coming decades (IPCC 2007) thereby affecting water quality and quantity within river basins in the Pacific Northwest (Mote and Salathé 2010; Mantua et al. 2010; Elsner et al. 2010). As a result, a clear need exists to understand how future environmental conditions may constrain the ability of NFHs to meet their fish propagation objectives, treaty obligations, and conservation goals. Robust and transparent evaluations are needed for (a) identifying facility and program-specific impacts and vulnerabilities to climate change and (b) developing adaptation and mitigation strategies to cope with those expected impacts and vulnerabilities.

In response, the USFWS is assessing the effects of climate change on the future viability of fish and wildlife resources under its federal jurisdiction. These efforts include identification of specific mitigation, engagement, and adaptation priorities (USFWS 2010a, b, c). One of the USFWS's priorities is the development of *climate change vulnerability assessments* (CCVAs) for species and habitats under federal jurisdiction including National Wildlife Refuges and National Fish Hatcheries.

In 2011, all NFHs in the United States underwent *qualitative* CCVAs based on a standardized spreadsheet template (Appendix A). The USFWS subsequently identified the need for *quantitative* CCVAs derived from scientific assessments of future modelled climates (USFWS 2010a, b). The Columbia-Pacific Northwest Region of the USFWS has responded to this priority by developing a strategy and plan for using downscaled, future climate projections at the local watershed level to assess, quantitatively, the vulnerability of 13 NFHs and their respective

[8] Pacific salmon refers collectively to five species of salmon of the genus *Oncorhynchus* native to the Pacific coast of North America: Chinook, Coho, Chum, Pink, and Sockeye Salmon. Steelhead are the anadromous form of rainbow trout, *Oncorhynchus mykiss*.

culture programs. Winthrop NFH in the upper Columbia River basin was chosen as the pilot assessment (USFWS 2013) followed by assessments at Quilcene NFH (USFWS 2016) and Makah NFH (USFWS 2019) on the Olympic Penninsula.[9]

The report presented here describes the results of the USFWS's quantitative CCVA for Warm Springs NFH and the one species propagated there: Spring Chinook Salmon (*O. tshawytscha*).[10] Warm Springs NFH is located at river mile (RM) 10.0 of the Warm Springs River, a tributary to the Deschutes River near Madras, Oregon on the east side of the Cascade Mountains in the Columbia River Basin (Figure B1, Appendix B).

III. METHODOLOGIES

A. Assessing future climate

Episodic environmental events (droughts, floods, wildfires, summer heatwaves, etc.) have occurred historically throughout the Pacific Northwest. Since the 1970s, our scientific understanding of the relationships of these events to global oceanic and atmospheric conditions has increased substantially. For example, winters in the Pacific Northwest tend to be warmer and dryer than average during *El Niño* events when sea surface temperatures (SSTs) in the equatorial eastern Pacific Ocean are significantly warmer than average. Conversely, winters in the Pacific Northwest tend to be cooler and wetter than average during *La Niña* events when SSTs in the equatorial eastern Pacific Ocean are significantly cooler than average. In the Pacific Northwest, summer drought conditions are more likely during an *El Niño*, while winter/spring floods are more likely during a *La Niña*.

More recently, functional relationships among atmospheric chemistry, heat retention by the atmosphere, mean air temperatures and precipitation have been established (IPCC 2007; 2014). Physics-based, thermodynamic *General Circulation Models* (GCMs) of global atmospheric temperatures and precipitation have been developed that quantify those relationships mathematically.[11] As a result, dynamic changes or trends in atmospheric parameters (e.g., mean concentration of carbon dioxide in the atmosphere, solar radiation intensity, etc.) can be modelled forward in time to project expected mean values for air temperature and precipitation at

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[9] Completed CCVA reports for NFHs in the Columbia-Pacific Northwest Region are available at: https://www.fws.gov/pacific/fisheries/CC%20Vulnerability%20Analyses/CCVulnerabilityIndex.cfm.

[10] Chinook Salmon are usually characterized by the time of year when adults enter freshwater to spawn. The Columbia River historically supported three seasonal "runs" of Chinook Salmon: fall-run, spring-run, and summer-run representing the time of the year when adults returned to freshwater and were available for harvest. Juvenile Spring Chinook Salmon in the Columbia River Basin rear in freshwater for approximately 18 months prior to smolting and outmigrating to the Pacific Ocean. In contrast, juvenile Fall Chinook and Summer Chinook Salmon rear in freshwater for only about six months prior to smolting and outmigrating.

[11] GCMs are large, three-dimensional mathematical models that incorporate the latest understanding of the physics, fluid motion, chemistry and other physical processes of the atmosphere to simulate weather and climate globally. They are often referred to colloquially as Global Climate Models.

both global and regional scales. Such projections can then be used by government agencies, the private sector, other organizations, and individuals to assess the vulnerability of natural resources and physical infrastructures to future climate conditions and extreme environmental events.

B. Vulnerability assessments: An introduction to concepts

The vulnerability of a species or system to an environmental change can be thought of as a function of four key factors: sensitivity, exposure, impact and adaptive capacity (Figure 1).

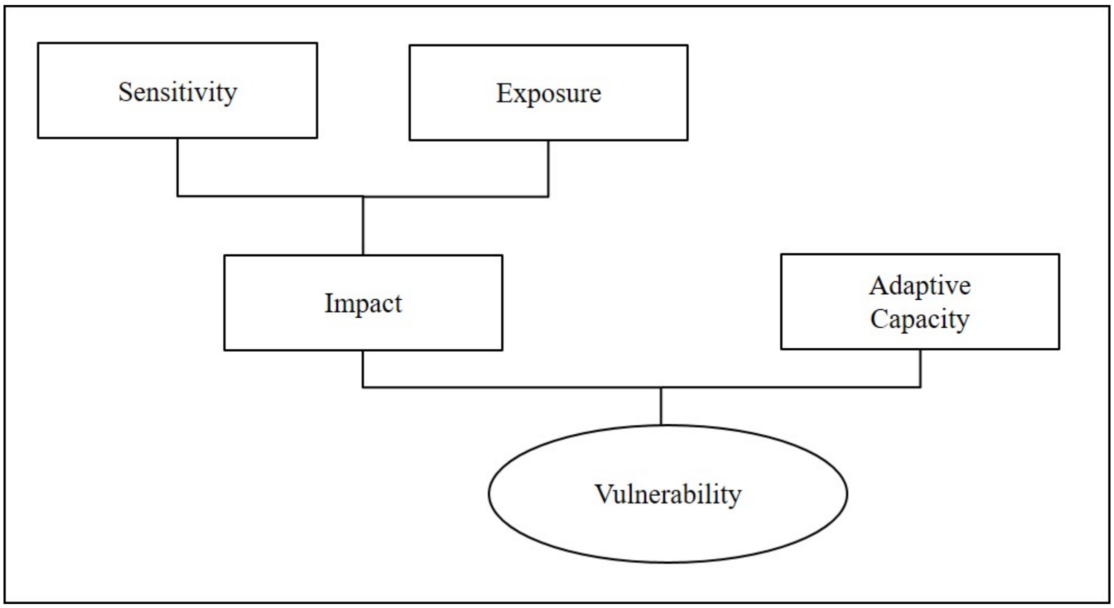

Figure 1. Key components of a vulnerability assessment.

Sensitivity is the degree to which a system or species is likely to be affected by an environmental disturbance like climate change. For example, a hatchery currently lacking adequate water during the summer months would be highly sensitive to prolonged periods of low summer flow conditions. We assess sensitivity here in terms of (a) future stressors to the water supply and infrastructure at Warm Springs NFH and (b) the current biomass capacity and productivity limitations of rearing Spring Chinook Salmon to the smolt age of development at Warm Springs NFH.

Exposure is the magnitude or degree to which a system or species is expected to be subjected to an environmental disturbance like climate change. We describe the climate change exposure anticipated in the Warm Springs River basin and the Warm Springs NFH based on downscaled climate projections for the 2040s.

Impact is the combination of sensitivity and exposure of a system or species to an environmental disturbance like climate change. To achieve a quantitative understanding of potential climate change impacts to the Spring Chinook Salmon program at Warm Springs NFH, we developed biological models that describe how fish growth and associated culture indices (density index and flow index) may change due to future projected changes in climate.

Adaptive capacity is the current ability or capacity of a system or species to adjust to the impact of an environmental disturbance like climate change. As part of our assessments, we considered adaptive strategies that could potentially mitigate for the future effects of climate change; however, we did not directly assess the practicality and economic cost of employing those adaptive strategies.

Vulnerability of a system or species represents future impacts of an environmental disturbance like climate change that cannot be adequately addressed by adaptive capacity. We describe climate change vulnerabilities as the impacts to the Spring Chinook Salmon program at Warm Springs NFH and hatchery infrastructure that, most likely, cannot be adequately addressed by existing adaptive capacity.

At a local (individual hatchery) level, a clear understanding of the future vulnerabilities of a NFH program to changes in climate can provide managers and biologists with the information necessary to plan for future demands and stressors as well as an ability to determine the most appropriate management direction. At the regional level (across NFHs and programs), this understanding allows resources to be more effectively allocated in a proactive manner rather than reactive in nature. A robust vulnerability assessment provides resource managers and stakeholders with the information needed to understand which NFHs and programs are most vulnerable to climate change. That understanding is expected to lead to discussions among parties as how best to address identified vulnerabilities.

NFH Vulnerability Assessments help determine:

- Which regional programs and species will be most affected by climate change.
- What aspects of a NFH's facilities and programs will be most affected by climate change.
- Why specific hatchery programs/species are most vulnerable to climate change.

This information will allow us to determine the most appropriate management response to climate change now and in the future.

NFH Vulnerability Assessments help us to:

- Establish practical/informed management and planning priorities (e.g., *What should we be doing differently?*).
- Inform adaptation planning (e.g., *What do we need to accomplish so we can continue to meet our goals?*).
- Efficiently allocate resources (e.g., *What resources do we need to obtain and how are they best distributed?*).

C. Assessment process

A NFH Climate Change Vulnerability Assessment Team (Assessment Team) was created to develop a process for assessing the projected future impacts of climate change on Columbia-Pacific Northwest Region NFH facilities and programs. This process, as described here, (a) allows assessments of individual facilities and culture programs and (b) complements existing planning and management efforts. This assessment process has three steps.

1. Outputs from an ensemble of ten GCMs are downscaled to the river basin of interest to project mean monthly air temperatures and precipitation quantities over the entire watershed for the period of interest (2040s). A hydraulic model is then coupled to the temperature and precipitation projections to obtain mean monthly surface water temperatures and flows (cubic feet per second, or cfs) at the vicinity of the hatchery (Appendix B).
2. Fish growth at the hatchery is modeled mathematically based on the projected water temperatures of the culture water derived from the climate change projections and watershed-specific hydrologic data. Species-specific biological parameters for fish growth and temperature sensitivities are combined with operational information at the hatchery to assess the exposure and future impacts of climate change to facilities and fish culture programs (Appendix B).
3. A team of experts – including NFH staff and the USFWS's Hatchery Evaluation Team (HET) for the hatchery – work collaboratively with relevant co-managers and partners to assess projected impacts that will likely impede the ability of a hatchery and its programs to meet their goals and then identifies possible adaptive measures. Ultimately, impacts with little or no adaptive capacity are vulnerabilities for the NFH.

IV. BACKGROUND[12]

A. Warm Springs River watershed

Warm Springs NFH is located at RM 10.0 of the Warm Springs River, approximately 14 miles north of the town of Warm Springs, Oregon (Figure 2). The Warm Springs River flows east into the Deschutes River at RM 85 near Madras, Oregon. The Deschutes River flows north, draining the northeast slope of the Cascade Mountains in Oregon, and enters the Columbia River at RM 206 near Biggs, Oregon. Adult fish returning to Warm Springs NFH must migrate upstream approximately 300 miles from the Pacific Ocean and ascend two Columbia River hydropower dams, Bonneville Dam and The Dalles Dam. The site elevation of the hatchery is 1,525 feet above sea level.

[12] Additional details regarding Warm Springs NFH and its hatchery programs can be found in the USFWS hatchery review report (USFWS 2006, 2013).

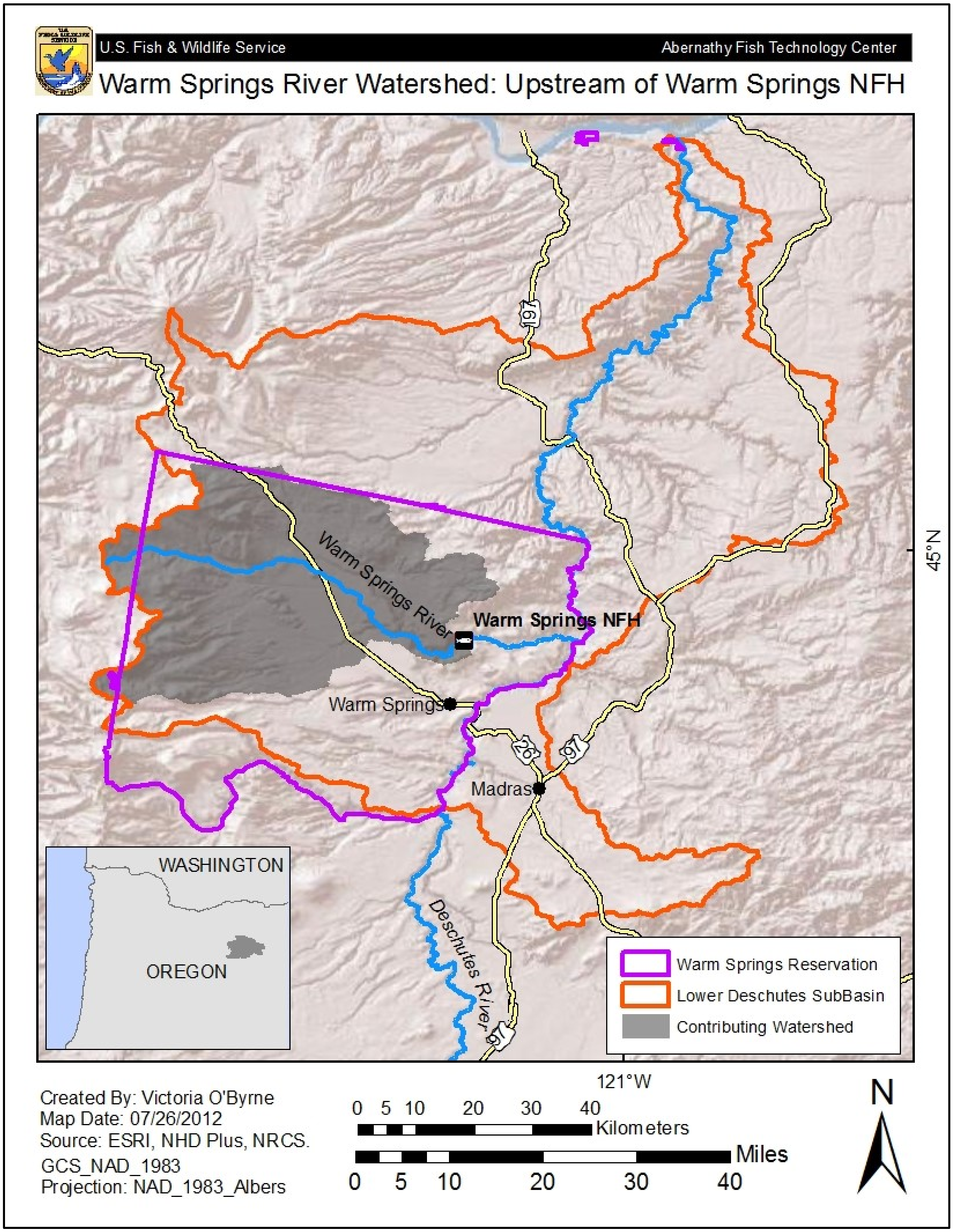

Figure 2. Location of the Warm Springs River watershed within the Deschutes River basin. Warm Springs National Fish Hatchery is located at river mile (RM) 10.0 of the Warm Springs River. The Deschutes River enters the Columbia River at RM 206 near Biggs, Oregon.

B. Warm Springs NFH infrastructure

Warm Springs NFH was authorized by Congress in 1966 and began operation in 1978. The hatchery is operated by the USFWS on reservation land leased from the Confederated Tribes of the Warm Springs Reservation in Oregon (CTWSRO). The hatchery includes a concrete barrier weir with a fish ladder, adult catch ponds for trapping broodstock, and a fish bypass channel/gate that can be operated manually to shunt fish upstream without physical handling. The hatchery includes pumps with sand filters and a UV sterilizer for supplying river water to the adult holding ponds and to the hatchery building for egg incubation and early rearing of hatched fry. Hatched fry are reared initially in 20 indoor nursery tanks prior to ponding in 30 outdoor raceways (modified Burrows raceways/ponds). Additional details are described in Appendix C.

C. Water resources at Warm Springs NFH

The Warm Springs River is the only source of water for fish culture at Warm Springs NFH. A well provides domestic water to the hatchery and residences on station.

Warm Springs River

Annual water temperatures of the Warm Springs River range widely from 0 °C in winter (32 °F) to 26 °C (78 °F) in summer. Air temperatures below -18 °C (0 °F) have been recorded at the hatchery and have, on occasion, remained substantially below freezing for several consecutive days.[13] Under those conditions, anchor ice can form on the debris screen bars to the water intake, thereby reducing water availability to hatchery. Hatchery staff maintain water flow into the hatchery by (a) the use of floating pumps that can draw deeper water that is ice-free and (b) spraying heated water (4 – 7 °C [40 – 45 °F]) on to the screen bars to reduce ice build-up. Despite those measures, at least one pump has been shut down in the past to prevent cavitation during icing conditions. Metabolic and water demands for salmon are much reduced at water temperatures near freezing, and hatchery staff have maintained fish during harsh winter conditions via reduced feeding and ice removal measures.

At the other extreme, water temperatures greater than 22 °C (72 °F) are common at Warm Springs NFH during the summer months and have reached as high as 26 °C (78 °F) as occurred during the summers of 2015 and 2016.

The magnitude of daily fluctuations in water temperature between morning and evening during the summer is particularly problematic. For example, during the summer of 2015, mean daily

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[13] On March 4, 1999, a tanker truck overturned on an icy highway (Highway 26) upstream of Warm Springs NFH and spilled over 2,000 gallons of gasoline into Beaver Creek, a tributary to the Warm Springs River (https://darrp.noaa.gov/warm-springs-river). In response, emergency procedures were implemented at the hatchery to prevent massive fish mortalities: yearling Spring Chinook Salmon were released from the hatchery approximately six weeks earlier than scheduled, and over 700,000 subyearling fish were transferred to a State of Oregon hatchery before gasoline reached the hatchery intake. This incident illustrates one indirect effect of sustained sub-freezing temperatures during winter that could be exacerbated or ameliorated by future climates.

water temperatures of the Warm Springs River exceeded 21 °C (70 °F) with daily fluctuations of 17 – 25 °C (63 – 78 °F). The number of hours during the day that water temperatures exceed 20 °C (68 °F) is critical for Spring Chinook Salmon because sustained temperatures greater than those thresholds can quickly lead to disease outbreaks and high mortalities. To prevent such outbreaks during the extreme summers of 2015 and 2016, all fish on station were transferred to Little White Salmon NFH on the Columbia River because this latter hatchery has a substantially cooler water supply.

Similar to water temperatures, flows of the Warm Springs River are highly variable during the course of a year. In summer and early fall, low flows of the Warm Springs River have occasionally reduced water availability to the hatchery. Although the lowest observed flows of the Warm Springs River (170 – 180 cfs) exceed the 100 cfs water right of the hatchery (Table 1), water flows into the sump basin during low flows have not been sufficient at times to prevent cavitation of the main pumps. Conversely, high turbidity and potential flooding can be a problem during very high flows of the Warm Springs River, particularly during rain-on-snow events. Operation of the hatchery depends on the use of sand filters for egg incubation and early rearing of hatched fry in indoor nursery tanks. Under normal operating conditions, each sand filter is backflushed every six to eight hours. However, during high turbidity conditions, filters must be backflushed every six to 12 minutes. Record flows of the Warm Springs River occurred during the winter of 1996 – 1997 when flows approached 10,000 cfs (Figure 3), and the water intake area of the hatchery building became flooded. By comparison, monthly flows of the Warm Springs River normally average 700 – 800 cfs during winter and early spring (Figure B8, Appendix B).

Groundwater

A domestic well on station provides water for the residences and other domestic use at the hatchery. This water is not used for irrigation of lawns or non-domestic uses. On occasion, the well has exhibited reduced flows (recharge rates) during the summer. The recharge rate of the well was measured in October 1991 at 20 gallons per minute (gpm).[14]

Several springs are located in the area around the hatchery. The potential use of those waters as a secondary supply to the hatchery – for either fish culture or domestic use – has not been investigated. Most of the springs are used by local wildlife.

[14] Terry Freije, Manager, Warm Springs NFH, personal communication.

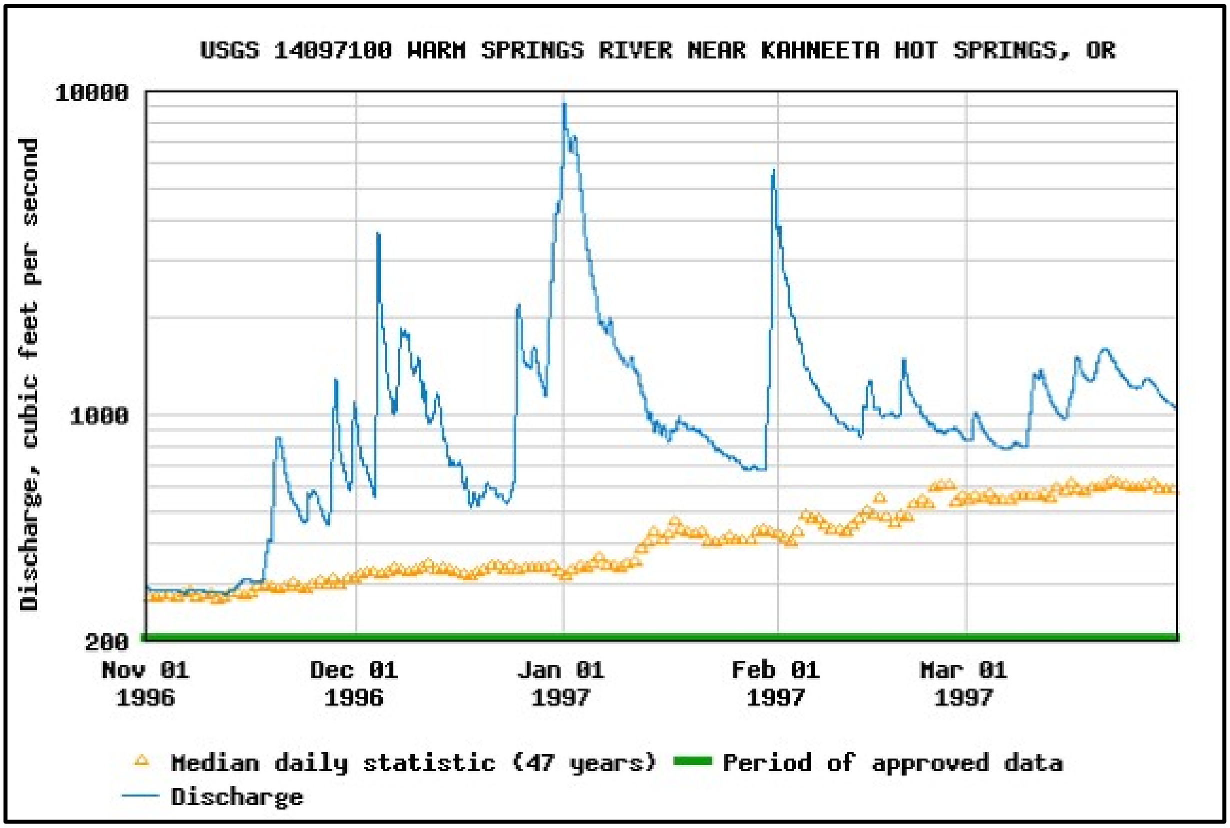

Figure 3. USGS hydrograph of the Warm Springs River during the winter of 1996 – 1997 as measured by the USGS gaging station near Kahneeta Hot Springs on the Warm Springs Reservation, Oregon.[15]

A geothermal exploratory well was drilled approximately 900 feet from the hatchery building in 2016. The measured temperature of the water was 54 C (130 °F). This geothermal water is considered a possible heat source for the nursery building and culture water used in the nursery building, possibly as a replacement for the existing boilers. Those boilers were built in 1973, are difficult to maintain (e.g., obtaining replacement parts), and are powered by electricity which consumes a significant portion of the energy budget for the hatchery. After initial testing, the well was collapsed less than one year after it was drilled, and additional drilling and exploration would be necessary to investigate the potential use of geothermal ground water as a heat source for the hatchery.

Water rights

The vast majority of the Warm Springs River watershed is located within the CTWSRO reservation, and competition for water rights in the basin is largely absent. Warm Springs NFH has water rights to both surface flows and the groundwater well (Table 1). At this time, the only

[15] Figure provided courtesy of Doug Olson, Columbia River Fish and Wildlife Conservation Office, USFWS, Vancouver, Washington.

other water users in the basin are the CTWSRO for minimal agricultural and domestic water purposes.

Table 1. Water rights appurtenant to the Warm Springs NFH and temperature range of sources.

Source	Certificate Number	Purpose of Use	Priority Date	Amount	Temperature Range
Warm Springs River	3552[16]	Fish culture: egg incubation, indoor nursery tanks, outdoor raceways	1993	100 cfs	0 – 26 °C (32 – 78 °F)
Groundwater: 1 well	34384	Domestic: hatchery and residences	1991	20 gpm	17 °C (62 °F)

D. Spring Chinook Salmon program[17]

The Warm Springs Tribes have depended on the annual return of Spring Chinook Salmon to the Warm Springs River for millennia. The current fisheries for Spring Chinook Salmon returning to Warm Springs NFH occur primarily in the lower reach of the Deschutes River (concentrated at Shearer's Falls) and in the lower Columbia River.

Warm Springs NFH has reared and released Spring Chinook Salmon annually since 1978 with native broodstock derived from adult fish trapped in the Warm Springs River. Supplemental fish from Round Butte State Hatchery[18] and Parkdale Tribal Fish Hatchery[19] have been released occasionally from Warm Springs NFH when collection of adult broodstock from the Warm Springs River did not meet program goals. Transferred fish from other hatcheries were differentially marked or tagged prior to release and were not used for broodstock nor were they allowed to pass upstream when they returned as adults to the hatchery.

Adult Spring Chinook Salmon migrating upstream in the Warm Springs River are typically captured for broodstock from early-May through mid-August following a defined schedule that apportions retained adults equitably by return date and weekly percentages based on the return timing of natural origin (NOR) adults. The broodstock retention goal is ~750 adults (450 females, 300 males). A current objective is to include 10 – 20% NOR adults among fish retained for broodstock but only if more than 1,000 NOR adults are forecasted to return to the Warm

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[16] Lease No. 3552 is between the CTWSRO and USFWS for *non-consumptive* use of water from the Warm Springs River for fish culture and domestic use.

[17] Source of information for this section: WSNFH 2019 Annual Operation Plan, prepared jointly by USFWS and the Natural Resources Branch of the CTWSRO. See Appendix E for additional operational details.

[18] The Round Butte Hatchery is operated by the Oregon Department of Fish and Wildlife on the Deschutes River.

[19] The Parkdale Tribal Hatchery is operated by the CTWSRO on the Middle Fork of the Hood River, Oregon.

Springs River. Under this objective, non-retained NOR fish are passed upstream by hatchery staff to spawn naturally. Since 2009, NOR fish have exceeded 1000 adults in only two years (2010 and 2015), and the natural population is currently considered critically depressed with only ~200 NOR adults returning annually in 2017, 2018, and 2019. In addition, pre-spawning mortality of NOR adults has been very high in recent years in the Warm Springs River upstream of the hatchery.

Current fish health protocols specify inoculation with Draxxin and Nuflor[20] of all adults retained for broodstock. Fish are inoculated on the day of arrival or during initial sorting in the capture ponds. Other antibiotics were used prior to 2015 (e.g., erythromycin and oxytetracycline), and fish health protocols have changed over the years in response to changing environmental conditions and other issues. Antibiotic injections of broodstock may be discontinued in the future at the discretion of Warm Springs NFH management and USFWS fish health staff. Historically, NOR adults passed upstream of the hatchery were inoculated with erythromycin but have not been inoculated with any antibiotics since 2005. In addition to antibiotic treatments, formalin is supplied to each adult holding pond for one hour at 170 – 250 ppm, five days per week, to reduce external loads of *Saprolegnia spp*. fungus and external parasites. Chloromine-T is added to each pond at 12 – 20 ppm to control *Flavobacterium columnare* bacterium. Hatchery staff do not inoculate or treat hatchery-origin (HOR) adults that are not retained for broodstock, but rather, these latter fish are made available to the Tribe for subsistence and consumption.

Fertilized eggs are water hardened in 75 ppm iodine for 30 minutes and incubated separately by female parent until ELISA results for the prevalence of *Renibacterium salmoninarum* are available (generally within one month). Fertilized eggs from female parents with ELISA optical density (O.D.) values greater than 0.2 are culled to control outbreaks of bacterial kidney disease (BKD). Formalin is administered to incubating eggs at 1,600 ppm via a 15-minute flow every other day prior to hatch to prevent fungal growth. Eggs hatch by mid-December. After absorption of their yolk sacs, hatched fry are transferred to indoor nursery tanks in the main hatchery building for initial feeding. Fry are ponded to outside raceways in February and March. Overall, Spring Chinook Salmon are reared on station for approximately 20 months prior to release as age-1+ fish (yearlings) in late March or early April of their second year. The current release goal at the hatchery is 750,000 yearling smolts at a size of 20 – 24 fish per pound (Table 2).

The USFWS's Columbia-Pacific Northwest Region Fish Health Program has recommended density index (DI) and flow index (FI) guidelines that are more stringent for Spring Chinook Salmon at Warm Springs NFH than at other NFHs.[21] The guidelines for Warm Springs NFH

[20] Draxxin and Nuflor are the tradenames of two USDA-approved antibiotics.

[21] DI = total weight of fish in pounds / [(mean length of fish in inches) x (volume of rearing vessel in cubic feet)]. FI = total weight of fish in pounds / [(mean length of fish in inches) x (water flow through rearing vessel in gallons per minute)]. The outside raceways are supplied with unfiltered ambient water from the Warm Springs River which presents higher fish health risks than the water supplies for other NFHs in the Columbia-Pacific Northwest Region.

recommend DI < 0.15 and FI < 0.6 with water exchange rates of less than 30 minutes when fish are in the outside raceways (Table 2). By comparison, the standard guidelines are DI < 0.2 and FI < 1.0 for Spring Chinook Salmon at other NFHs. The DI guideline at Warm Springs NFH is even more stringent during the summer months (DI $\leq$ 0.1) when water temperatures frequently exceed 21 °C (70 °F). Despite those guidelines, the current infrastructure of Warm Springs NFH may preclude achieving FI < 0.6 when the hatchery is at "full production" of 750,000 juveniles. For example, the 2019 Annual Operating Plan for Warm Springs NFH stipulates FI < 1.0. The more general guidelines of FI < 1.0 and DI < 0.2 are used for the indoor nursery tanks; however, the total capacity of those tanks (n = 20) is insufficient to maintain FI < 1.0 and DI < 0.2 during the last month prior to ponding fish to outside raceways.

Table 2. Fish culture parameters at Warm Springs NFH.

Species	Density Index (DI) (Maximum)	Flow Index (FI) (Maximum)	Target release size (fish/lb.)	Target release date	Pathogens / Diseases of concern[a]
Chinook Salmon	0.15[b]	0.6	20 – 24	April 10	BKD, Ich, *F.col.*

[a] BKD (Bacterial Kidney Disease) is caused by the bacterium *Renibacterium salmoninarum.* Ich is caused by the parasite *Ichthyophthirius multifiliis*. *F.col.* is *Flavobacterium columnare*, the bacterium that causes Columnaris.

b The DI guideline maximum value of 0.15 is reduced to DI $\leq$ 0.1 during the summer months.

E. Disease history at Warm Springs NFH

Warm Springs NFH faces many fish health challenges including high water temperatures during the summer and a surface water source with anadromous fish. The two pathogens of greatest concern during the summer are (a) the bacterium that causes Columnaris (*Flavobacterium columnare*) and (b) the parasite that causes Ich (*Ichthyophthirius multifiliis*). These two pathogens often co-infect Spring Chinook Salmon at Warm Springs NFH, thus requiring complicated treatments with chemicals and drugs. Infections have been sufficiently severe in the past to warrant relocation of subyearling and adult Chinook Salmon to cooler water at Little White Salmon NFH, particularly during periods of rising water temperatures when high pathogen loads in the Warm Springs River pose significant disease risks (e.g., in 2015 and 2016). After river temperatures began to drop in 2015 and 2016 and flows increased, thus decreasing pathogen loads, juvenile Chinook Salmon were moved back to Warm Springs NFH to continue the rearing cycle. Since 2015, BKD has also been a significant disease issue (3 of 5 years) in March and April prior to the release of smolts into the Warm Springs River. In addition, adults returning to the Warm Springs River are exposed to the parasite *Ceratonova shasta* and are often infected with the parasite when they are trapped for broodstock (see Appendix D for details).

Warm Springs NFH relies on prophylactic and therapeutic use of antibiotics to prevent and treat bacterial infections of Spring Chinook Salmon during the summer (June – September) when water temperatures exceed 15 °C (60 °F) and approach 21 °C (70 °F). Based on their experience and empirical observations, fish health experts of the USFWS have concluded that the majority of fish on station during the summer would most likely die without antibiotic treatments. Juvenile Chinook Salmon on station have been treated annually with Teramycin-200 or Aquaflor since 2011 to control Columnaris and Motile Aeromonas Septicemia (MAS).

General conclusions: Survival of Spring Chinook Salmon at Warm Springs NFH has relied increasingly on the routine use of chemicals and antibiotics to minimize disease and mortalities. USFWS staffs at Warm Springs NFH and the Columbia-Pacific Northwest Region Fish Health Program have concluded that the extensive use of drugs and chemicals, both prophylactically and therapeutically, to maintain population viability is not sustainable because of long-term impacts to fish health and environmental safety. In addition to Columnaris and Ich, accumulated stress from non-optimal conditions and other handling stresses have caused outbreaks of BKD among juvenile Chinook Salmon prior to release in April as yearlings. Appendix D provides additional details regarding the disease history and pathogens of concern at Warm Springs NFH.

V. SENSITIVITY

Sensitivity is the degree to which a system or species is likely to be affected by an environmental disturbance like climate change.

We assessed the known sensitivities of Warm Springs NFH and the population of Spring Chinook Salmon propagated there relative to current culture protocols and environmental conditions.

A. High air and water temperatures in summer

Spring Chinook Salmon at Warm Springs NFH are especially sensitive to warm water temperatures of the Warm Springs River, both in terms of magnitude and the number of continuous hours that water temperatures exceed 20 °C (68 °F). Water temperatures peaked at ~24 °C (~76 °F) for several hours in 2018, and all fish on station had to be relocated to Little White Salmon NFH in 2015 and 2016 when peak temperatures reached 26 °C (78 °F). Daily fluctuations in water temperature can exceed 6 °C (10 °F) during the summer, and any future increase in mean, overnight low temperatures is expected to increase the duration that high daytime temperatures pose a severe stress to Spring Chinook Salmon on station. Any potential increase in future water temperatures of the Warm Springs River during the summer would further increase the current high sensitivity of Spring Chinook Salmon to Ich, Columnaris, and BKD, as described previously.

B. Low air and water temperatures in winter

Air temperatures below -18 °C (0 °F) have been recorded during winter at Warm Springs NFH. During sustained freezing, water flow into the hatchery can be impeded by the formation of anchor ice on the water intake rack. In addition, under sustained sub-freezing conditions, raceways become partially (or wholly) covered with ice that can be a source of mortality when fish jump onto the ice and become stranded. Loose ice at the water intake can also be pumped directly into the raceways. The hatchery and Spring Chinook Salmon program are thus considered sensitive to any future conditions that would increase the magnitude or duration of sub-freezing temperatures.

C. Low surface flows in summer

During summer low flows, the quantity of water flowing into the pump sump basin may not be sufficient to meet the water demands of the hatchery. Although the lowest observed flows of the Warm Springs River (170 – 180 cfs) exceed the 100 cfs water right of the hatchery (Table 1), pump cavitation has occurred in the past during very low summer flows, thereby reducing water flows to the raceways and increasing disease risks to Spring Chinook Salmon. Consequently, the hatchery is considered sensitive to low surface flows during summer under its currently operating infrastructure.

D. High surface flows in winter and spring

Currently, the Warm Springs River is largely a snow-driven watershed but does receive supplemental inputs from natural springs and rain. Peak flows have occurred historically February – April, averaging approximately 800 cfs in March (Figure B8). The room of the hatchery building housing the pumps and sump area is considered sensitive to very high flows of the Warm Springs River as occurred during the winter of 1996 – 1997 when flows approached 10,000 cfs with extensive flooding and siltation of the sump basin.

E. Fire risks

Warm Springs NFH is sensitive to wildfires. The hatchery is located in a semi-arid area dominated by grassland, scattered pine trees, and sagebrush. In the recent past, wildfires on the Warm Springs Reservation have disrupted telephone communications and electricity transmissions to the hatchery. These risks may have increased in recent years because of a series of droughts since 2010 and generally warmer air temperatures along the east slope of the Cascade Mountains. Two new 500 kilowatt generators were installed in 2019 that should reduce previous sensitivities to power loss due to wildfires. In addition, the hatchery grounds are surrounded by high-volume irrigation cannons that can supersaturate the area around the hatchery to create a fire suppression zone. Only one road, down the north slope of the Warm Springs River canyon, provides vehicle access to the hatchery, thus necessitating early evacuation of personnel whenever fire risks are imminent.

F. Sensitivity main points:

- Warm Springs NFH is especially sensitive to high water temperatures and disease risks during the late spring and summer. Spring Chinook Salmon at Warm Springs NFH are particularly sensitive to Ich and Columnaris during the summer (as subyearlings) and BKD the following spring prior to release as yearlings into the Warm Springs River.

- Warm Springs NFH is sensitive to sustained low temperatures below freezing during winter when anchor ice forms on the water intake screen and surface ice forms on the outside raceways.
- Warm Springs NFH is sensitive to very low flows of the Warm Springs River during summer when water flows into the sump basin may be insufficient to meet the water demands of the hatchery.
- Warm Springs NFH, particularly the room housing the pumps and sump basin, is considered sensitive to very high surface flows and flood risks from the Warm Springs River.
- The physical facilities and infrastructure of Warm Springs NFH are sensitive to wildfire risks. These risks have increased in recent years because of droughts and generally warmer air temperatures along the east slope of the Cascade Mountains.

VI. EXPOSURE

Exposure is the magnitude or degree to which a system or species is expected to be subjected to an environmental disturbance such as climate change.

The methods we used to quantitatively assess the future exposure of Warm Springs NFH to climate change are described in Appendix B. Those methods are summarized below.

A. Methods

Projected water temperatures at Warm Springs NFH in the 2040s

Historic mean weekly air temperatures for the Warm Springs River watershed upstream from Warm Springs NFH were modeled from historic air temperatures (1915 – 2006) downscaled from 10 GCMs (Appendix B; see Figure B3).[22] The methods of Mohseni et al. (1998) and Mantua et al. (2010) were then used to parameterize the non-linear regression relationship between (a) estimated historic mean weekly air temperatures of the watershed upstream of the hatchery and (b) historic water temperatures of the Warm Springs River measured at the intake diversion for the hatchery (Figs. B3, B4; Table B3). The parameterized regression relationship between air and water temperature was then used to project future water temperatures of the Warm Springs River in the 2040s from the projected future air temperatures generated from the 10 GCM models under the A1B emissions scenario.

[22] Data flux files were obtained from the Climate Impacts Group at the University of Washington from the following website: http://warm.atmos.washington.edu/2860

Projected water availability at Warm Springs NFH in the 2040s

The Variable Infiltration Capacity (VIC) hydrologic model of Liang et al. (1994) was used to project future, mean-monthly stream flows of the Warm Springs River at the hatchery under the A1B emissions scenario as forced by output from the same ensemble of 10 GCMs used to project future air and water temperatures (Appendix B). We assumed that the actual quantity of water available to the hatchery from all sources in the 2040s would change in direct proportion to any change in mean monthly flows estimated by the VIC model with the exception that the hatchery could not use additional water in excess of mean historic use for those months when a future increase in mean flow was projected (Scenario A). We also considered two additional scenarios that could affect water use at the hatchery: (1) water use would decrease *and* increase proportionally to projected future river flows (Scenario B), and (2) water use by the hatchery would remain unchanged in future years (relative to current historical levels) despite projected changes in surface water flow (Scenario C).[23]

B. Results and Discussion

Climate and hydrologic modeling under the A1B emissions scenario indicate that the Warm Springs River basin will most likely experience (a) warmer air and stream temperatures, (b) reduced snowpack and earlier snowmelt runoff, (c) lower base flows in summer, and (d) higher surface flows in winter and greater-magnitude 100-year peak flows (Table B5; Figures B5 – B15).

Temperature projections

Mean air temperature over the entire Warm Springs River watershed is projected to increase in every month in the 2040s compared to historic values (mean increase = 2.0 °C [3.5 °F]). The largest absolute increases are projected to occur in July, August, and September (range = 2.7 – 3.1 °C [4.9 – 5.6 °F]; Table B3 and Figure B4). Similarly, water temperatures of the Warm Springs River at the hatchery intake are projected to be higher in every month in the 2040s compared to the historic baseline period (Table B5; Figure B15). The mean annual water temperature was projected to increase by 1.3 °C (2.3 °F) with monthly increases of 1.0 – 1.7 °C (1.8 – 3.1 °F). Mean monthly water temperatures in July and August are projected to exceed 18.4 °C (65.1 °F) by the 2040s.

Precipitation projections

Total annual precipitation was projected to be within about 2% of the historic baseline (historic = 66 mm; 2040s = 67 mm). The mean historic monthly precipitation was generally within the range of values projected from the 10 GCMs for the 2040s, although small seasonal differences are likely (Table B3; Figure B5).

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[23] Projected future water flows of the Warm Springs River in the 2040s were never less than the current quantities of water used by the hatchery.

In contrast to the projected results for total annual precipitation, the maximum *snow water equivalent* (SWE, aka snow pack) was projected to decline by nearly 62% from 65 mm to 25 mm with the peak snow pack occurring in February instead of March (Table B3; Figure B6). Similarly, the mean monthly SWE for the entire year was projected to decline by 65% in the 2040s compared to historic baseline values (historic monthly mean = 23 mm; monthly mean in the 2040s = 8 mm; Table B3; Figure B6). These projections for the Warm Springs River watershed indicate a substantially greater proportion of precipitation will fall as rain and substantially less as snow in the 2040s than historically.

Hydrographic projections

Mean *annual* flow projected for the Warm Springs River in the 2040s was slightly higher than the modeled historic value (historic = 520 cfs; 2040s ensemble mean = 553 cfs) but was within the range of projections from the 10 GCMs (Table B5). The same pattern is apparent when the flow data are plotted by stream segment across the contributing sub-basins (Figure B7). However, the *shape* of the modeled monthly hydrograph for the 2040s differs considerably from historic monthly averages (Figure B8). The projected hydrograph at the location of the hatchery shows lower flows in May and June (projected mean decrease ≈ 220 and 120 cfs, respectively) but substantially higher flows in December through March with a shift in the month of peak flow from March to January (projected mean flow in January > 1,000 cfs with a modeled range ≈ 800 – 1400 cfs; Figures B8 and B9). These changes most likely reflect the transition of the Warm Springs River from primarily a snowmelt-driven watershed to a mixed snow-and-rain-driven watershed.

The calendar date when 50% of the annual discharge of the Warm Springs River is achieved was projected to be more than 11 days earlier in the 2040s than historically (Figure B10). In general, summer low-flow events (7Q10) in the 2040s were not predicted to be more severe than historically, although considerable variability existed among the 10 GCMs (Figures B11 and B12). In contrast, the magnitude of maximum high flows is expected to increase in the 2040s compared to the historic average, with the magnitude of the largest flows (100-year recurrence interval) projected to increase from about 8,800 cfs to 10,300 cfs on average (Figure B14). Three of the 10 GCMs projected peak 100-years flows greater than 12,000 cfs. These modeled projections for the 2040s are consistent with record floods of the Warm Springs River that occurred during the winter of 1996 – 1997, suggesting that peak flows around 10,000 cfs (or greater) will be more frequent in the 2040s (Figure 3).

C. Exposure main points:

- Surface water temperatures of the Warm Springs River are expected to be higher in all months in the 2040s compared to the historic average: mean annual water temperatures at the hatchery intake are projected to increase by 1.3 °C (2.3 °F) with (a) monthly increases of 1.0 – 1.7 °C (1.8 – 3.1 °F) and (b) mean temperatures during July and August in excess of 18.4 °C (65.1 °F).

- Total annual and mean monthly precipitations in the 2040s for the Warm Springs River basin are projected to be largely unchanged from historic values. However, substantially more precipitation will fall as rain and substantially less precipitation will fall as snow, with a projected 62% reduction in peak SWE in March and a 65% reduction in mean monthly snowpack.
- Mean *annual* flows projected for Warm Springs River in the 2040s will be similar or slightly higher than the modeled historic values. However, the shape of the modeled hydrograph for the 2040s is projected to be quite different from the historic average with substantially higher mean flows in winter, a shift in peak mean flows from March to January, and substantially lower flows in May and June. The magnitude of the lowest flows during the summer and early fall are projected to decrease slightly from historic levels.
- The magnitude of 20-year, 50-year, and 100-year peak flows are expected to increase substantially with mean projected 50-year and 100-year peak flows exceeding 9,000 and 10,000 cfs, respectively. Three of 10 GCM models projected 100-year peak flows greater than 12,000 cfs.
- Overall, the Warm Springs River basin will most likely transition from primarily a snowmelt-driven watershed to a mixed snow-and-rain-driven watershed with substantial increases in peak flows in winter and lower base flows in summer.

VII. IMPACT

Impact is the combination of sensitivity and exposure of a system or species to an environmental disturbance such as climate change.

To assess the vulnerability of Warm Springs NFH to climate change projections, we first addressed the following question: Could the Spring Chinook Salmon program at the hatchery continue to operate successfully under the climatic conditions projected for the 2040s assuming current fish-culture paradigms, schedules and targets? To address this question, we focused primarily on future changes in water temperature and water availability at the hatchery, as summarized in the preceding Exposure section. Our specific objectives were to: (a) determine if future environmental conditions are likely to preclude culture of Spring Chinook Salmon at Warm Springs NFH, and (b) identify the magnitude and timing of sub-lethal effects (altered growth rates, disease risks, etc.) that may affect survival and growth of Spring Chinook Salmon at the hatchery. Details of our analyses are presented in Appendix B. Our methods are summarized below.

A. Methods

To achieve the foregoing objectives, we first collated physiological tolerance data for Chinook Salmon (Table B1) and thermal growth data for common salmon pathogens (Table B2). We then used the fish growth model of Iwama and Tautz (1981), coupled with empirical data on recent rearing conditions at the hatchery (e.g., number of fish reared), to predict the future mean size and total biomass of fry and juvenile Spring Chinook Salmon by month as a function of projected water temperatures in the 2040s assuming an unlimited food ration. We then modeled flow and density indexes (Piper et al. 1982, Wedemeyer 2001) for each month of culture based on (a) in-hatchery environmental conditions projected for the 2040s, (b) the mean number of fish on station each month based on recent historic numbers (assuming no fish are relocated off-station prior to release), and (c) the total rearing capacity of the hatchery for each monthly life history stage assuming no infrastructure changes between current and future conditions. Flow and density index values projected for the 2040s were then bias–corrected based on the ratio of the empirical (observed) mean historic values to the modeled mean historical values (see Appendix B for details).

B. Results and Discussion

Spring Chinook Salmon program

Adult Spring Chinook Salmon returning to Warm Springs NFH are typically captured for broodstock starting in April and are retained in holding ponds until spawning is completed in early September. During their upstream migration, adults are exposed to the parasite *C. shasta* and may be infected when they arrive at the hatchery (Appendix D). By the 2040s, water temperatures in the holding ponds between May and September are projected to increase by 1.2 – 1.7 °C (2.2 – 3.1 °F), compared to historic baseline values, with mean monthly water temperatures reaching a high of 18.5 °C (65 °F; Table B6; Figure B16).[24] These projected water temperatures exceed the optimal spawning temperatures for Chinook Salmon (5.7 – 11.7 °C; 42 – 53 °F; Table B1) and are expected to exasperate *C. shasta* infections. Overall, adult Spring Chinook Salmon trapped for broodstock will likely experience higher physiological stress during holding and spawning in the 2040s than historically.

Juvenile Spring Salmon at Warm Springs NFH will be exposed to warmer rearing conditions in all months in the 2040s with projected increases in mean monthly temperatures ranging from 1.0 to 1.7 °C (1.8 – 3.0 °F; Table B6, Figure B17). Projected water temperatures in the 2040s exceed the optimal upper temperature threshold for eggs and fry in September and for juveniles June through September (Table B1). In addition, projected water temperatures in July and August exceed the optimal upper growth temperature of 18.4 °C (65 °F) for Chinook Salmon (Table B6; Figure B17). These higher water temperatures are expected to increase disease risks, particularly during the spring and summer (Table B2). Indeed, since 2015, BKD has become increasingly problematic to pre-smolt juveniles in March and April prior to release. Also, recent

[24] The adult holding pond at Warm Springs NFH was recently rebuilt with the capability to chill water down to approximately 10 °C (50 °F). The climate projections and assessed impacts described here were completed before modification of the adult holding pond could be evaluated. This recent modification of the adult holding pond reduces the projected impacts to adult broodstock substantially (see Adaptation and Vulnerability sections that follow).

outbreaks of Ich and Columnaris during the summer months have necessitated complicated treatments including chemicals, drugs, and relocation of juvenile fish off-station during rising water temperatures and high pathogen prevalence in the Warm Springs River. Despite those temperature increases, projected *mean* water temperatures in the 2040s at the time of smolt release in April (9.6 °C; 49.3 °F) are well within the upper threshold limit for proper smoltification of Chinook Salmon (14.0 °C [57 °F]; Table B1).

Warmer water temperatures projected for the 2040s will increase the growth rates of juvenile Spring Chinook Salmon throughout the rearing period (Table B7). Chinook Salmon smolts from Warm Springs NFH are predicted to be, on average, 36.6% heavier and 10.8% longer at release when compared to historic sizes, assuming no culture modifications or compensatory biological responses (e.g., modified feeding rates, precocious sexual maturation that reduces growth, etc.; Table B7).

Flow index values for Spring Chinook Salmon in the 2040s are expected to increase relative to historic values assuming water availability to the hatchery declines in proportion to projections for lower flow in summer (Scenario A, Table B8, Part B; Figure B18a). If the hatchery can use more water when river flows are projected to increase relative to historic values (Scenario B), then flow density values may be the same or slightly lower than historic averages during the winter and early spring before smolts are released (Table B8B, Figure B1a). Even if water use by the hatchery does not change relative to projected future river flows (Scenario C), flow index values would still increase in all months because higher water temperatures would be forcing greater growth rates of juvenile salmon. Despite those increases, mean monthly flow index values after ponding are projected under all three scenarios to remain below the stringent value of FI < 0.6 recommended by USFWS Columbia-Pacific Northwest Region Fish Health Program staff for Spring Chinook Salmon at Warm Springs NFH (Figure B18a).

Mean monthly density index values are also projected to increase by the 2040s, but those index values would not exceed the general fish health guideline value of DI < 0.2 after fish are ponded to outdoor raceways (Table B8, Part B; Figure B18b). On the other hand, density index (DI) values are projected in the 2040s to exceed the DI ≤ 0.1 operating protocol for Spring Chinook Salmon at Warm Springs NFH during the summer months, as stipulated in the 2019 DRAFT Annual Operations Plan.

General conclusions: Water temperatures in the 2040s are projected to exceed the physiological thresholds for Chinook Salmon at multiple life history stages with water temperatures in spring through early fall being especially problematic. All life stages of Spring Chinook Salmon at Warm Springs NFH may experience substantial physiological stress when projected mean water temperatures exceed 16 °C (60 °F) and approach or exceed the optimal or minimal outbreak temperatures for several pathogens (Table B2). Indeed, USFWS staff have concluded that Spring Chinook Salmon returning to the Warm Springs River are already experiencing the impacts of climate change based on water temperatures and pathogen prevalence. Overall, the impacts of future climate condition to juvenile Chinook Salmon at Warm Springs NFH appear to be driven more by increased water temperatures than reduced water availability during the summer, although our projections for flow index values in the 2040s may be conservative (see Appendix B for a full discussion). We conclude that elevated water temperatures projected for the 2040s will present the most significant challenge to the continued rearing of 700,000+ Spring Chinook Salmon at Warm Springs NFH.

Hatchery infrastructure

Our hydrologic projections suggest that flood risks at Warm Springs NFH may increase significantly by the 2040s (Figure B14). The Warm Springs River will most likely transition from primarily snowmelt-driven watershed to mixed snow-and-rain-driven as suggested by a projected 65% reduction in mean monthly SWE with little change in mean annual precipitation. Modeling indicated that peak flows in excess of 10,000 cfs (similar to those observed during the winter of 1996 – 1997; Figure 3) will occur with increasing frequency and possibly greater magnitude. As noted previously, three of the 10 GCMs projected 100-year peak flows greater than 12,000 cfs and 50-year peak flows between 10,000 and 12,000 cfs. Major reductions in overall snowpack with little change in mean monthly precipitation, due to increases in mean winter temperatures and higher snow-level elevations, suggest a higher likelihood of rain-on-snow events in the Warm Springs River watershed by the 2040s. Although flood risks to Warm Springs NFH are likely to increase in the future, we defer to hatchery staff and USFWS hydrology engineers to assess the impacts of higher peak flows of the Warm Springs River to the hatchery infrastructure as it is configured currently.

Projected increases in mean air temperature are expected to reduce the number of days and duration of conditions that lead to the formation of anchor ice on the water intake rack and surface ice in the raceways. However, projected mean temperatures for January in the 2040s are still below freezing, suggesting that icing conditions will continue to occur in the future but with reduced intensity or duration.

Projected increases in mean summer air temperature in the 2040s (Figure B4), coupled with little change or slight decreases in precipitation during the spring and summer (Figure B5), suggest that summer fire risks in the Warm Springs River basin will continue to increase in the future. These projections and interpretations are consistent with recent events along the east slope of the Cascade Mountains and southern Oregon where the incidence of summer wildfires has increased significantly since 2000. We should note that we did not attempt to model future wind speeds (sustained or peak) or relative humidity associated with projected increases in mean summer air temperatures. Both relative humidity and wind speed can significantly affect the risks and impacts of wildfires.

C. Impact main points:

- Increasing water temperatures of the Warm Springs River through the 2040s will challenge Spring Chinook Salmon biologically and may lead to significant physiological stress at several life history stages.

- Higher water temperatures are expected to increase disease risks in the future, particularly to juvenile salmon during the summer months (Columnaris, Ich), smolts prior to release (BKD), and adult broodstock prior to spawning (*C. shasta*).[25]
- Higher water temperatures are projected to increase growth rates of Spring Chinook Salmon such that smolts, on average, will be 36.6% heavier and 10.8% longer at release compared to historic sizes.
- While flow and density indexes projected for the 2040s are still within the specific fish health guidelines for Spring Chinook Salmon at Warm Springs NFH (FI < 0.6; DI < 0.15), density index values during the summer months will exceed the more stringent guideline of DI < 0.1 recommended for those months at Warm Springs NFH.
- Transition of the Warm Springs River from primarily a snowmelt-driven watershed to a mixed snow-and-rain-driven watershed is expected to significantly increase flood risks to Warm Springs NFH by the 2040s.
- Higher mean air temperatures during the spring and summer, coupled with reduced snowpack and little change in mean monthly precipitation, are expected to further increase fire risks to Warm Springs NFH through the 2040s and beyond.

VIII. ADAPTIVE CAPACITY

Adaptive capacity is the ability or capacity of a system or species to adjust or adapt to the impact of an environmental disturbance such as climate change.

The Assessment Team identified two types of adaptation strategies in response to each of the climate change impacts described in the preceding section: (1) infrastructure adaptations to the physical plant of the hatchery, and (2) protocol and management adaptations of the culture programs.

A. Methods

The Assessment Team led a meeting on January 27, 2021 to discuss possible adaptation strategies in response to projected climate impacts at Warm Springs NFH in the 2040s (Appendix E). The purposes of the meeting were: (a) assess the ability of WSNFH to maintain its current Spring Chinook Salmon program in view of future climate impacts, and (b) propose possible adaptation strategies to reduce those impacts consistent with the mission and goals of the hatchery and its programs. Meeting participants consisted of the Assessment Team, the HET for Warm Springs NFH, and biologist/manager representatives of the Confederated Tribes of the Warm Springs Reservation in Oregon (CTWSRO). Members of the HET provided technical expertise and experience to assess the capability of Warm Springs NFH and its programs to adapt to the projected impacts of climate change. Staff from the CTWSRO provided key insights

[25] The adult holding pond at Warm Springs NFH was recently rebuilt with the capability to chill water down to approximately 10 °C (50 °F). This recent modification reduces projected impacts to adult broodstock substantially.

regarding tribal needs and goals. In particular, representatives of the CTWSRO emphasized the importance of Spring Chinook Salmon to the cultural and fishing subsistence needs of tribal members. CTWSRO representatives also noted the high intrinsic value of the Warm Springs River population of Spring Chinook Salmon and the very high priority of the CTWSRO to maintain that population into the future.

The Workgroup identified a limited number of adaptive capacity options. Some of those options have already been implemented in recent years in response to high water temperatures. Several of the infrastructure options would require large monetary investments for which funding would need to be identified. Those options are indicated by an asterisk (*).

B. Results and Discussion

Spring Chinook Salmon program

1. ***Impact:*** Increasing water temperatures of the Warm Springs River through the 2040s will challenge Spring Chinook Salmon biologically and will most likely lead to significant physiological stress at several life history stages. Warm Springs NFH is currently able to chill water in the hatchery building (incubating eggs and fry) and adult holding ponds, but the hatchery is not able to chill water in the outside raceways for juveniles prior to release.

    a) ***Infrastructure adaptations***:

    (1) Investigate the groundwater source used for domestic water as a possible source of cool water for fish culture. The domestic water well taps into a cool water source, whereas a recent test well tapped into a geothermal water source. However, the recharge rate of the domestic well appears to be only ~20 gpm.

    (2) *Build a Partial Reuse-Water Aquaculture System (PRAS) equipped with chilling at Warm Springs NFH. Cost: ~ $11.1 – 12.4 million to rear 750,000 smolts (20 fish per pound) as per a 2017 engineering study.[26]

    (3) *Rear Spring Chinook Salmon in the upper watershed at Schoolie Springs, about 27 river miles upstream of the hatchery. Cost: ~ $10.6 million to rear 750,000 pre-smolts (30 fish per pound) on single-pass water or ~ $9.8 – $11.3 million to rear 750,000 pre-smolts in a PRAS. The 2017 engineering report included a design for a PRAS and fish rearing facility at Schoolie Springs. Groundwater from the Schoolie Springs site would not require chilling, but providing 3-phase electricity to that site would be a major expense (~ $1.05 million).[27]

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[26] The engineering study is a report by McMillen Jacobs Associates, Consulting Engineers, available at: https://mcmjac.com/. The costs and capacities of a PRAS at WSNFH or Schoolie Springs were obtained from the engineering report.

[27] IBID.

b) Protocol and management adaptations:

(1) *Chill water in the outside adult holding ponds to 15 – 18 °C (60 – 65 °F) during the summer instead of going down to the optimum temperature of 10 °C (50 °F) when the Warm Springs River reaches the critical temperature of 22 °C (72 °F). This measure could yield some cooling capacity for juveniles in raceways. However, this measure would most likely be impractical with existing infrastructure.[28]

(2) Use Warm Springs NFH as an adult collection and smolt-release facility, but rear the juveniles off station at another NFH (e.g., Little White Salmon NFH) or at a rearing facility on the Deschutes River (e.g., Round Butte State Fish Hatchery). "Rearing fish on the Deschutes River could create a new fishery opportunity for the CTWSRO that would be worth exploring."[29]

(3) Rear Fall Chinook Salmon at Warm Springs NFH and Spring Chinook Salmon elsewhere. A relatively healthy population of Fall Chinook Salmon exists in the Deschutes River and could be a broodstock source at Warms Springs NFH. Another scenario would be a cooperative agreement between Warm Springs NFH and another NFH where Warm Springs NFH would rear Fall Chinook Salmon from a Gorge hatchery in exchange for a Gorge hatchery rearing Spring Chinook Salmon from Warm Springs NFH.[30]

(4) Rear Coho Salmon instead of Spring Chinook Salmon at Warm Springs NFH. The number of Coho Salmon ascending the Warm Springs River has increased in recent years with over 400 Coho Salmon passed upstream in 2019 and over 700 Coho Salmon passed upstream in 2020. The feasibility of this option is questionable because Coho Salmon released as yearling smolts would encounter the same high summer water temperatures as projected for Spring Chinook Salmon.

2. ***Impact:*** Higher water temperatures during the summer months are expected to further increase disease risks in the future, particularly to juvenile salmon maintained in outdoor raceways and adult broodstock held on station prior to spawning.

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[28] Approximately 10,750 gallons per minute (gpm) of ambient river water are supplied to the raceways, but the current capacity of the chilling system is only 370 gpm down to 10 °C (50 °F). At most, only 100 gpm of chilled water (< 1% of total required water for the raceways) could be added to the main water line for the raceways and still maintain sufficient chilling capacity of the adult ponds. Source: Terry Freije, Manager, Warm Springs NFH, personal communication.

[29] The Warm Springs Tribes used to have a fishery on the Warm Springs River, but that fishery has been closed for many years. The fishery for Summer Steelhead on the Warm Springs River is also closed. The major fishery for Spring Chinook Salmon currently occurs at Shearers Falls on the Deschutes River.

[30] Fall Chinook Salmon (aka "ocean type") have a different life history than Spring Chinook Salmon (aka "stream type"). Fall Chinook Salmon undergo smoltification and outmigrate to sea as subyearlings in the spring of their first year, approximately 5 to 6 months after hatching, whereas Spring Chinook Salmon reside in freshwater for approximately 1.5 year before outmigrating to sea. As such, Fall Chinook Salmon are not maintained in hatcheries during the warm summer months.

a) Infrastructure adaptations:

(1) *Develop a PRAS for rearing juvenile Spring Chinook Salmon at Warm Springs NFH. A PRAS system connected to a chilling system with both mechanical filtration and UV sterilization would reduce both water temperature and disease risks.

(2) *Add a combination of mechanical filtration and UV sterilization to the water supplied to the outside raceways. UV-treated water needs to be filtered mechanically prior to irradiation, and some combination of filtration and irradiation would be expected to reduce pathogen loads and disease risks to juvenile fish in outdoor raceways.

(3) *Construct an ozonation facility for the water supply from the Warm Springs River.

b) Protocol and management adaptations:

(1) Develop a vaccine protocol as part of overall fish health management at Warm Springs NFH to reduce the use of antibiotics and chemical treatments.

(2) Reduce the size of the program (i.e., the number of adults spawned and the number of juvenile fish reared) to reduce density index (DI) and flow index (FI) values with a consequential decrease in disease risks.

3. ***Impact:*** Although higher water temperatures are projected to increase growth rates of Spring Chinook Salmon, flow and density indexes projected for the 2040s are still within the fish health guidelines for Warm Springs NFH (FI < 0.6; DI < 0.15) but would exceed the more stringent guideline of DI < 0.1 recommended for Warm Springs NFH during the summer months.

a) Infrastructure adaptations:

(1) *Improve or replace the water intake structure to increase the quantity of water available to the hatchery during low river flows (see discussion under impact #4 below). With permits, the USFWS may be able to start construction in 2023.

(2) *Install a PRAS to allow for higher FI and DI values, if needed to maintain production goals.

b) Protocol and management adaptations:

(1) Reduce the size of the program to maintain DI < 0.1 and FI < 0.6 in future years.

(2) Modulate fish growth by adjusting the quantity of feed provided so that juvenile Chinook Salmon do not achieve the larger mean sizes projected from the climate and fish growth models. Reducing feed levels would also increase the concentration of dissolved oxygen, an additional benefit.

(3) Reduce flow indexes in raceways by removing a dam board at the tail end of each raceway to increase water turnover rates of raceways. In general, water turnover rates are a better measure of overall water quality than FI values.

Hatchery infrastructure

1. ***Impact:*** Transition of the Warm Springs River from primarily a snowmelt-driven watershed to a mixed snow-and-rain-driven water is expected to significantly increase flood risks to Warm Springs NFH by the 2040s.

   a) ***Infrastructure adaptations:***

   (1) *Construct a new water intake for the hatchery, currently a high priority for Warm Springs NFH. High flow events in the past have damaged/displaced the drum screens for the water intake. The new intake and screen desired for Warm Springs NFH would be below the water surface and would be less vulnerable from floating debris during high flows than the current drum screens. A new screen would also be more self-cleaning than the current screen.

   (2) *Install an Obermeyer gate in the current weir to reduce backwater behind the weir and flood risks to the hatchery during high flows.

   (3) *Construct an earthen berm around the hatchery to divert floodwaters around the hatchery.

   (4) *Construct new facilities outside the floodplain to reduce flood risks; this new location might be the preferred location for the proposed PRAS.

   b) ***Protocol and management adaptations:*** None identified.

2. ***Impact:*** Higher mean air temperatures during the spring and summer, coupled with little change or slight decreases in mean monthly precipitation, is expected to further increase fire risks to Warm Springs NFH through the 2040s.[31]

   a) ***Infrastructure adaptations:***

   (1) Modify a fish hauling truck, currently maintained at Little White Salmon NFH, as a water tender and maintain the truck at Warm Springs NFH during the summer.

   (2) Install metal roofs on residences when current fiberglass shingles need replacement. The hatchery buildings currently have metal roofs.

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[31] Several fire protection measures are currently present at Warm Springs NFH, as noted at the workgroup meeting. (a) The hatchery is currently surrounded by water cannons and sprinklers for fire suppression (Appendix E). (b) A fire crew is stationed at Malheur NWR and could be called in an emergency, although the refuge is approximately 225 miles away. (c) Two boats are currently available that could provide emergency egress from the hatchery to the other side of the Warm Springs River if the road to the hatchery was inaccessible because of a rapidly moving wildfire. (d) All staff have cell phones that can be used for emergency communications.

(3) Construct a bunkhouse at the hatchery that could be used by firefighters.

(4) Ensure emergency access to the raceways by fire-tending tanker trucks for rapid access to the water supply of the hatchery (see *protocol adaptation* 3 below).

b) Protocol and management adaptations:

(1) Provide fire-fighting training to hatchery staff. None of the current hatchery staff has fire-fighting certification (red cards).

(2) Continue ongoing fire preventive measures such as continued removal junipers and other fire-prone vegetation on and around the perimeter of the hatchery grounds.

(3) Maintain an established protocol for the emergency release of juvenile fish on station in case of a rapidly approaching wildfire. An early release may be desired for some raceways to provide unobtrusive access by water-tender trucks during active firefighting.

C. Adaptive Capacity main points (options):[32]

- *Build a Partial Reuse-Water Aquaculture System (PRAS) equipped with chilling and UV disinfection at Warm Springs NFH so that juvenile Spring Chinook Salmon can be maintained on station from late spring through early fall.
- *Add mechanical filtration and UV sterilization (or ozonation) to the existing flow-through raceway system to reduce disease risks associated with warm water temperatures.
- Maintain Warm Springs NFH as an adult collection and smolt release facility for Spring Chinook Salmon, but rear the juveniles off station at another NFH with a year-round cool-water supply.
- *Same as preceding bullet but rear the juveniles off-station at a new facility constructed at a location with a cool water source (a) in the upper Warm Springs River watershed or (b) on the mainstem Deschutes River.
- *Improve or replace the water intake structure to ensure an adequate water supply to the hatchery during the projected low-flow months of summer and early fall.[33]
- *Install an Obermeyer gate in the existing weir and/or construct an earthen berm around the hatchery to reduce flood risks to the hatchery during projected high flows of the Warm Springs River in winter.
- Implement one or more fire-safety measures in addition to those already in place.

[32] Infrastructure adaptation options indicated by an asterisk (*) would require large monetary investments for which funding would need to be identified.

[33] Replacing the water intake structure is already planned because the current water intake structure is prone to damage during high flows of the Warm Springs River.

IX. VULNERABILITY

Vulnerability is the effect of impacts from an environmental disturbance, such as climate change, that cannot be adequately addressed by existing adaptive capacity.

A. Spring Chinook Salmon program

Spring Chinook Salmon at Warm Springs NFH are considered highly vulnerable to the projected impacts of climate change. Most adaptive measures outlined in the preceding section would require major infrastructure modifications and new construction at the hatchery or elsewhere.

Another vulnerability of potentially equal or greater significance to Spring Chinook Salmon occurs in the Warm Springs River. Although we did not specifically model the vulnerability of adults or smolts in the migration corridor, our projections clearly indicate a major shift in the hydrology of the Warm Springs River from primarily a snowmelt-driven watershed to a mixed rain-and-snowmelt watershed. Those changes will result in higher mean flows in winter and lower mean flows in spring with warmer water temperatures (~1.5 – 2.0 °C or ~3 – 4 °F) year round. A major uncertainty is whether the shifting hydrology of the Warm Springs River, with peak flows in January instead of March, will result in a commensurate shift in the return timing of adults. Questions also exist regarding the biological ability of Spring Chinook Salmon to adapt physiologically and/or genetically to those projected changes. Returns of adult Spring Chinook Salmon currently peak during the last week of May and continue through June before flows drop precipitously during summer (Figure B8).[34] That general hydrology is projected to occur two months earlier in the 2040s with peak mean flows beginning to decrease significantly in March instead of May. Although recent adaptations at the hatchery will most likely allow the hatchery to maintain adults on station in the future during the summer[35], the timing and ability of adults to reach the hatchery in the 2040s and beyond remain unknown.

The anticipated vulnerability of the Spring Chinook Salmon program and the Warm Springs River population could be reduced by constructing a new facility on the Deschutes River. During our workshop discussions, two possible locations for new juvenile-rearing facilities were mentioned: (1) confluence of the White and Deschutes rivers and (2) the base of the Pelton, Round Butte Dam complex near the site of the current Round Butte State Fish Hatchery (Oregon Department of Fish and Wildlife). Whether adult collection facilities are possible at either of those two locations is unknown.

B. Hatchery infrastructure

Flooding during peak winter flows appears to be the greatest infrastructure vulnerability of Warm Springs NFH to the future impacts of climate change. Some form of new construction

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[34] Source: Terry Freije, USFWS, Manager, Warm Springs NFH, personal communication.

[35] For example, the recent modification of the adult holding ponds that are now supplied with chilled water.

may be necessary to reduce those potential impacts. In the near term, replacement of the water intake (already planned) and construction of an earthen berm around the hatchery could potentially reduce the vulnerability of the hatchery to future peak flows of the Warm Springs River (> 10,000 cfs). However, such measures would not prevent back-up of flood waters behind the existing weir. The vulnerability of the hatchery could potentially be reduced further by construction of an Obermeyer Gate in the existing weir structure. A bypass channel with a high water spillway upstream of the hatchery may also reduce flood vulnerabilities to the hatchery and the weir structure itself.

Although the risk of wildfires in the Warm Springs River watershed is expected to increase in the future, Warm Springs NFH currently has infrastructure in place (e.g., water cannons, sprinklers) that reduces the vulnerability of the hatchery to those increased risks.

C. Vulnerability main points:

- Spring Chinook Salmon at Warm Springs NFH are highly vulnerable to the future impacts of climate change, due primarily to warmer water and lower flows of the Warm Springs River during summer when juveniles are reared in outside raceways. Those climate changes will also increase vulnerability to disease.
- The vulnerabilities of adult Spring Chinook Salmon in the migration corridor in the late spring and early summer, particularly in the Warm Springs River, are largely unknown and a major uncertainty.
- Warm Springs NFH may be highly vulnerable to future floods of the Warm Springs River if adaptive measures are not implemented.

X. BIOLOGICAL AND ENVIRONMENTAL UNCERTAINTIES

The vulnerability assessment presented here does not address two major uncertainties: (1) the effect of climate change on the marine environment and ecosystems, including the *migration corridor* from the Pacific Ocean to the Warm Springs River via the mainstem Columbia and Deschutes Rivers, and (2) the future epidemiology of fish pathogens and disease under the climates projected for the 2040s. Both factors could greatly affect the ability of hatcheries in the Columbia River Basin of the Pacific Northwest to propagate Pacific salmon and Steelhead through the 21st Century. Details regarding these uncertainties are described in Appendix F.

XI. CONCLUSIONS

1. The projected effects of climate change will likely preclude the future rearing of Spring Chinook Salmon at Warm Springs NFH unless adaptive measures are implemented that reduce those vulnerabilities.

2. Major new construction at Warm Springs NFH will likely be necessary to maintain juvenile Spring Chinook Salmon on station from late spring through early fall in the 2040s. Chilling with some form of water disinfection for the outside raceways will likely be necessary to prevent lethal temperatures and disease outbreaks.
3. Warm Springs NFH may be able to continue its current role as an adult collection and smolt-release facility for Spring Chinook Salmon in the 2040s if juveniles are reared elsewhere, either at another NFH with a cool water supply or at new facilities constructed in the upper Warm Springs River watershed or on the mainstem Deschutes River.
4. Warm Springs NFH appears to be highly vulnerable to future flood risks because of a major shift in hydrology from primarily a snowmelt-driven watershed to a mixed rain and snowmelt-driven watershed.
5. Wildfire risks from late spring through early fall are expected to increase through the 2040s and beyond.
6. Major uncertainties exist regarding the ability of adult Spring Chinook Salmon to ascend the Warm Springs River in the 2040s because of higher water temperatures and a temporal shift in peak flows from spring to winter. As a result, a mismatch exists between current return timing of Spring Chinook Salmon in the Warm Springs River and projected flows in the 2040s.

XII. RECOMMENDATIONS

1. In the near term, develop a standard operating procedure (SOP) for rearing juvenile Spring Chinook Salmon at another hatchery with a cooler water supply. Transfers of fish for rearing at another hatchery would best occur at the eyed egg stage, if possible, to reduce fish health risks. Pre-smolts could be transferred back to Warm Springs NFH in mid to late winter as yearlings prior to release as smolts in April. If successful, this SOP could potentially be a long-term solution for maintaining a hatchery-propagated population of Spring Chinook Salmon at Warm Springs NFH.
2. Implement proactive measures to reduce flood risks at Warm Springs NFH. The planned replacement of the water intake structure would be a first step. Construction of an earthen berm around the hatchery may be a short-term solution. Construction of a flow gate in the existing weir structure or a high-flow bypass channel with spillway around the weir may also be desired to reduce back-up of flood waters upstream of the hatchery during extremely high flow events.
3. The Assessment Team has no preferred recommendations for potential construction of new facilities for maintaining juvenile Spring Chinook Salmon within the Warm Springs or Deschutes River watersheds. Three alternative adaptation strategies were presented:

(1) construction of a PRAS at Warm Springs NFH; (2) construction of new rearing facilities in the upper Warm Springs River watershed; and (3) construction of new facilities on the Deschutes River. As noted in Conclusion #6, major uncertainties exist regarding the future viability of Spring Chinook Salmon in the Warm Springs River, even for a hatchery-propagated population.

4. Ensure that a wildfire-response protocol manual is developed and available to all staff at Warm Springs NFH. The manual should include procedures for emergency fish release, fire suppression, and emergency evacuation of personnel.

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XIV. APPENDICES

A. Appendix A. Qualitative Assessments of Climate Change Vulnerability of National Fish Hatcheries in the Columbia-Pacific Northwest Region: Warm Springs National Fish Hatchery.

B. Appendix B. Modeling the Potential Effects of Changed Water Availability and Water Temperature on Pacific Salmon Culture Programs at Warm Springs National Fish Hatchery.

C. Appendix C. Major Physical Facilities at Warm Springs NFH.

D. Appendix D. Disease History and Pathogen Risks at Warm Springs NFH.

E. Appendix E. Work Group Meeting Notes, January 27, 2021.

F. Appendix F. Biological and Environmental Uncertainties.