U.S. Fish and Wildlife Service – Pacific Region

Climate Change Assessment Team for National Fish Hatcheries

Winthrop National Fish Hatchery

Climate Change Vulnerability Assessment
December 2013

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SUMMARY

The Government must exercise a leadership role to address climate impacts on Federal infrastructure interests and on natural, cultural, and historic resources that it has statutory responsibilities to protect. The Federal Government should identify its most significant adaptation risks and opportunities and incorporate response strategies into its planning to ensure that Federal resources are invested wisely and that its services and operations remain effective in the context of a changing climate. Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy (WHCEQ 2010).

Purpose

One of the ways the US Fish and Wildlife Service's (Service) Pacific Region Fisheries Resources Program (Program) is addressing the challenge presented by climate change is by conducting an extensive evaluation of the vulnerability of its National Fish Hatcheries (NFHs). The Climate Change Assessment Team (Assessment Team) for NFHs, with input from the Program, initiated quantitative vulnerability assessments in 2011 with a pilot facility, Winthrop NFH.

The Assessment Team focused on NFH vulnerabilities at the local level, recognizing that while other agencies and researchers have been evaluating climate change vulnerabilities of migration corridors, ocean conditions and other risks (Battin et al. 2007, Beechie et al. 2012, Crossin et al. 2008, ISAB 2007, Mantua et al. 2010), no other entity would be evaluating the vulnerability of Service facilities and programs to the changing climate.

Definitions

The vulnerability of a species or system to an environmental disturbance such as climate change is a function of several components: sensitivity, exposure, impact, and adaptive capacity. Sensitivity is the degree to which a system is responsive to changes in climate and exposure is the magnitude or degree of change expected due to climate change. The combination of sensitivity and exposure is the expected impact of climate change on a given system or species. Adaptive capacity is the capacity of a system to adapt to the impact of climate change. Potential climate impacts that cannot be adequately addressed using existing adaptive capacity can be thought of as vulnerabilities. This report elucidates these components for Winthrop NFH using information provided by the NFH together with climate change projections to determine sensitivity, exposure, and impact and expert opinion to summarize the NFH's possible adaptive strategies and vulnerability to climate change by the year 2040.

Sensitivity of Winthrop NFH

Winthrop NFH propagates three species within four rearing schemes or programs: spring Chinook salmon, coho salmon, and summer steelhead (one year and two year rearing cycles), and each species varies in its degree of sensitivity to disturbance in the NFH rearing environment. Current infrastructure sensitivities at the NFH revolve around low flow conditions in the summer and freezing conditions in the winter as well as threats due to forest fire. Current biological sensitivities include increased susceptibility of fish to disease outbreaks due in part to low water turnover rates in the summer.

Projected exposure due to climate change

Water temperature and availability are projected to be altered by future climate change when compared to the 2001-2010 ten-year historical averages for Winthrop NFH sources. Methow River surface water temperatures are projected to increase in most months, albeit by less than 1°C. However, the maximum change in monthly average temperature of both surface and ground water sources is expected to be relatively modest (<2°C).

The Methow River is projected to have increased surface flows from October to May, with the greatest increases in river flow (>50%) occurring between December and March. Conversely, Methow River flows are projected to decline in June (-22.5%), July (-47.0%), August (-32.6%), and September (-17.2%) compared to the ten-year baseline.

Impact of climate change on Winthrop NFH

The combination of sensitivity and exposure provides the expected impact of climate change on Winthrop NFH, and water temperature and availability at Winthrop NFH are both projected to be impacted by future climate change. The relatively modest increases to groundwater and surface water temperatures projected indicate that the facility should not become thermally unsuitable for Pacific salmon. However, increased temperatures will result in increased fish growth rates for all species.

The model-based climate scenarios suggest Winthrop NFH may experience relative increases of 26 to 102% in the flow index (a surrogate for carrying capacity that integrates growth and water use information) due to decreased stream flows from June to September for all programs. Flow indices may approach or exceed threshold values for each species during the summer months, suggesting that negative biological effects are possible (e.g., reduced growth and immune function, disease outbreaks).

Adaptability of Winthrop NFH to climate change

The Winthrop NFH Hatchery Evaluation Team (HET) worked collaboratively with the Assessment Team and relevant partners (e.g. Yakama Nation) to integrate current infrastructure and biological sensitivities and projected impacts of climate change on Winthrop NFH with details about the NFH's programs and facilities to provide an assessment of the NFH's adaptive capacity. The consensus was that environmental alterations projected to occur at Winthrop NFH due to climate change are not unexpected, and that adaptation strategies can be employed to mitigate for many of the impacts to salmon rearing programs.

Winthrop NFH has already adapted to control fry emergence date by installing incubation chillers resulting in smaller fish in the summer, thereby decreasing density and flow indices during the low flow / high temperature periods of the year. Additional strategies to adapt to projected increases in summer flow indices could include: implementing a reuse water system, developing additional ground water sources, using chillers with altered feeding or rearing regimes to better control growth and development of juvenile fish, changing stocks or species, rearing less fish, using more efficient pumps, and supplementing with oxygen.

Vulnerability of Winthrop NFH to climate change

The impact of future climate change to rearing conditions at Winthrop NFH may be manageable with existing adaptation strategies, but alterations to the timing and quantity of water resources may cause unpredictable conflicts between water users (including the NFH) due to increased competition for Methow River water during low flow periods. Decreases to summer flows coupled with increased air temperatures in the area may increase the demands for water from the Methow River, further impacting water quality and quantity. A more thorough understanding of Winthrop NFH's water rights as well as the amount of water diverted by more senior water users in the Methow River basin is needed to accurately determine the impact of declining summer flows.

An additional critical vulnerability of the hatchery programs at Winthrop NFH is the size, status and health of salmon and steelhead populations in the Methow River. All of the programs at Winthrop NFH are intended to be integrated with the natural origin populations meaning that returning hatchery origin adults are expected to mix and spawn with returning natural origin adults. It is critical that work be conducted to adequately predict, monitor, and evaluate the impact of climate induced changes on native fish populations in the Methow River basin.

Lastly, there are a number of regional uncertainties and information gaps that may affect the vulnerability of Winthrop NFH and Methow River natural populations: the response of indigenous pathogens and the spread of novel pathogens in response to a changing climate, climate induced changes to the migratory corridor and impacts on juvenile and adult migrations, and the impact of a changing climate on conditions in the ocean environment.

INTRODUCTION

As a Service and Department we must act decisively, recognizing that climate change threatens to exacerbate other existing pressures on the sustainability of our fish and wildlife resources. We must act boldly, without having all the answers, confident that we will learn and adapt as we go. And most importantly, we must act now, as if the future of fish and wildlife and people hangs in the balance — for indeed, all indications are that it does. Rising to the Urgent Challenge: Strategic Plan for Responding to Accelerating Climate Change (USFWS 2010a).

The U.S. Fish and Wildlife Service (Service) has charted a course for its climate change efforts by identifying specific mitigation, engagement, and adaptation priorities (USFWS 2010b, c). One of the Service's adaptation priorities includes the development of vulnerability assessments for species and habitats, National Wildlife Refuges, and NFHs. One priority action for NFHs reads as follows: *complete development of a model to assess vulnerability of National Fish Hatcheries… including testing of the model.* Responsibility for this task was assigned at the national level, and a qualitative assessment was developed in the Headquarters Office and distributed to all NFHs in 2011. The results and conclusions of the qualitative vulnerability assessment for Winthrop NFH, comprehensive information about the assessment including detailed methods unique to the Pacific Region, and additional information used to complete the qualitative assessment are available in Appendices A, B, and C.

Although a qualitative assessment was underway, within the Pacific Region there was tremendous interest expressed by field offices, the Fishery Resources Program (Program), and the Regional Directorate in conducting more rigorous quantitative vulnerability assessments. The programs at Winthrop NFH were chosen by the Program to serve as a pilot evaluation for the Region. A team of experts including the Hatchery Evaluation Team (HET) worked collaboratively with relevant partners (e.g. Yakama Nation) to integrate current infrastructure and biological sensitivity information and projected impacts of climate change on Winthrop NFH with details about the NFH's programs and facilities to provide an assessment of its adaptive capacity and vulnerability.

Vulnerability Assessments: An Introduction to Concepts

The vulnerability of a species or system can be thought of as a function of several key factors (Glick et al. 2011), sensitivity, exposure, impact and adaptive capacity (Figure 1). Sensitivity is the degree to which a system is responsive to changes in climate or other environmental disturbances. For example, a NFH that is currently lacking adequate water in the summer months would be highly sensitive to prolonged periods of low summer flow conditions due to climate change. We have assessed sensitivity as the current limitation to the programs at Winthrop NFH. Exposure is the magnitude or degree of change expected due to an environmental disturbance such as climate change. We have described the climate change exposure anticipated in the Methow River basin using statistically downscaled climate data. The combination of sensitivity and exposure is the expected impact of an environmental disturbance such as climate change on a given system or species. To achieve a quantitative understanding of potential climate impacts to the hatchery programs at Winthrop NFH, we have developed a model that describes how fish growth may change in the future due to climate change. Adaptive capacity is the ability or capacity of a system to cope or adapt to the impact(s) of environmental disruptions. We have considered adaptive strategies that might be useful in the future; however, additional work is needed to assess the practicality of employing these strategies. We have presented the use of chillers or cool water sources to delay emergence of hatchery fry as an example of how to mitigate for the impact of increased water temperatures on growth. In order to fully describe adaptive capacity at Winthrop NFH, we have discussed the potential impacts of climate change with the HET and have explored available strategies to respond to the impacts. Consideration of the combined effect of future climate impacts and adaptive capacity leads to an understanding of the vulnerability of a given system or species to climate change. We have summarized the potential climate impacts that cannot be adequately addressed using the existing adaptive capacity as vulnerabilities to the programs at Winthrop NFH.

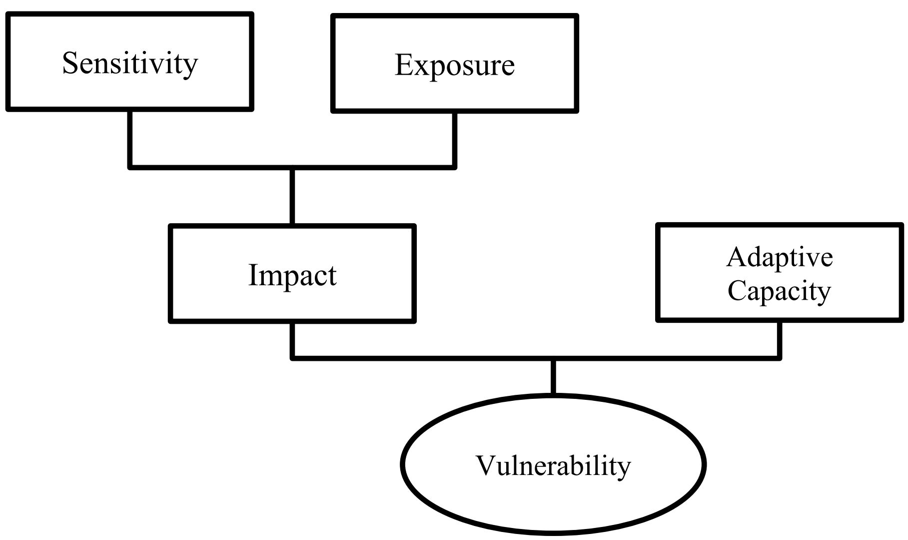

Figure 1. Key components of a vulnerability assessment.

NFH Vulnerability Assessments help determine:

- Which programs or 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 NFH 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.
  - What should we be doing differently?
- Inform adaptation planning.
  - What do we need to accomplish so we can continue to meet our goals?
- Efficiently allocate resources.
  - What resources do we need to gather and how are they best distributed?

At a local (individual NFH or program) 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 better determine the most appropriate management direction. At the regional (across NFHs/programs) level, this understanding allows resources to be more effectively allocated in a manner that is proactive rather than reactive in nature. A robust vulnerability assessment process provides local and regional managers and stakeholders with the information needed to understand which NFHs and programs are vulnerable to climate change and may lead to discussions between parties as how best to address these vulnerabilities.

Need

The Service manages 15 NFH facilities that annually release more than 60 million juvenile Pacific salmon in the Columbia River basin and the Olympic Peninsula (USFWS 2009). Collectively, there are more than 150 State, Tribal, Federal, and Provincial fish hatcheries in Oregon, Washington, and British Columbia that annually produce more than 100 million salmon and steelhead (ODFW 2011; www.wdfw.wa.gov/hatcheries/overview.html; www.pac.dfo-mpo.gc.ca/sep-pmvs/hatcheries-ecloserieseng.htm). Regionally, fisheries driven by these hatcheries annually generate billions of dollars in economic activity (Lichatowich and McIntyre 1987). Despite the biological, economic, and cultural significance of hatchery fish, little attention has been spent evaluating how current or future trends in climate will affect hatchery operations in the Pacific Northwest (Hanson and Ostrand 2011). Increased stream temperature, earlier timing of snowmelt runoff, and reduced snowpack have already been observed in the western U.S. (Kaushal et al. 2010; Luce and Holden 2009; Mote et al. 2008; Pederson et al. 2013). Further thermal and hydrologic changes are anticipated to accelerate in coming decades (IPCC 2007) which likely will result in changes in water quality and quantity within some river basins in the Pacific Northwest (ISAB 2007; Cassola et al. 2009; Mote and Salathé 2010; Mantua et al. 2010; Elsner et al. 2010; Beechie et al. 2012; Sproles et al. 2013). Consequently, there is a need to evaluate how future environmental conditions will constrain the ability of NFHs to meet production objectives or treaty obligations and potentially affect the conservation status of the associated stock. The Service has identified modeling the vulnerability of NFHs to climate change as a priority (USFWS 2010a, b). A methodology that considers how to integrate different types of data and contextual information (Dawson et al. 2011) and formally considers the uncertainty in climate projections at the appropriate scale (Wiens and Bachelet 2010) will help identify facility or program specific impacts and vulnerabilities to climate change and support the development of strategies to cope with expected changes.

Assessment process

A Climate Change Assessment Team for NFHs (Assessment Team) was created to develop a process for assessing the possible future impacts of climate change on Pacific Region NFH facilities and programs utilizing Winthrop NFH as a pilot. The process allows assessments at individual facility and program levels, complements existing planning and management efforts (e.g. NFH Hatchery Review Team recommendations), and has three critical elements. The first critical element utilizes output from global circulation models downscaled to the river basin. Biotic and abiotic hatchery data are integrated into a framework to provide consistent and transparent evaluations of the effects of projected climate change on NFHs. The second element synthesizes information generated from the modeling effort with NFH operational and local information to produce facility specific summaries of possible impacts to individual programs and facilities. In the final step of the process, the possible impacts are discussed by the Winthrop NFH HET, partners, and other technical experts. They determine which impacts might significantly affect programs/species and possible adaptive measures. Ultimately, impacts for which there is little or no adaptive capacity are vulnerabilities for the NFH.

This report merges information derived from diverse sources including a complex modeling process (Appendix D) and from meetings with individuals having professional experience and/or technical expertise. The results of this vulnerability assessment process are intended to be available and useful for Regional, Program, and local (NFH) level decision making and prioritization.

BACKGROUND

Watershed

Winthrop NFH is located on the Methow River near the town of Winthrop, WA (Figure 2). The Methow River enters the Columbia River at river kilometer (rkm) 843 on the Columbia River in north central Washington State. The Methow River watershed extends northward from the confluence with the Columbia River to its headwaters along the crest of the Cascade Mountains and the Canadian border (Figure 2). The Methow River drains a nearly 4,700 square kilometer watershed, extending approximately 140 river kilometers from its mouth to its headwaters. Topography within the basin is varied and ranges from mountainous sub-alpine and alpine terrain along the Cascade Crest to the gently sloping, wide valley found along the middle reaches of the Methow River. The elevation ranges from over 2,590 meters in the headwaters of the basin to approximately 244 meters at the confluence of the Methow and Columbia rivers.

Elevation, topography and geographic location on the east side of the Cascade Mountains influence the climate of the Methow River basin. Annual precipitation ranges from over 203 centimeters along the Cascade Crest to approximately 25 centimeters near the town of Pateros, WA, at the confluence with the Columbia River. The temporal distribution of precipitation has a high degree of seasonality with approximately two-thirds of the precipitation occurring between October and March, mostly in the form of snow. Summers are generally hot and dry with precipitation coming from brief and intense thunderstorms. In fall, precipitation increases and generally peaks in the winter as snowfall occurring between December and February.

The natural characteristics of the Methow River watershed, including spatial and temporal variation in precipitation as well as variation in elevation, aspect, geology, soils and vegetation, affect runoff patterns and water storage in the basin. The seasonal distribution of runoff is influenced by snow storage and melt, and the runoff regime in the basin is primarily snowmelt dominated. The maximum volume of flow and the highest peak flows occur during spring and early summer. Approximately 60 percent of the annual runoff volume, as measured at Pateros, occurs during May and June. Additional peak flows occur in November and December generally resulting from rain-on-snow events.

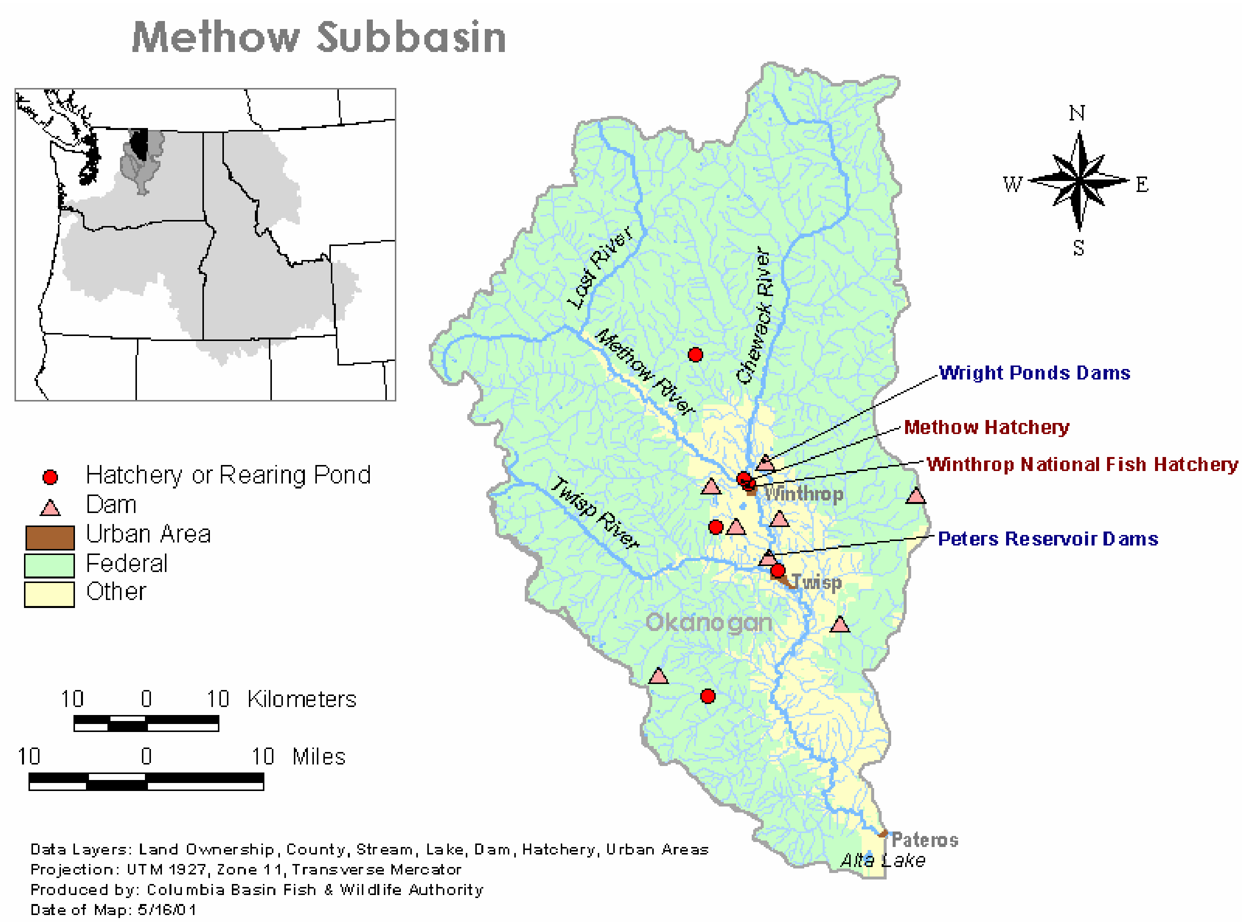

Figure 2: The location of Winthrop NFH within the Methow River watershed. Figure first appeared as Figure 6 in USFWS (2007).

Programs

Winthrop NFH primarily propagates three species within four rearing schemes or programs: spring Chinook salmon, coho salmon, and summer steelhead (one year and two year rearing cycles). Additional information and a description of current rearing conditions at Winthrop NFH can be found in Appendix E.

Spring Chinook salmon

The spring Chinook salmon program at Winthrop NFH began in 1974 utilizing the Carson NFH stock as a segregated program to mitigate for fish losses due to the construction of Grand Coulee Dam (A segregated hatchery program is used primarily for harvest purposes and is managed to be reproductively isolated from naturally-spawning populations). When Upper Columbia River spring Chinook were listed as endangered under the Endangered Species Act (ESA) in 1999, Winthrop NFH began to phase-out the unlisted, non-indigenous Carson NFH stock and began to propagate a Methow River Composite stock. The Methow River Composite stock was considered a hatchery component of the Upper Columbia River spring Chinook Evolutionary

Significant Unit (ESU). This hatchery stock was initiated by the Washington Department of Fish and Wildlife (WDFW) at the Methow Fish Hatchery (MFH) and incorporated hatchery origin and natural origin adults returning to the Methow River and Chewuch River basins when possible. Currently this stock is cooperatively managed by MFH and Winthrop NFH and is the only spring Chinook stock propagated at Winthrop NFH. Although the Methow River Composite is a listed stock, there has been little integration with the natural population due to a lack of natural origin adults available for incorporation into the brood stock. This lack of integration may pose a genetic risk to the natural population. Furthermore the Upper Columbia River Salmon Recovery Board (UCSRB; UCSRB 2007), the Service's Hatchery Review Team (HRT; USFWS 2007), and the Hatchery Science Review Group (HSRG; HSRG 2009) all suggested that the large number of hatchery origin adults returning to the Methow River basin (between the Winthrop NFH and the MFH programs) are unnecessary for recovery and conservation. In an effort to lessen the potential genetic and ecological impacts to the natural origin population presented by the over-escapement of hatchery origin adults, a number of changes are being implemented to the Winthrop NFH spring Chinook program including: 1) reducing the annual release of yearling smolts from 600,000 to 400,000; 2) transferring the remaining 200,000 as parr or eyed eggs to the Confederated Colville Tribes (CCT) for use in the Okanogan basin or mainstem Columbia River releases (until sufficient returning adults are available to support these CCT programs which may require 12 or more years); and 3) actively controlling the escapement of hatchery origin returns to natural spawning areas through removal in selective fisheries and from the hatchery ladder.

Summer steelhead

In 1995, the summer steelhead (Wells Fish Hatchery, WFH, Composite stock collected at Wells Dam) program at Leavenworth NFH was moved to Winthrop NFH. Since the ESA listing of Upper Columbia River steelhead in 1997, the program has moved towards aiding in the recovery of this stock. The current goal of the program is to compensate for lost fish production due to the construction of Grand Coulee Dam by producing summer steelhead for the restoration and recovery of threatened upper Columbia River steelhead in the Methow River basin. When recovery goals are met, this program will transition back to a more traditional mitigation goal of providing fish primarily for sport and tribal harvest.

The summer steelhead program at Winthrop NFH is currently undergoing changes per recommendations of the HRT and HSRG. A new Hatchery Genetic Management Plan (HGMP) has been developed and submitted to NOAA Fisheries that includes a number of important changes to address the recommendations. Anticipated program changes include the development of a local Methow River stock as a substitute for the WFH Composite stock. The local Methow River stock is collected and spawned later in the season (April/May), and due to the relatively cool water available at Winthrop NFH, the stock requires a two year rearing period in order to meet size at release goals. A study is currently underway to evaluate differences in performance, fitness, and survival between the 2-year local and the 1-year WFH steelhead smolts. The current program size is a release of 100,000 smolts (50,000 of each stock), but as the local stock is developed, the program will transition to 100% local stock with a 2-year rearing cycle. Assuming adequate broodstock availability (given limited ability to collect wild adults for broodstock), the Service intends to increase the size of the steelhead program at Winthrop NFH to a release goal of 200,000 smolts (2-year rearing cycle, local stock). This change is contingent on ESA permitting and other considerations and will likely not be fully implemented for a number of years.

Coho salmon

The Yakama Nation (YN) is attempting to re-establish coho salmon in the Mid-Columbia River basin. The goal of the program is to establish a coho salmon population which is at or near carrying capacity and provide harvest opportunities for tribal and non-tribal fisheries. Coho salmon were first brought to the Winthrop NFH in 1996 from hatcheries on the Lower Columbia River. The transfer of coho salmon juveniles from the lower Columbia River was gradually phased out over the years until 2007 when returns to the Methow River became consistent enough to provide all of the broodstock for the program.

The current coho salmon program goal is to collect enough adults to provide 500,000 smolts for release in the Methow River basin. Half of these smolts are reared full term at Winthrop NFH, while the other 250,000 are reared from the eyed-egg stage to the yearling stage at Willard NFH and subsequently returned to the Methow River basin (to various acclimation ponds) as pre-smolts for acclimation and release.

NFH Environment

Infrastructure

The major physical facilities which comprise the Winthrop NFH include:

- 1 hatchery building
- 2 adult holding ponds/spawning building
- 30 raceways (8' x 80')
- 16 raceways (12' x 102')
- 16 foster lucas ponds
- 1 diversion and intake structure – Foghorn Dam
- 3 infiltration gallery pumping systems
- 1 isolation building
- 4 storage/water control buildings
- 1 feed and storage building
- 1 pollution abatement pond
- 2 predator control structures
- 1 generator building

- 3 residences
- 1 visitor comfort station

Water rights
A summary of the water rights associated with Winthrop NFH activities are presented in Table 1.

Table 1. Water Rights appurtenant to the Winthrop NFH (sorted by priority date).

Certificate Number	**Source**	**Purpose of Use**	**Priority Date**	**Amount**
CCVOL1206	Spring Branch Springs	Operation of NFH	7/23/1891	10 cfs
848 Original certificate 201 Certificate of Change S4-00705C Application to change	Methow River or groundwater, Infiltration Gallery #3	Originally for hydro-electric power; purpose and place of use changed to fish propagation for the NFH in 1942. Infiltration Gallery #3 added as a point of diversion in 2003.	1/10/1922	50 cfs total. Up to 10 cfs can be diverted through Infiltration Gallery #3, per the 2003 change
7209-A Record No. G4-*08664CWRIS	Groundwater, Infiltration Gallery #1	Fish propagation	4/6/1967	3.34 cfs, 1500 gpm, 2,400 ac. ft. per year
7590-A Record No. G4-*11685CWRIS	Groundwater, Infiltration Gallery #2	Fish propagation Operation and maintenance of NFH	2/17/1971	3.34 cfs, 1,500 gpm, 2,400 ac. ft. per year
G4-429152 GWC7209-A Application only	Groundwater, Infiltration Gallery #1	Fish propagation	11/5/1986	2.89 cfs, 1300 gpm, 2,100 ac. ft. per year

The Spring Branch Springs water source produces less than 1 cfs and is only used as a back-up source. The output of this spring has diminished over time with the development of other wells in the area, the lining of the Wolf Creek Ditch, and a possible natural reduction in flow. As this spring contains brook trout and is not a pathogen free water source, it is not an ideal water source for NFH uses.

Two applications for change were filed with the Washington State Department of Ecology on November 5, 1986 to increase the diversion from Infiltration Gallery #1 and Infiltration Gallery #2 by an additional 1300 gpm and 3250 gpm, respectively. The applications have not been completely processed to date, however the Winthrop NFH continues to withdraw water at the requested rate. In 2013, the Service filed a request with the Department of Ecology to transfer these additional water rights for Infiltration Galleries #1 and #2 from the existing 50 cfs surface water right (certificate 848) as a change in point of diversion.

Water availability and withdrawal

Three sources of water are presently utilized at Winthrop NFH. The main water source is the Methow River, from which the NFH has the right to 50 cfs. Spring Branch Springs and a system of three infiltration galleries provide approximately 25 cfs combined. The infiltration galleries are important because they provide comparatively warmer water during the cold winter months as well as a relatively pathogen free water source which is beneficial to egg incubation and the rearing of very young fish.

The Foghorn Dam on the Methow River is a rock and boulder structure which impounds and diverts river water to the Foghorn Ditch and, subsequently, to the Winthrop NFH, MFH, and the irrigation district (Foghorn Ditch Company). The structure has existed in some form for irrigation purposes since before the construction of the Winthrop NFH in 1938. The Foghorn Diversion structure adjacent to the south side of the dam collects water for the Foghorn Ditch and provides fish passage around the dam by means of a fish ladder. The structure also has an adult salmon trap for collecting wild adult salmon. However this trap has proven to be ineffective since the dam is not a barrier to fish. The Winthrop NFH is responsible for operating and maintaining the Foghorn Diversion intake structure and dam as well as the Foghorn Ditch from the intake down to where it crosses Twin Lakes Road below the NFH.

The Winthrop NFH and MFH facilities use surface water from the Foghorn Ditch primarily from October through April, while the irrigation district is shut down. The Foghorn Ditch Company has a 25 cfs water right and diverts a maximum of 20 cfs from late April through September. Although the Winthrop NFH has a legal right to 50 cfs from this source, the NFH typically only uses up to 22 cfs during its primary use period; the MFH has a water right of 18 cfs which is used near capacity during the winter months.

Surface water shortages sometimes occur during freeze-up events in the winter months when river flows are low and both hatcheries are using substantial amounts of river water. Both the

MFH and Winthrop NFH have the capability of mixing ground water during the winter to compensate for temporary shortages in surface water.

Winthrop NFH uses 100% groundwater for all incubation and early rearing of salmonids. Steelhead in the 1-year smolt program remain on ground water for an extended period during winter months to maximize growth, while the remainder of the yearling fish and 2-year steelhead are on a mixture of ground and surface water to slow winter growth.

Winthrop NFH installed an incubation chiller in the fall of 2010. The chiller has reduced water use during several months of the year since slowing early development delays the emergence of fry and reduces the rearing space and flow required during early rearing.

Water temperature and quality

At Winthrop NFH surface water temperatures are measured and recorded weekly by hand. In addition, there is a thermograph (paper type) that graphs the temperature on a daily basis. The temperature of the surface water varies daily and seasonally from a low of approximately 0°C in the winter to 20°C in the summer.

Presently, the Methow River has two water quality classifications from the Washington State Department of Ecology: the lower river is Class A (excellent) and the upper watershed is Class AA (extraordinary). There has been consideration of reclassifying the lower Methow River to Class AA (Willms and Kendra 1990). A review of historical data showed that high summer water temperatures have continually been a major water quality concern. In-stream temperature monitoring during August indicated water temperature criteria violations at both rkm 8 and 80. However, violations were more extreme at the lower site. Less stream shading and higher air temperatures probably contribute to naturally elevated temperatures in the lower river. Both historical and present temperature data indicated that if the lower river had been classified AA, only slight increases in criteria violations would have occurred. Differences in water quality between Class AA and A sites were minimal, though some nutrients were significantly higher at Class A sites. Mainstem N:P ratios indicate that phosphorus may be a growth limiting nutrient for in-stream plants. Plant productivity may explain the observed phosphorus loss and higher pH in the lower river.

Groundwater temperatures at Winthrop NFH are measured and recorded weekly. Groundwater temperatures range from 7°C in the winter to 11°C during the summer. The water is produced from shallow (4 to 5 meters deep) infiltration galleries; temperature does not fluctuate noticeably on a daily basis, but changes are noticed from week to week. The groundwater pumped from the three infiltration galleries is essentially filtered river water which provides a high quality water source in regard to pathogen load, turbidity, and temperature. This source is not 100% pathogen free, but it is certainly much cleaner than the unfiltered surface water.

SENSITIVITY

Sensitivity is the degree to which a system is or is likely to be affected by climate change. For example, a NFH that is already rearing fish at maximum fish densities will be very sensitive to negative impact(s) of climate change.

The infrastructure and rearing programs for each species at Winthrop NFH vary in the degree of sensitivity to disturbance in the hatchery rearing environment. We qualitatively assessed known sensitivities that occur at the facility during current operations with the assumption that these problems are most likely to be exacerbated by the impact of climate change. Additional information regarding the baseline rearing conditions and the data can be found in Appendix E.

Ground water shortages in the summer and fall
The ground water source for Winthrop NFH is directly related to the Methow River water level since the infiltration galleries collect shallow ground water in horizontal perforated pipes which drain into a well sump. When the river reaches low levels in the late summer and fall, infiltration gallery pumps begin to cavitate. To avoid gas bubble trauma in the juvenile fish, the pumps must be turned down, alternated, or turned off to minimize cavitation resulting in less than ideal turnover rates in the ponds.

At the same time ground water is in short supply, surface water from the Methow River is mostly unavailable due to irrigation withdrawal. However, summer Methow River water may be undesirable due to pathogen concerns from naturally spawning spring Chinook salmon.

Surface water freezing in the winter
The Winthrop NFH relies on surface water during the winter months to slow the growth of most of the yearling fish on station. The irrigation district does not function during the winter and water is usually available in good quantity through the winter except during extreme cold periods. Low river flows in the winter coupled with extreme cold, freeze the intake at the Foghorn Diversion, preventing or reducing flow into the Foghorn Ditch. The NFH responds to these situations by reducing flows to each rearing unit and using a combination of groundwater and available surface water. Fortunately, these cold periods (air temps below -18ºC) are usually short lived and have not resulted in any major fish losses in recent years.

Winter air temperatures have warmed over the last several decades and the number and degree of extreme cold periods at Winthrop NFH has diminished over time based on data collected by the National Weather Service at NWS weather station Winthrop 1 WSW, WA 459376 (Chris Pasley pers. comm.; Figure 5 Appendix F). This is corroborated by information summarized at the regional level (Appendix F). Previous to 1990, emergency releases and fish losses were more common due to freezing. The development of additional ground water has helped alleviate water reductions during extreme cold periods.

Disease outbreaks in the summer and fall

Fish at the Winthrop NFH are susceptible to several common salmon pathogens and diseases (Table 2). These are exacerbated during conditions of reduced flows and elevated water temperatures. In the summer and fall (August/September), Ich (*Ichthyophthirius multifiliis)* becomes an issue with the spring Chinook salmon reared at Winthrop NFH and lowered turnover rates compound the problem. Ich is often treated with increased turnover rates because the organism is passive in the water column and can be flushed out with high turnover rates. When Winthrop NFH cannot adequately increase turnover rates, formalin treatments are used as soon as the parasite is discovered. Increased stress from the formalin treatments and the infection itself sometimes allows for additional outbreaks of opportunistic pathogens such as bacterial kidney disease (*Renibacterium salmina)*.

Table 2. Common salmon pathogens and diseases found at Winthrop NFH.

Species	Density Index (Maximum)	Flow Index (Maximum)	Size at Release (fish/lb)	Release Timing	Pathogens / Diseases of Concern*
Spring Chinook Salmon	0.11	1.0	15 – 18	April 15-20	BKD, Ich, Trich., Costia
Summer Steelhead	0.20	1.0	5 – 6	April 20-May 15	CWD, Steatitis, IHN, Trich.
Coho Salmon	0.20	1.0	15 - 17	April 20-May 1	CWD, Steatitis, Trich.

* Ich (*Ichthyophthirius multifiliis*), BKD (bacterial kidney disease, *Renibacterium salmoninarum*), Costia (*Ichthyobodo necatrix, I. pyrifornis*), Trich. (*Trichodina truttae*), CWD (cold-water disease, *Flavobacterium psychrophilum*), IHN (Infectious hematopoietic necrosis, *Novirhabdovirus* spp.).

Risk of forest fire

The facilities and physical resources at Winthrop NFH are at some risk due to forest fires. The Upper Methow River is currently experiencing high levels of tree loss due to damage by invasive insects (spruce budworm, *Choristoneura* spp. and pine bark beetles, *Dendroctonus ponderosae*) and may be especially susceptible to fire in the future. The Chewuch River (a tributary of the Methow River located below the hatchery) is vulnerable to fires due to its aspect and current poor condition as evidenced by dramatic forest fires that have occurred in the recent past within the Chewuch basin. These fires have reduced water quality and significantly increased fine sediment loads in the Chewuch basin. If forest fires of this magnitude (or greater) were to occur in the Upper Methow River basin there could be significant impacts to the quality of water (turbidity, fine sediments) available for use at Winthrop NFH.

EXPOSURE AND IMPACT

A detailed description of how we quantitatively assessed the exposure of Winthrop NFH to climate change and the potential impacts to the NFH are provided in Appendix D. A summary of methods and results are provided below.

To quantitatively assess the exposure and impact of projected climate change to Winthrop NFH, our overall goal was to determine whether NFH programs can operate in a "business as usual" paradigm following existing rearing schedules and production targets under the projected climatic conditions for the 2040s. Our specific objectives were to: (a) determine if future environmental conditions are likely to preclude rearing of certain stocks; (b) identify the magnitude and timing of sub-lethal effects (altered growth rates, disease outbreaks, etc.) that may affect production; and (c) suggest general mitigation strategies given the impacts detected in (a) and (b). To do this, we synthesized physiological tolerance data for Pacific salmon stocks at Winthrop NFH and common salmon pathogens, adapted a temperature-driven growth model to predict fish growth, and developed a modeling framework using flow index and density index (Piper et al. 1982, Wedemeyer 2001) that integrates the effects of changing temperature and water availability within the Winthrop NFH. We briefly summarized the important hydrologic changes anticipated for the Methow River basin upstream from the NFH. Using empirical data on recent rearing conditions within the NFH, we then predicted the future production characteristics of each of four salmon stocks by implementing the growth model and modeled flow and density indices based on in-hatchery environmental conditions projected for the 2040s under one greenhouse gas scenario (A1B) and associated changes in water temperature and availability.

Exposure

> *Exposure is the character or magnitude of an effect such as climate change. This is the quantified prediction of change that may occur at a particular NFH.*

Methods

To derive projections of the future climate at Winthrop NFH in the 2040s, air temperature data from the statistically downscaled global circulation model (GCM) simulations for the A1B greenhouse gas emissions scenario were used to estimate air temperatures in the local watershed. Air temperatures were then converted to surface water temperatures in the Methow River and groundwater temperatures available to Winthrop NFH through a series of regression models. The projected 2040s temperatures were then compared to baseline thermal rearing conditions measured at the facility's surface and ground-water intake locations from 2000 – 2009 (Table 1 Appendix D).

Results and discussion

Climate and hydrologic modeling under the A1B emissions scenario project the Methow River basin will experience warmer air temperatures, reduced snowpack, earlier snowmelt runoff, and lower summer base flows by the 2040s (Figure 1-5 Appendix D). Mean monthly air temperature is expected to increase, an average of 2.07°C (S.D. = 0.54) from the present to the 2040s, with the largest absolute increases predicted in summer (June – September). Water temperature in the 2040s based upon the A1B scenario and statistical downscaling of GCMs show impacts of varying degrees to surface and groundwater temperatures at Winthrop NFH. Methow River surface water temperatures are predicted to increase in most months, albeit by less than 1°C when compared to ten year historical averages (Table 1, Figure 6 Appendix D). Groundwater at this facility is collected from shallow infiltration galleries, and increases in groundwater temperatures track those of the surface waters of the Methow River with the largest increases projected for May (+0.7°C) and June (+0.9°C). The climate models do not project large changes in total precipitation, but the amount that falls as snow and persists as snowpack is expected to decline. Changes in runoff, average flow, winter floods, and summer drought severity are projected for the Methow River basin upstream from the Winthrop NFH. Concurrent with changes in water temperature, the monthly surface flows in the Methow River near the town of Winthrop, WA, are also projected to change by the 2040s. The Methow River is projected to have increased flows from October to May annually when compared to the 10 year baseline (2000 - 2009). The greatest increases in river flow (>50%) are projected to occur between December and March. Conversely, surface flows are projected to decline in June (-22.5%), July (-47.0%), August (-32.6%), and September (-17.2%) when compared to the 10 year baseline (Table 3 Appendix D). Snow levels are projected to rise as air temperatures increase, and the basin may shift from a snowmelt to a so-called transitional or rain-driven system in the future.

Exposure main points

- Mean annual air temperature will increase, mean winter snowpack will decrease, snowmelt runoff will occur earlier, and summer base flows will decrease in the Methow River basin by the 2040s.
- Mean surface water temperatures of the Methow River will increase slightly (<1°C) in most months.
- Groundwater temperatures are correlated with surface water temperatures and will increase slightly in May (+0.7°C) and June (+0.9°C).
- Mean annual precipitation may not change significantly, but the amount that falls as snow and rain will decrease and increase, respectively.

- Mean water flows/volume of the Methow River at Winthrop NFH will increase from October through May but decrease in June (-22%), July (-47%), August (-33%) and September (-17%).

Impact

Impact is defined as the combination of sensitivity and exposure. A sensitive NFH may be impacted by even a small change in climate. Conversely, if the exposure is large enough, it may affect even less sensitive NFHs.

Water temperature
Groundwater temperatures are not expected to increase above the physiological tolerance of any of the salmon species currently spawned at Winthrop NFH (Table 2, Figure 7, 12, 22, Appendix D). Additionally, water temperatures are not expected to exceed physiological tolerances for any of the salmon species reared at the facility (Table 2, Figure 8, 13, 23 Appendix D). However, increases in water temperature approaching 1°C in May and June coupled with minor increases of less than 0.25°C in other months may impact rearing conditions for all species within the facility. In particular, fish growth rates are likely to increase as a result of increased water temperatures with fish from all rearing programs attaining a larger size at release (Chinook = 5.6% heavier, 1.8% longer Table 4 Appendix D; one year steelhead = 5.6% heavier, 1.8% longer Table 7 Appendix D; two year steelhead = 6.1% heavier, 2.0% longer Table 10 Appendix D; coho salmon = 6.4% heavier, 2.1% longer Table 13 Appendix D). Water temperatures are not projected to rise to within the optimal growth temperature for common salmon pathogens (Table A.2 Appendix D), though increases in water temperatures approaching 1°C in May and June may increase the risk for disease outbreaks in these months for all species. Regardless of fish species, no physiological thresholds are violated, indicating that temperatures that cause physiological dysfunction and mortality are not likely to result in the catastrophic failure of any existing program. However, high water temperatures are inherently stressful to all Pacific salmon, and increased exposure to high temperatures will induce chronic stress, decrease immune function in individual fish, and cause an increased potential for disease outbreaks in the population. The timing of standard hatchery practices that are stressful to fish (e.g., handling, mass marking, moving fish between rearing containers) may need to be altered to avoid portions of the year that will experience higher temperatures in the 2040s.

Water availability
The model-based climate scenarios suggest Winthrop NFH may experience relative increases of 26 to 102% in the flow index (calculated by dividing weight of fish production [pounds] by flow [gallons per minute] and fish length [inches], Piper et al. 1982) during the summer months of June to September for all programs (Figures 10, 15, 19, 25 Appendix D). These increases in flow index are primarily driven by reduced water availability and, to a lesser extent, increased water temperatures acting through increased fish growth. For the summer months when flow

index values are predicted to increase or exceed target values for a program, the change is largely the result of reduced water availability. Flow index integrates growth and water use, and can be interpreted as a surrogate for carrying capacity that considers dissolved oxygen levels and removal of metabolic waste (Wedemeyer 2001). Flow indices will approach or exceed threshold values for each species during the summer months, suggesting that biological effects are possible (e.g., reduced growth and immune function, disease outbreaks). The density index for each program is also predicted to increase and peak in summer, but overall the relative increases were minor (≤7.7%). Both density and flow index integrate fish growth (because temperature is a variable in the index), but the larger relative changes predicted for the flow index suggests that decreases in water availability during the summer may be a more significant challenge to rearing each species in the 2040s than increases in water temperature.

Discussion

For the A1B emissions scenario, projected decreases in summer flow were concordant across the ten GCMs (see Appendix B, C, and D for further information). The general inference that there will be less water in the Methow River during the summer months which could lead to potential problems at Winthrop NFH is plausible. We caution however that there are a number of assumptions and uncertainties with any modeling approach and available data limits our ability to make more precise predictions. For example, we assumed that hydrologic conditions at the nearest stream gauge downstream from Winthrop NFH are and will be representative of conditions at the hatchery. Efforts are underway to generate the comparable site-specific hydrologic data that can be used to refine the modeling results. The effect of increased mean discharge projected for some winter months has not been explicitly considered in our modeling. Additional water beyond what is currently used could potentially be utilized when it is available, but this may not benefit the rearing programs which appear to need more water during summer. The effects of elevated discharge and floods on infrastructure (infiltration galleries, water filtration systems, etc.) have also not been explicitly modeled. We have modeled only incremental changes in water availability, but the human dimension of water use and state water law could conceivably result in changes that are more dramatic or abrupt. The modeling predictions and inferences notwithstanding, the modeling exercise helped to identify uncertainties warranting further investigation, such the relationship between surface flow and temperature and groundwater conditions adjacent to the NFH and surface water levels that correlate with cavitation of the infiltration galleries. Obtaining these data would facilitate a more robust, detailed assessment of climate impacts and facilitate adaptation planning.

Impacts main points

- Increases in mean water temperatures are expected to boost fish growth rates, resulting in either a larger size at release or earlier dates of release if mean release size remains unchanged; however, increases in mean water temperature alone are not expected to pose a physiological stress to the fish species currently reared at Winthrop NFH.

- Increases in mean water temperature during the summer months will increase disease risks to all species.
- Water availability June-September will decrease, thus increasing density and flow indexes, and posing additional fish health risks.
- Future water availability to Winthrop NFH during the summer months is a major uncertainty, not just due to the effects of climate change, but also due to the higher seniority of the water rights held by irrigators and other users in the Methow River basin.

ADAPTATION AND VULNERABILITY

The Winthrop NFH HET provided guidance and advice for all parts of this assessment. For example, the HET's technical experts in fish health, culture, and biology, provided input as to how exposure due to climate change might be expected to impact NFHs as a whole. However, the HET's input was particularly critical for the adaptation and vulnerability sections of this assessment since they had the specific NFH related experience necessary to determine whether Winthrop NFH could adapt to predicted climate change impacts or is vulnerable to climate change.

A workgroup (Group) lead by the HET worked collaboratively with others, including the Assessment Team and relevant partners (e.g., Yakama Nation), to integrate the quantitative information about possible impacts of climate change on Winthrop NFH with details about the NFH's programs and facilities. The Group discussed strategies for helping Winthrop NFH adapt to climate change and helped to clarify the NFH's vulnerability to the effects of climate change. The result of the Group's discussions is summarized below.

Adaptation

> *Adaptation is defined as how well a system may be able to adapt to change. Some NFHs will be able to adapt to climate change impacts better than others.*

As facilities for artificially rearing fish, NFHs are experienced at adapting to environmental change by adjusting infrastructure, water usage and sources, and fish production protocols. A vulnerability assessment provides the opportunity to adjust to anticipated future change and the ability to adapt in a proactive rather than reactive fashion. The climate impacts predicted for Winthrop NFH under 2040s climate projections are not unexpected, and a number of adaptation strategies were suggested by the HET. In general, these adaptation strategies focused on infrastructure or programmatic changes designed to mitigate for high water temperatures (and concomitant increased fish growth, stress, and disease outbreaks) and decreased water availability (and increased flow indices). An adaptation strategy that was briefly discussed included the rearing of alternative species or stocks. Alternative species or stocks could include those having a shorter freshwater residence or run timing more aligned with periods of low temperature and greater water availability. This strategy should only be considered if conditions in the natural environment change such that ocean growth or migratory success is impacted in a significant or dramatic fashion. However, preparations for anticipated dramatic, large scale changes in the environment will need to be covered in another analysis.

Ground water shortages in the summer and fall

Infrastructure adaptations

Decreases in water availability during the summer and fall will impact key areas of existing infrastructure at Winthrop NFH that are already very sensitive to levels of ground and surface water, especially in July and August. The facility currently has three groundwater infiltration galleries (~5 meters in depth) that are closely tied to the available groundwater input by the surface water flows in the Methow River. At low river discharge levels, the infiltration pumps cannot efficiently pump water to the NFH. Converting the infiltration pumps to variable speed drive instead of direct drive may reduce cavitation and maximize groundwater pumping. Additional ground water sources may be available and need to be investigated, with the possibility of requiring an additional deep well (as opposed to the shallow infiltration galleries) to avoid the effects of seasonal low flow conditions on groundwater availability. However, this would require substantial infrastructure investment, and the amount of available deep groundwater is uncertain.

Other adaptation strategies include installing an oxygen injection system or implementing water reuse during the summer months. However, without new infrastructure to treat water and to ensure that adequate water temperatures are maintained, the reuse option has significant disease risks during a period of time when the NFH already experiences the majority of its disease outbreaks.

Biological adaptations

To mitigate for increased water temperatures leading to increased growth rates, additional use of chilled water and alternative growth and rearing strategies may be needed as adaptation strategies at Winthrop NFH. The NFH has already changed its rearing conditions by chilling incubation water to delay egg development and fry emergence. Currently, fish that would normally emerge in January using ambient water temperatures emerge in March/April using chilled incubation water, resulting in smaller fish in the summer and emergence timing similar to fish in the natural environment. However, if the programs at Winthrop NFH are operated using current production protocols, climate induced increases in water temperature in the future will result in a significant increase in fish size by the end of the standard rearing period. Similarly, if fish growth is not managed, the flow index in the future is projected to almost double in the middle of summer. Alternative rearing strategies resulting in lower rearing densities should be investigated. Multiple strategies have the potential to compensate for the proportions of the alterations to flow and density indices due to the anticipated effects of increased water temperatures and fish growth. Feeding regimes could also be altered to constrain fish sizes and growth rates throughout the rearing period. Chillers could also be used to cool water during the hottest months. Increased use of chilled water and judicious feeding might allow Winthrop NFH to continue to maintain fish at its current capacity in the future. If all of the above methods were to fail, the number of fish reared in a raceway could be altered to meet target flow and density index constraints. However, this would impact the ability of the Winthrop NFH to meet production objectives for its programs.

Disease outbreaks in the summer and fall

General adaptations

There is a great deal of uncertainty concerning the magnitude and mechanism of climate induced changes to pathogen prevalence and disease risk. There is little to no information concerning how climate induced changes to the natural environment may alter the distribution, prevalence and virulence of current salmonid pathogens or how climate change may influence the rise of novel or unknown pathogens. This is a critical information gap for salmonid hatchery programs throughout the Pacific Northwest and efforts to help address these questions should be initiated.

Overall, climate change is projected to increase rearing temperatures and reduce water availability during the summer. It is not expected to result in temperatures exceeding the thermal tolerance of any species reared at Winthrop NFH but may result in increased stress for the fish. The mid-summer timing of some NFH practices, such as mass marking and tagging operations, will likely coincide with a period of reduced water availability and increasing water temperature. Transitioning these activities to earlier or later in the calendar year may help alleviate the stress and negative impacts of marking and tagging on fish health. Increased rearing temperatures and increases to density and flow indexes may increase pathogen outbreaks for all species particularly since pathogen prevalence is often quite responsive (increased risk) to reductions in water turnover rate within the rearing unit.

Species specific adaptations

Steelhead on a one-year rearing cycle are currently the stock least affected by disease and stress and most resistant to increases in flow index at Winthrop NFH. Coho are more similar to steelhead, but coldwater disease (*Flavobacterium psychrophilum*) does impact coho salmon juveniles at Winthrop NFH. Spring Chinook are the most vulnerable to the effects of pathogens and climate induced changes to pathogen prevalence and risk is likely to impact this program the most.

There are program specific concerns for steelhead reared at Winthrop NFH. Steelhead raised in a two-year rearing cycle will be the most vulnerable program to the impact of climate change because of the greater amount of time spent in the NFH. Extended rearing schedules may need to be re-evaluated; a transition back to a one-year rearing schedule for steelhead would be relatively non-disruptive and could be accommodated with the current NFH infrastructure if climate induced changes to the environment warrant a switch.

Surface water freezing in the winter

The Winthrop NFH relies on surface water during the winter months to slow the growth of most of the yearling fish on station. Low river flows in the winter coupled with extreme cold can freeze the intake at the Foghorn Diversion, resulting in fish losses due to low water levels in the NFH. Previous to 1990, emergency releases and fish losses were more common due to freezing. However, winter air temperatures have warmed over the last several decades and the number and degree of extreme cold periods at Winthrop NFH has diminished over time (Chris Pasley pers. comm.; Figure 5 Appendix F).

The Winthrop NFH has already adapted to freezing periods by developing additional ground water to help alleviate water reductions during extreme cold periods. Given that winter air temperatures are projected to increase slightly (Appendix D) due to climate change, extreme cold freezes should continue to decrease in frequency. Therefore, this NFH sensitivity should improve with climate change.

Risk of forest fire

The risk of forest fire affecting facilities and physical resources at Winthrop NFH will undoubtedly increase with the projected increase in air temperatures. However, the Group did not discuss adaptive strategies for the facility except to recommend involvement in fire prevention and emergency response programs. The impact of upper watershed forest fires on water quality was discussed, but no additional adaptive strategies were given beyond those already proposed to address water quality in the summer months.

Adaptation main points

- Decreases in water availability during the summer and fall will impact critical components of Winthrop NFH operations. Improved infrastructure, water conservation, and development of additional ground water sources are all possible means to address these impacts.
- Winthrop NFH already utilizes chilled water to delay the emergence of summer steelhead in order to avoid density and flow related issues later in the rearing cycle. The NFH should evaluate if wider or altered use of chilled water is a feasible means of adapting to some of the impacts of increased flow indices due to climate change.
- There is considerable uncertainty concerning the effect of climate change on the distribution, prevalence, and virulence of pathogens. The consensus at this time is that climate change will likely increase the risk and impact of fish disease within the NFH environment. Given this, Winthrop NFH should consider transitioning the timing of tagging operations to earlier or later in the calendar year as a means to avoid the summer and early fall months which are the highest risk time of the year for disease outbreaks.

Vulnerability

Vulnerability is the combined effect of impact and adaptive capacity. Vulnerability provides a summary of sensitivity, exposure, and adaptive capacity for a particular NFH.

While the changes expected in the natural environment are significant, adaptation strategies can be employed to mitigate for many of the impacts to salmon rearing programs. In particular, the maximum change in monthly average temperature of both surface and ground water sources is relatively modest (<2°C), indicating that the facility should not become thermally unsuitable for Pacific salmon. However, reductions in water availability during the summer and fall may impact rearing practices at Winthrop NFH, and these impacts may be exacerbated when considered at the landscape level. Decreases to summer flows coupled with increased air temperatures in the area may increase the demand for irrigation water removal from the Methow River. Currently, the seniority of the water rights of Winthrop NFH in comparison to upstream users are unknown, so there is the possibility that more senior water users may remove a sufficient quantity of water from the river to impact salmon rearing activities. A more thorough understanding of Winthrop NFH's water rights as well as the volumes of water diverted by more senior water users in the Methow River basin is required to accurately determine the impact of declining summer flows. A recently completed water inventory for Winthrop NFH will be useful in this effort (Mayer and Strachan 2012). Additional water rights or sources of ground water may need to be secured to ensure sufficient water access for fish rearing activities during the drier months.

A critical vulnerability of the hatchery programs at Winthrop NFH is the size, status and health of salmon and steelhead populations in the Methow River. Changes to the natural environment may have significant negative effects on these already depressed populations. All of the programs at Winthrop NFH are intended to be integrated with the natural origin populations meaning that returning hatchery origin adults are expected to mix and spawn with returning natural origin adults and that returning natural origin adults are expected to make up a significant portion of the broodstock for the steelhead and coho programs. The spring Chinook program at Winthrop NFH is integrated using a "stepping stone" model of broodstock management where returning hatchery adults from the nearby conservation program at MFH are used as brood. The conservation program at MFH utilizes natural origin spring Chinook adults as the primary broodstock source, and in this fashion the program at Winthrop NFH is only a "stepping stone" away from integration with the natural origin population. Currently the status of the spring Chinook and steelhead populations are such that they warrant ESA listing, and any decreases in population size could have significant impacts on the ability to obtain sufficient numbers of fish for broodstock. The Service, working with its cooperators in the basin, should immediately undertake work to better understand how these populations will respond to changes in climate, what adaptation strategies are necessary, and begin a process for implementing these strategies to ensure that the current programs at Winthrop NFH can continue to operate in a biologically sound fashion that meets mitigation and conservation goals.

Vulnerability main points

- Winthrop NFH may be vulnerable to reduced water availability by the 2040s due to both climate change and increased water demands by senior water right users.
- A critical vulnerability of the programs at Winthrop NFH is the size, status and health of salmon and steelhead populations in the Methow River.
- The Service and its cooperators in the basin, should immediately undertake work to better understand how Methow River salmon and steelhead populations will respond to changes in climate, what adaptation strategies are necessary, and begin a process for implementing these strategies to ensure that the current programs at Winthrop NFH can continue to operate.

RECOMMENDATIONS

Presented below is a summary of key information needs and work efforts recommended by the Assessment Team. Having this information would allow a more comprehensive understanding of the impacts of climate change on the programs at Winthrop NFH as well as providing information pertinent to hatchery programs throughout the Columbia River basin. Most importantly, many of the actions described below have the potential to increase the ability of the Service to adapt and respond to the impacts of climate change at Winthrop NFH.

Winthrop NFH

- **Assess the Development of Additional Water Sources for Winthrop NFH:** A key concern raised by this vulnerability assessment is the impact of increased periods of summer low flow conditions in the Methow River and the likely impact on the ability of Winthrop NFH to obtain sufficient water for optimum rearing conditions. The Service should investigate the feasibility of an adaptation to develop additional water sources and/or water conservation strategies.

- **Investigate Methow River Water Rights:** The impacts of climate change will undoubtedly result in greater competition for existing water resources. Water is already over allocated among water users in the Columbia River basin and climate change will likely exacerbate this issue. The Service should have a clear understanding of how water in the Methow River is allocated and what standing water rights held by Winthrop NFH has in comparison to existing users.

- **Implement Hatchery Reform:** Hatchery Reform is a critical means to add resiliency to the impacts of climate change for the listed populations of salmon and steelhead in the Methow River basin. Aiding in the recovery of endangered spring Chinook salmon and threatened summer steelhead is a key objective of the programs at Winthrop NFH. Essential to this effort is the implementation of Hatchery Reform; specifically, the transition to local brood stocks, management of hatchery escapement on the spawning grounds, and management of broodstock composition to ensure integration of the hatchery with the wild population. Failure to follow these guidelines will likely increase the extinction risk for these populations through genetic and demographic factors and will only increase the sensitivity of these populations (and the related hatchery programs) to the impacts of climate change.

- **Determine the Impact of Climate Change on Wild Populations:** All of the programs at Winthrop NFH are intended to supplement naturally spawning populations of summer steelhead, spring Chinook, and Coho salmon in the Methow River basin. Now that the effect of climate change on the rearing conditions at Winthrop NFH is better understood, the logical next step for the vulnerability assessment process is to develop a better understanding of what the likely effect(s) of climate change is on the freshwater spawning and juvenile rearing conditions within the Methow River basin. This effort should involve a joint effort between all of the relevant co-managers including State, Tribal, and Federal interests. Linking this assessment with the local recovery planning efforts already underway by the Upper Columbia Salmon and Steelhead Recovery Board could provide additional resources and result in a more comprehensive and powerful assessment.

Regional Scale Impacts to Pacific Region NFHs

- **Effects of Climate Change on the Ocean Environment:** Predicting the future effects of climate change on marine ecosystems is extremely difficult, although many effects have been documented and postulated (see review by Hoegh-Guldberg and Bruno 2010). Global mean temperatures have risen approximately 0.2° C over the past 30 years with most of that heat energy absorbed by the oceans. The oceans have also absorbed approximately one-third of all anthropogenic CO_2, thus reducing the mean pH of the oceans globally. Continued warming of the upper layers of the oceans is expected to increase temperature stratification, thus decreasing dissolved O_2 concentrations in deeper waters and potentially reducing nutrient availability in the phototrophic zone. Indeed, total phytoplankton production has decreased by more than 6% since 1980 with over 70% of this reduction concentrated at higher latitudes, particularly in the Pacific Ocean and Indian Ocean gyres. Although the effects of sea-level rise and ocean acidification on nearshore estuarine ecosystems can be assessed to some extent, the overall effects of climate change on the trophic dynamics of marine ecosystems and salmon productivity are major uncertainties (Schindler et al. 2008).

Modeling efforts to date do provide some insights regarding projected effects of climate change on marine survival and productivity of Pacific salmon in the North Pacific Ocean. Based on the A1B emission scenario, summer habitats in the North Pacific are projected to decrease by 86% for Chinook salmon, 45% for sockeye salmon, 36% for steelhead, and 30% for coho salmon by the year 2100 (Abdul-Aziz et al. 2011). A general decline in the marine abundance of coho salmon and Chinook salmon in the eastern North Pacific Ocean since the mid-1970's has been attributed to climate-related changes (Irvine and Fukuwaka 2011). Peterson et al. (2010) report that the abundance of yearling Chinook salmon (but not coho salmon) in the California Current was negatively correlated with marine temperatures which influence coastal upwelling and zooplankton abundance. In general, warm ocean conditions associated with the Pacific Decadal Oscillation suppress upwelling and reduce marine survival and productivity of Pacific salmon in the Pacific Northwest (Mantua et al. 1997; Scheuerell and Williams 2005; Mantua 2009). However, climate change is projected to increase the incidence and intensity of Pacific storms in the Gulf of Alaska, and stronger onshore winds are projected to increase upwelling and nutrient turnover rates in the eastern North Pacific. The interaction effects of climate-change increases in ocean temperature, ocean acidification, and onshore winds are major uncertainties with respect to marine primary production and marine food webs. These uncertainties confound attempts to assess the vulnerability of Pacific salmon populations to climate change in specific watersheds (e.g. Columbia River) and sub-basins (e.g., Methow River). Consequently, much research and monitoring are necessary to understand the future effects of climate change on the marine survival and productivity of Pacific salmon and steelhead originating from rivers in the Pacific Northwest.

- **Effects of Climate Change on Migratory Conditions in the Columbia River:** Critical to the life history of Pacific salmon in the Methow River is the ability to migrate to the ocean through the mainstem Columbia River corridor. Information is starting to be compiled that will aid in our understanding of how climate change will affect the environmental conditions within this key area. For instance, mean water temperatures in the mainstem Columbia River at Bonneville and TheDalles dams are projected to increase by nearly 10 º F during the 21st Century (A1B emission scenario, Figure B2 Appendix B). As a consequence, mean water temperatures at Bonneville Dam are projected to exceed 70º F continuously from about July 1 to September 15 (weeks 27-37) by the year 2100 (Figure C1 Appendix C; Mantua et al. 2010). This potential thermal barrier to upstream migration by salmon and steelhead is projected to first develop during the 2030's such that, by the year 2040, mean water temperatures of the Columbia River at Bonneville Dam are projected to exceed 70º F from about mid-July through mid-August

(Figure C1 Appendix C). The potential existence of a thermal barrier to upstream migration in the mainstem Columbia River is expected to affect the life histories and run timings of salmon and steelhead returning to streams and hatcheries upstream of Bonneville Dam. The general expectation is that the spring Chinook returning to the upper Columbia River (e.g., Methow River) will need to complete their upstream migration past the Snake River by July 1. Conversely, initiation of upstream migration of summer steelhead past Bonneville Dam may be delayed until after mid- to late August by the mid-2030s. The expected result in all cases is a shift in the mean and range of dates of returning adults as populations of each species adapt to changing thermal regimes of the mainstem migration corridor. It is critical that the Service continue to work cooperatively with researchers and managers throughout the Columbia River Basin to ensure that the region is prepared for these effects of climate change and that appropriate measures are in place to ameliorate or adapt to these changes to the freshwater migratory corridor.

- **Effects of Climate Change on Fish Disease and Pathogen Prevalence:** Basic metabolic rates, physiological homeostasis, and immune function of fish are direct functions of water temperatures. Water temperatures in the upper range of physiological tolerance can stress the immune system of fish in favor of pathogenic organisms, particularly bacteria and parasites (Wedemeyer 1970, 1996). Pacific salmon, especially spring Chinook salmon in the Columbia River Basin, are particularly susceptible to *Renibacterium salmoninarum*, the causative agent of bacterial kidney disease. All species of salmonid fishes are vulnerable to the infectious parasite *Ichthyophthirius multifiliis* (Ich) at elevated water temperatures.

  Increased water temperatures resulting from climate change are expected to (a) increase physiological stress and reduce immune function in salmon and steelhead and (b) increase the propagation and transmission rates of aquatic parasites and pathogens (Marcogliese 2008). A recent example of this synergistic interaction between water temperature and disease resistance in fish occurred in 2002 on the Klamath River, California, where over 33,000 adult salmonids, primarily Chinook salmon, died during their upstream migration at a time of low water flows and warm water temperatures. Pathology reports concluded that the fish died from Ich and columnaris (*Flavobacterium columnare*), not elevated water temperatures (CDFG 2004). Many fish biologists view this latter example as a harbinger of future events over broader, geographic scales. In general, climate-induced increases in the prevalence of pathogens in existing habitats, and the spread of those pathogens to new habitats, are expected to reduce the abundance and viabilities of many fish species within their native geographic ranges (Harvell et al. 2009). This is a key uncertainty identified by Service Fish Health and NFH staff throughout the Region and the Service should work to conduct additional research as well as contemplating enhanced monitoring and evaluation efforts to better understand how climate change will affect distribution, prevalence, and virulence of fish pathogens.

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APPENDICES

Appendix A. Qualitative Assessments of Climate Change Vulnerability of National Fish Hatcheries in the Pacific Region: Winthrop National Fish Hatchery

Appendix B. Climate and Hydrology Projection Graphs

Appendix C. Graphic Representations of Climate Change Projections for Washington State (from Mantua et al. 2010)

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

Appendix E. Baseline Information and Data for Winthrop National Fish Hatchery, 2011

Appendix F. Climate Change Trends and Projections for the Pacific Northwest