EXHIBIT C

Fish Restoration and Enhancement Program
Project Completion Report

Applicant Information

Project Number: 21-021 **Project Title:** Hatcheries Climate Resiliency Analysis, Rock Creek

Organization: Oregon Department of Fish and wildlife

Organization Type: ■ ODFW ☐ Non-Profit 501(c)(3) ☐ Governmental

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Project Funding

Total R&E Funds: $ 100,000

Total Match Funding: $ 208,250

Total Project Cost: $ 308,250

Amount of R&E Funding Returned: $ 0
(amount awarded but not utilized for project)

Project Information

Project End Date: 6/30/2023 *(for R&E work)*

Watershed/Basin: Umpqua/statewide **County:** Douglas, others

Name of Stream, Lake or Estuary: Umpqua

Recreational Area/Facility: Rock Creek Hatcheries

Participation

List all organizations that participated in this project (volunteer groups, schools, public event, etc.)

ODFW, Lynker Technologies LLC

Project Accomplishments and Comments

Did you meet your objectives?

Yes, Climate Change Risk Assessment for Select Oregon Salmon Hatcheries (March 2023). ODFW contracted with Lynker to develop an assessment of current conditions for Rock Creek Hatchery and evaluate vulnerabilities to procedures and infrastructure that reflect changing needs based on climate and program priorities. Lynker assessed 15 environmental variables that included natural hazards categorized as operational, environmental, or pathogens. The final report included a qualitative vulnerability rankings system based on severity of impact to fish production based on current hatchery conditions and likely future trends of the respective environmental climate that poses a risk to production.

Additional Materials

Submit Report to ODFW R&E Program, 4034 Fairview Industrial Drive SE, Salem Oregon 97302

Climate Change Risk Assessment for Select Oregon Salmon Hatcheries

February 22, 2023

Submitted to Oregon Department of Fish and Wildlife

Oregon Department of Fish and Wildlife
4034 Fairview Industrial Drive SE
Salem, OR 97302

Prepared by Lynker

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Executive Summary

The Oregon Department of Fish and Wildlife seeks to modernize and upgrade its salmon hatcheries, ensuring the continuation of operations into the future even in the face of challenges posed by changing climate. Lynker conducted risk assessments of six selected hatcheries to help determine and prioritize the most pressing issues facing the hatchery system's ability to raise healthy fish. These hatcheries cover a wide geographic range across the state of Oregon: Alsea, Bandon, Cole Rivers, Leaburg, Oak Springs, and Rock Creek Hatcheries. The hatcheries face a variety of challenges, including rising water and air temperatures, reduced summer streamflows, changes in precipitation across the year, water rights struggles, and power supply reliability. Using a combination of historical, current, and projected future datasets related to these risks, as well as site visits and interviews with hatchery staff, Lynker calculated risk scores for each hatchery and each potential vulnerability, using values for Exposure, Sensitivity, and Adaptive Capacity. The following report further details the methodology and results of these scores.

The following impacts are considered the highest risks for each hatchery:

- Rock Creek Hatchery: The hatchery experienced widespread destruction from the Archie Creek Fire of September 2020. The highest risks are water temperature, watershed conditions, and pathogens, with the adaptive capacity to most effectively reduce some of these risks by installing recirculating RAS (Recirculating Aquaculture System) systems and chillers.
- Alsea Hatchery: This hatchery, located between the coast and the mountains, faces the highest risks in the form of pathogens, low flows, water rights, and streamflow timing, with adaptive capacity to reduce some of these risks by installing RAS and UV ozone systems.
- Bandon Hatchery: This coastal hatchery faces the highest risks in the form of water availability due to water rights and competition in the basin, low flows, and streamflow timing, with adaptive capacity to reduce some of these risks through installing a RAS, coordinating with neighboring water users to relocate surface water intakes downstream of the hatchery, and exploring use of supplemental groundwater. Earthquakes also pose a high risk for the hatchery's water source reservoir, with the possibility to renovate the dam.
- Cole Rivers Hatchery: The hatchery is located downstream of Lost Creek Lake, a reservoir managed by US Army Corps of Engineers (USACE). This hatchery faces the highest risks in the form of power supply and flooding. The hatchery has high adaptive capacity to mitigate power losses through large-scale renewable energy installations such as solar, and some adaptive capacity to mitigate flooding through coordinated management of the upstream dam releases.

- Leaburg Hatchery: The hatchery is located downstream of Leaburg Lake formed by Leaburg Dam. This hatchery faces the highest risks in the form of flooding and increasing water temperatures. The hatchery has some adaptive capacity to mitigate high flows through coordinated management of upstream dam releases, and adaptive capacity to mitigate water temperatures through chillers and shade covers.
- Oak Springs Hatchery: Located in the high desert east of the Cascades, this hatchery experiences the highest risks in the form of watershed conditions, water rights, and drought. The hatchery has adaptive capacity to mitigate decreased water availability using a RAS system and coordination with neighboring water users.

Common solutions to problems faced across the board between all the hatcheries include Recirculating Aquaculture Systems (RAS), which can reduce water needs by upwards of 90% and thus allay problems related to low flows, limited water availability, changes in streamflow timing, and drought; and the installation of chillers, which can reduce water temperature to keep salmonids healthier and will function more efficiently when used with smaller volumes of water such as those in a RAS. UV Ozone setups can reduce high pathogen and pollutant loads, and improved sediment screening and filtration can reduce the risks for those hatcheries facing high sediment loads worsened by wildfires. These solutions are high-cost and require installation of new infrastructure but can also provide more effective mitigation against changes in water availability and rising temperatures. Less expensive options such as shade cover are less effective but can still provide some amount of mitigation. Transporting fish away from impacted hatcheries during periods of low water availability or high temperatures to less-impacted hatcheries is relatively inexpensive, assuming the receiving hatchery has sufficient capacity to take on extra production.

In support of ODFW's commitment to become carbon-neutral by the mid-century, Lynker provided recommendations for renewable and emerging technologies that can reduce emissions due to electricity use and the breakdown of fish waste. These recommendations include the transition to an electric vehicle fleet and the installation of solar power, hydropower, wind power, biodigesters, and constructed wetlands on hatchery premises where appropriate. Each hatchery has the potential to provide its own power through some combination of renewable energy sources, and those hatcheries that currently depend on electricity from fossil fuel-based sources have the highest potential to generate their own power onsite and reduce emissions.

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1 Introduction

1.1 Purpose

The Oregon Department of Fish and Wildlife (ODFW) is in the process of upgrading the salmon hatcheries it manages, modernizing technology throughout the hatchery system to improve the health of fishes raised and to reduce greenhouse gas emissions. Oregon's wild fish populations and fish hatchery operations are already experiencing impacts due to climate change, including warming water temperatures, decreasing water access, elevated aquatic pathogen loads, and extreme wildfires. By taking into account current conditions as well as potential future environmental conditions, ODFW can effectively redesign hatchery operations to continue providing healthy fish for Oregon's waters into the mid-century and beyond.

Lynker conducted an assessment of selected ODFW hatcheries, their current conditions, and potential climate change-associated risks. This document describes the results of the Risk Assessment. It includes the methodology used to categorize hatchery and program vulnerability to current conditions and future climate change, documents the key vulnerabilities, and outlines potential solutions for climate-resilient hatcheries and carbon-neutral operations to allow for production of healthy salmon into the foreseeable future.

1.2 Hatcheries

ODFW selected six hatcheries of interest for this climate change risk assessment. These hatcheries represent a variety of strengths and vulnerabilities exhibited by hatcheries across the state, and are located across different geographic locations and river basins. The hatcheries for this assessment are Alsea, Bandon, Cole Rivers, Leaburg, Oak Springs, and Rock Creek Hatcheries, shown in the following image.

Bandon represents coastal hatcheries, with Alsea having some coastal influence, while Oak Springs serves as an example of eastern high-desert hatcheries. Cole Rivers and Leaburg are federally-built and utilize water from reservoirs. Rock Creek Hatchery is of particular interest in 2022 because it suffered extreme damage to its infrastructure in the Archie Creek Fire in 2020, and the Department is currently considering options at the site.

For each of the hatcheries of interest, Lynker examined a range of potential vulnerabilities, looking at historical trends, current conditions, and future projected trends. These vulnerabilities include water temperature; pathogens; streamflow and precipitation changes; wildfires; earthquakes and landslides; drought; flooding; water rights; and sea level rise. Risk scores were calculated for each hatchery's vulnerabilities and are presented in this document along with the justification and datasets used to develop the scores. Additional supporting information and datasets are included in a separate Appendix document. These risk scores take into account potential impacts as well as a hatchery's ability to counteract these impacts.

Figure 1: Location of ODFW hatcheries selected for this risk assessment

1.3 Definitions

In this section we define the terms used to characterize hatchery vulnerability to current and future climate change. Vulnerability is calculated from *Exposure, Sensitivity, and Adaptive Capacity*, as shown below in Figure 2. There are often different terms used when defining risk, therefore we have defined each term, which we will use throughout this document (see Table 1).

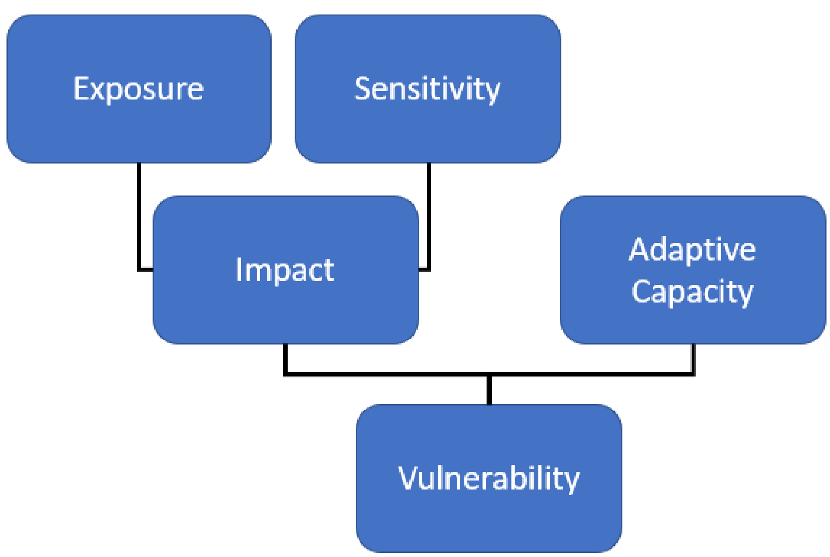

Figure 2: Vulnerability Schematic

Table 1: Definitions

Definitions
Exposure: the magnitude or degree to which a system or species is expected to be subjected to an environmental disturbance (i.e., is the hatchery in a location that is proximal to the hazard?) Evaluated on a scale of 1-5, with 5 being the highest exposure.
Sensitivity: the degree to which a system or species is likely to be affected by an environmental disturbance (i.e., any existing infrastructure, processes, or traits that increase or decrease the susceptibility of the hazard impact). Evaluated on a scale of 1-5, with 5 being the most sensitive.
Adaptive Capacity: the potential for infrastructure, behavioral, physiological, or other adaptive response to ameliorate an environmental disturbance (i.e., reasonable measures we can take to reduce or eliminate risk). Evaluated on a scale of 1-5, with 5 being the highest adaptive capacity. Higher Exposure and Sensitivity values and lower Adaptive Capacity values are associated with higher Vulnerability.
Vulnerability: the vulnerability of a species or system is the impact (exposure + sensitivity) that cannot be adequately addressed by existing adaptive capacity. Evaluated according to the equation: Vulnerability = Exposure + Sensitivity – Adaptive Capacity, where higher values (e.g., 9) indicate higher vulnerability than lower values (e.g., 1), which indicate lower vulnerability.

The vulnerability scores are calculated as *Exposure + Sensitivity - Adaptive Capacity*. The potential impact is Exposure + Sensitivity, and Adaptive Capacity is the amount of that potential impact that can be counteracted. For each potential hazard, the score of each of these three elements (exposure, sensitivity, adaptive capacity) is listed along with the justification explaining how this score was reached. The methods are provided in Section 2.

2 Methods

A list of potential hazards was identified for all six hatcheries in coordination with ODFW staff. Once the hazards were identified, each hatchery was evaluated according to the components of vulnerability: exposure, sensitivity, and adaptive capacity. In this section, we briefly describe the methods used to score the vulnerability components on a standardized scale from 1 to 5.

2.1 Exposure

Exposure values are normalized on a scale from 1-5, with 1 being the lowest level of exposure and 5 being the highest level. Each evaluated sector has been mapped onto this 1-5 scale in a way that is relevant to the particular sector and its affiliated datasets, allowing reasonable comparisons to be made even between very different categories. A more comprehensive analysis of each hatchery's exposure scores can be found in the Appendix.

Exposure Methodology (All Hatcheries)

2.1.1 Wildfire

Method:

We calculated wildfire exposure using **burn probability** from the Oregon Wildfire Explorer dataset within a 5 mile buffer of each hatchery, which uses data from the US Forest Service and Oregon Department of Forestry (2018), using the following category scores from the burn probability dataset:

1 – Nonburnable & Low
2 – Low-Moderate
3 – Moderate & Moderate-High
4 – High & Very high
5 – Very high

For hatcheries with higher probability of high **flame lengths**, flames 8 feet or greater, we increased the wildfire exposure score, because those flame lengths correspond with fires that are very difficult to control.

2.1.2 Drought

Method:

We obtained **drought category** timeseries data for the hatchery's county from the UNL Drought Monitor (National Drought Mitigation Center 2022) and quantified drought over the past 22 years, scoring the percentage of county area in a drought category with the following scores:

1 – >=40% in D0 (abnormally dry)
2 – >= 20% in D1 (moderate drought)

3 – >= 15% in D2 (severe drought)
4 – >= 5% in D3 (extreme drought)
5 – >= 5% in D4 (exceptional drought)

A hatchery's score reflects the highest and most extreme of these conditions met. Additional scoring considerations included recent drought, noting any change in drought frequency or severity that may be indicative of increasing air temperatures due to climate change.

2.1.3 Flooding

Method:

We conducted flood hazard analysis of the hatchery using FEMA FIRM data (FEMA 2022) for 100-year flood events, where available, and calculated the **percentage of the hatchery footprint** that would be flooded in these events. This footprint covers the main active infrastructure and buildings of the hatchery but does not take into account unused acreage owned by the hatchery that does not actively contribute to production or staff housing. The 500-year floodplain was also taken into account, where available. For hatcheries without current inundation maps available from FEMA, scores were estimated based on proximity to rivers, terrain, and in-person knowledge from hatchery visits and interviews. The scores also take into consideration that a warmer climate is expected to bring more extreme weather events such as large precipitation events; therefore, climate change is expected to shorten the recurrence intervals of flood events (Queen et al. 2021). Percentages were translated to scores as follows:

1 – 0-20% of hatchery footprint within 100-year floodplain
2 – 20-40% of hatchery footprint within 100-year floodplain, or 40-60% of footprint within 500-year floodplain
3 – 40-60% of hatchery footprint within 100-year floodplain, or 60-80% of footprint within 500-year floodplain
4 – 60-80% of hatchery footprint within 100-year floodplain, or 80-90% of footprint within 500-year floodplain
5 – 80-100% of hatchery footprint within 100-year floodplain, or >90% of footprint within 500-year floodplain

2.1.4 Sea Level Rise

Method:

We analyzed current and projected sea levels from NOAA datasets (NOAA 2022) and looked at sea level rise values as high as 10m. We calculated whether or not rising waters would **intersect hatchery footprints**, and also took into account whether **saltwater intrusion** was already occurring at the site based on interviews. We scored the results as follows:

1 – no direct effects from sea level rise
3 – existing saltwater intrusion (to be worsened by encroaching waters)
5 – direct effects of sea level rise water

2.1.5 Precipitation

Method:

We analyzed **historical observed precipitation and trends** from United States Historical Climatology Network (USHCN) data from the past century (University of Washington 2021) and **statewide projected precipitation** data from the Fifth Oregon Climate Assessment (Dalton and Fleishman, 2021). Unless otherwise specified, summer refers to June, July, and August, and winter refers to December, January, and February. The overall score is an average of these datasets' scores using the following % change values:

1 – changes in summer or winter precipitation of 0%
2 – changes in summer or winter precipitation of 1-2%
3 – changes in summer or winter precipitation of 3-5%
4 – changes in summer or winter precipitation of 6-9%
5 – changes in summer or winter precipitation of >10%

2.1.6 Air Temperature

Method:

We analyzed **historical observed air temperature** from United States Historical Climatology Network (USHCN) data from the past century (University of Washington 2021) and **statewide projected air temperature** data from the Fifth Oregon Climate Assessment (Dalton and Fleishman 2021). Unless otherwise specified, summer refers to June, July, and August, and winter refers to December, January, and February. The overall score is an average of these datasets' scores using the following absolute change values:

1 – increases in air temperature of 0 or <0°C
2 – increases in air temperature of up to 1°C
3 – increases in air temperature of 2-3°C
4 – increases in air temperature of 3-4°C
5 – increases in air temperature of >4°C

2.1.7 Earthquakes

Method:

We analyzed data from the Oregon Statewide Geohazards dataset (Oregon DOGAMI n.d.) from Oregon Department of Geology and Mineral Industries, and classified earthquake hazards based on the following scoring utilizing **expected shaking** and **liquefaction**. We also took into account **proximity to active faults**:

1 – Light shaking without nearby faults or expected liquefaction
2 – Moderate shaking, with score increased by high liquefaction value or nearby active faults or quake epicenters
3 – Strong to Very Strong Shaking, with score increased by high liquefaction value or nearby active faults or quake epicenters
4 – Severe shaking, with score increased by high liquefaction value or nearby active faults or quake epicenters
5 – Violent shaking

2.1.8 Watershed Conditions

Method:

We analyzed **land use** around the hatchery and in the surrounding watershed from 2019 National Land Cover Data (MRLC n.d.), **soil erodibility** data from the USDA SSURGO dataset (NRCS n.d.), **hillslope** based on SRTM DEMs (USGS 2014), and **landslide risk** from the statewide geohazards dataset (Oregon DOGAMI n.d.).

Scoring is based on the following average values for the hatchery footprint and its surrounding watershed:

1 - high % forested landscape, low landslide risk, low erodibility (close to 0), low hillslopes (close to 0%)
2 - low to moderate landslide risk, low hillslopes, low erodibility, high % forested
3 - moderate landslide risk, hillslopes around 5%, erodibility around 0.2
4 - moderate to high landslide risk with hillslopes approaching 10% or erodibility >0.3
5 - majority hillslopes over 10%, erodibility > 0.3, very high landslide risk

2.1.9 Power Supply

Method:

Based on **interviews** with hatchery staff and information about power outages for the area, scoring for power supply was based on the following scale:

1 – infrequent or minor power losses
3 – moderate frequency power losses, or infrequent but extreme loss
5 – constant power loss

2.1.10 Water Rights

Method:

We queried the Oregon Water Rights Database and examined the **seniority of water rights** claims for the hatchery in relation to other water rights users (Oregon Water Resources Department n.d.a), and analyzed **water availability** in the water source basins (OWRD n.d.b). We verified this information with **interviews** from hatchery staff. Scores were developed based on the following criteria:

1 – No known production issues due to water rights
3 – Production impacts due to water availability, but with unallocated water remaining in the basin or hatchery having seniority in the basin
5 – Production impacts due to water availability and all water allocated in basin

2.1.11 Streamflow Timing

Method:

We summarized mid-century climate change impacts showing **average monthly streamflow** and percent change for historical (1977-2006) and mid-century (2030-2059), based on a USDA-funded climate change analysis that used worse-case scenario climate change impacts (RCP8.5) for five different GCMs as inputs for the VIC (Variable Infiltration Capacity) model (USDA Forest Service OSC 2022; Authors in review; Wenger et al. 2010, Reclamation 2014). Unless otherwise specified, summer refers to June, July, and August, and winter refers to December, January, and February. This category's scoring reflects changes in the month of peak flows as well as changes in the magnitudes of flow associated with those peak times. We scored the results as follows:

1 – no change in streamflow or peak flow month
2 – <5% change in peak or minimum streamflow, or peak flow month shift of 1 month
3 – 5-10% change in peak or minimum streamflow, or less with change in streamflow with peak flow month shift of 1 month
4 – 10-15% change in peak or minimum streamflow, or peak flow month shift of 2 months
5 – >15%, or less streamflow change with peak flow month shift of 2 months

2.1.12 Low Flows

Method:

We utilized the same climate-adjusted datasets and method as for streamflow timing, with a focus on the minimum (summer) streamflows and verified model results with historical observations by analyzing **low flows (lowest 10th percentile) for USGS gage data** for each hatchery's water source for all available years. Unless otherwise specified, summer refers to June, July, and August. We scored values as follows:

1 – no change in streamflow or minimum flow month
2 – <5% decrease in summer streamflow

3 – 5-10% decrease in summer streamflow
4 – 10-15% decrease in summer streamflow
5 – >15% decrease in summer streamflow

2.1.13 Sedimentation

Method:

We analyzed **turbidity** data from USGS gages where available and **watershed burn** % from Oregon Wildfire Explorer and National Interagency Fire Center (NIFC) (NIFC 2022). We scored results based on the following criteria:

1 – decrease in turbidity or watershed burns of <20%
2 – increasing trends in turbidity or watershed burns of up to 40%
3 – significantly increasing trends in turbidity or watershed burns of up to 100%
4 – increasing trends in turbidity and watershed burns of up to 40%
5 – significantly increasing trends in turbidity and watershed burns of up to 100%

2.1.14 Water Temperature

Method:

Based on historical water temperature observations from relevant USGS gages between 1998-2022, and applying projected water temperature differences for that same dataset for the mid-century, we calculated the **number of days** with means above 16°C and above 21°C and the **number of days projected** to be above those thresholds based on projected increases from USDA Forest Service's NorWeSt (Chandler et al. 2016; Isaak et al. 2016) project at each relevant hatchery site. The temperature thresholds are based on average results across numerous studies of thresholds for optimal salmonid growth and the point at which mortality and health issues begin to increase. Unless otherwise specified, summer refers to June, July, and August, and winter refers to December, January, and February.

1 – no increase in days above temperature thresholds and no means over 16°C during summer
2 – 1-2% increase in days with mean temperature >16°C, or up to an additional 3 days >16°C, or mean summer temps >16°C during any month and steady or slightly increasing trends
3 – 3-5% increase in days with mean temperature >16°C, or up to an additional 5 days >16°C, or mean summer temps >16°C most months and increasing trends
4 – 6-9% increase in days with mean temperature over 16°C, or up to an additional 10 days >16°C, or mean summer temps >16°C in all months and increase to >18°C
5 – >10% increase in days with mean temperature over 16°C, or up to an additional 15 days >16°C, or current monthly mean >18°C for any month with expected increases

2.1.15 Pathogens

Method:

Because the majority of pathogens of interest within the ODFW system experience optimal infectivity at higher temperature ranges, we use the same data and scale from the Water Temperature section. While individual temperature thresholds for infectivity vary by pathogen, these thresholds are still appropriate because above them fish will experience higher levels of stress that make them more susceptible to the pathogens. We also incorporate information from hatchery staff interviews about known existing problems with pathogens. Unless otherwise specified, summer refers to June, July, and August, and winter refers to December, January, and February.

1 – no increase in days above temperature thresholds and no means over 16°C during summer, and no known issues with pathogens
2 – 1-2% increase in days with mean temperature >16°C, or up to an additional 3 days >16°C, or mean summer temps already >16°C during any month and steady or slightly increasing trends; or known issues with pathogens and no water temperature issues trending
3 – 3-5% increase in days with mean temperature >16°C, or up to an additional 5 days >16°C, or mean summer temps >16°C most months and increasing trends; or known issues with pathogens and previous (lower) category
4 – 6-9% increase in days with mean temperature over 16°C, or up to an additional 10 days >16°C, or mean summer temps >16°C in all months and increase to >18°C; or known issues with pathogens and previous (lower) category
5 – increase in days with mean temperature >21°C or >10% increase in days with mean temperature over 16°C, or up to an additional 15 days >16°C, or current monthly mean >18°C for any month with expected increases; or known issues with pathogens and previous (lower) category

2.2 Sensitivity

Like Exposure, Sensitivity is normalized on a scale of 1-5, with 1 being the least sensitive and 5 being the most sensitive. Sensitivity scoring relies on specific knowledge about the hatchery, and as such the scores have been informed by site visits and feedback from hatchery managers. A hatchery with characteristics that greatly or completely limit the impact of a given hazard have low sensitivity and lower scores (e.g., 1-2). A hatchery with characteristics that greatly increase its susceptibility to a given hazard will have high sensitivity and higher scores (e.g., 3-5).

2.2.1 Wildfire

Sensitivity to wildfire was evaluated based on the construction materials of the hatchery infrastructure (concrete, wood, etc.), surrounding landscape, and ability for the hatchery to operate during a fire event. The use of concrete structures decreases sensitivity, as does a loss of vegetation in the area due to recent burns or the development of defensible space for wildfire protection.

2.2.2 Drought

Sensitivity to drought was determined by the number of water supply sources and the average streamflow and temperature conditions at the hatchery. Multiple water supply sources decrease sensitivity, while decreasing streamflows and precipitation and rising air temperatures increase sensitivity.

2.2.3 Flooding

Sensitivity to flooding was evaluated according to building materials in or near the floodplain and the existence of pumps or other critical infrastructure in the floodway or floodplain that may be affected during a flood event. It includes a focus on the buildings and infrastructure in the floodplains, not just the overall footprint that is used in the exposure calculation.

2.2.4 Sea Level Rise

Similar to flooding, sensitivity to sea level rise was evaluated according to buildings or critical infrastructure affected by projected high water levels. Saltwater intrusion was also considered, especially for those hatcheries where water levels are not anticipated to reach the actual hatchery facilities; groundwater and aquifers closer to the coast have the potential to be encroached on and contaminated by saline water, which would require desalination treatment before any use in typical freshwater settings such as in raceways or for domestic drinking water. Saltwater intrusion information was based on hatchery interviews.

2.2.5 Precipitation

Sensitivity to precipitation was analyzed by examining the impact of more rainfall during winter or less water during summer on a hatchery. A hatchery dependent on summer rainfall to maintain summer flows may be more susceptible, as will a hatchery dependent on snowmelt that shifts water availability earlier in the year.

2.2.6 Air Temperature

Sensitivity to air temperature was evaluated by examining a hatchery's average existing water temperatures, as an increase in air temperature would likely affect water temperature at the hatchery. Higher sensitivity values reflect hatcheries that are already near or struggling with water temperature thresholds.

2.2.7 Earthquake

Sensitivity to earthquake was evaluated by building construction material and age and condition of the structures. Hatcheries in high-risk seismic zones with structures designed to withstand such shaking have less sensitivity than those without earthquake-specific designs.

2.2.8 Watershed Conditions

Sensitivity to watershed conditions evaluates the hatchery infrastructure in relation to the hazards of erosion, landslide, and land use or land cover conditions. A defensible space between the hazards and the facility helps to reduce its sensitivity.

2.2.9 Power Supply

Sensitivity is based on the dependence on grid-provided power, availability of a backup generator, and fuel limitations of said generator. A hatchery with backup power is less sensitive than one without, but a backup generator with strict fuel delivery requirements increases sensitivity. Gravity-fed systems that do not require electricity to keep fish alive with flowing water are less sensitive to power loss than systems with pumps. Note that these sensitivities are based on current gravity-fed systems and not on electricity-requiring RAS systems.

2.2.10 Water Rights

Sensitivity to water rights issues were evaluated according to the seniority of the hatchery's water rights portfolio and availability of additional water sources.

2.2.11 Streamflow Timing

A hatchery may experience new periods of low flows (or higher flows) than it has historically, given that climate change is expected to decrease the snowpack, hasten snowmelt, and produce earlier peak runoff. A hatchery is more sensitive if it has seasonal programs (typically in summer) that could be affected by a decrease in water availability; a hatchery is less sensitive if it does not have much production over the summer for a shift in streamflow timing to affect. A hatchery is less sensitive to streamflow timing and magnitude changes throughout the year if it is located downstream of large reservoirs that manage discharges, typically accounting for environmental flows necessary for salmonid survival.

2.2.12 Low Flows

Sensitivity to low flows will be evaluated by the impact of historical flows at the hatchery and projections for changes in flow during the low-flow months due to climate change. Hatchery flow requirements and annual program timeline characterize sensitivity to low flow, with active summer programs being more sensitive to low flow. Hatcheries sensitivity is decreased by the use of technology to improve water quality problems caused by low flows, and by the availability of multiple water sources. A hatchery is less sensitive to low flows if it is located downstream of large reservoirs that manage discharges, typically accounting for environmental flows necessary for salmonid survival.

2.2.13 Sedimentation

The sensitivity to sedimentation will be based on the impact of existing or potential sediment loading to its fish programs. Hatcheries that have experienced recent burns in the watershed may be more sensitive to sedimentation, but those hatcheries with lower existing sediment loading may be less sensitive to those future increases. Additionally, engineering controls or best management practices that reduce sediment loading reduce sensitivity as well.

2.2.14 Water Temperature

The sensitivity to water temperature is based on the existing conditions at the hatchery and its future projected increases in water temperature. By extracting projected changes in summer water temperature, we can analyze how historical stream temperatures may increase in the future and which fish programs are at risk based on the species' life histories. A hatchery is more sensitive if it has fish programs with major life stages such as release, migration, and spawning that occur during late spring or summer months, such as Spring Chinook and Summer Steelhead.

2.2.15 Pathogens

The sensitivity to pathogens is based on the existing effects at the hatchery and the projected increasing disease risks and uncertainties because of climate change (e.g., reduced summer streamflow, increased summer water temperature, leading to increased disease outbreaks or shifting communities of pathogens and parasites). Some hatchery programs may be more sensitive for these reasons as well, similar to the water temperature section. Hatchery programs with higher sensitivity are those with migration and spawning occurring during summer months, when infectivity typically increases with many of the hatchery pathogens and can affect fitness and, ultimately, survival rates. Higher sensitivity is also associated with existing pathogen loads, especially those that are difficult to control, and warming water temperatures.

2.3 Adaptive Capacity

Adaptive Capacity is scored on a scale of 1-5, but in this case, the values are reversed with higher scores being "better," with 1 representing little to no capacity to adapt to or mitigate against a particular risk, and 5 representing strong capacity to against said risk. This scoring is based on potential solutions and alternatives to each risk and the overall combined ability of these solutions to address a risk. Low adaptive capacity means that there are not many ways to counteract potential impacts due to a vulnerability, while a higher adaptive capacity value means that there is one or more methods to balance out potential impacts, possibly through the installation of new technology or procedural changes.

The range of adaptive strategies may be associated with different costs and ease of implementation; inherent adaptive capacity of the hatchery or changes to protocol and management are likely to be less expensive than the installation of new technology and infrastructure, though the expensive, technology- or infrastructure-based options are often more effective tools to mitigate risk. Adaptive capacity scores combine these inherent and technology-based solutions as one score, as they reflect the full scope of the hatchery's ability to adapt to and mitigate potential risks, and those scores that are based on the effective use of expensive solutions or ones requiring more time and effort are marked with an asterisk (*). Adaptive capacity scores are subtracted from the potential impacts (Exposure + Sensitivity) to give a total overall score for each vulnerability, and scores closer to 0 mean that a vulnerability can be largely overcome through some change in infrastructure or practices.

3 Risk Assessment

The hatcheries are presented with Rock Creek Hatchery first, due to its priority focus for rebuilding, followed by the remaining hatcheries in alphabetical order. Related supporting geospatial data and tables for each hatchery and associated risks can be found in a separate Appendix document.

3.1 Rock Creek Hatchery

Rock Creek Hatchery is a state-run fish hatchery managed by the Oregon Department of Fish & Wildlife (ODFW). It is situated on approximately 26.5 acres of land at the confluence of Rock Creek and the North Umpqua River near Idleyld Park, Oregon, and has been in place since 1925 with a period of closure and reconstruction in the 1970s.

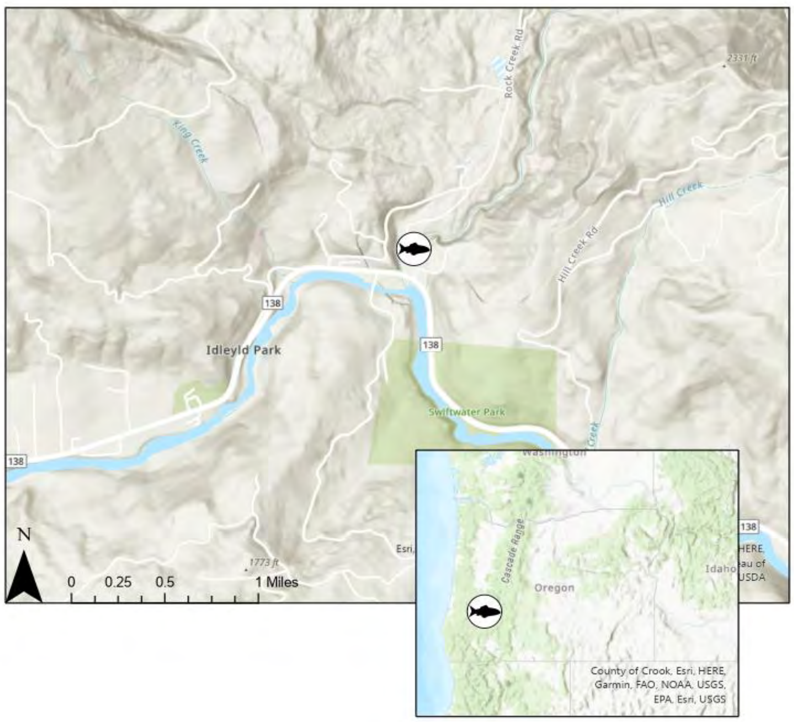

Figure 3: Rock Creek Hatchery near Idleyld Park, OR

The Rock Creek Hatchery risk assessment scores for each hazard are provided in Table 2 below. The exposure and sensitivity scores are summed to calculate the potential impact. At the Rock Creek Hatchery, water temperature, watershed conditions, pathogens, and low flows have been identified as the most potentially impactful hazards. However, vulnerability is the sum of the potential impact and the adaptive capacity, which can reduce the potential impact of each hazard.

Table 2. Rock Creek Hatchery Scores, ordered by descending Potential Impact values. Adaptive Capacity options that require significant costs to implement are denoted with a (*)

Potential Vulnerability	Exposure	Sensitivity	Potential Impact	Adaptive Capacity	Vulnerability
Water temperature	5	4	9	5*	4
Watershed conditions	5	4	9	2	7
Pathogens	5	4	9	3*	6
Low flow	5	3	8	4*	4
Streamflow timing	5	2	7	5*	2
Wildfire	4	3	7	2	5
Drought	4	2	6	5*	1
Earthquake	4	2	6	2	4
Air temperature	4	1	5	5*	0
Power supply	3	3	6	5*	1
Sediment	3	3	6	3*	3
Flooding	3	2	5	2	3
Precipitation	2	2	4	4*	0
Water rights	1	1	2	5*	-3
Sea level rise	1	1	2	1	1

Hatchery Description

Name: Rock Creek Hatchery

Location: Douglas County, near Idleyld Park, OR

Technical Assessment

3.1.1 Wildfire

Hatchery Summary:

Exposure: 4. Most of the land surrounding Rock Creek Hatchery has a burn probability rated as “Moderate-High” (71% of land within a 5-mile buffer). The hatchery’s exposure score based on the weighted distribution of burn probability is 2.9 (out of 5). However, the most probable flame lengths are greater than or equal to 8 ft (52% of the surrounding area). Therefore, the wildfire exposure score was increased from 3 to 4.

Note: calculations for Rock Creek Hatchery are based on data from 2018; more recent data are not yet available. The Archie Creek Fire burned a substantial part of the hatchery and surroundings, lessening potential fuel for future fires, which could lessen risk. However, buildings still exist on the structure, with new temporary structures having been added in the past year and with new trees having been planted on the surrounding hillsides, so there is still significant wildfire risk as the hatchery rebuilds.

Sensitivity: 3. Rock Creek is moderately sensitive due to non-concrete structures and surrounding vegetation, and the hatchery is dependent on pumps in summer months when conditions are best for extreme fires.

Adaptive Capacity: 2. Hatchery adaptive capacity against fires is low, and the high-intensity fire that hit the hatchery in 2020 demonstrated that even concrete structures can sustain damage from the fire; the best the hatchery can do is rebuild with as much defensible perimeter space as possible, fire extinguishing systems to protect structures, and making sure staff are evacuated promptly.

Vulnerability Score:
Exposure 4 + Sensitivity 3 – Adaptive Capacity 2

3.1.2 Drought

Hatchery Summary:

Exposure: 4. Rock Creek Hatchery, located in Douglas County, Oregon historically has experienced moderate levels of drought and on average (2000-2022), 48% of the county has spent time in drought category D0 (abnormally dry), 31% of the county in D1 (moderate drought), 19% of the county in D2 (severe drought), 6% of the county in D3 (extreme drought), and 0% of the county in D4 (exceptional drought). The county is currently experiencing a sustained period of dryness since 2020, and much of the county was in drought stage D3 (extreme drought) for the latter half of 2020, and again in 2021.

Sensitivity: 2. Rock Creek Hatchery is not as sensitive to drought due to its multiple water sources (Rock Creek and North Umpqua River). Additionally, the North Umpqua River has sufficient streamflow but is fully allocated throughout the year, and no additional surface or ground water sources will be easily available.

Adaptive Capacity: 5*. Rock Creek has the ability to mitigate drought impacts by installing a RAS or partial RAS (pRAS) system, which would reduce water needs by as much as 90%, or to relocate fish during the summer months when drought impacts might be most visible.

An adaptive capacity score of 5 is possible through both of the above options. The use of a RAS system requires significant initial and ongoing costs but has the benefit of maintaining operations onsite at the hatchery. Relocating fish during summer months to other hatcheries is far less expensive, but it requires another hatchery (such as Cole Rivers) that has the capacity and available water to raise additional fish. It also increases stress to fish through additional handling and transport, which should have low mortality on its own but can leave fish more vulnerable to pathogens at the receiving hatchery.

Vulnerability Score:
Exposure 4 + Sensitivity 2 – Adaptive Capacity 5*

3.1.3 Flood

Hatchery Summary:

Exposure: 3. Rock Creek Hatchery's flood exposure is uncertain due to a lack of FEMA flood rate insurance maps (FIRMs) for Douglas County; therefore the 100-year and 500-year floodplains are unknown. The hatchery is bordered by Rock Creek approximately 100 feet to the south. Additional uncertainty stems from climate change, where a warmer climate is expected to bring more extreme weather events such as large precipitation events. Thus, climate change is expected to shorten the recurrence intervals of flood events (Queen et al, 2020). The hatchery was given a moderate exposure rating to account for its unknown flood exposure and proximity to Rock Creek.

Sensitivity: 2. Rock Creek's intake is the closest point to the floodplain, and it is highly reinforced solid concrete. The pump station on the North Umpqua could potentially be vulnerable in a massive flood, which would remove the water source in the summer, though such summer flooding is not anticipated based on precipitation and streamflow patterns; the pump station would require a quick repair between any catastrophic winter flooding and summer pumping.

Adaptive Capacity: 2. Rock Creek's new buildings and existing pumphouse could be reinforced, and collaborations with local emergency management can be strengthened to ensure advance warning systems for staff (expanding beyond fire warning systems, which effectively alerted hatchery staff to various levels of response during the Archie Creek Fire).

Vulnerability Score:
Exposure 3 + Sensitivity 2 – Adaptive Capacity 2

3.1.4 Sea Level Rise

Hatchery Summary:

Exposure: 1. Sea level rise will not directly affect Rock Creek Hatchery, and will only indirectly affect the hatchery if it is tasked with taking on production from coastal hatcheries affected by water or saltwater intrusion.

Sensitivity: 1. N/A.

Adaptive Capacity: 1. N/A.

Vulnerability Score:
Exposure 1 + Sensitivity 1 – Adaptive Capacity 1

3.1.5 Precipitation

Hatchery Summary:

Exposure: 2. An analysis of Rock Creek Hatchery's historical observed precipitation changes from the late 1870s to the 2020s show there is no statistically significant monthly or annual trend in precipitation changes. Statewide climate change results from the Fifth Oregon Climate Assessment project a 6-9% decrease in summer precipitation and a 5-8% increase in winter precipitation, with a mean annual precipitation increase of 2-3%. However, there is uncertainty around Oregon's precipitation projections with individual model projections showing both increases and decreases in annual precipitation. The 6-9% decrease in summer precipitation received an exposure score of 2.

Sensitivity: 2. Changes in precipitation could affect conditions of the hatchery during both the rainy season and the dry season. The hatchery is not sensitive to an increase of 2-3% precipitation annually, or an increase of 5-8% in the winter. However, a reduction of 6-9% during summer could exacerbate low flow conditions if the statewide projections occur for the hatchery (see Low Flow section).

Adaptive Capacity: 4*. The hatchery can mitigate decreases in precipitation through reduced water needs with a RAS or pRAS system, and new structures can be rebuilt to withstand any possible additional winter flooding due to increased precipitation.

An adaptive capacity score of 4 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A RAS system will help mitigate decreases in precipitation but will not help mitigate increases in precipitation (and subsequent increased flooding risks). Rebuilding additional structures to withstand flooding provides lower adaptive capacity, but the costs of reinforcing or redesigning infrastructure may be relatively low on top of the requisite rebuilding costs.

Vulnerability Score:
Exposure 2 + Sensitivity 2 – Adaptive Capacity 4*

3.1.6 Air Temperature

Hatchery Summary:

Exposure: 4. An analysis of historical trends from the USHCN air temperature data show a statistically significant increase of 0.29°F per decade from 1894 to 2020 with the largest monthly increases occurring in July (+0.43°F per decade), August (+0.46°F per decade), and September (+0.49°F per decade) (University of Washington, 2021). The Fifth Oregon Climate Assessment projects statewide air temperature increases of 4.5-6.3°F in the summer, with smaller increases during the rest of the year. The average annual temperature increase statewide at mid-century (2040-2069) is 3.6°F (RCP4.5) to 5.0°F (RCP8.5) (Dalton and Fleishman, 2021).

Sensitivity: 1. The Rock Creek Hatchery currently has concerns around air temperature, in that increasing air temperatures will likely affect water temperature at the hatchery. These concerns are addressed in the section on water temperature.

Adaptive Capacity: 5*. The hatchery can mitigate impacts of rising air temperatures through the use of chillers to cool water (influenced by air temperatures) and the use of shade cover.

An adaptive capacity score of 5 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising air temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures that rise as a result of air temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can mitigate fish losses, though the ultimate goal is to entirely eliminate fish loss due to warming waters.

Vulnerability Score:
Exposure 4 + Sensitivity 1 – Adaptive Capacity 5*

3.1.7 Earthquakes

Hatchery Summary:

Exposure: 4. There are no active faults within 5 miles, and the closest active fault is 15 miles northwest in Oakland. The nearest earthquake epicenter for quakes from 1971-2008 is 6 miles away. The area around the hatchery has moderate risks for liquefaction (soft soil hazard) and severe expected shaking as part of its general earthquake hazard risk. There is a risk that if the dam far upstream of the hatchery failed due to flood or earthquake, the hatchery would receive a devastating wall of water with little to no warning time.

Sensitivity: 2. Rock Creek's intake structure and raceways are built of solid concrete, potentially maintaining stability even in a quake. Other structures would not be expected to fare as well.

Adaptive Capacity: 2. An advance warning system can be put in place in conjunction with emergency management to evacuate staff in case of earthquakes (expanding beyond fire warning systems, which effectively alerted hatchery staff to various levels of response during the Archie Creek Fire), and structures that are rebuilt can incorporate additional reinforcement and strengthening in their designs.

Vulnerability Score:
Exposure 4 + Sensitivity 2 – Adaptive Capacity 2

3.1.8 Watershed Conditions

Hatchery Summary:

Exposure: 5. The hatchery has a very high risk of landslide hazards, which is a product of the steep surrounding hillslopes with moderate soil erodibility. While the surrounding watersheds are mostly forested, these forests are active timber logging areas, and the various stands are in a range of ages and succession with various abilities to stabilize the soil. In the post-fire environment in which 80-100% of the surrounding watershed burned, these trees will mostly be logged, and those remaining stumps and roots can be expected to rot away within the next 5-10 years, loosening their hold on the soil even more. Debris slides are visible below the access road, which is itself beginning to crack.

Sensitivity: 4. The hatchery is located in a valley at the base of steep slopes at the toe of an active landslide, with raceways open and exposed to slides, though the hatchery has a small boundary around its infrastructure which might be enough to prevent debris slides from damaging any structures.

Adaptive Capacity: 2. The hatchery does not have much capacity to modify the terrain, geology, and surroundings that could threaten it with land and debris slides, though actions to revegetate the watershed can help; small-scale protective efforts such as berms around the hatchery and water quality protection at the intake can make a small difference.

Vulnerability Score:
Exposure 5 + Sensitivity 4 – Adaptive Capacity 2

3.1.9 Power Supply

Hatchery Summary:

Exposure: 3. Rock Creek faces infrequent but extreme power loss scenarios, such as power loss during the Archie Creek Fire when the power company cut power to the area for days.

Sensitivity: 3. Water must be pumped from the North Umpqua River during the summer, and power loss to the pump system has deadly consequences for fish. Rock Creek's sensitivity to power loss is mitigated in part by the presence of generators, but the generator is not suitable for long-term power loss, especially without ongoing fuel deliveries.

Adaptive Capacity: 5*. Renewable energy sources could help mitigate power loss scenarios (assuming the infrastructure isn't damaged by the same things that caused the power loss, i.e., fire).

An adaptive capacity score of 5 is dependent on installing a renewable power supply, which will require significant upfront costs. However, these costs should be allayed by cost savings (and potential earnings by contributing energy back into the local power grid), with estimated payback periods of around 10 years for a full transition to renewable energy.

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 5*

3.1.10 Water Rights

Hatchery Summary:

Exposure: 1. Rock Creek is not anticipated to experience issues with its water rights even with drought declarations in place, as the North Umpqua has provided sufficient streamflow when it is used as the primary water source in the summer and fall. The hatchery has water rights for 30 cfs on Rock Creek and 25 cfs on the North Umpqua River (Rock Creek HMP ODFW, 2020c).

Sensitivity: 1. Rock Creek's sensitivity to water rights issues is low due to its seniority.

Adaptive Capacity: 5*. The hatchery could reduce its water needs with a RAS or pRAS system and can seek additional instream water rights in the North Umpqua basin to ensure sufficient fish habitat for migration.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through obtaining additional water rights, which also requires a significant initial financial investment. Both options can mitigate problems with water rights by either reducing the water needs of the hatchery or by supplementing available water for hatchery use. As of November 2022, the hatchery does not face threats to water availability due to water rights issues.

Vulnerability Score:
Exposure 1 + Sensitivity 1 – Adaptive Capacity 5*

3.1.11 Streamflow Timing

Hatchery Summary:

Exposure: 5. The timing of peak and minimum flows is not anticipated to shift by mid-century (2030-2059) given climate change projections (RCP8.5); peak flows on Rock Creek and the North Umpqua River are projected to occur in February, and minimum flows are projected to occur in September. However, the magnitude of peak and minimum flows is expected to change, with high winter flows increasing by up to 16% and low summer flows decreasing by up to 38% in the North Umpqua River. Rock Creek itself projected to experience increases up to 6% in winter and decreases up to 15% in summer.

Sensitivity: 2. The hatchery is moderately sensitive to changes in streamflow timing due to summer water needs; see Section 3.1.12 on Low Flows.

Adaptive Capacity: 5*. The hatchery has the ability to withstand changes in streamflow timing through reducing its water needs with a RAS or pRAS, or by storing water.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through the addition of water storage, which also has significant upfront costs. Both options can mitigate changes in streamflow timing and availability throughout the year by reducing hatchery water needs or by storing excess water for later in the year when water availability is lower than water needs.

Vulnerability Score:
Exposure 5 + Sensitivity 2 – Adaptive Capacity 5*

3.1.12 Low Flows

Hatchery Summary:

Exposure: 5. Rock Creek Hatchery draws water from Rock Creek and the North Umpqua River. Water availability on Rock Creek during low flow months (June through October) was limited in the past and was the basis of the ODFW acquiring water rights on the North Umpqua River. Climate change projections for Rock Creek estimate streamflow decreases of approximately 12% June through September. Climate change projections for the North Umpqua River estimate average streamflow decrease of 32% June through September. The North Umpqua exhibits large variances in summer low flows, with many of the most recent years experiencing lower-than-average discharge. Climate change projections show smaller reductions in summer streamflow for Rock Creek compared to North Umpqua, during the time of year the hatchery withdraws exclusively from the North Umpqua.

Sensitivity: 3. Before the Archie Creek Fire, the hatchery was active in all seasons reflecting its work with multiple fish programs (Fall and Spring Chinook, Summer and Winter Steelhead, and Rainbow Trout) (Rock Creek HMP ODFW, 2020). The hatchery is expected to be sensitive to projected reductions in flow in summer months. The hatchery has an existing UV Ozone system to mitigate against water quality issues exacerbated by low flows. Low flows within the watershed can impede fish migration, which is relevant to programs at this hatchery and are difficult to mitigate against, short of trapping fish further downstream and transporting them by truck. Low flows can also exacerbate already-high water temperatures.

Adaptive Capacity: 4*. The hatchery can help mitigate low flow conditions on the North Umpqua River by obtaining additional water rights from within the basin to supplement low flows. (The summer low flows on Rock Creek are too low to adequately supplement hatchery intake water and are likely to be reduced further by climate change.) The hatchery can also mitigate against low flow impacts through the use of a RAS or pRAS system and can improve water treatment with additional UV Ozone treatment and additional aeration.

An adaptive capacity score of 4 is dependent on installing a RAS system and incorporating UV Ozone and additional water conditioning to improve water quality issues due to low flows. Both of these systems have significant upfront costs, and a RAS has high ongoing costs and maintenance requirements. Both require reliable, constant electricity as well. A score of 4 is also possible through obtaining additional water rights, which itself requires a significant initial financial investment. These options can mitigate problems with low flows by either reducing the water needs of the hatchery or by supplementing available water for hatchery use, and improving water quality of the reduced water volumes.

Vulnerability Score:
Exposure 5 + Sensitivity 3 – Adaptive Capacity 4*

3.1.13 Sedimentation

Hatchery Summary:

Exposure: 3. Because the Rock Creek watershed experienced such high soil burn severity and vegetation loss, there is increased potential for erosion and sediment delivery to the stream that ultimately supplies the hatchery. Turbidity trends for the area were slightly decreasing over time but are anticipated to increase as burned trees rot away and lose their hold on sediments in the watershed.

Sensitivity: 3. The intake screen system was damaged by the Archie Creek Fire.

Adaptive Capacity: 3*. Rock Creek has moderate adaptive capacity against increased sedimentation that will be occurring steadily over the next decade through the use of improved screens and settling tanks, plus watershed-wide practices such as reestablishing vegetation and the Private Forest Accord wherein the timber industry will engage in improved forestry practices.

An adaptive capacity of 3 is dependent on the installation of settling tanks, which are effective but very expensive and must be sized appropriately, and additional screening infrastructure, which could include self-cleaning screens and trash rakes. Screens are relatively inexpensive but require frequent manual cleaning, unless an automated cleaning system is installed (with higher initial cost). Watershed-wide practices have low adaptive capacity and require large-scale coordinated efforts between multiple agencies.

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 3*

3.1.14 Water Temperature

Hatchery Summary:

Exposure: 5. Historical temperature data at Rock Creek Hatchery is limited, but in a 2016 dataset, average monthly water temperature in June, July, and August exceeded 16°C (16.1°C, 17.7°C, and 17.5°C, respectively). Longer historical water temperature records are available from nearby USGS gage stations. At Rock Creek near Glide (USGS 14317600, 2021-2022) approximately one mile upstream from the hatchery, average daily and average daily maximum water temperatures were about 20.5°C and 23.4°C, respectively for both July and August. At the North Umpqua River near Idleyld Park (USGS 14317450, 1998-2021) approximately one mile upstream from the hatchery, average daily water temperatures were 17.4°C and 16.8°C for July and August, respectively, and average daily maximum water temperatures were 18.5°C and 17.8°C for July and August, respectively. The latter site is closest to where Rock Creek Hatchery withdraws its water for production needs during the months of June through October.

Climate change projections of water temperature in Rock Creek and the North Umpqua River estimate increases of approximately 1.1°C in June, 1.7°C in July, 1.4°C in August, and 0.8°C in September (Chandler et al. 2016; Isaak et al. 2016). Therefore, the number of days per year with average water temperature above 16°C is projected to increase from 68 to 82 at the North Umpqua River (at USGS gage 14317450 near Idleyld Park) in 2045 according to stream temperature modeling by the USDA (Chandler et al. 2016; Isaak et al. 2016). Similarly, the number of days with average water temperature above 21°C is projected to increase from 2 to 15. Fish migrating during these time periods will experience warm temperatures in streams, potentially to the point that it interferes with their migration, and fish over-summering at the hatchery will experience these temperatures from intake waters.

Sensitivity: 4. The programs most at risk at Rock Creek Hatchery are Spring Chinook and Summer Steelhead due to the approximate time periods of their migration, with Spring Chinook migration and collection taking place from April to June and Summer Steelhead collection starting in June and lasting into the fall, as well as during any over-summering. Early returning Fall Chinook could encounter increased temperatures during their migration in August and September, and Rainbow Trout collected throughout the summer are likely to experience increased temperatures in the basin as well. Coho and Winter Steelhead are only anticipated to have problems during their over-summering at the hatchery but not in their migration stages or spawning periods, which occur during cooler parts of the year.

Adaptive Capacity: 5*. Rock Creek has the ability to mitigate rising water temperatures through the use of chillers paired with a RAS or pRAS setup, transporting fish to a different hatchery during warm months, plus installation of shade cover and other best practices such as reduced feeding.

An adaptive capacity score of 5 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising water temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures; however, evidence from other hatcheries such as Speelyai Hatchery in Washington has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can mitigate fish losses, though the ultimate goal is to eliminate fish loss due to warming waters. Transporting fish to other hatcheries during the summer months is an effective and relatively inexpensive solution, assuming a different hatchery has available capacity, but additional handling and transport can increase fish stress, leaving them more vulnerable to pathogens.

Vulnerability Score:
Exposure 5 + Sensitivity 4 – Adaptive Capacity 5*

3.1.15 Pathogens

Hatchery Summary:

Exposure: 5. Pathogens and infectivity are already a problem at Rock Creek Hatchery and will be exacerbated by rising summer temperatures and reduced summer streamflows projected with climate change. Common pathogens found in Rock Creek Hatchery fish in the past include Ich, Columnaris, and Furunculosis, which tend to flourish and cause outbreaks at higher temperatures; coldwater disease is one of the few pathogens at the hatchery that proliferates best at cooler temperatures and would not necessarily be exacerbated by warmer waters. As per the section on water temperature, the hatchery can expect temperature increases of 0.8-1.7°C from June to September which may promote conditions favorable to pathogens. The number of days with mean temperatures above 16°C at USGS 14317450 is anticipated to increase from 68 to 82 and over 21°C from 2 to 15 days per year, which could lead to increased infectivity and pathogen loads.

Sensitivity: 4. All fish that over-summer at the hatchery could face increasing pathogen exposure and infectivity, with subsequent declining health. Summer Steelhead and Spring Chinook are at particular risk due to migration and spawning periods that occur during the months with warmest water temperature, which can lead to higher infectivity and reduced fitness during that life stage.

Adaptive Capacity: 3*. Rock Creek has the ability to mitigate rising infections and pathogens caused by warmer water temperatures through the use of chillers paired with a RAS or pRAS setup, plus UV ozone treatment of incoming water and continuation of established best practices for fish health. The installation of chillers at the scale needed for Rock Creek Hatchery and a RAS or PRAS system has high upfront and ongoing costs and therefore may be cost prohibitive. An additional UV Ozone system is also expensive, though several magnitudes cheaper than the previous systems, and it is effective at neutralizing incoming pathogens, and staff at Rock Creek Hatchery are already familiar with how to use such a system, as the hatchery already utilizes UV Ozone in production to some extent.

Vulnerability Score:
Exposure 5 + Sensitivity 4 – Adaptive Capacity 3*

The exposure and sensitivity for each hazard have been presented in an easy-to-read graphical format, where exposure increases from left to right (5 is the most severe) and sensitivity increases from top to bottom (5 is the most sensitive). From this graphic, it is easier to identify the most potentially impactful hazards, and the exposure and sensitivity scores that contribute to the potential impact.

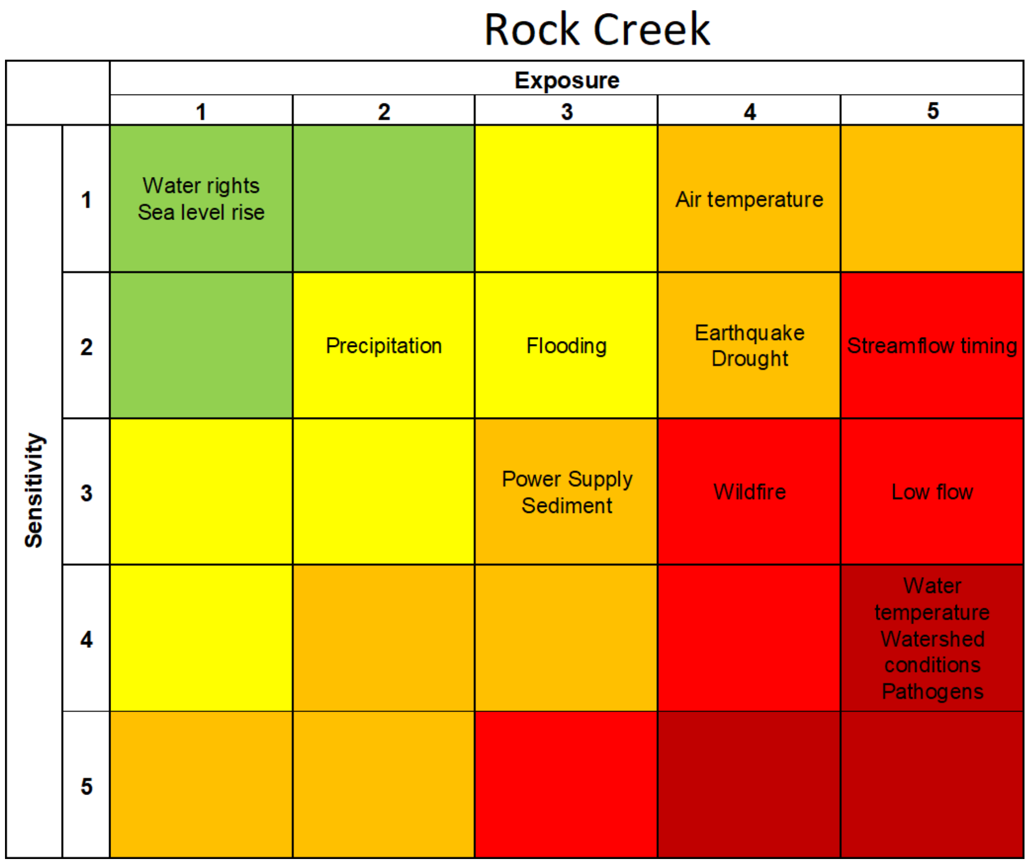

Figure 4: Rock Creek Hatchery Vulnerability Matrix: Exposure (columns) and sensitivity (rows).

3.2 Alsea Hatchery

The Alsea Hatchery risk assessment scores for each hazard are provided in Table 3 below. The exposure and sensitivity scores are summed to calculate the potential impact. At the hatchery, pathogens, low flows, water rights, and streamflow timing have been identified as the most potentially impactful hazards. However, vulnerability is the sum of the potential impact and the adaptive capacity, which can reduce the potential impact of each hazard.

Table 3. Hatchery Scores, ordered by descending Potential Impact values. Adaptive Capacity options that require significant costs to implement are denoted with a (*)

Potential Vulnerability	Exposure	Sensitivity	Potential Impact	Adaptive Capacity	Vulnerability
Pathogens	5	4	9	3*	6
Low flow	5	3	8	4*	4
Water rights	5	3	8	5*	3
Streamflow timing	5	3	8	5*	3
Water temperature	4	2	6	5*	1
Sediment	4	2	6	3*	3
Watershed conditions	4	1	5	2	3
Air temperature	3	4	7	5*	2
Earthquake	3	3	6	1	5
Power supply	3	3	6	3*	3
Sea level rise	3	3	6	4*	2
Drought	2	4	6	5*	1
Precipitation	2	3	5	4*	1
Wildfire	1	3	4	2	2
Flooding	1	3	4	2*	2

Hatchery Description

Name: Alsea Hatchery

Location: Near Corvallis, OR

Technical Assessment

3.2.1 Wildfire

Hatchery Summary:

Exposure: 1. Most of the land surrounding Alsea Hatchery has a burn probability rated as "Low" (60% of land within a 5-mile buffer). The hatchery's exposure score based on the weighted distribution of burn probability is 1.5 (out of 5). The most probable flame lengths are less than 4 ft (44% of the surrounding area) and flame lengths greater than or equal to 8 ft are likely on 29% of the surrounding area.

Note: calculations for Alsea Hatchery are based on data from 2018; more recent data are not yet available.

Sensitivity: 3. Alsea is moderately sensitive to fire due to vegetation (forests and scrub/shrub) in the surrounding area and a lack of defensible space, but it is also less sensitive because of good relations with the local fire department and emergency responders and concrete raceway infrastructure.

Adaptive Capacity: 2. The hatchery can work to create defensible perimeter space around infrastructure to protect structures. Fire suppression systems may provide some protection for infrastructure in smaller, easier-to-control wildfires.

Vulnerability Score:
Exposure 1 + Sensitivity 3 – Adaptive Capacity 2

3.2.2 Drought

Hatchery Summary:

Exposure: 2. Alsea Hatchery, located in Benton County, Oregon historically has experienced minor levels of drought and on average (2000-2022), 41% of the county has experienced drought category D0 (abnormally dry), 22% has experienced D1 (moderate drought), 11% D2 (severe drought), 1% D3 (extreme drought), and 0% has experienced D4 (exceptional drought). Most of the time spent in D3 extreme drought (2000-2022) has occurred in 2021.

Sensitivity: 4. The hatchery has one water source, which is at risk due to streambank erosion, and groundwater is not a good option due to saltwater intrusion in test wells; the hatchery has also experienced decreasing summer streamflows over the past 5 years and rising air temperatures.

Adaptive Capacity: 5*. The hatchery has the ability to mitigate drought impacts due to low flows and increased temperatures by installing a RAS or pRAS system, which would reduce water needs by as much as 90%, or to relocate fish during the summer months when drought impacts might be most visible. Leaking raceways can be resealed and refurbished.

An adaptive capacity score of 5 is possible through both RAS installation and fish relocation. The use of a RAS system requires significant initial and ongoing costs but has the benefit of maintaining operations onsite at the hatchery. Relocating fish during summer months to other hatcheries is far less expensive, but it requires another hatchery (such as Cole Rivers) that has the capacity and available water to raise additional fish. It also increases stress to fish through additional handling and transport, which should have low mortality on its own but can leave fish more vulnerable to pathogens at the receiving hatchery. Resealing leaky raceways is inexpensive but does not provide a large amount of adaptive capacity against drought.

Vulnerability Score:
Exposure 2 + Sensitivity 4 – Adaptive Capacity 5*

3.2.3 Flood

Hatchery Summary:

Exposure: 1. Alsea Hatchery's exposure to flooding is low as less than 0.5% of the Alsea hatchery footprint resides within the 100-year floodplain (1% annual flood probability) according to the FEMA FIRM. No additional hatchery structures are located within the 500-year floodplain (0.2% annual flood probability) beyond those in the 100-year floodplain.

Sensitivity: 3. The hatchery is moderately sensitive to flooding. Flooding and high waters could further scour the streambank that holds the intake pipe; high waters could reduce already limited head pressure across the hatchery, limiting the addition of hydropower.

Adaptive Capacity: 2*. The streambank supporting the intake pipe can be restored and reinforced, and collaborations with local emergency management can be strengthened to ensure advance warning systems for staff.

Streambank restoration and reinforcement can be relatively expensive, and adaptive capacity is moderately low, as large floods could still damage the intake pipe and its associated streambank with scouring flows and debris.

Vulnerability Score:
Exposure 1 + Sensitivity 3 – Adaptive Capacity 2*

3.2.4 Sea Level Rise

Hatchery Summary:

Exposure: 3. The hatchery has already experienced some degree of saltwater intrusion in groundwater test wells drilled in the past. With global air temperature increases of 2-4°C by the end of century, the relative sea level in the Pacific Northwest will likely increase 1.3-2.6 feet. The hatchery is not anticipated to experience any direct impacts of rising waters.

Sensitivity: 3. The hatchery already experienced saltwater intrusion in testing wells, and further saltwater intrusion or migration into the water table could affect domestic well water.

Adaptive Capacity: 4*. The hatchery should maintain monitoring of the well water and could invest in desalination or reverse osmosis systems for domestic water use, as well as consider rainwater cisterns, or transferring surface water rights from fish production to domestic use after reducing production water needs with a RAS system.

An adaptive capacity score of 4 is dependent on treatment of well water with desalination or reverse osmosis, both of which require high upfront costs and ongoing maintenance. Storage tanks and cisterns also have high upfront costs. The option of transferring fish production water rights to domestic use could only occur by first reducing production water needs, which would be most effectively done with a RAS system (high initial and ongoing costs).

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 4*

3.2.5 Precipitation

Hatchery Summary:

Exposure: 2. An analysis of Alsea Hatchery's historical observed precipitation changes from USHCN precipitation data from 1889 to 2020 show no statistically significant monthly or annual trend in precipitation (University of Washington, 2021). Statewide climate change results from the Fifth Oregon Climate Assessment project a 6-9% decrease in summer precipitation and a 5-8% increase in winter precipitation, with a mean annual precipitation increase of 2-3%. However, there is uncertainty around Oregon's precipitation projections with individual model projections showing both increases and decreases in annual precipitation

(Dalton and Fleishman, 2021). The 6-9% decrease in summer precipitation received an exposure score of 2.

Sensitivity: 3. The hatchery is sensitive to decreases in summer precipitation that could exacerbate already low flows at the hatchery.

Adaptive Capacity: 4*. The hatchery can mitigate decreases in precipitation through reduced water needs with a RAS or pRAS system.

An adaptive capacity score of 4 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A RAS system will help mitigate decreases in precipitation but will not help mitigate increases in precipitation (and subsequent increased flooding risks).

Vulnerability Score:
Exposure 2 + Sensitivity 3 – Adaptive Capacity 4*

3.2.6 Air Temperature

Hatchery Summary:

Exposure: 3. An analysis of historical trends from the USHCN air temperature data show a statistically significant increase of 0.14°F per decade from approximately 1890 to 2020 (University of Washington, 2021). The Fifth Oregon Climate Assessment projects statewide air temperature increases of 4.5-6.3°F in the summer, with smaller increases during the rest of the year. The average annual temperature increase statewide at mid-century (2040-2069) is estimated to be 3.6°F for RCP4.5 and 5.0°F for RCP8.5 (Dalton and Fleishman, 2021).

Sensitivity: 4. The hatchery is sensitive to rising air temperatures because water temperatures at the hatchery and in the surrounding area are already too warm and rising, with temperature Total Maximum Daily Loads (TMDLs) in place across the Alsea basin.

Adaptive Capacity: 5*. The hatchery can mitigate impacts of rising air temperatures through the use of chillers to cool water (influenced by air temperatures) and the use of shade cover.

An adaptive capacity score of 5 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising air temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures that rise as a result of air temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can mitigate fish losses, though the ultimate goal is to eliminate fish loss due to warming waters.

Vulnerability Score:
Exposure 3 + Sensitivity 4 – Adaptive Capacity 5*

3.2.7 Earthquakes

Hatchery Summary:

Exposure: 3. There are no active faults within 5 miles, and the closest active fault is 8 miles northeast of the hatchery. The nearest earthquake epicenter for quakes from 1971-2008 is 7 to 12 miles away. The area around the hatchery has moderate risks for liquefaction (soft soil hazard) and very strong expected shaking as part of its general earthquake hazard risk.

Sensitivity: 3. The hatchery is moderately sensitive due to its concrete construction dating from the 1930s that is in generally poor to fair condition, based on the Hatchery Management Plan and observational site visits.

Adaptive Capacity: 1. Infrastructure currently in poor to fair condition can be rebuilt and reinforced with earthquakes in mind, and the remaining existing buildings and structures can be reinforced.

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 1

3.2.8 Watershed Conditions

Hatchery Summary:

Exposure: 4. The hatchery has surrounding land use consisting mostly of forests, with some pasture. Slopes are generally >5%, with erodibility between 0.1-0.4 in the surrounding area and moderate to high landslide risks.

Sensitivity: 1. The hatchery is not sensitive to watershed conditions due to the hatchery property containing large amounts of undeveloped land that provide a buffer around the hatchery itself.

Adaptive Capacity: 2. The hatchery does not have much capacity to modify the terrain, geology, and surroundings that could threaten it with land and debris slides, though actions to revegetate the watershed can help; small-scale protective efforts such as berms around the hatchery and water quality protection and filtration at the intake can make a small difference. The implementation of the Private Forest Accord will help watershed-scale conditions related to timber harvest and disturbed soils.

Vulnerability Score:
Exposure 4 + Sensitivity 1 – Adaptive Capacity 2

3.2.9 Power Supply

Hatchery Summary:

Exposure: 3. The hatchery regularly experiences dozens of days of power loss throughout the year, namely due to bad weather in the winter.

Sensitivity: 3. The hatchery is moderately sensitive due to limited backup power available only in the form of a battery system to power critical alarm systems.

Adaptive Capacity: 3*. There are several options for installation of onsite renewable power generation. Installation of micro-hydro, solar panels, biodigester, and power storage capacity could help prevent power loss though hydropower is potentially limited due to low head across the hatchery, and solar power is less viable in the winter when there is more likely to be bad weather that causes power losses.

An adaptive capacity score of 3 is dependent on installing a renewable power supply, which will require significant upfront costs. However, these costs should be allayed by cost savings (and potential earnings by contributing energy back into the local power grid), with estimated payback periods of around 10 years for a full transition to renewable energy. Alsea Hatchery has less optimal prospects for various renewable energy sources than many other hatcheries, due to above-mentioned factors (low head and power losses in winter during storms).

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 3*

3.2.10 Water Rights

Hatchery Summary:

Exposure: 5. Alsea Hatchery has begun to experience limitations on water available for production, pulling all the available water during low flow summers from the North Fork Alsea River, which is fully allocated during the months of April and June through November. The hatchery's water rights are for 47 cfs on North Fork Alsea River (ODFW, 2022).

Sensitivity: 3. The hatchery is somewhat sensitive due to lack of additional water resources in the basin and competing uses with decreasing flows, but its sensitivity is decreased by its seniority in the basin.

Adaptive Capacity: 5*. The hatchery could reduce its water needs with a RAS or pRAS system and continue to maintain good informal relations with neighboring water users.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. Maintaining good relations with neighbors is low-cost but low adaptive capacity and, on its own, would be unlikely to solve water availability issues due to water rights.

Vulnerability Score:
Exposure 5 + Sensitivity 3 – Adaptive Capacity 5*

3.2.11 Streamflow Timing

Hatchery Summary:

Exposure: 5. The timing of peak and minimum flows is not anticipated to shift by mid-century (2030-2059) with climate change; peak flows on Alsea River are projected to occur in January and minimum flows are projected to occur in August. However, the magnitude of peak winter flows and minimum summer flows is expected to change in nearby gages, with high winter flows increasing by up to 12% (November) and low summer flows decreasing by up to 15% (September).

Sensitivity: 3. The hatchery is sensitive to changes in streamflow magnitude (see discussion of Low Flows in Section 3.2.12), but that sensitivity is reduced because there is not anticipated to be a shift in the timing of the hydrograph. Since Alsea Hatchery's largest fish programs are Rainbow Trout and Winter Steelhead, with the hatchery's highest water demand in winter and spring, seasonal low flows on the Alsea River (July-September) will continue to align with the lower water use requirements in summer. Projected streamflow increases in the fall and winter months will align with the hatchery's higher water use.

Adaptive Capacity: 5*. The hatchery has the ability to withstand changes in streamflow timing through reducing its water needs with a RAS or pRAS, or by storing water.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through the addition of water storage, which also has significant upfront costs. Both options can mitigate changes in streamflow timing and availability throughout the year by reducing hatchery water needs or by storing excess water for later in the year when water availability is lower than water needs.

Vulnerability Score:
Exposure 5 + Sensitivity 3 – Adaptive Capacity 5*

3.2.12 Low Flows

Hatchery Summary:

Exposure: 5. Streamflow at the North Fork Alsea River near the hatchery is projected to decrease up to 16% in September with an average decrease of -12% over summer (July - September) in 2045, according to USDA downscaled modeled streamflow metrics focused on the more severe emissions scenario, RCP8.5.

Sensitivity: 3. The hatchery's production is currently limited by summer low flows, when the hatchery withdraws all water available in the North Fork Alsea River to meet its production needs. The hatchery is sensitive to low flows because climate change models project decreases in summer flow, which could exacerbate existing issues with water rights during periods of low water availability. Its sensitivity is decreased by the fact that summer is the time of year with the lowest water use and needs for hatchery production.

Adaptive Capacity: 4*. The hatchery can mitigate against low flow impacts through the use of a RAS or pRAS system and can improve water treatment with UV Ozone treatment and additional aeration.

An adaptive capacity score of 4 is dependent on installing a RAS system and incorporating a UV Ozone and additional water conditioning to improve water quality issues due to low flows. Both of these systems have significant upfront costs, and a RAS has high ongoing costs and maintenance requirements. Both require reliable, constant electricity as well.

Vulnerability Score:
Exposure 5 + Sensitivity 3 – Adaptive Capacity 4*

3.2.13 Sedimentation

Hatchery Summary:

Exposure: 4. Sediment in the hatchery's intake has increased over the past few decades, with the settling pond onsite cleaned out every 3-5 years. There are no recent burns recorded in the NIFC historic data or the Oregon Wildfire Risk Explorer that would be expected to worsen incoming sediment loads. The surrounding watershed has had ongoing disturbances through land use and active modification for several decades.

Sensitivity: 2. The hatchery is somewhat sensitive due to existing sediment loads but lessened by the presence of a small reservoir that acts as a settling basin.

Adaptive Capacity: 3*. The hatchery has moderate adaptive capacity against steadily increasing sedimentation using improved screens and additional settling tanks, plus watershed-wide practices such as reestablishing vegetation and the Private Forest Accord wherein the timber industry will engage in improved forestry practices that could reduce sedimentation into the rivers.

An adaptive capacity of 3 is dependent on the installation of settling tanks, which are effective but very expensive and must be sized appropriately, and additional screening infrastructure, which could include self-cleaning screens and trash rakes. Screens are relatively inexpensive but require frequent manual cleaning, unless an automated cleaning system is installed (with higher initial cost). Watershed-wide practices have low adaptive capacity and require large-scale coordinated efforts between multiple agencies.

Vulnerability Score:
Exposure 4 + Sensitivity 2 – Adaptive Capacity 3*

3.2.14 Water Temperature

Hatchery Summary:

Exposure: 4. Historical temperature data at Alsea Hatchery is limited, but in a 2016 dataset average monthly water temperature in June, July, and August were 14.9°C, 16.5°C, and 18.1ºC, respectively. Historical water temperature records are available from a USGS gage on Alsea River near Tidewater, OR (USGS 14306500) for a limited period of record (1979-1981) about 26 miles downstream from the hatchery. Daily average maximum water temperatures for USGS 14306500 were about 16ºC in June and 20°C in both July and August.

Climate change projections of water temperature in the Alsea River adjacent to the hatchery estimate increases of approximately 1.1°C in June, 1.7°C in July, 1.4°C in August, and 0.8°C in September by 2045 (Chandler et al. 2016; Isaak et al. 2016). Therefore, the number of days per year with average water temperature above 16°C is projected to increase from 88 to 94 in the Alsea River (at USGS 14306500 near Tidewater) by 2045 according to stream temperature modeling by the USDA (Chandler et al. 2016; Isaak et al. 2016). Similarly, the number of days with average water temperature above 21°C is projected to increase from 6 to 12. Fish migrating during these time periods will experience warm temperatures in streams, potentially to the point that it interferes with their migration, and fish over-summering at the hatchery will experience these temperatures from intake waters.

Sensitivity: 2. Alsea currently raises Winter Steelhead and Rainbow Trout, which are less affected by increasing temperatures than other programs operating in the summer.

Adaptive Capacity: 5*. The hatchery has the ability to mitigate rising water temperatures within the hatchery through the use of chillers paired with a RAS or pRAS setup, plus installing shade and other best practices such as reduced feeding during exceptionally warm periods or even transporting fish to a hatchery with appropriate water temperatures.

An adaptive capacity score of 5 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising water temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can mitigate fish losses, though the ultimate goal is to eliminate fish loss due to warming waters. Transporting fish to other hatcheries during the summer months is an effective and relatively inexpensive solution, assuming a different hatchery has available capacity, but additional handling and transport can increase fish stress, leaving them more vulnerable to pathogens. Reduced feeding is a protocol management option that has low adaptive capacity.

Vulnerability Score:
Exposure 4 + Sensitivity 2 – Adaptive Capacity 5*

3.2.15 Pathogens

Hatchery Summary:

Exposure: 5. The hatchery had average monthly temperatures above 16°C in July and over 18°C in August of 2016. Modeled historical (1993-2011) stream temperature data were over 16°C in July and August, with projections for 2045 based on this modeled data reaching over 18°C for both those months (Chandler et al. 2016; Isaak et al. 2016). The hatchery currently experiences problems with cold water disease and ich, the latter of which causes outbreaks at higher temperatures.

Sensitivity: 4. The hatchery is sensitive to pathogen loads because it already experiences problems with cold water disease and ich, as well as notably warming waters, though its fish programs do not have major life stages occurring in warmer months when ich and many other pathogens are more likely to proliferate.

Adaptive Capacity: 3*. Alsea Hatchery has the ability to mitigate rising infections and pathogens exacerbated by high water temperatures through the use of chillers paired with a RAS or pRAS setup to reduce water temperature, plus UV ozone treatment of incoming water to kill pathogens before they interact with the hatchery programs.

An adaptive capacity score of 3 is dependent on the installation of chillers to maintain cool waters and minimize outbreak potential of pathogens that prefer warmer temperatures. A chiller system will be most effective on a smaller volume of water, and would thus perform best with a RAS installation that reduces water needs. This chiller and RAS setup will have significant upfront and ongoing costs. UV Ozone treatment of incoming water is also expensive, though far less than a RAS setup, and works most effectively on well-filtered water, which requires installation of additional filtration.

Vulnerability Score:
Exposure 5 + Sensitivity 4 – Adaptive Capacity 3*

Alsea

		Exposure				
		1	**2**	**3**	**4**	**5**
Sensitivity	**1**				Watershed conditions	
	2				Water temperature Sediment	
	3	Flooding Wildfire	Precipitation	Earthquake Power supply Sea level rise		Low flow Water rights Streamflow timing
	4		Drought	Air temperature		Pathogens
	5					

Figure 5: Alsea Hatchery Vulnerability Matrix: Exposure (columns) and sensitivity (rows).

3.3 Bandon Hatchery

The Bandon Hatchery risk assessment scores for each hazard are provided in Table 4 below. The exposure and sensitivity scores are summed to calculate the potential impact. At the hatchery, low flows, water rights, streamflow timing, and earthquakes have been identified as the most potentially impactful hazards. However, vulnerability is the sum of the potential impact and the adaptive capacity, which can reduce the potential impact of each hazard.

Table 4. Hatchery Scores, ordered by descending Potential Impact values. Adaptive Capacity options that require significant costs to implement are denoted with a (*)

Potential Vulnerability	Exposure	Sensitivity	Potential Impact	Adaptive Capacity	Vulnerability
Low flow	5	4	9	4*	5
Water rights	5	3	8	5*	3
Streamflow timing	5	3	8	5*	3
Earthquake	4	4	8	3*	5
Flooding	3	4	7	2	5
Wildfire	2	5	7	2	5
Watershed conditions	3	2	5	2	3
Sea level rise	3	2	5	2*	3
Pathogens	3	2	5	3*	2
Drought	4	3	7	5*	2
Air temperature	3	1	4	5*	-1
Water temperature	2	2	4	5*	-1
Sediment	2	2	4	3*	1
Precipitation	2	2	4	3*	1
Power supply	1	3	4	3*	1

Hatchery Description

Name: Bandon Hatchery

Location: Bandon, OR

Technical Assessment

3.3.1 Wildfire

Hatchery Summary:

Exposure: 2. Most of the land surrounding Bandon Hatchery has a burn probability rated as "Low" (60% of land within a 5-mile buffer). The hatchery's exposure score based on the weighted distribution of burn probability is 1.8 (out of 5). The most probable flame length category is less than 4 ft (48% of the surrounding area) with flame length categories 0 ft and <4 ft totaling 91% of the surrounding area.

Note: calculations for Bandon Hatchery are based on data from 2018; more recent data are not yet available.

Sensitivity: 5. The hatchery is very sensitive to wildfire due to surrounding vegetation and much of the hatchery infrastructure (including raceways) being made from wood, with little defensible space.

Adaptive Capacity: 2. Bandon Hatchery should create as much of a defensible perimeter space as possible, given the lush vegetation of the surroundings; install fire suppression systems, which might protect structures in smaller, more easily controlled wildfires; and ensure staff are evacuated promptly in the event of an encroaching wildfire.

Vulnerability Score:
Exposure 2 + Sensitivity 5 – Adaptive Capacity 2

3.3.2 Drought

Hatchery Summary:

Exposure: 4. Bandon Hatchery, located in Coos County, Oregon historically has experienced minor levels of drought and on average (2000-2022), 43% of the county experienced drought category D0 (abnormally dry), 26% experienced D1 (moderate drought), 17% experienced D2 (severe drought), 6% experienced D3 (extreme drought), and 0% experienced D4 (exceptional drought). The county is currently experiencing a sustained period of dryness since 2020, and much of the county was in drought stage D3 (Extreme Drought) for most of 2020.

Sensitivity: 3. The hatchery is somewhat sensitive to drought due to competing water uses in the basin and because low flows in summer prevent full production. Its sensitivity is decreased because it has two water sources and has the potential to add groundwater.

Adaptive Capacity: 5*. The hatchery has the ability to mitigate drought impacts such as low flow and rising temperatures by installing a RAS or pRAS system, which would reduce water needs by as much as 90%. Fish could also be transported to a different hatchery that has greater water availability.

An adaptive capacity score of 5 is possible through both of the above options. The use of a RAS system requires significant initial and ongoing costs but has the benefit of maintaining operations onsite at the hatchery. Relocating fish during summer months to other hatcheries is effective and far less expensive, but it requires another hatchery (such as Cole Rivers) that has the capacity and available water to raise additional fish. It also increases stress to fish through additional handling and transport, which should have low mortality on its own but can leave fish more vulnerable to pathogens at the receiving hatchery.

Vulnerability Score:
Exposure 4 + Sensitivity 3 – Adaptive Capacity 5*

3.3.3 Flood

Hatchery Summary:

Exposure: 3. Bandon Hatchery's flood exposure is moderate as approximately 12% of the Bandon Hatchery footprint resides within the 100-year floodplain (1% annual flood probability), based on the FEMA FIRM. No additional hatchery structures are located within the 500-year floodplain (0.2% annual flood probability) beyond those in the 100-year floodplain. However, the structures within the 100-year floodplain include two raceways and a portion of one building.

Sensitivity: 4. A portion of the hatchery's raceway infrastructure and buildings are in the 100-year floodplain.

Adaptive Capacity: 2. The hatchery's infrastructure in the floodplain could be reinforced, which includes the spawning building, main office, and abatement pond, and the current portable toilet can be moved further uphill out of the floodplain or replaced with a permanent bathroom building. Collaborations with local emergency management can be strengthened to ensure advance warning systems for staff.

Vulnerability Score:
Exposure 3 + Sensitivity 4 – Adaptive Capacity 2

3.3.4 Sea Level Rise

Hatchery Summary:

Exposure: 3. With global air temperature increases of 2-4°C by the end of century, the relative sea level in the Pacific Northwest will likely increase 1.3-2.6 feet. The hatchery is not anticipated to experience any direct impacts of rising waters. However, with its proximity to the coast and to the boundaries of 10 feet of sea level rise, the hatchery could see saltwater intrusion into any possible groundwater sources, and nearby infrastructure and roads could become inundated and unusable.

Sensitivity: 2. The hatchery is somewhat sensitive due to the possibility of saltwater intrusion affecting groundwater (though groundwater is not currently used for operations).

Adaptive Capacity: 2*. The hatchery could invest in desalination or reverse osmosis systems to treat affected groundwater and reseal hatchery raceways and ponds to ensure separation of intake water and the water table.

An adaptive capacity score of 2 is dependent on treatment of well water with desalination or reverse osmosis, both of which require high upfront costs and ongoing maintenance.

Vulnerability Score:
Exposure 3 + Sensitivity 2 – Adaptive Capacity 2*

3.3.5 Precipitation

Hatchery Summary:

Exposure: 2. An analysis of Bandon Hatchery's historical observed precipitation changes from 1897 through 2020 shows a statistically significant precipitation decrease in January (-1.9 %/decade), February (-1.9 %/decade), and September (-3.2 %/decade) at the precipitation gage closest to Bandon Hatchery, North Bend FCWOS, with no statistically significant annual trends. Statewide climate change results from the Fifth Oregon Climate Assessment project a 6-9% decrease in summer precipitation and a 5-8% increase in winter precipitation, with a mean annual precipitation increase of 2-3%. However, there is uncertainty around Oregon's precipitation projections with individual model projections showing both increases and decreases in annual precipitation. The 6-9% decrease in summer precipitation received an exposure score of 2.

Sensitivity: 2. The hatchery is sensitive to decreases in streamflow in fall and winter since those are the times of greatest production and thus highest water needs. The hatchery is sensitive to decreasing low flows over the summer, which will further threaten its already-limited production during that time (see discussion of Low Flows).

Adaptive Capacity: 3*. The hatchery can mitigate decreases in precipitation through reduced water needs with a RAS or pRAS system, and structures can be reinforced to withstand any possible additional winter flooding due to increased precipitation.

An adaptive capacity score of 3 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A RAS system will help mitigate decreases in precipitation but will not help mitigate increases in precipitation (and subsequent increased flooding risks). Rebuilding additional structures to withstand flooding provides lower adaptive capacity.

Vulnerability Score:
Exposure 2 + Sensitivity 2 – Adaptive Capacity 3*

3.3.6 Air Temperature

Hatchery Summary:

Exposure: 3. An analysis of historical trends from the USHCN air temperature data in the area show a statistically significant increase of 0.25°F per decade from 1895 to 2020 (University of Washington, 2021). The Fifth Oregon Climate Assessment projects statewide air temperature increases of 4.5-6.3°F in the summer, with smaller increases during the rest of the year. The average annual temperature increase statewide at mid-century (2040-2069) is estimated to be 3.6°F for RCP4.5 and 5.0°F for RCP8.5 (Dalton and Fleishman, 2021).

Sensitivity: 1. The hatchery is not too sensitive to rising air temperatures due to current and projected water temperatures and its surrounding shady vegetation.

Adaptive Capacity: 5*. The hatchery can mitigate impacts of rising air temperatures through the use of chillers to cool water (influenced by air temperatures) and the use of additional shade cover over exposed ponds.

An adaptive capacity score of 5 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising air temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures that rise as a result of air temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can help mitigate fish losses. Bandon Hatchery already has significant shade cover due to vegetation and might not gain additional benefits from shade cover installation.

Vulnerability Score:
Exposure 3 + Sensitivity 1 – Adaptive Capacity 5*

3.3.7 Earthquakes

Hatchery Summary:

Exposure: 4. There are active faults within 5 miles; the closest fault is 1 mile from the hatchery and goes through the city of Bandon, with another fault 4 miles northeast of Parkersburg. The nearest earthquake epicenter for quakes on land from 1971-2008 is 8 miles away. The area around the hatchery has moderate to high risks for liquefaction (soft soil hazard) and very strong expected shaking as part of its general earthquake hazard risk.

Sensitivity: 4. The hatchery is sensitive to large or nearby earthquakes that could damage the upstream reservoirs and even lead to an earthen dam break. A geotechnical analysis of the Ferry Creek Dam found that the substrate under the dam would likely experience liquefaction during seismic events of strength 6.6 within a 5-9 km radius or a 9.0 event located within 15 km of the site (Foundation Engineering Inc, 2014). Such events include earthquakes of magnitude 6.2 to 6.6 within 5-10 kilometers of the dam or magnitude 9.0 originating within 15 kilometers of the dam. The hatchery was built in the 1920s and has concrete infrastructure dating from the 1950s and earlier, ranging in condition from poor to good based on the Hatchery Management Plan and observational site visits.

Adaptive Capacity: 3*. An advance warning system can be put in place in conjunction with emergency management to evacuate staff in case of earthquakes. The dam at risk of collapse could be rebuilt or reinforced, which would require significant financial investment.

Vulnerability Score:
Exposure 4 + Sensitivity 4 – Adaptive Capacity 3*

3.3.8 Watershed Conditions

Hatchery Summary:

Exposure: 3. The hatchery has surrounding land use consisting mostly of forested area, with development downstream and assorted wetlands and light agriculture upstream. Slopes are mixed in the area near the hatchery with values mostly <5%, with erodibility index between 0.1-0.2 in the surrounding area and moderate to high landslide risks.

Sensitivity: 2. The hatchery is somewhat sensitive to debris and landslides because there is not a defensible space around the hatchery and its infrastructure.

Adaptive Capacity: 2. The hatchery does not have much capacity to modify the terrain, geology, and surroundings that could threaten it with land and debris slides; small-scale protective efforts such as berms around the hatchery and water quality protection, screens, and filtration at the intake can help at the local scale.

Vulnerability Score:
Exposure 3 + Sensitivity 2 – Adaptive Capacity 2

3.3.9 Power Supply

Hatchery Summary:

Exposure: 1. The hatchery does not experience frequent or extreme issues with power loss.

Sensitivity: 3. The hatchery is moderately sensitive to power loss due to a lack of backup power, but its sensitivity is decreased by its use of gravity-fed systems that continue to function in the absence of electricity.

Adaptive Capacity: 3*. Renewable energy from solar panels could somewhat mitigate power loss scenarios, as the location and available area are usable but not optimal for solar. A mini-hydropower generator could be installed on the water source dams.

An adaptive capacity score of 3 is dependent on installing a renewable power supply, which will require significant upfront costs. However, these costs should be allayed by cost savings (and potential earnings by contributing energy back into the local power grid), with estimated payback periods of around 10 years for a full transition to renewable energy. A large portion of Bandon Hatchery is vegetated, which limits solar panel installation locations.

Vulnerability Score:
Exposure 1 + Sensitivity 3 – Adaptive Capacity 3*

3.3.10 Water Rights

Hatchery Summary:

Exposure: 5. The hatchery has already begun to experience limitations to production due to water availability (or lack thereof), especially during the fall and early winter, when hatchery production needs are highest which coincides with the months cranberry farmers utilize the most water for harvesting. The City of Bandon has year-round needs from the hatchery's water source reservoir. Ferry Creek does not have any unallocated water available, while the greater Coquille River watershed has some availability between November-July. Water supplies from the hatchery come from Ferry Creek and Geiger Creek, which account of a total water right of 5.5 cfs (ODFW, 2020a).

Sensitivity: 3. The hatchery is moderately sensitive due to the over-allocated nature of water resources in the same basins, and its sensitivity is decreased by its seniority in the area as well as its good working relationship with the City of Bandon.

Adaptive Capacity: 5*. The hatchery could reduce its water needs with a RAS or pRAS system, which would negate any problems with water rights. It could collaborate with neighboring water users to relocate the City of Bandon's water intake downstream of the hatchery, and work toward a similar setup with the upstream farmers.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 3 is also possible through coordinated low-cost efforts to relocate upstream users' points of diversion downstream of the hatchery; it is likely that upstream groundwater users could continue to have an impact on downstream surface water supplies through pumping, though the numbers of users could be limited through the afore-mentioned relocation efforts and coordination.

Vulnerability Score:
Exposure 5 + Sensitivity 3 – Adaptive Capacity 5*

3.3.11 Streamflow Timing

Hatchery Summary:

Exposure: 5. Bandon Hatchery is at the confluence of Ferry Creek and Geiger Creek, both of which have peak flows in March and minimum flows in September. However, peak flows are nearly equal for February and March (within 1%). Climate change projections for mid-century (2030-2059) show peak flow occurring in February instead of March and low flows still occurring in September. However, the difference in flow from February to March is small (within 1%) and within any climate change uncertainty. While the timing of peak and minimum flows is not anticipated to shift in a meaningful way, the magnitude of peak and minimum flows is expected to change in nearby gages, with high winter flows increasing by up to 3% at Ferry Creek and 5% at Geiger Creek and low summer flows decreasing by up to 17% (September) at Ferry Creek and 16% (September) at Geiger Creek.

Sensitivity: 3. The hatchery is sensitive to large changes in streamflow timing and magnitude. While there is not anticipated to be a major shift in timing by mid-century, current low flows in the summer already hinder production and prevent any possible expansion, and further decreases in magnitude will be problematic for the hatchery. See low flows discussion in Section 3.3.12.

Adaptive Capacity: 5*. The hatchery has the ability to withstand changes in streamflow timing through reducing its water needs with a RAS or pRAS, or by storing water.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through the addition of water storage, which also has significant upfront costs. Both options can mitigate changes in streamflow timing and availability throughout the year by reducing hatchery water needs or by storing excess water for later in the year when water availability is lower than water needs.

Vulnerability Score:
Exposure 5 + Sensitivity 3 – Adaptive Capacity 5*

3.3.12 Low Flows

Hatchery Summary:

Exposure: 5. Bandon Hatchery already experiences low flows during summer and fall months, to the extent that reduced streamflow has affected current and historical operations as reported by hatchery operators. Climate change projections of streamflow in Ferry Creek near the hatchery show an average decrease up to 17% in September, and an average decrease of 11% in summer months (June-October) for 2045 using RCP8.5 (high emissions scenario). Climate change projections for Geiger Creek estimate an average decrease up to 16% in September, and average decreases of 10% in summer months (June-October) in 2045 using RCP8.5.

Sensitivity: 4. The hatchery is sensitive to decreasing low flows over the summer, which will further threaten its already-limited production during that time. This sensitivity will increase if an additional Fall Chinook program is started up at the hatchery, which would require the hatchery to maintain its water use levels year-round in order to raise fish prior to their release. Hatchery operators currently move fish from Bandon to Cole Rivers Hatchery during summer months due to limited water availability.

Adaptive Capacity: 4*. The hatchery can mitigate against low flow impacts through the use of a RAS or pRAS system and can improve water treatment with additional UV Ozone treatment (along with tannin pre-treatment utilizing membrane filtration, ion exchange, or activated charcoal).

An adaptive capacity score of 4 is dependent on installing a RAS system, which has high initial and ongoing costs but is effective at reducing production water needs. Incorporating a UV Ozone and additional water conditioning to improve water quality of low flows has high upfront costs, though much lower than a RAS. Both require reliable, constant electricity as well.

Vulnerability Score:
Exposure 5 + Sensitivity 4 – Adaptive Capacity 4*

3.3.13 Sedimentation

Hatchery Summary:

Exposure: 2. The hatchery sources its water from reservoirs that have acted as settling ponds and allowed sediments to settle out before flowing into the hatchery, but the reservoirs have filled to the point that they cannot contain all the sediment that flows into them. There are no recent burns recorded nearby.

Sensitivity: 2. The hatchery is somewhat sensitive to an influx of sediment due to the existing sediment loads in the reservoir water sources.

Adaptive Capacity: 3*. The hatchery has moderate adaptive capacity against increased sedimentation that will be occurring steadily over the next decade through the use of improved screens and settling tanks, plus watershed-wide practices such as reestablishing vegetation and the Private Forest Accord wherein the timber industry will engage in improved forestry practices.

An adaptive capacity of 3 is dependent on the installation of settling tanks, which are effective but very expensive and must be sized appropriately, and additional screening infrastructure, which could include self-cleaning screens and trash rakes. Screens are relatively inexpensive but require frequent manual cleaning, unless an automated cleaning system is installed (with higher initial cost). Watershed-wide practices have low adaptive capacity and require large-scale coordinated efforts between multiple agencies.

Vulnerability Score:
Exposure 2 + Sensitivity 2 – Adaptive Capacity 3*

3.3.14 Water Temperature

Hatchery Summary:

Exposure: 2. Historical water temperature data at Bandon Hatchery is limited, but a 2016 dataset showed that average monthly water temperature in July and August were 13.7°C, below the 16°C or 18°C optimal temperature thresholds for fish. There is no supplementary water temperature data from nearby USGS gages on Geiger Creek and Ferry Creek.

Climate change projections of water temperature in Geiger Creek and Ferry Creek upstream of the hatchery estimate increases of approximately 1.1°C in June, 1.6°C in July, 1.4°C in August, and 0.8°C in September by 2045 (Chandler et al. 2016; Isaak et al. 2016). Combining the water temperature offsets projected under climate change with measured data, we expect that average monthly water temperature will stay below 16°C during summer. However, daily maximum water temperatures may increase above this threshold.

Historical modeled stream temperatures on Geiger Creek and Ferry Creek upstream of the hatchery, estimated average monthly temperatures of up to 15.5°C in July and August between 1993-2011. Climate change projections applied to modeled estimates of stream temperature show temperatures reaching up to 17°C in July and August by 2045. We note that the modeled stream temperature data is added to provide context due to the limited observational data at Bandon Hatchery.

Sensitivity: 2. Bandon currently raises Fall Chinook, Winter Steelhead, and Rainbow Trout, which are less affected by increasing temperatures than other programs that have sensitive life stages in the late spring and summer months.

Adaptive Capacity: 5*. The hatchery has the ability to mitigate rising water temperatures through the use of chillers paired with a RAS or pRAS setup and adding additional shade cover. Fish can also be transported to a different hatchery with lower water temperatures.

An adaptive capacity score of 5 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising water temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can mitigate fish losses. Transporting fish to other hatcheries during the summer months is an effective and relatively inexpensive solution, assuming a different hatchery has available capacity, but additional handling and transport can increase fish stress, leaving them more vulnerable to pathogens.

Vulnerability Score:
Exposure 2 + Sensitivity 2 – Adaptive Capacity 5*

3.3.15 Pathogens

Hatchery Summary:

Exposure: 3. The hatchery had average monthly temperatures below 16°C for all summer months in 2016, which is supported by modeled historical stream temperature for summer months between 1993-2011 on Geiger Creek and Ferry Creek. Climate change projections estimate water temperature increases of 1.4-1.6°C in July and August by 2045, which may increase daily maximum water temperature above the 16°C threshold for fish. Cold water disease is known to be a problem at the hatchery, and temperatures will still remain optimal for disease outbreaks at some points in the year.

Sensitivity: 2. The hatchery is moderately sensitive to pathogen loads because it already experiences problems with cold water disease. It is less sensitive to issues with those pathogens that have increased infectivity at higher temperatures, partly because water temperatures will stay reasonably low and also because it does not currently have any programs that have sensitive life stages occurring during warmer months.

Adaptive Capacity: 3*. The hatchery has the ability to mitigate rising infections and pathogens that thrive in warmer water temperatures through the use of chillers paired with a RAS or pRAS setup, plus UV ozone treatment (and its requisite pre-treatment for tannins) of incoming water and the continuation of established best practices for fish health.

An adaptive capacity score of 3 is dependent on the installation of chillers to maintain cool waters and minimize future outbreak potential of pathogens that prefer warmer temperatures. A chiller system will be most effective on a smaller volume of water, and would thus perform best with a RAS installation that reduces water needs. This chiller and RAS setup will have significant upfront and ongoing costs. UV Ozone treatment of incoming water is also expensive, though far less than a RAS setup, and works most effectively on well-filtered water, which requires installation of additional filtration.

Vulnerability Score:
Exposure 3 + Sensitivity 2 – Adaptive Capacity 3*

Bandon

Sensitivity \ Exposure	1	2	3	4	5
1			Air temperature		
2		Water temperature Sediment Precipitation	Watershed conditions Sea level rise Pathogens		
3	Power supply			Drought	Water rights Streamflow timing
4			Flooding	Earthquake	Low flow
5		Wildfire			

Figure 6: Bandon Hatchery Vulnerability Matrix: Exposure (columns) and sensitivity (rows).

3.4 Cole Rivers Hatchery

The Cole Rivers Hatchery risk assessment scores for each hazard are provided in Table 5 below. The exposure and sensitivity scores are summed to calculate the potential impact. At the hatchery, power supply and flooding have been identified as the most potentially impactful hazards. However, vulnerability is the sum of the potential impact and the adaptive capacity, which can reduce the potential impact of each hazard.

Table 5. Hatchery Scores, ordered by descending Potential Impact values. Adaptive Capacity options that require significant costs to implement are denoted with a (*)

Potential Vulnerability	Exposure	Sensitivity	Potential Impact	Adaptive Capacity	Vulnerability
Power supply	5	4	9	5*	4
Flooding	3	5	8	2	6
Streamflow timing	5	1	6	5*	1
Low flow	5	1	6	4*	2
Drought	4	2	6	5*	1
Earthquake	4	2	6	3	3
Precipitation	3	3	6	3*	3
Watershed conditions	4	1	5	2	3
Wildfire	4	1	5	2	3
Air temperature	3	2	5	3*	2
Water temperature	2	3	5	5*	0
Pathogens	2	3	5	4*	1
Sediment	2	1	3	2	1
Water rights	1	1	2	5*	-3
Sea level rise	1	1	2	1	1

Hatchery Description

Name: Cole Rivers Hatchery

Location: Near Medford, OR (Jackson County)

Technical Assessment

3.4.1 Wildfire

Hatchery Summary:

Exposure: 4. Most of the land surrounding Cole Rivers Hatchery has a burn probability rated as "Moderate-High" (85% of land within a 5-mile buffer). The hatchery's exposure score based on the weighted distribution of burn probability is 3.1 (out of 5). The most probable flame lengths are 4-8 ft (36% of the surrounding area), but flame lengths greater than or equal to 8 ft are likely on 42% of the surrounding area. Therefore, the wildfire exposure score was increased from 3 to 4.

Note: calculations for Cole Rivers Hatchery are based on data from 2018; more recent data are not yet available.

Sensitivity: 1. The hatchery is not especially sensitive to fire due to its extensive use of concrete structures and paved surroundings with little vegetation nearby. It has served as emergency shelter during other fires for this very reason.

Adaptive Capacity: 2. The hatchery should maintain defensible space from vegetation, as well as install backup renewable energy sources so that the hatchery's power is not reliant on fuel delivery trucks being able to access the hatchery. Installation of fire suppression systems could protect infrastructure from smaller, more manageable fires.

Vulnerability Score:
Exposure 4 + Sensitivity 1 – Adaptive Capacity 2

3.4.2 Drought

Hatchery Summary:

Exposure: 4. Cole Rivers Hatchery, located in Jackson County, Oregon historically has experienced moderate to severe levels of drought and on average (2000-2022), 56% of the county has experienced drought category D0 (abnormally dry), 35% has experienced D1 (moderate drought), 25% D2 (severe drought), 10% D3 (extreme drought), and 0% has experienced D4 (exceptional drought). The hatchery is currently experiencing a progression of drought that started in 2020.

Sensitivity: 2. The hatchery is somewhat sensitive to drought due to having only one water source. However, the water source is from Lost Creek Lake which is managed by the US Army Corps of Engineers (USACE) who will likely manage flows to maintain fish habitat as much as possible (though do not have the legal obligation to do so).

Adaptive Capacity: 5*. The hatchery has the ability to mitigate drought impacts by installing a RAS or pRAS system, which would reduce water needs by as much as 90%, or to relocate fish during the summer months when drought impacts might be most visible.

An adaptive capacity score of 5 is possible through both of the above options. The use of a RAS system requires significant initial and ongoing costs but has the benefit of maintaining operations onsite at the hatchery. Relocating fish during summer months to other hatcheries is far less expensive, but it requires another hatchery that has the capacity and available water to raise additional fish. (Cole Rivers has historically served as the receiving hatchery for other hatcheries experiencing limits to production.) Relocation also increases stress to fish through additional handling and transport, which should have low mortality on its own but can leave fish more vulnerable to pathogens at the receiving hatchery.

Vulnerability Score:
Exposure 4 + Sensitivity 2 – Adaptive Capacity 5*

3.4.3 Flood

Hatchery Summary:

Exposure: 3. Cole Rivers Hatchery's exposure to flooding is moderate as approximately 18% of the Cole Rivers Hatchery footprint resides within the 100-year floodplain (1% annual flood probability) according to the FEMA FIRM and approximately 64% of the hatchery footprint is within the 500-year floodplain (0.2% annual flood probability), including most hatchery buildings and infrastructure.

Sensitivity: 5. Even though a relatively small amount of the hatchery footprint is in the 100-year floodplain, over half of the hatchery's raceway infrastructure and several buildings fall within that boundary, and all hatchery buildings and infrastructure except residence buildings fall within the 500-year floodplain. Additionally, the hatchery is adjacent to the Lost Creek Lake spillway should additional large releases from the reservoir be needed during a large storm event.

Adaptive Capacity: 2. The hatchery can strengthen collaborations with local emergency management to ensure advance warning systems for staff, and should work with USACE to ensure that reservoir releases are managed in such a way to minimize hatchery damage. Infrastructure within the floodplain can be reinforced and strengthened to withstand flooding.

Vulnerability Score:
Exposure 3 + Sensitivity 5 – Adaptive Capacity 2

3.4.4 Sea Level Rise

Hatchery Summary:

Exposure: 1. The hatchery is not anticipated to experience any direct impacts from sea level rise.

Sensitivity: 1. N/A.

Adaptive Capacity: 1. N/A.

Vulnerability Score:

Exposure 1 + Sensitivity 1 – Adaptive Capacity 1

3.4.5 Precipitation

Hatchery Summary:

Exposure: 3. An analysis of Cole Rivers Hatchery's historical observed precipitation changes from the early 1890s to the 2020s show a statistically significant monthly decrease in precipitation for the month of February (-2.2% per decade). SNOTEL data from 1955-2020 show decreasing trends for April snowpack for the mountainous areas upstream of the hatchery. Statewide climate change results from the Fifth Oregon Climate Assessment project a 6-9% decrease in summer precipitation and a 5-8% increase in winter precipitation, with a mean annual precipitation increase of 2-3%. However, there is uncertainty around Oregon's precipitation projections with individual model projections based on different GCMs showing both increases and decreases in precipitation at the hatchery site.

Sensitivity: 3. The hatchery is sensitive to decreases in winter precipitation. Streamflow for the Rogue River originates in the mountains, so decreases in precipitation amounts during the winter in the form of snowfall could affect streamflow amounts in spring at the hatchery's water source. A shift of precipitation from snow to rain will also affect streamflow timing, which could affect major life stages of the hatchery's more sensitive programs, Summer Steelhead and especially Spring Chinook whose release and migration periods overlap with snowmelt-driven streamflow time periods.

Adaptive Capacity: 3*. The hatchery can mitigate decreases in precipitation through reduced water needs with a RAS or pRAS system, and structures can be reinforced to withstand any possible additional winter flooding due to increased precipitation.

An adaptive capacity score of 3 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A RAS system will help mitigate decreases in precipitation but will not help mitigate increases in precipitation (and subsequent increased flooding risks). Rebuilding additional structures to withstand flooding provides lower adaptive capacity.

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 3*

3.4.6 Air Temperature

Hatchery Summary:

Exposure: 3. An analysis of historical trends from the USHCN air temperature data in the area show statistically significant changes of 0.23°F and 0.27°F per decade at Prospect and Grants Pass, respectively, from the early 1890s through 2020 (University of Washington, 2021). Fifth Oregon Climate Assessment projects statewide air temperature increases of 4.5-6.3°F in the summer, with smaller increases during the rest of the year. The average annual temperature increase statewide at mid-century (2040-2069) is estimated to be 3.6°F for RCP4.5 and 5.0°F for RCP8.5 (Dalton and Fleishman, 2021).

Sensitivity: 2. The hatchery is somewhat sensitive to rising air temperatures because the open-air concrete infrastructure does not have any shade cover, which will cause water temperatures to increase.

Adaptive Capacity: 3*. The hatchery can mitigate impacts of rising air temperatures through the use of chillers to cool water (influenced by air temperatures) and the use of shade cover.

An adaptive capacity score of 3 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising air temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures that rise as a result of air temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can mitigate fish losses. However, the hatchery's large-scale open-air concrete infrastructure makes it more difficult to mitigate against air temperature.

Vulnerability Score:
Exposure 3 + Sensitivity 2 – Adaptive Capacity 3*

3.4.7 Earthquakes

Hatchery Summary:

Exposure: 4. There are no active faults within 5 miles, and the closest active fault is 21 miles west in the Rogue River National Forest. The nearest earthquake epicenter for quakes from 1971-2008 is 8 miles away. The area around the hatchery has high risks for liquefaction (soft soil hazard) and severe expected shaking as part of its general earthquake hazard risk.

Sensitivity: 2. The hatchery is less sensitive due to its more recent 1970s infrastructure consisting of mostly concrete in fair to good condition.

Adaptive Capacity: 3. An advance warning system can be put in place in conjunction with emergency management to evacuate staff in case of earthquakes (expanding beyond fire warning systems), and existing structures can be further strengthened with earthquakes in mind. The incorporation of renewable energy sources could provide backup power in case fuel trucks lose access to the hatchery.

Vulnerability Score:
Exposure 4 + Sensitivity 2 – Adaptive Capacity 3

3.4.8 Watershed Conditions

Hatchery Summary:

Exposure: 4. The hatchery has surrounding land use consisting mostly of forest, with some shrub/scrub. Slopes are mixed in the area near the hatchery with values mostly >5%, with erodibility between 0.2-0.4 in the surrounding area and moderate to high landslide risks.

Sensitivity: 1. The hatchery is not sensitive to watershed conditions due to the large upstream reservoir that can intercept some of the watershed's erosion or landslide debris.

Adaptive Capacity: 2. The hatchery does not have much capacity to modify the terrain, geology, and surroundings that could threaten it with land and debris slides, though actions to revegetate and stabilize the watershed can help. The hatchery should maintain coordination with USACE management of the upstream reservoir to ensure that debris and landslide issues do not impede intake waters to the hatchery.

Vulnerability Score:
Exposure 4 + Sensitivity 1 – Adaptive Capacity 2

3.4.9 Power Supply

Hatchery Summary:

Exposure: 5. As of November 2022 the hatchery has been powered by diesel generators for over a year and a half due to the power supply line to the hatchery failing.

Sensitivity: 4. The hatchery is very sensitive due to the requirement of weekly fuel deliveries to its three available generators, with potential loss of up to a million juvenile fish without those deliveries.

Adaptive Capacity: 5*. Complete power loss can be avoided through the installation of renewable power production on site, maintenance of sufficient onsite fuel storage, and prepped emergency generators. USACE is in the process of rebuilding the power supply line to the hatchery. This solution requires time and money and should provide reliable power once it is completed. The installation of renewable power production is also expensive but would ensure that the hatchery never again faces a scenario where it must rely on fossil fuel-based generators for power. An adaptive capacity score of 5 is dependent on implementing the new power line and on installing a renewable power supply.

Vulnerability Score:
Exposure 5 + Sensitivity 4 – Adaptive Capacity 5*

3.4.10 Water Rights

Hatchery Summary:

Exposure: 1. The hatchery has not experienced limitations to production due to water availability. It has the rights to a total of 224 cfs from Lost Creek Reservoir and the Rogue River.

Sensitivity: 1. The hatchery is not sensitive to water rights, due to available water and medium seniority in the basin.

Adaptive Capacity: 5*. The hatchery could reduce its water needs with a RAS or pRAS system and can seek additional instream water rights in the Rogue basin to ensure sufficient fish habitat for migration.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through obtaining additional water rights, which also requires a significant initial financial investment. Both options can mitigate potential problems with water rights by either reducing the water needs of the hatchery or by supplementing available water for fish migration.

Vulnerability Score:
Exposure 1 + Sensitivity 1 – Adaptive Capacity 5*

3.4.11 Streamflow Timing

Hatchery Summary:

Exposure: 5. The timing of peak and minimum flows is anticipated to shift two months earlier by mid-century (2030-2059) due to the impacts of climate change for RCP8.5, a high emissions scenario. Historical peak flows on the Rogue River occur in June and under climate change are projected to peak in April, while historical minimum flows occur in October and under climate change are projected to occur in September. Due to the large change in streamflow timing, there is projected to be an average increase of 30% in winter runoff (January-March) and an average decrease of 37% in summer flow (June-September). The large change in streamflow timing is due to projected changes in the snow-dominated system of the Rogue River which has its headwaters in the Cascade Mountains. Warming temperatures are expected to decrease the number of days where precipitation falls as snow causing earlier runoff, larger winter flows, and reduced summer flows. The Fifth Oregon Climate Assessment states that Oregon's mountains have already observed lower peak snow water equivalent (SWE) and melted earlier in a historical analysis (1982-2017) (Dalton and Fleishman, 2021).

Sensitivity: 1. Lost Creek Reservoir, immediately upstream of Cole Rivers Hatchery is operated by the US Army Corps of Engineers (USACE) for the purposes of fisheries enhancement, irrigation, and municipal and industrial water supply (USACE, 2018). The hatchery has fairly consistent water use throughout the year, but the highest withdrawal rates occur from May through July. Although the hatchery has a high exposure to changes in streamflow timing, its sensitivity is reduced because the streamflow is managed by releases from the reservoir. In the 2018 Rogue Basin Conservation Season Operating Plan, May and June reservoir releases are approximately 2,150 – 2,500 cfs, while July through September releases are approximately 1,050 – 1,500 cfs based on the inflow forecast in May 2018 (USACE, 2018). Coordination between the ODFW and the USACE should continue to facilitate the use of Lost Creek Reservoir to meet the water supply needs of Cole Rivers Hatchery.

Adaptive Capacity: 5*. The hatchery's streamflow is controlled by Lost Creek Reservoir, which provides stability in the timing of streamflow at the site. The hatchery has the ability to withstand changes in streamflow timing through reducing its water needs with a RAS or pRAS, or by storing water. The hatchery could also maintain close coordination with USACE to ensure that management decisions of dam discharges consider potential impacts to the hatchery.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through the addition of water storage, which also has significant upfront costs. Both options can mitigate changes in streamflow timing and availability throughout the year by reducing hatchery water needs or by storing excess water for later in the year when water availability is lower than water needs. Coordination with USACE is the lowest cost option and could prove highly effective, even rendering a RAS or storage unnecessary, as dam releases can be used to modify streamflow and storage.

Vulnerability Score:
Exposure 5 + Sensitivity 1 – Adaptive Capacity 5*

3.4.12 Low Flows

Hatchery Summary:

Exposure: 5. Streamflow near the hatchery is projected to decrease up to 45% in July and 38% during summer months (June-September) in 2045 according to downscaled USDA stream flow metrics climate change modeling based on the more severe emissions scenario, RCP8.5. The pronounced decrease in summer streamflow is in part due to a shift in streamflow timing (see Section 3.4.11) as more winter precipitation is projected to transition from snow to rain with climate change.

Sensitivity: 1. The hatchery's highest withdrawal rates are May through July to support its oversummering programs, when streamflow is projected to have the largest decreases in flow. However, the sensitivity to decreases in summer flows is reduced by a stable water supply provided by Lost Creek Lake located immediately upstream of the hatchery. The Lost Creek Reservoir is operated in part for fisheries enhancement (with the hatchery providing mitigation for the installation of large upstream dams that reduced salmonid habitat), so Cole Rivers Hatchery has reduced sensitivity to projected low flow in 2045. See section on Streamflow Timing for additional discussion.

Adaptive Capacity: 4*. The hatchery's streamflow is controlled by Lost Creek Reservoir, which provides minimum flows based on forecasts of spring runoff. The hatchery can further mitigate against low flow impacts through the use of a RAS or pRAS system. It can improve water quality issues worsened by less diluted low flows with additional UV Ozone treatment and additional aeration.

An adaptive capacity score of 4 is dependent on installing a RAS system and incorporating a UV Ozone and additional water conditioning to improve water quality issues due to low flows. Both of these systems have significant upfront costs, and a RAS has high ongoing costs and maintenance requirements. Both require reliable, constant electricity as well.

Vulnerability Score:
Exposure 5 + Sensitivity 1 – Adaptive Capacity 4*

3.4.13 Sedimentation

Hatchery Summary:

Exposure: 2. The hatchery does not have increasing trends of sediment in its intake water, but additional sediments are expected to enter its water source from the surrounding watershed that experienced large burns in 2017 and 2018.

Sensitivity: 1. The hatchery is less sensitive to sediment loading due to the upstream reservoir which settles out sediments and has multiple intakes available at different heights. The reservoir has a turbidity conduit that is used to flush sediments from the lake several times throughout the year, which should maintain low sediment levels in the hatchery intake water.

Adaptive Capacity: 2. The hatchery has moderate adaptive capacity against sedimentation in the watershed through the use of improved screens, as well as utilizing different intakes in the reservoir. Watershed-wide practices such as reestablishing vegetation and the Private Forest Accord wherein the timber industry will engage in improved forestry practices should ultimately lead to less sediment flowing into the reservoir.

Vulnerability Score:
Exposure 2 + Sensitivity 1 – Adaptive Capacity 2

3.4.14 Water Temperature

Hatchery Summary:

Exposure: 2. The Cole Rivers Hatchery has cold water temperatures due to its location in the upper watershed and below Lost Creek Lake. Historical water temperature data at the hatchery in 2016 show that the average temperatures did not exceed the 16°C or 18°C optimal temperature thresholds for fish (the average monthly water temperature was 11.4°C in July, 13.7°C in August, and 11.1°C in September).

At the Rogue River near Cole Rivers Hatchery (USGS 14335072, 2012-2022) average water temperature was 11.5°C, 13.1°C, and 11.2°C, respectively in July, August, and September, while daily maximum water temperature was 13.6°C, 14.7°C, and 14.6°C, respectively in July, August, and September.

Climate change projections of water temperature in the Rogue River estimate increases of approximately 1.0°C in June, 1.5°C in July, 1.3°C in August, and 0.7°C in September by 2045 (Chandler et al. 2016; Isaak et al. 2016). Combining the water temperature offsets projected under climate change with measured data, we expect that average monthly water temperature will stay below 16°C during summer. However, daily maximum water temperatures may reach 16°C in August. It is projected to have 0 days with mean water temperatures greater than 21°C.

Sensitivity: 3. The hatchery is very sensitive to warming and higher water temperatures because of Spring Chinook and Summer Steelhead fish programs, but that sensitivity is decreased by the possibility to utilize lower intakes in the water source reservoir and access cooler water.

Adaptive Capacity: 5*. The USACE 2018 operating plan for Lost Creek Reservoir (immediately upstream of Cole Rivers Hatchery) has identified temperature targets for reservoir releases of 66-69°F (18.9-20.6°C), all of which are below the temperature threshold of 69.8°F (21°C) (USACE, 2018). Additionally, the hatchery has the ability to mitigate rising water temperatures within the hatchery through the use of chillers paired with a RAS or pRAS setup, plus shade cover and other best practices such as reduced feeding on days with warmer water temperatures.

An adaptive capacity score of 5 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising water temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can mitigate fish losses, though the ultimate goal is to eliminate fish loss due to warming waters. Reduced feeding is a no-cost protocol change that is not effective on its own against warm water temperatures. If USACE continues to maintain water temperature below those established in the 2018 operating plan for Lost Creek Reservoir, rising water temperatures will be mitigated without requiring the use of chillers and RAS systems.

Vulnerability Score:
Exposure 2 + Sensitivity 3 – Adaptive Capacity 5*

3.4.15 Pathogens

Hatchery Summary:

Exposure: 2. The Rogue River at Cole Rivers Hatchery had zero days with observed mean temperatures greater than 16°C and is projected to remain under the threshold in 2045 with climate change. These current and projected temperature ranges are favorable for minimizing pathogen loads at the hatchery, as the majority of diseases seen in the ODFW hatchery system have higher potential for outbreaks with increasing water temperatures, both due to the life cycles of the pathogens and because of the negative effect of increasing temperatures on salmonid health (see Appendix for preferred and optimal thresholds for pathogens and fish species.) Cold water disease is a notable outlier as a pathogen that thrives at lower temperatures (below 10°C) for which the hatchery should stay vigilant. The hatchery currently struggles with algal control in the raceways.

Sensitivity: 3. The hatchery is moderately sensitive due to its Spring Chinook and Summer Steelhead programs that have major life transitions in the warmer months, when many pathogen loads are likely to increase, but its sensitivity is decreased due to the possibility to lower its intake in the upstream reservoir and access cooler water to help with pathogen control.

Adaptive Capacity: 4*. As noted in the temperature section, the Lost Creek Reservoir makes releases (in coordination with ODFW recommendations) to satisfy flow and temperature targets for the hatchery (USACE, 2018). The 2018 Conservation Season Operating Plan identifies temperature targets of 66-69°F for the reservoir releases, which are below the temperature threshold of 69.8°F (21°C) and will help to reduce pathogens at the hatchery. Additionally, the hatchery has the ability to mitigate rising infections and pathogens due to water temperatures through the use of chillers paired with a RAS or pRAS setup, plus UV ozone treatment of incoming water and continuation of established best practices for fish health. Shade cover can help reduce algal growth in the raceways as well.

An adaptive capacity score of 4 is dependent on the installation of chillers to maintain cool waters and minimize outbreak potential of pathogens that prefer warmer temperatures. A chiller system will be most effective on a smaller volume of water, and would thus perform best with a RAS installation that reduces water needs. This chiller and RAS setup will have significant upfront and ongoing costs. UV Ozone treatment of incoming water is also expensive, though far less than a RAS setup, and works most effectively on well-filtered water, which requires installation of additional filtration. Shade cover is a relatively inexpensive but potentially effective solution to limit algal growth. If USACE continues to maintain water temperatures according to its temperature targets, pathogen risks related to rising water temperatures will be mitigated, though intake water disinfection would still be required.

Vulnerability Score:
Exposure 2 + Sensitivity 3 – Adaptive Capacity 4*

Cole Rivers

		Exposure				
		1	2	3	4	5
Sensitivity	1	Water rights Sea level rise	Sediment		Watershed conditions Wildfire	Streamflow timing Low flow
	2			Air temperature	Drought Earthquake	
	3		Water temperature Pathogens	Precipitation		
	4					Power supply
	5			Flooding		

Figure 7: Cole Rivers Hatchery Vulnerability Matrix: Exposure (columns) and sensitivity (rows).

3.5 Leaburg Hatchery

The Leaburg Hatchery risk assessment scores for each hazard are provided in Table 6 below. The exposure and sensitivity scores are summed to calculate the potential impact. At the hatchery, flooding and water temperature have been identified as the most potentially impactful hazards. However, vulnerability is the sum of the potential impact and the adaptive capacity, which can reduce the potential impact of each hazard.

Table 6. Hatchery Scores, ordered by descending Potential Impact values. Adaptive Capacity options that require significant costs to implement are denoted with a (*)

Potential Vulnerability	Exposure	Sensitivity	Potential Impact	Adaptive Capacity	Vulnerability
Flooding	4	5	9	2	7
Water temperature	3	5	8	5*	3
Streamflow timing	5	2	7	5*	2
Low flow	5	2	7	4*	3
Pathogens	2	5	7	3*	4
Wildfire	3	3	6	2	4
Sediment	3	3	6	2*	4
Precipitation	3	3	6	3*	3
Air temperature	2	4	6	3*	3
Earthquake	3	2	5	3	2
Watershed conditions	3	1	4	3	1
Power supply	3	1	4	5*	-1
Drought	2	2	4	5*	-1
Water rights	1	1	2	5*	-3
Sea level rise	1	1	2	1	1

Hatchery Description

Name: Leaburg Hatchery

Location: Near Eugene, OR (Lane County)

Technical Assessment

3.5.1 Wildfire

Hatchery Summary:

Exposure: 3. Most of the land surrounding Leaburg Hatchery has a burn probability rated as "Moderate" (79% of land within a 5-mile buffer). The hatchery's exposure score based on the weighted distribution of burn probability is 2.7 (out of 5). The most probable flame lengths are 4-8 ft (34% of the surrounding area), but flame lengths greater than or equal to 8 ft are likely on 40% of the surrounding area, which increases the exposure score. However, the exposure score is again decreased because the recent Holiday Fire burned much of the vegetation in the area and reduced fuel for future wildfires in the near-term.

Note: calculations for Leaburg Hatchery are based on data from 2018; more recent data are not yet available.

Sensitivity: 3. The hatchery is moderately sensitive to fire, having experienced recent burns that came right to the edge of the hatchery buildings, but still having lots of vegetation on the premises.

Adaptive Capacity: 2. The hatchery can increase defensible perimeter space and install fire extinguishing and suppression systems to protect structures.

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 2

3.5.2 Drought

Hatchery Summary:

Exposure: 2. Leaburg Hatchery, located in Lane County, Oregon historically has experienced moderate levels of drought and on average (2000-2022), 46% of the county has experienced drought category D0 (abnormally dry), 27% has experienced D1 (moderate drought), 13% D2 (severe drought), and 3% D3 (extreme drought), and 0% of the county has experienced D4 (exceptional drought), with the more extreme drought levels having occurred largely since 2018.

Sensitivity: 2. The hatchery is somewhat sensitive to drought since it has one source of water (Leaburg Lake on the McKenzie River), which is managed by US Army Corps of Engineers (USACE), and rising air temperatures.

Adaptive Capacity: 5*. The hatchery has the ability to mitigate drought impacts by installing a RAS or pRAS system, which would reduce water needs by as much as 90%, or to relocate fish during the summer months when drought impacts might be most visible.

An adaptive capacity score of 5 is possible through both of the above options. The use of a RAS system requires significant initial and ongoing costs but has the benefit of maintaining operations onsite at the hatchery. Relocating fish during summer months to other hatcheries is far less expensive, but it requires another hatchery (such as Cole Rivers) that has the capacity and available water to raise additional fish. It also increases stress to fish through additional handling and transport, which should have low mortality on its own but can leave fish more vulnerable to pathogens at the receiving hatchery.

Vulnerability Score:
Exposure 2 + Sensitivity 2 – Adaptive Capacity 5*

3.5.3 Flood

Hatchery Summary:

Exposure: 4. Leaburg Hatchery's flood exposure is high, as 30% of the Leaburg Hatchery footprint resides within the 100-year floodplain (1% annual flood probability) according to the FEMA FIRM and approximately 85% of the hatchery footprint is within the 500-year floodplain (0.2% annual flood probability).

Sensitivity: 5. The hatchery is sensitive to flooding because a portion of its infrastructure and buildings are in the 100-year floodplain, and most of the infrastructure required for production (i.e., raceways and non-residential buildings) falls within the 500-year floodplain.

Adaptive Capacity: 2. The hatchery can strengthen collaborations with local emergency management to ensure advance warning systems for staff, and should work with USACE to ensure that reservoir releases are managed in such a way to minimize hatchery damage. Infrastructure within the floodplain can be reinforced and strengthened to withstand flooding.

Vulnerability Score:
Exposure 4 + Sensitivity 5 – Adaptive Capacity 2

3.5.4 Sea Level Rise

Hatchery Summary:

Exposure: 1. The hatchery is not anticipated to experience any direct impacts from sea level rise.

Sensitivity: 1. N/A. The hatchery is not sensitive to sea level rise.

Adaptive Capacity: 1. N/A.

Vulnerability Score:
Exposure 1 + Sensitivity 1 – Adaptive Capacity 1

3.5.5 Precipitation

Hatchery Summary:

Exposure: 3. An analysis of Leaburg Hatchery's historical observed precipitation changes from 1902 to 2020 show a statistically significant increase in April precipitation (+3.5 %/decade) and a statistically significant decrease in January (-2.5 %/decade), February (-2.1 %/decade), September (-2.9 %/decade) and annually (-1.2 %/decade) at the closest long-term precipitation station McKenzie Bridge, OR. Statewide climate change results from the Fifth Oregon Climate Assessment project a 6-9% decrease in summer precipitation and a 5-8% increase in winter precipitation, with a mean annual precipitation increase of 2-3%. However, there is uncertainty around Oregon's precipitation projections with individual model projections showing both increases and decreases in annual precipitation.

Sensitivity: 3. The hatchery is sensitive to decreases in precipitation during the winter. Streamflow for the McKenzie River originates in the nearby mountains, so decreases in precipitation amounts during the winter in the form of snowfall could affect streamflow amounts in spring at the hatchery's water source. A shift of precipitation from snow to rain will also affect streamflow timing, which could affect major life stages of the hatchery's more sensitive programs, Summer Steelhead and especially Spring Chinook whose release and migration periods overlap with snowmelt-driven streamflow time periods.

Adaptive Capacity: 3*. The hatchery can mitigate decreases in precipitation through reduced water needs with a RAS or pRAS system, and structures can be reinforced to withstand any possible additional flooding due to increased precipitation.

An adaptive capacity score of 3 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A RAS system will help mitigate decreases in precipitation but will not help mitigate increases in precipitation (and subsequent increased flooding risks). Rebuilding additional structures to withstand flooding provides lower adaptive capacity.

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 3*

3.5.6 Air Temperature

Hatchery Summary:

Exposure: 2. An analysis of historical trends from the USHCN air temperature data in the area show statistically significant changes in air temperature in June (+0.2°F per decade), July (+0.15°F per decade), August (+0.19°F per decade), and October (-0.16°F per decade) from 1904 to 2020. The was no statistically significant trend in historical annual temperature data (University of Washington, 2021). The Fifth Oregon Climate Assessment projects statewide air temperature increases of 4.5-6.3°F in the summer, with smaller increases during the rest of the year. The average annual temperature increase statewide at mid-century (2040-2069) is estimated to be 3.6°F for RCP4.5 and 5.0°F for RCP8.5 (Dalton and Fleishman, 2021).

Sensitivity: 4. The hatchery is sensitive to rising air temperatures due to its regulatory obligations to discharge cool water, which it already struggles to do.

Adaptive Capacity: 3*. The hatchery can mitigate impacts of rising air temperatures through the use of chillers to cool water (influenced by air temperatures) and the use of shade covers.

An adaptive capacity score of 3 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising air temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures that rise as a result of air temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can mitigate fish losses, though it is likely that the hatchery will also require active cooling to meet its regulatory obligations.

Vulnerability Score:
Exposure 2 + Sensitivity 4 – Adaptive Capacity 3*

3.5.7 Earthquakes

Hatchery Summary:

Exposure: 3. There are no active faults within 5 miles, and the closest active fault is 30 miles east of the hatchery. The nearest earthquake epicenter for quakes from 1971-2008 is 3 miles away. The area around the hatchery has moderate risks for liquefaction (soft soil hazard) and very strong expected shaking as part of its general earthquake hazard risk.

Sensitivity: 2. The hatchery is somewhat sensitive due to its construction in the 1950s, with its concrete infrastructure being considered in good condition.

Adaptive Capacity: 3. An advance warning system can be put in place in conjunction with emergency management to evacuate staff in case of earthquakes, and existing structures can be further strengthened with earthquakes in mind.

Vulnerability Score:
Exposure 3 + Sensitivity 2 – Adaptive Capacity 3

3.5.8 Watershed Conditions

Hatchery Summary:

Exposure: 3. The hatchery has surrounding land use consisting mostly of forested, with some shrub/scrub. Slopes are mixed in the area near the hatchery with values mostly >5%, with erodibility between 0.2-0.3 in the surrounding area and moderate to high landslide risks.

Sensitivity: 1. The hatchery is not sensitive due to the upstream reservoir that can intercept some of the watershed's erosion of landslide debris, plus the use of an effective self-cleaning screen system.

Adaptive Capacity: 3. The hatchery does not have much capacity to modify the terrain, geology, and surroundings that could threaten it and its water supply with land and debris slides, though actions to revegetate the watershed can help. The hatchery should maintain coordination with USACE management of the upstream reservoir to ensure that debris and landslide issues do not impede intake waters to the hatchery. The hatchery can maintain its current screen system.

Vulnerability Score:
Exposure 3 + Sensitivity 1 – Adaptive Capacity 3

3.5.9 Power Supply

Hatchery Summary:

Exposure: 3. The hatchery suffers from power losses several times a year.

Sensitivity: 1. The hatchery is not sensitive due to the availability of gasoline and propane backup power and the use of the gravity-fed water intake system. Power is necessary for the automated screen-cleaning system on the intake.

Adaptive Capacity: 5*. Complete power loss can be avoided through the installation of renewable power production on site, maintenance of sufficient onsite fuel storage, and prepped emergency generators. The hatchery could effectively produce power from solar panels, mini-hydropower, or a biodigester.

An adaptive capacity score of 5 is dependent on installing a renewable power supply, which will require significant upfront costs. However, these costs should be allayed by cost savings (and potential earnings by contributing energy back into the local power grid), with estimated payback periods of around 10 years for a full transition to renewable energy.

Vulnerability Score:
Exposure 3 + Sensitivity 1 – Adaptive Capacity 5*

3.5.10 Water Rights

Hatchery Summary:

Exposure: 1. The hatchery has not yet experienced limitations to production due to water availability; its water rights total 44,900 gallons per minute (gpm) (or 100 cfs) from the McKenzie River (ODFW, 2020b).

Sensitivity: 1. The hatchery is not sensitive to water rights issues due to its relative seniority in the basin.

Adaptive Capacity: 5*. The hatchery could reduce its water needs with a RAS or pRAS system and can seek additional instream water rights in the McKenzie basin to ensure sufficient fish habitat for migration.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through obtaining additional water rights, which also requires a significant initial financial investment. Both options can mitigate problems with water rights by either reducing the water needs of the hatchery or by supplementing available water for fish migration.

Vulnerability Score:
Exposure 1 + Sensitivity 1 – Adaptive Capacity 5*

3.5.11 Streamflow Timing

Hatchery Summary:

Exposure: 5. The timing of peak and minimum flows on the McKenzie River is not anticipated to shift by mid-century (2030-2059) with climate change, but the magnitude of peak and minimum flows is expected to change in nearby gages, with high winter flows increasing between December and April by up to 16% and low summer flows from June through October decreasing by up to 38%.

Sensitivity: 2. The direct intake of the hatchery is located in Leaburg Lake, a 345 acre-foot backwater section of the McKenzie River established by the Leaburg Dam, which is owned and operated by the Eugene Water & Electric Board (EWEB). Leaburg Dam will be decommissioned and partially or fully removed by the 2030s, based on recent decisions by EWEB. This dam removal will change streamflow at the hatchery intake, with the possibility that the intake will have to be moved to allow continued access to water. EWEB and USACE manage a series of reservoirs upstream of the hatchery which can decrease its sensitivity to changes in streamflow timing. Upstream of the Leaburg Hatchery on tributaries to the McKenzie River are two reservoirs managed by the USACE: Blue River Lake on Blue River and Cougar Reservoir on South Fork McKenzie River. The Blue River reservoir can hold 85,000 acre-feet of storage and provides runoff control in an 88-square-mile drainage area. The Cougar Reservoir can hold 153,500 acre-feet of storage and provides runoff control from a 208-square-mile drainage area. These large managed reservoirs have the ability to shield the hatchery from a large degree of the anticipated changes in streamflow. Along the McKenzie River further upstream are EWEB-managed reservoirs Trail Bridge, Carmen, and Smith, which have the potential to further decrease sensitivity to changing streamflow timing and availability.

The hatchery has consistent water use from July through January, with slightly lower withdrawals from February to June. The climate change impacts to the McKenzie River are projected to increase peak runoff from December through April and decrease summer streamflow (June through October). Decreased flow from July through October overlap with the hatchery's higher water needs.

Adaptive Capacity: 5*. The hatchery has the ability to mitigate changes in streamflow timing through reducing its water needs with a RAS or pRAS, or by storing water.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through the addition of water storage, which also has significant upfront costs. Both options can mitigate changes in streamflow timing and availability throughout the year by reducing hatchery water needs or by storing excess water for later in the year when water availability is lower than water needs.

Vulnerability Score:
Exposure 5 + Sensitivity 2 – Adaptive Capacity 5*

3.5.12 Low Flows

Hatchery Summary:

Exposure: 5. Streamflow on the McKenzie River near the hatchery is projected to decrease up to 38% in September with an average decrease of 28% during summer and fall months (June through October) in 2045 using RCP8.5 (high emissions scenario).

Sensitivity: 2. The hatchery's highest withdrawals are July through January, with slightly lower withdrawals from February to June. Streamflow is projected to decrease in the summer and fall months, so the hatchery will be most sensitive to decreased flow and high water needs from July through October. The hatchery's intake on the McKenzie River is located in Leaburg Lake, which can leave it susceptible to the operations of the EWEB when the canal is in use. However, the future of the EWEB's Leaburg Canal is uncertain, which may mean there is uncertainty regarding Leaburg Dam as well. The operation of Blue River Lake and Cougar Reservoir by the USACE on upstream tributaries to the McKenzie River may reduce its sensitivity to low flows as long as the reservoirs are releasing enough water to meet environmental flows.

Adaptive Capacity: 4*. The hatchery can mitigate against low flow impacts through the use of a RAS or pRAS system. It can improve water quality issues worsened by less diluted low flows with additional UV Ozone treatment, filtration, and additional aeration.

An adaptive capacity score of 4 is dependent on installing a RAS system and incorporating a UV Ozone and additional water conditioning to improve water quality issues due to low flows. Both of these systems have significant upfront costs, and a RAS has high ongoing costs and maintenance requirements. Both require reliable, constant electricity as well.

Vulnerability Score:
Exposure 5 + Sensitivity 2 – Adaptive Capacity 4*

3.5.13 Sedimentation

Hatchery Summary:

Exposure: 3. Leaburg Lake settles out large sediments before water enters the hatchery intake system, but suspended particles smaller than 25-30um are too small for drum filters and can still pass through to the hatchery. The Holiday Fire, which burned over 173,000 acres in 2020, occurred in the vicinity of the hatchery, which is anticipated to increase sediment loads into the watershed over the coming decade.

Sensitivity: 3. The hatchery is moderately sensitive due to recent wildfires in the watershed, one of which even reached the edge of the hatchery. Its sensitivity is decreased by the use of an automated self-cleaning screen.

Adaptive Capacity: 2*. The hatchery has moderate adaptive capacity against sedimentation in the watershed through the use of improved screens and filtration. Watershed-wide practices such as reestablishing vegetation and the Private Forest Accord wherein the timber industry will engage in improved forestry practices should ultimately lead to less sediment flowing into the reservoir.

An adaptive capacity of 2 is dependent on the installation of settling tanks, which are effective but very expensive and must be sized appropriately, and additional screening or filtration infrastructure to supplement its existing self-cleaning screen system. Watershed-wide practices have low adaptive capacity and require large-scale coordinated efforts between multiple agencies.

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 2*

3.5.14 Water Temperature

Hatchery Summary:

Exposure: 3. Historical water temperature data at Leaburg Hatchery show that temperatures do not exceed the 16°C or 18°C optimal temperature thresholds for fish (the average monthly water temperature is 14.2°C in July, 14.2°C in August, and 12.1°C in September). At the McKenzie River near Leaburg Hatchery (USGS 14163150, 1992-2022) located about 1.3 miles downstream the hatchery record average stream water temperatures around 14.4ºC, 14.4°C, and 12.1°C, respectively, for July, August, and September. Daily mean maximum water temperatures were recorded at 15.5°C, 15.4°C, and 12.8°C, respectively, for July, August, and September.

Climate change projections of water temperature in the McKenzie River estimate increases of approximately 1.1°C in June, 1.6°C in July, 1.3°C in August, and 0.8°C in September by 2045 (Chandler et al. 2016; Isaak et al. 2016). Combining the water temperature offsets projected under climate change with measured data, we expect that average monthly water temperature will likely exceed 16°C, but not 18ºC, during summer.

The McKenzie River at Leaburg Hatchery had about 6 days with observed mean temperatures greater than 16°C and is projected to have 13 days with means greater than 16°C by the mid-century. It is projected to have 0 days with mean water temperatures greater than 18°C. The hatchery had average monthly temperatures below 16°C for all summer months in 2016 and had mean observed USGS gage temperatures of up to 14.5°C for summer months. However, the hatchery has legal obligations to discharge water below 16°C and has struggled to meet those goals; the hatchery has no thermal buffer between its intake water and its requisite discharge temperature.

Sensitivity: 5. The hatchery is very sensitive due to its Spring Chinook and Summer Steelhead programs, which have major life stages (release, migration, and spawning) that occur during warmer months and could have fitness and survival rates impacted by increased water temperatures. The hatchery is also sensitive due to its regulatory obligations to discharge cool water.

Adaptive Capacity: 5*. The hatchery has the ability to mitigate rising water temperatures within the hatchery through the use of chillers paired with a RAS or pRAS setup, plus shade cover and other best practices such as reduced feeding on days with warmer water temperatures.

An adaptive capacity score of 5 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising water temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and can mitigate fish losses. However, shade cover alone is unlikely the help the hatchery meet its regulatory obligations to discharge cool water.

Vulnerability Score:
Exposure 3 + Sensitivity 5 – Adaptive Capacity 5*

3.5.15 Pathogens

Hatchery Summary:

Exposure: 2. The hatchery had average monthly temperatures sufficiently below 16°C in 2016. Modeled historic data were below 16°C for all summer months, with projections for 2045 reaching up to 15.9°C in July. The hatchery currently experiences problems with Trichodina and Proliferative Kidney Disease (PKD), and projected temperatures are expected to be in the range of outbreaks for these pathogens. Hatchery staff have noted that Trichodina outbreaks are worse in years with dampened high flows, when the protozoan can more easily proliferate in the McKenzie River without being discharged downstream.

Sensitivity: 5. The hatchery is sensitive because it already has been experiencing a new-to-its-basin outbreak of PKD, and intake waters will likely continue to warm, as the upstream water discharger does not have obligations to cool the water. Warming waters will affect its more sensitive programs, as noted in the temperature section.

Adaptive Capacity: 3*. The hatchery has the ability to mitigate rising infections and pathogens due to water temperatures through the use of chillers paired with a RAS or pRAS setup, plus UV ozone treatment (and its requisite treatment of very fine sediment) of incoming water and continuation of established best practices for fish health.

An adaptive capacity score of 3 is dependent on the installation of chillers to maintain cool waters and minimize outbreak potential of pathogens that prefer warmer temperatures. A chiller system will be most effective on a smaller volume of water, and would thus perform best with a RAS installation that reduces water needs. This chiller and RAS setup will have significant upfront and ongoing costs. UV Ozone treatment of incoming water is also expensive, though far less than a RAS setup, and works most effectively on well-filtered water, which requires installation of additional filtration.

Vulnerability Score:
Exposure 2 + Sensitivity 5 – Adaptive Capacity 3*

Leaburg

		Exposure				
		1	2	3	4	5
Sensitivity	1	Water rights Sea level rise		Watershed conditions Power supply		
	2		Drought	Earthquake		Streamflow timing Low flow
	3			Wildfire Sediment Precipitation		
	4		Air temperature			
	5		Pathogens	Water temperature	Flooding	

Figure 8: Leaburg Hatchery Vulnerability Matrix: Exposure (columns) and sensitivity (rows).

3.6 Oak Springs Hatchery

The Oak Springs Hatchery risk assessment scores for each hazard are provided in Table 7 below. The exposure and sensitivity scores are summed to calculate the potential impact. At the hatchery, watershed conditions, water rights, and drought have been identified as the most potentially impactful hazards. However, vulnerability is the sum of the potential impact and the adaptive capacity, which can reduce the potential impact of each hazard.

Table 7. Hatchery Scores, ordered by descending Potential Impact values. Adaptive Capacity options that require significant costs to implement are denoted with a (*)

Potential Vulnerability	Exposure	Sensitivity	Potential Impact	Adaptive Capacity	Vulnerability
Watershed conditions	5	4	9	1	8
Water rights	5	3	8	5*	3
Drought	4	4	8	5*	3
Wildfire	3	4	7	2	5
Pathogens	4	2	6	3*	3
Low flow	4	2	6	4*	2
Earthquake	3	3	6	2	4
Precipitation	3	3	6	5*	1
Water temperature	4	1	5	5*	0
Air temperature	3	2	5	4*	1
Streamflow timing	3	1	4	5*	-1
Sediment	2	2	4	3*	1
Flooding	2	2	4	2	2
Power supply	1	1	2	5*	-3
Sea level rise	1	1	2	1	1

Hatchery Description

Name: Oak Springs Hatchery

Location: Near Maupin, OR

Technical Assessment

3.6.1 Wildfire

Hatchery Summary:

Exposure: 3. Most of the land surrounding Oak Springs Hatchery has a burn probability rated as “Moderate-High” (50% of land within a 5-mile buffer), followed by “High” (35%) and “Moderate” (15%). The hatchery’s exposure score based on the weighted distribution of burn probability is 3.3 (out of 5). The most probable flame lengths are 4-8 ft (76% of the surrounding area) and flame lengths greater than or equal to 8 ft are likely on only 3% of the surrounding area.

Note: calculations for Oak Springs Hatchery are based on data from 2018; more recent data are not yet available.

Sensitivity: 4. The hatchery is sensitive to fire due the extensive dry sage and juniper vegetation surrounding the area, as well as the steep slopes and single access road that require staff to stay on a higher alert level than neighboring properties in order to evacuate safely.

Adaptive Capacity: 2. The hatchery should work to maintain a defensible perimeter space around infrastructure. Installing fire suppression systems might help protect those structures in smaller or more manageable fires. ODFW should maintain good relations with local emergency management to ensure that staff can be evacuated promptly.

Vulnerability Score:
Exposure 3 + Sensitivity 4 – Adaptive Capacity 2

3.6.2 Drought

Hatchery Summary:

Exposure: 4. Oak Springs Hatchery, located in Wasco County, Oregon historically has experienced moderate to severe levels of drought and on average (2000-2022), 58% of the county has experienced drought category D0 (abnormally dry), 33% has experienced D1 (moderate drought), 17% D2 (severe drought), 7% D3 (extreme drought), and 2% has experienced D4 (exceptional drought). The county is currently experiencing a sustained period of dryness since 2020, and much of the county was in drought stage D3 (extreme drought) for most of 2020, and D4 (exceptional drought) for parts of 2021-2022.

Sensitivity: 4. The hatchery is sensitive to drought due to decreasing water availability from its single water source (Oak Springs Creek) and rising air temperatures due to climate change.

Adaptive Capacity: 5*. The hatchery has the ability to mitigate drought impacts such as low flows by installing a RAS or pRAS system, which would reduce water needs by as much as 90%. Fish could be transported to a hatchery with sufficient water availability. ODFW could also apply for additional water rights from the nearby Deschutes River, which would require additional disinfection.

An adaptive capacity score of 5 is possible through both of the above options. The use of a RAS system requires significant initial and ongoing costs but has the benefit of maintaining operations onsite at the hatchery. Relocating fish during summer months to other hatcheries is far less expensive, but it requires another hatchery (such as Cole Rivers) that has the capacity and available water to raise additional fish. It also increases stress to fish through additional handling and transport, which should have low mortality on its own but can leave fish more vulnerable to pathogens at the receiving hatchery. Additional water rights require high upfront costs, as would disinfection systems.

Vulnerability Score:
Exposure 4 + Sensitivity 4 – Adaptive Capacity 5*

3.6.3 Flood

Hatchery Summary:

Exposure: 2. Oak Springs Hatchery's flood exposure is uncertain due to a lack of FEMA FIRMs for Wasco County; therefore the 100-year and 500-year floodplains are unknown for the purpose of this report. The hatchery is bordered by two rivers, the Deschutes River approximately 300 feet to the east and the smaller Oak Springs Creek approximately 200 feet to the west. Additional uncertainty stems from climate change, where a warmer climate is expected to bring more extreme weather events such as large precipitation events. Therefore, climate change is expected to shorten the recurrence intervals of flood events (Queen et al, 2020).

Sensitivity: 2. The hatchery's lowest ponds and outfalls are near the Deschutes River and likely reside within the 100- or 500-year floodplain. The hatchery's infrastructure is spread across a number of terraces along the steep hillsides, which provides protection for the main hatchery buildings, raceways, and ponds located on higher terraces, but uncertainty for much of the infrastructure on the lower terraces, which includes the afore-mentioned ponds and outfalls, spawning building, and some of the residences.

Adaptive Capacity: 2. The hatchery could rebuild and reinforce the raceways and building infrastructure that is closest to the Deschutes River floodplain. Housing near the springs and their associated wetlands could be additionally protected through the installation of elevated berms.

Vulnerability Score:
Exposure 2 + Sensitivity 2 – Adaptive Capacity 2

3.6.4 Sea Level Rise

Hatchery Summary:

Exposure: 1. The hatchery is not anticipated to experience any direct impacts from sea level rise.

Sensitivity: 1. N/A.

Adaptive Capacity: 1. N/A.

Vulnerability Score:
Exposure 1 + Sensitivity 1 – Adaptive Capacity 1

3.6.5 Precipitation

Hatchery Summary:

Exposure: 3. An analysis of Oak Springs Hatchery's historical observed precipitation changes from 1895 to 2020 show there is a statistically significant decrease in September precipitation (-3.9 %/decade) and a statistically significant increase in December (+8.3 %/decade) at the closest long-term precipitation station Dufur, OR. Statewide climate change results from the Fifth Oregon Climate Assessment project a 6-9% decrease in summer precipitation and a 5-8% increase in winter precipitation, with a mean annual precipitation increase of 2-3%. However, there is uncertainty around Oregon's precipitation projections with individual model projections showing both increases and decreases in annual precipitation.

Sensitivity: 3. The hatchery is not sensitive to increases in winter precipitation, but reduced summer and fall precipitation could hurt recharge to the springs the hatchery uses as a water source.

Adaptive Capacity: 5*. The hatchery can mitigate decreases in precipitation through reduced water needs with a RAS or pRAS system.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment.

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 5*

3.6.6 Air Temperature

Hatchery Summary:

Exposure: 3. An analysis of historical trends from the USHCN air temperature data in the area show statistically significant changes for the months of February (+0.23°F per decade), May (+0.14°F per decade), June (+0.17°F per decade), July (+0.13°F per decade), August (+0.13°F per decade), and September (+0.21°F per decade) and on an annual basis (+0.07°F per decade) from 1894 to 2020 (University of Washington, 2021). The Fifth Oregon Climate Assessment projects statewide air temperature increases of 4.5-6.3°F in the summer, with smaller increases during the rest of the year. The average annual temperature increase statewide at mid-century (2040-2069) is estimated to be 3.6°F for RCP4.5 and 5.0°F for RCP8.5 (Dalton and Fleishman, 2021).

Sensitivity: 2. The hatchery is somewhat sensitive to rising air temperatures because the open-air hatchery infrastructure allows water temperatures to be affected as well.

Adaptive Capacity: 4*. The hatchery can mitigate impacts of rising air temperatures through the use of chillers to cool water (influenced by air temperatures) and the use of shade cover.

An adaptive capacity score of 4 is dependent on installing chillers, which requires significant initial and ongoing financial investment. Chillers will work more effectively on smaller volumes of water and would thus work optimally when installed in conjunction with a RAS system, which would add to the cost but would also allow for effective mitigation against rising air temperatures. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures that rise as a result of air temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive.

Vulnerability Score:
Exposure 3 + Sensitivity 2 – Adaptive Capacity 4*

3.6.7 Earthquakes

Hatchery Summary:

Exposure: 3. There are no active faults within 5 miles, but the closest active fault is 5.2 miles northwest and north of the hatchery. The nearest earthquake epicenter for quakes from 1971-2008 is 4 miles away. There are no data for liquefaction risks (soft soil hazard) but is expected to experience moderate shaking as part of its general earthquake hazard risk.

Sensitivity: 3. The hatchery was built in the 1920s, with updates and additions from the 1930s through the 1990s. The lower ponds are in poor condition, with visible sinking, settling, and crumbling of concrete, while infrastructure higher up the hillside is in better condition.

Adaptive Capacity: 2. An advance warning system can be put in place in conjunction with emergency management to evacuate staff in case of earthquakes, existing structures can be reinforced, and old ponds can be rebuilt with earthquakes in mind.

Vulnerability Score:
Exposure 3 + Sensitivity 3 – Adaptive Capacity 2

3.6.8 Watershed Conditions

Hatchery Summary:

Exposure: 5. The hatchery has surrounding land use consisting mostly of shrub/scrub and cultivated cropland. Slopes are mixed in the area near the hatchery with values >10%, with erodibility between 0.3-0.6 in the surrounding area and high landslide risks.

Sensitivity: 4. The hatchery is sensitive to landslides, which occur in the area and can damage hatchery property or block access to and from the hatchery.

Adaptive Capacity: 1. The hatchery does not have much capacity to modify the terrain, geology, and surroundings that could threaten it with land and debris slides; small-scale protective efforts such as berms around the hatchery and water quality protection at the springs intake can make a small difference.

Vulnerability Score:
Exposure 5 + Sensitivity 4 – Adaptive Capacity 1

3.6.9 Power Supply

Hatchery Summary:

Exposure: 1. The hatchery does not experience frequent issues with power loss.

Sensitivity: 1. The hatchery is not sensitive to power loss due to the use of an onsite hydropower installation and gravity-fed intake and reuse systems.

Adaptive Capacity: 5*. Additional renewable energy sources could help mitigate power loss scenarios, provide lower carbon-emission power for the hatchery, and receive paybacks for extra energy contributed to the power grid. The hatchery could reasonably consider solar power, wind power, additional hydropower, and a biodigester on the premises.

An adaptive capacity score of 5 is dependent on installing a renewable power supply, which will require significant upfront costs. However, these costs should be allayed by cost savings (and potential earnings by contributing energy back into the local power grid), with estimated payback periods of around 10 years for a full transition to renewable energy.

Vulnerability Score:
Exposure 1 + Sensitivity 1 – Adaptive Capacity 5*

3.6.10 Water Rights

Hatchery Summary:

Exposure: 5. The hatchery has begun to experience limitations to production due to water availability. It has senior water rights in the area; surface water overuse is not the sole culprit of this limited water availability, but rather a combination with ongoing drought and nearby groundwater pumping. The entire Deschutes River watershed has unallocated water available only from March to May, and the hatchery does not currently use that as a source. The hatchery's current water rights total 56.5 cfs from Oak Springs, as well as the ability to reuse up to 15 cfs of water.

Sensitivity: 3. The hatchery is moderately sensitive to water rights issues due to decreasing and lack of available water resources, with its sensitivity decreased due to its seniority in the basin.

Adaptive Capacity: 5*. The hatchery could reduce its water needs with a RAS or pRAS system and can seek additional water rights in the Deschutes River. Additionally, the hatchery can maintain good informal relationships with neighboring water users to collaboratively manage water resources in the basin.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through obtaining additional water rights, which also requires a significant initial financial investment. Both options can mitigate problems with water rights by either reducing the water needs of the hatchery or by supplementing available water for hatchery use. Maintaining good relations with neighboring water users is low-cost but also provides low adaptive capacity.

Vulnerability Score:
Exposure 5 + Sensitivity 3 – Adaptive Capacity 5*

3.6.11 Streamflow Timing

Hatchery Summary:

Exposure: 3. Oak Springs Hatchery is fed by several springs adjacent to the hatchery. There is not a readily available climate change analysis to project changes in discharge from the springs. However, hatchery staff have observed decreases in the spring discharges over time. An analysis of Oak Springs Creek, which is adjacent to the hatchery, showed that the timing of peak and minimum flows is not anticipated to shift by mid-century (2030-2059). Summer low flows are projected to decrease by less than 1% and winter high flows are projected to increase by as much as 8% in January.

The timing of peak and minimum flows of the Deschutes River (which the hatchery does not currently use or have rights to withdraw water from) is anticipated to shift by mid-century

(2030-2059) with climate change. Currently, the Deschutes River peaks in June reflecting the snow-dominated hydrology of the system, whereas peak flow is projected to occur in March with climate change. This change in the timing of the hydrograph increases winter flows by up to 24% (January-February) and decreases summer flows by approximately 25% (July-August). The hatchery does not currently use Deschutes River water, though there is water availability within the Deschutes River basin such that the hatchery could acquire water rights to it; additionally, these changes in the Deschutes River could be indicative of how groundwater and springs will change over time.

Sensitivity: 1. The hatchery has mostly consistent water withdrawals throughout the year, so a change in timing would have minimal effect on hatchery operations. The springs sourced from Oak Springs Creek are not anticipated to change timing or flow amount based on modeled projections; however, coupled interactions between the springs and nearby surface and groundwater supplies are uncertain and could lead to a decrease in spring water.

Adaptive Capacity: 5*. The hatchery has the ability to withstand any changes in streamflow timing through reducing its water needs with a RAS or pRAS, or storing water.

An adaptive capacity score of 5 is dependent on installing a RAS system, which requires significant initial and ongoing financial investment. A score of 5 is also possible through the addition of water storage, which also has significant upfront costs. Both options can mitigate changes in streamflow timing and availability throughout the year by reducing hatchery water needs or by storing excess water for later in the year when water availability is lower than water needs.

Vulnerability Score:
Exposure 3 + Sensitivity 1 – Adaptive Capacity 5*

3.6.12 Low Flows

Hatchery Summary:

Exposure: 4. Climate change projections for Oak Springs Creek adjacent to the hatchery indicate minimal change in summer flows (<1%). However, the hatchery's water supply is obtained from several springs adjacent to the hatchery, which do not have readily available climate change projections. Hatchery staff have observed decreases in the springs over time, but the cause of the decline is unclear since comprehensive historical records are unavailable. Streamflow in the Deschutes River is projected to decrease up to 26% in July and on average decrease by 23% in the summer months (July-September), but the hatchery does not use this river as a source of water supply.

Sensitivity: 2. The hatchery has mostly consistent water withdrawals throughout the year, and the springs sourced from Oak Springs Creek are not anticipated to experience decreased discharge based on modeled projections (though spring water volumes have been observed by hatchery staff to be decreasing over time).

Adaptive Capacity: 4*. The hatchery can mitigate against low flow impacts through the use of a RAS or pRAS system and can improve water treatment with UV Ozone treatment and additional aeration of intake water. ODFW could also seek water rights on the Deschutes River.

An adaptive capacity score of 4 is dependent on installing a RAS system and incorporating a UV Ozone and additional water conditioning to improve water quality issues due to low flows. Both of these systems have significant upfront costs, and a RAS has high ongoing costs and maintenance requirements. Both require reliable, constant electricity as well. A score of 3 is also possible through obtaining additional water rights, which itself requires a significant initial financial investment to obtain rights and then to sufficiently treat river water.

Vulnerability Score:
Exposure 4 + Sensitivity 2 – Adaptive Capacity 4*

3.6.13 Sedimentation

Hatchery Summary:

Exposure: 2. There are no known issues with sediment loads coming into the hatchery, especially through spring water. There was a small wildfire in the area in 2017, plus several wildfires on the other side of the Deschutes River over the past several years, which will likely increase sediment loads into the river that could serve as an alternate water source to the hatchery if additional water rights were obtained.

Sensitivity: 2. The hatchery is somewhat sensitive due to the water reuse system, which propagates any water quality problems through multiple use stages.

Adaptive Capacity: 3*. The hatchery has excellent water quality from its intake but could utilize additional screens to exclude rare salamanders from accidentally ending up in the intake. Screen systems, filtration, and a settling tank would be required for Deschutes River water use as well.

An adaptive capacity of 3 is dependent on additional screening infrastructure, which can be relatively inexpensive but require frequent manual cleaning, unless an automated cleaning system is installed (with higher initial cost). If Deschutes River water were ever used in production, settling tanks, screens, and filtration would be required, at high initial costs.

Vulnerability Score:
Exposure 2 + Sensitivity 2 – Adaptive Capacity 3*

3.6.14 Water Temperature

Hatchery Summary:

Exposure: 4. Historical water temperature data at Oak Springs Hatchery is limited, but a 2016 dataset showed average monthly temperatures of 15.9°C, 16.7°C, 16.5°C, and 14.5°C for June, July, August, and September, respectively. Temperatures exceed the 16°C optimal temperature thresholds for fish in July and August, but not the 18°C threshold. Additional water temperature data is collected by the USGS on the nearby Deschutes and White Rivers, but both locations are not comparable to the spring-fed system at the hatchery.

Climate change projections of water temperature in the Oak Springs Creek (and the Deschutes River) estimate increases of approximately 1.5°C in June, 1.7°C in July, 1.5°C in August, and 0.9°C in September by 2045 (Chandler et al. 2016; Isaak et al. 2016). Combining the water temperature offsets projected under climate change with measured data in 2016, we expect that average monthly water temperature will exceed the 16°C threshold in June, July, and August.

Historical modeled stream temperatures (1993-2011) on the Deschutes River downstream of the hatchery, estimated average monthly temperatures of up to 17.8°C in July and August. Historical modeled stream temperatures (1993-2011) on Oak Springs Creek reached about 16.1ºC in August. Climate change projections applied to modeled estimates of stream temperature show temperatures reaching up to 19.5°C on the Deschutes River and 17.6°C on Oak Springs Creek in July and August by 2045. We note that the modeled stream temperature data is added to provide context due to the limited observational data at Oak Springs Hatchery.

Sensitivity: 1. The hatchery is less sensitive to rising water temperatures because it does not currently have any particularly sensitive programs onsite, as well as due to the consistently low water temperature of the water source springs.

Adaptive Capacity: 5*. The hatchery has the ability to mitigate rising water temperatures through the use of chillers paired with a RAS or pRAS setup, plus installing shade covers. These measures are not currently necessary for the springs intake water, but could prove useful for reuse water that makes its way through the hatchery and experiences warming with each additional use.

An adaptive capacity score of 5 is dependent on installing chillers, which requires significant initial and ongoing financial investment. As Oak Springs Hatchery does not currently have temperature issues with its spring water, a chiller could potentially be used without first reducing the water volume. The installation of shade covers has a smaller associated adaptive capacity (2), and cannot actively decrease water temperatures; however, evidence from other hatcheries such as Speelyai Hatchery has shown the use of shade covers to decrease fish losses that were due to warm waters. This option is relatively inexpensive and could be sufficient to maintain water temperatures at a low enough temperature as the water passes through the hatchery reuse system.

Vulnerability Score:
Exposure 4 + Sensitivity 1 – Adaptive Capacity 5*

3.6.15 Pathogens

Hatchery Summary:

Exposure: 4. The hatchery had average monthly temperatures over 16°C for July and August in 2016. Additionally, climate change projections of water temperature in Oak Springs Creek estimate increases of approximately 1.5°C in June, 1.7°C in July, 1.5°C in August, and 0.9°C in September by 2045 (Chandler et al. 2016; Isaak et al. 2016). Rising water temperatures increase the likelihood of pathogen outbreaks, especially those pathogens that are most likely to cause outbreaks at higher temperatures (see Appendix for a list of these thermal preferences); however, the springs that the hatchery uses as a water source are generally cooler than the Deschutes River and are not anticipated to experience this same range of increases. The hatchery currently struggles with cold water disease, which fares better in lower temperature waters and thus may still be expected to cause outbreaks in the future unless additional disinfection procedures are put into place.

Sensitivity: 2. The hatchery is sensitive to pathogens, such as cold water disease, which it has struggled to control in the past. Its sensitivity is decreased by its trial uses of bacterial CWD-resistant fry and by its cool springs water source.

Adaptive Capacity: 3*. The hatchery has the ability to mitigate rising infections and pathogens due to water temperatures through the use of chillers paired with a RAS or pRAS setup, plus UV ozone treatment of incoming water and continuation of established best practices for fish health.

An adaptive capacity score of 3 is dependent on the installation of chillers to maintain cool waters and minimize outbreak potential of pathogens that prefer warmer temperatures. Chillers have high upfront costs and ongoing electricity needs. UV Ozone treatment of incoming water also has relatively high upfront costs and works most effectively on well-filtered water, which requires installation of additional filtration.

Vulnerability Score:
Exposure 4 + Sensitivity 2 – Adaptive Capacity 3*

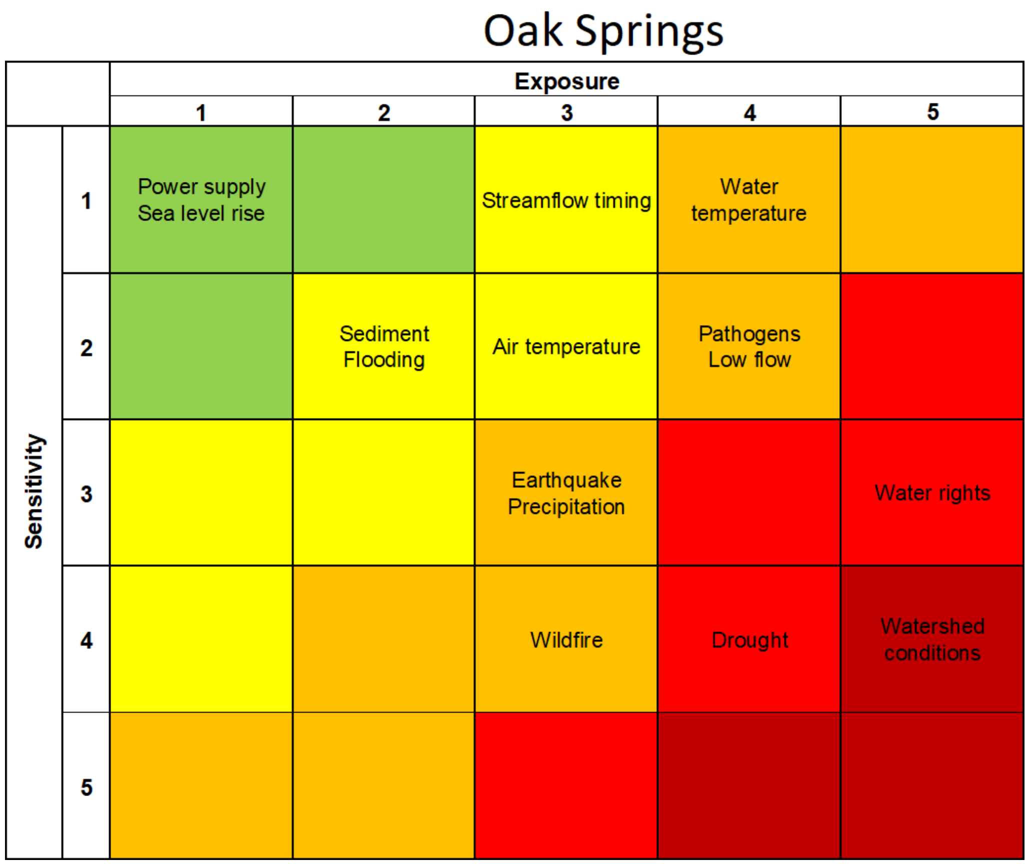

Figure 9: Oak Springs Hatchery Vulnerability Matrix: Exposure (columns) and sensitivity (rows).

3.7 Risk Summary by Hatchery

The risk assessment scored 15 hazards that can potentially impact the hatcheries causing vulnerability to current and future conditions. Here we summarize the highest scoring hazards (the hazards with the most severe impacts, scores of 8 and 9) for each hatchery using the potential impact score, which does not account for adaptive capacity reductions (i.e., reductions due to the ability of the hatchery to absorb or adapt to the potential impact).

Rock Creek Hatchery

1. Water temperature (9)
2. Watershed conditions (9)
3. Pathogens (9)
4. Other potential impacts: Low flow (8)

The Rock Creek Hatchery is most vulnerable to increases in water temperature, changes in watershed conditions due to the large amounts of burned areas from the Archie Creek Fire, and various pathogens impacting all the fish programs at the hatchery. Decreasing low flows is another hazard that received high potential impact scores because of decreasing low flows on the North Umpqua River.

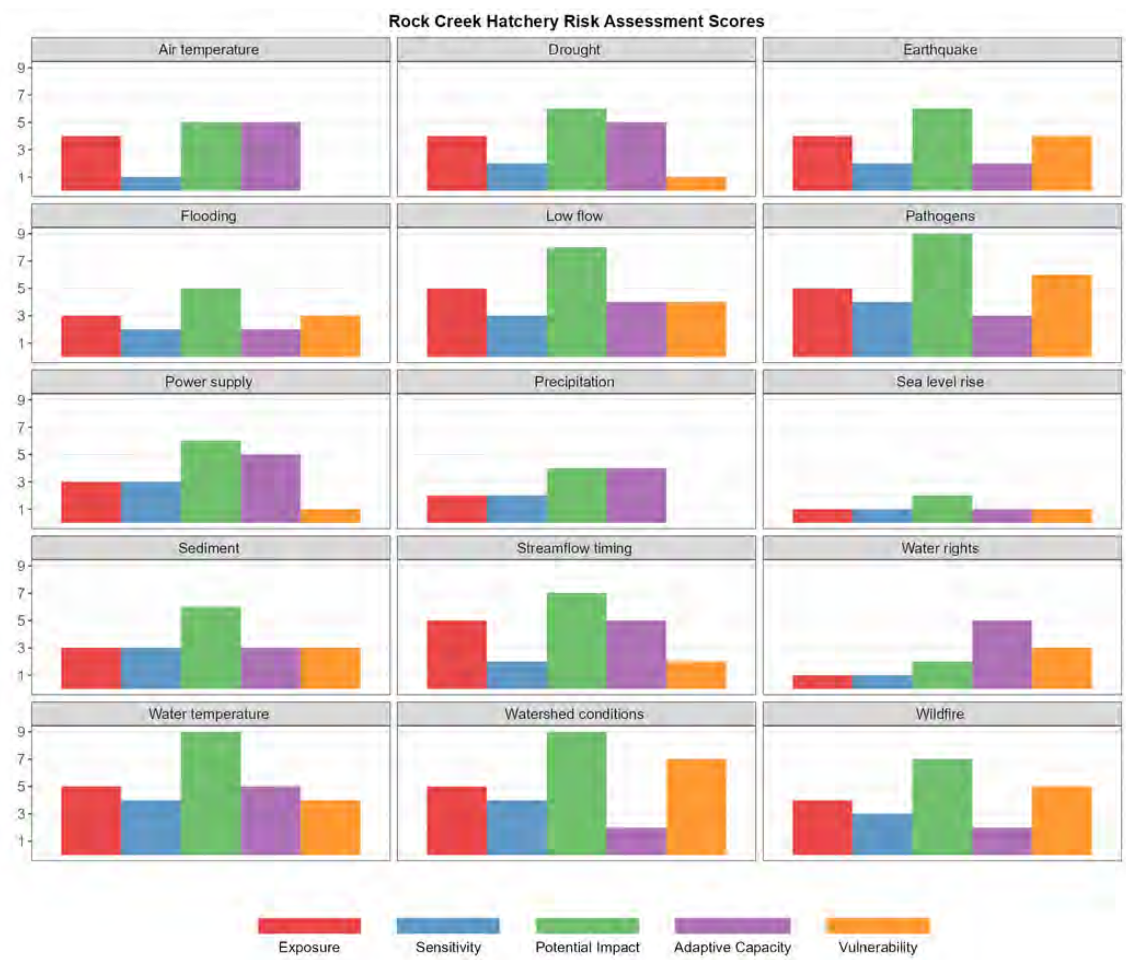

Figure 10: Rock Creek Hatchery Vulnerability Summary

Alsea Hatchery

1. Pathogens (9)
2. Low flow (8)
3. Water rights (8)
4. Other potential impacts: Streamflow timing (8)

The Alsea Hatchery is most vulnerable to pathogens impacting the fish programs at the hatchery (exacerbated by rising water temperatures in the basin and existing pathogen issues), low flows during summer months, and water availability issues on the North Fork Alsea River.

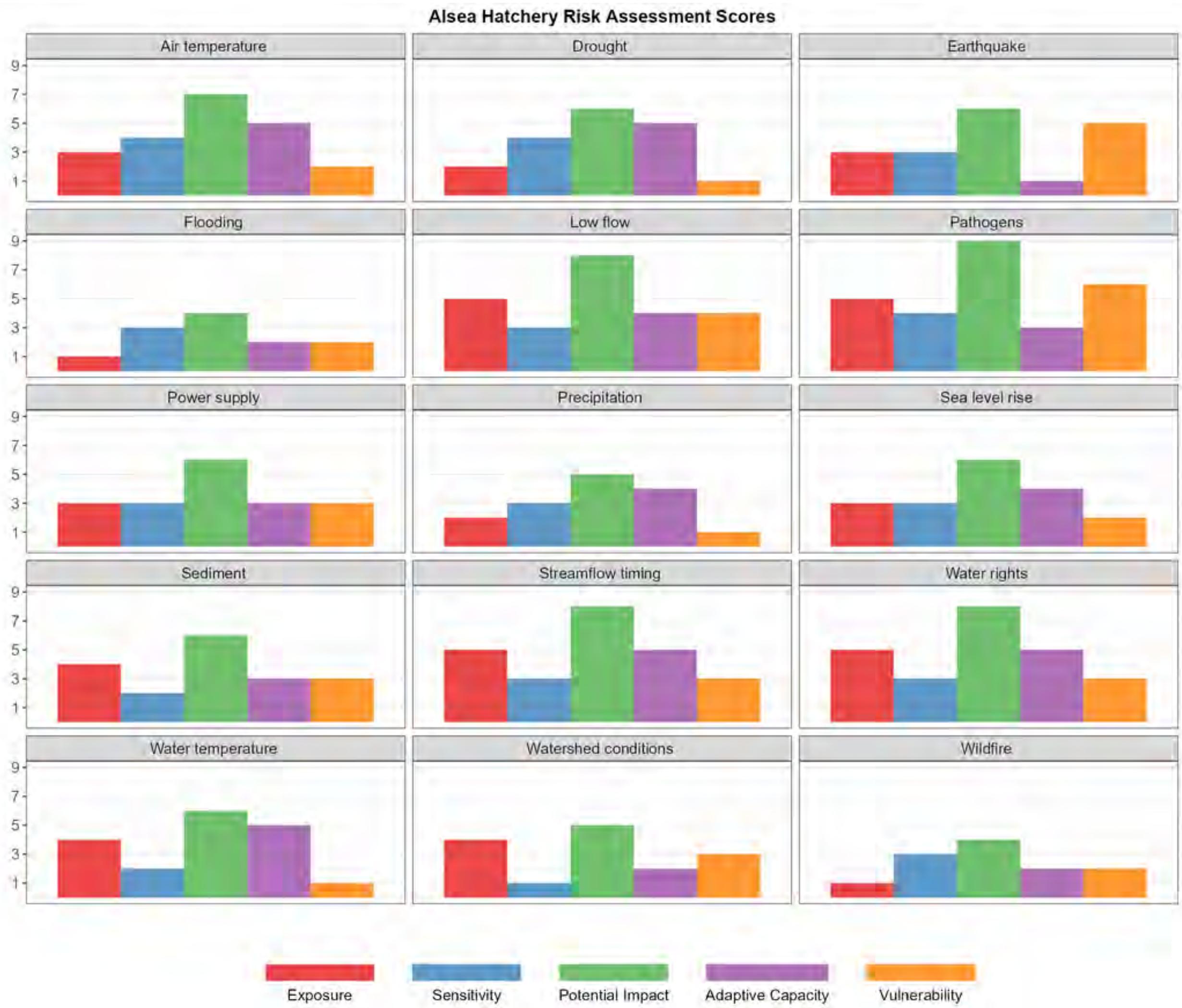

Figure 11: Alsea Hatchery Vulnerability Summary

Bandon Hatchery

1. Low flows (9)
2. Water rights (8)
3. Streamflow timing (8)
4. Other potential impacts: Earthquakes (8)

The Bandon Hatchery is most vulnerable to reduced water availability due to water rights issues on Ferry and Geiger Creeks and diminishing low flows in the summer. It is also vulnerable to earthquake damage of the earthen dam at Ferry Creek Reservoir.

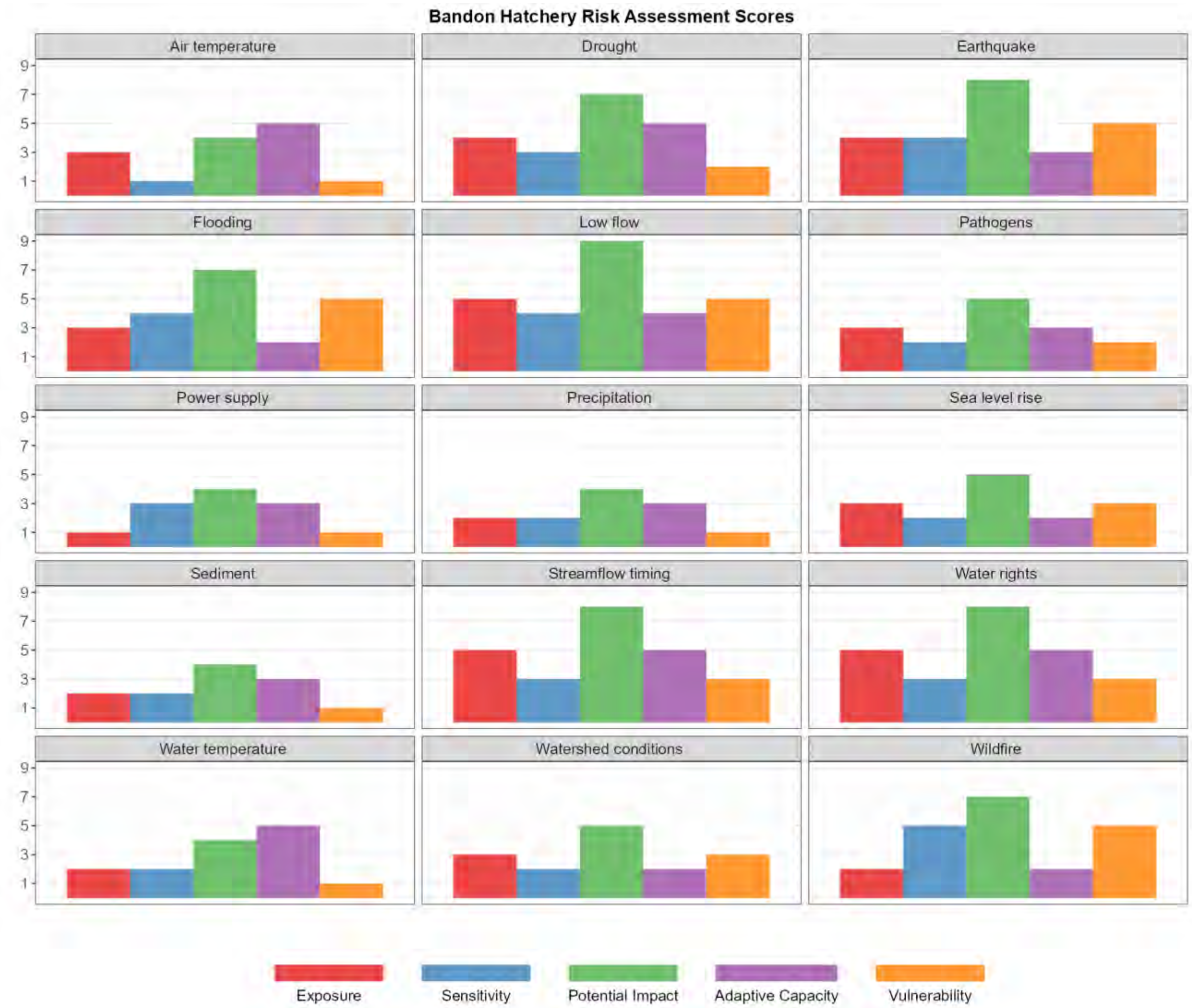

Figure 12: Bandon Hatchery Vulnerability Summary

Cole Rivers Hatchery

1. Power supply (9)
2. Flooding (8)

The Cole Rivers Hatchery is most vulnerable to power supply issues as the hatchery is completely dependent on diesel generators for nearly two years as of November 2022. Changes in streamflow timing and low flows in the upstream rivers will be largely mitigated by the complex of reservoirs and managed streamflow upstream of the hatchery. However, the hatchery remains vulnerable to flooding since much of the hatchery footprints resides within the 100-year and 500-year floodplains. More specifically, over half of the hatchery's raceway infrastructure and several buildings fall within the 100-year floodplain, and all hatchery buildings and infrastructure except residence buildings fall within the 500-year floodplain.

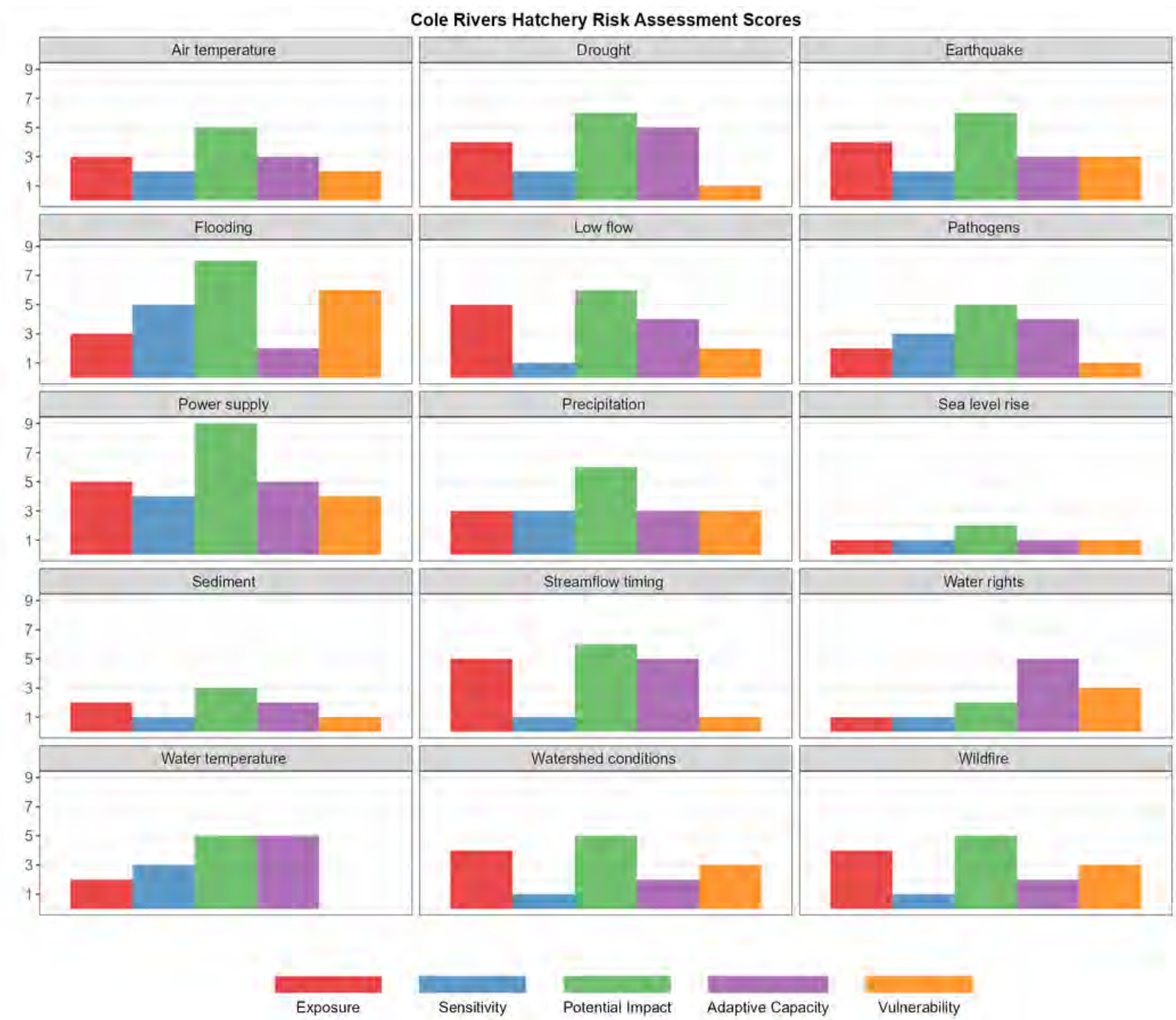

Figure 13: Cole Rivers Hatchery Vulnerability Summary

Leaburg Hatchery

1. Flooding (9)
2. Water temperature (8)
3. Other potential impacts: Streamflow, low flow, pathogens (7)

The hatchery will be shielded from most of the effects of changes in streamflow timing and low flows upstream because of the complex of managed reservoirs and streamflows. EWEB has made the decision to decommission Leaburg Dam and will likely include removing the existing dam structure within the coming decade. Changes to streamflows are anticipated, though such changes are difficult to anticipate currently; over the next several years (even possibly into the 2030s), EWEB may repair the Leaburg Canal as well as modify access areas along the river. Thus, the McKenzie River can be expected to exhibit different streamflow patterns at the hatchery intake site, but upstream dams along the McKenzie, South Fork McKenzie, and Blue River have the potential to continue stabilizing the streamflow timing and availability. The hatchery remains vulnerable to flooding since much of the hatchery footprints resides within the 100-year and 500-year floodplains. A portion of its infrastructure and buildings are in the 100-year floodplain, and most of the infrastructure required for production (i.e., raceways and non-residential buildings) falls within the 500-year floodplain. The hatchery is also vulnerable to rising water temperatures, as it already has existing problems with discharging water at too high of a temperature. We anticipate that the hatchery is less sensitive to the effects of changes in streamflow timing and low flows due to the complex of managed reservoirs and streamflow on upstream tributaries to the McKenzie River (Trail Bridge, Carmen, and Smith Reservoirs on the McKenzie River, and Blue River Lake and Cougar Reservoir whose outlets have confluences with the McKenzie River upstream of the hatchery).

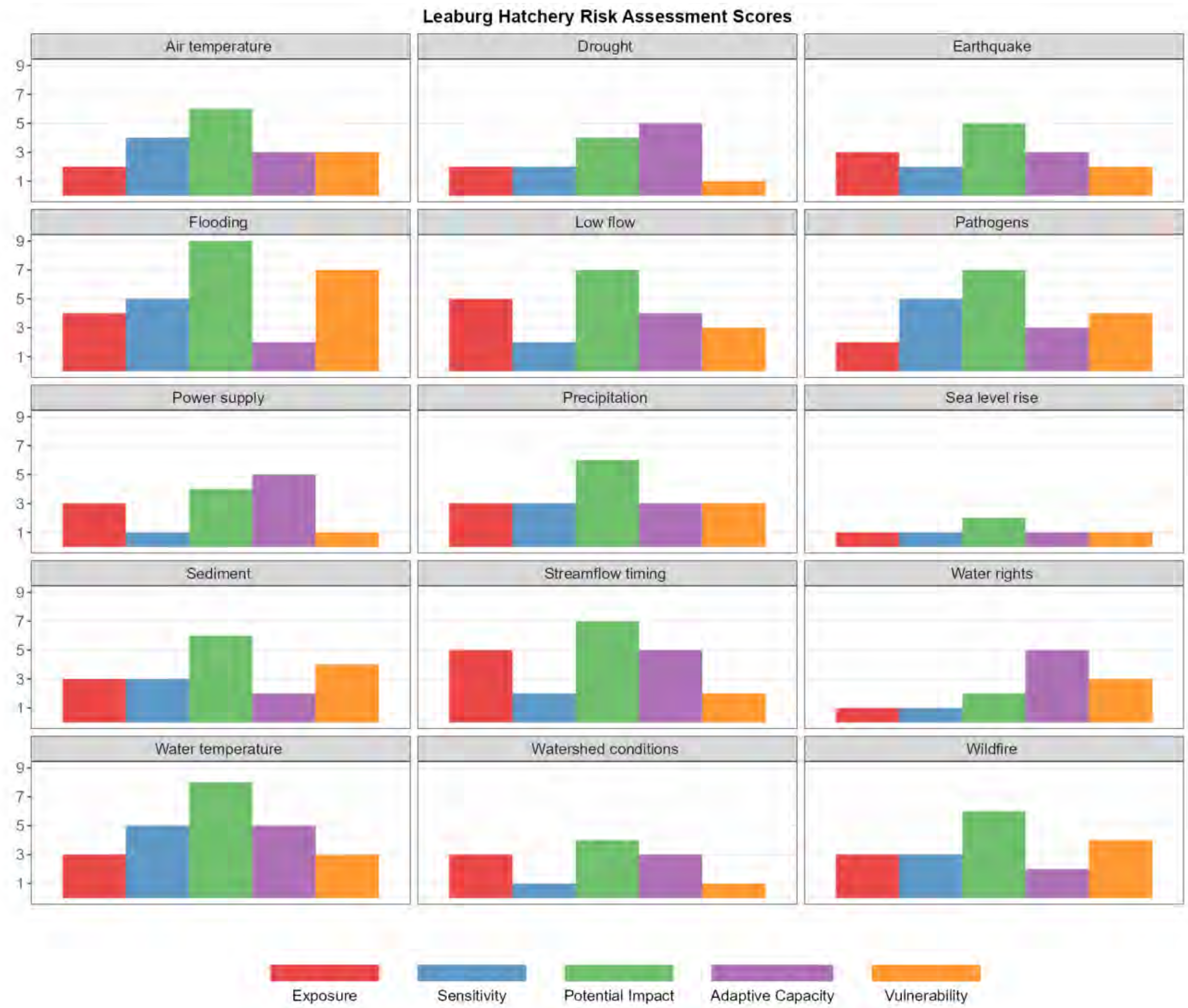

Figure 14: Leaburg Hatchery Vulnerability Summary

Oak Springs Hatchery

1. Watershed conditions (9)
2. Water rights (8)
3. Drought (8)

The Oak Springs Hatchery is most vulnerable to watershed conditions because of the steep surrounding slopes with high landslide risks (coupled with a single point of access to the hatchery), and water availability due to potential water rights issues and the presence of extreme drought in the area.

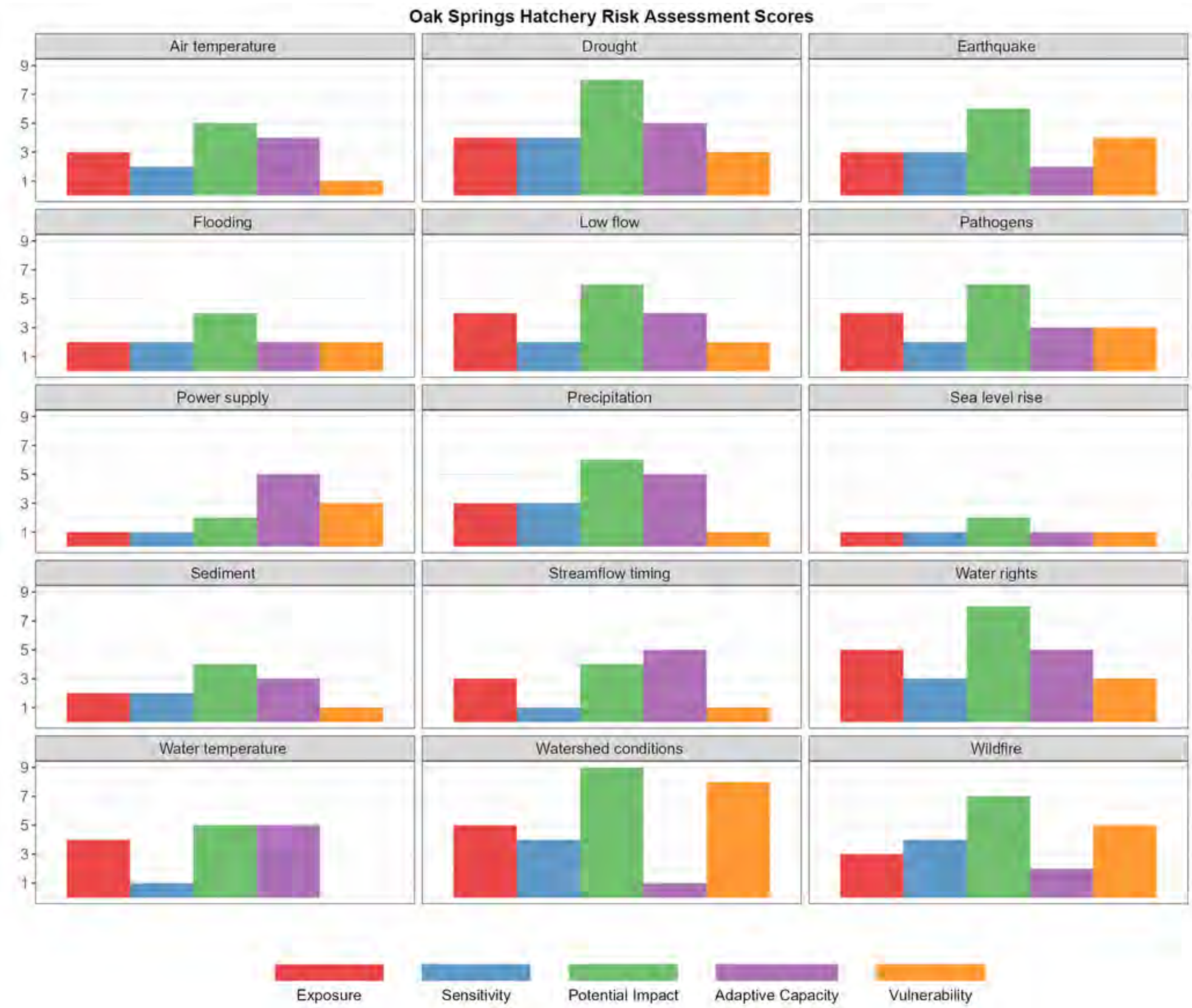

Figure 15: Oak Springs Hatchery Vulnerability Summary

3.8 Risk Summary by Hazard

Across each of the 15 potential risks examined, different sets of hatcheries exhibited similarities to one another. No overall pattern emerged of hatchery groups that were similar across all the risks. While it is possible that "similar hatchery" risk groupings might emerge from an assessment of randomly sampled hatcheries, these results speak to the ubiquity of climate change impacts across the State hatchery system: all hatcheries have the potential to be impacted, even across varying geography and terrain.

However, there are general groupings that can be discussed related to the individual risks. Water temperatures and pathogens have high potential impact values for Rock Creek, Alsea, and Leaburg Hatcheries; these potential impacts were not so high for Oak Springs, Cole Rivers, or Bandon Hatcheries, which have some temperature mitigation through the use of spring water, variable temperature dam intakes, and coastal moderation. Other hatcheries managed by ODFW that possess some of these mitigating traits could also see reduced potential impacts due to water temperature and pathogens.

Drought potential impacts are highest for Oak Springs and Alsea, followed by Cole Rivers and Rock Creek and Bandon, then Leaburg, based on the surrounding counties. Coastal moderation again plays a key role (in reducing risk), as does Oak Springs' high-desert location east of the Cascades (in increasing risk). All the hatcheries have moderately high risks for wildfire and earthquake, with Bandon having the highest risks for both, due to its underlying infrastructure. Bandon and Alsea have the highest sea level rise potential impacts due to their coastal proximity.

Rock Creek, Alsea, and Oak Springs Hatcheries have the highest risks related to watershed conditions, i.e., landslides and debris, with the other three hatcheries having moderate risks. These three hatcheries have experienced ongoing disturbance in their surrounding watersheds, in the form of disruptive land use or wildfires, in addition to steep slopes, with no large reservoirs to shield them from incoming debris.

Flood risks are highest for Leaburg and Cole Rivers based on the hatchery footprints in relation to available floodplain maps, followed by Bandon. This risk is simply related to location decisions made when building the hatchery infrastructure. Alsea and Bandon have high potential impacts from streamflow timing and low flow changes, due to limited water availability in summer that already affects operations. Leaburg and Cole Rivers will have impacts from any future streamflow timing and magnitude changes mitigated by managed releases of the upstream reservoir network. Hatcheries that raise sensitive fish, particularly those with major life stage events that occur in warmer months, could face higher potential impacts due to streamflow timing and magnitude changes.

Power supply has a high potential impact for Cole Rivers, with Rock Creek and Alsea having moderate potential impacts based on their reported number of power losses throughout the year and dependence on pumps and generators.

Despite their very different locations and settings, Bandon and Oak Springs have the highest potential water rights impacts, followed by Alsea, with the remaining three hatcheries having low risks. This risk is not dependent on geography but rather on the seniority of water rights, the competition for water use in the basin, and the timing of water use versus the timing of low flows.

Thus, a few generalizations emerge that could be applicable across the state to other hatcheries. Coastal hatcheries may see moderation in changes in precipitation, streamflow, and temperatures, but increases in potential impacts due to natural disasters (namely the addition of sea level rise and tsunamis [not examined in this study] to wildfire, earthquakes, and landslides). Hatcheries with temperature mitigation methods or technologies, including constant-temperature springs, groundwater inputs, or cool-water reservoir intakes may see reduced potential impacts not just in water temperature but relatedly in pathogen loads. Hatcheries that raise fish with major life stages that occur during lower flow months could face higher potential impacts due to shifts in streamflow seasonality.

All six hatcheries examined in this risk assessment would benefit from additional water security. Additional water rights are expensive, and groundwater levels across the state are typically decreasing as drought increases alongside additional demand. Rather than increasing water availability, this security can be attained through a reduction in production water needs such as through recirculating RAS systems. Hatcheries would benefit from methods such as chillers and shade covers to keep rising water temperatures in check. Watersheds left unstable from wildfire and disruptive land uses increase sediment and debris loads into the hatcheries, which can be mitigated with screens and filtration; reducing the sediment and pollution load in hatchery intake water also allows for the use of purifying and sterilizing technology such as UV Ozone systems that can further reduce pathogen loads.

4 Recommendations and Conclusions

4.1 Rock Creek Hatchery

Risk Analysis and Recommendations:

Rock Creek Hatchery is most at risk due to water temperature, pathogens and issues related to low flows. The ODFW took steps in the past to mitigate low summer streamflow on Rock Creek by obtaining rights to North Umpqua River water to supply Rock Creek Hatchery during the summer and fall months. Climate change is projected to exacerbate water availability by reducing July through September streamflow by approximately 34% in the North Umpqua River (July-September) and up to 38% in July. Low flow conditions during summer contribute to high water temperatures which are observed June to October and is identified as a hazard at Rock Creek Hatchery. Increased water temperatures can lead to increased fish stress and mortality and reduces the effectiveness of hatchery operations. Spring Chinook and Summer Steelhead are most sensitive to increases in water temperature since their migration and collection occur during periods of warmer temperature. Additionally, increased water temperatures can increase the presence of pathogens which increase the fish mortality.

The installation of a RAS or pRAS system would help to alleviate many issues related to low flow, water temperature, and pathogens. However, a RAS system will not help increase downstream flows along migration corridors. Transferring additional water rights on the North Umpqua River to the hatchery's point of diversion (pumping site) would help to supplement summer flows to the hatchery from the North Umpqua, but at the expense of increased costs, fuel, and greenhouse gas emissions from pumping. The installation of solar panels have already been recommended in the Rock Creek vulnerability report; the hatchery has sufficient area available to build a solar panel-based system large enough to power the hatchery's previous electricity needs (prior to the Archie Creek Fire) and even has the capacity to build a larger system that could power (and limit carbon emissions from) any new pumping.

Wildfire risk remains elevated at the site, and the burned landscape surrounding the hatchery poses additional risk for landslides and debris flows, which can lead to sedimentation problems during rain events. Engineering controls may need to be implemented as best management practices (BMPs) to reduce the impact of these changes in the watershed. Flooding remains a risk, especially to generator and intake infrastructure. The installation of renewable backup power sources reduces the risks associated with losing pumping abilities along the North Umpqua during the summer and fall.

With the damage to the Rock Creek Hatchery caused by the Archie Creek Fire, hatchery operations have been supported by Cole Rivers and Leaburg Hatcheries. High pathogen loads in the fish from Rock Creek Hatchery have been problematic for these other hatcheries; Rock Creek fish are no longer raised at Leaburg in part due to difficulties in controlling the pathogen load. Utilizing Cole Rivers may not be sustainable, as that hatchery faces its own set of challenges (see Section 3.4). Rock Creek Hatchery should likely consider the inclusion of a RAS system or additional use of North Umpqua River to alleviate the risk associated with summer streamflow at the hatchery.

Recommendations and Priorities:

- Water temperature must be addressed, and can be successfully addressed through the installation of chillers (chillers will be most efficient with reduced water needs as in with a RAS or pRAS) and shade cover structures
- Pathogens must be addressed, and addressing water temperature will help immensely
- Wildfire and flooding will remain a risk and should be considered while rebuilding
- Watershed conditions pose hazards for landslides, with fewer ways for the hatchery to adapt

Additional Discussion:

- Addressing water temperature will also minimize risks from projected increases to air temperature
- Installation of RAS to address water temperature will also address risks from low flows, drought, and streamflow timing
- RAS and chiller system will require significant initial and ongoing financial investment but can effectively deal with extreme water temperatures

4.2 Alsea Hatchery

Risk Analysis and Recommendations:

Alsea Hatchery is at risk of limited water availability with existing issues caused by competing uses in the basin exacerbated by summer low flows that limit production. Climate change is anticipated to exacerbate low flow problems on the North Fork Alsea, with decreases across all summer months and decreases of up to 15% in September according to mid-century RCP8.5 model projections. Low flows contribute to increasing water temperatures that are an ongoing problem across the entire Alsea River basin, and those increasing temperatures further exacerbate existing issues with pathogens. The installation of a RAS or pRAS system would help to alleviate many issues related to low flow, water temperature, and pathogens at the hatchery.

Existing problems with high incoming sediment loads are likely to continue into the future, unless best management practices (BMPs) are implemented on a widescale throughout the basin. Watershed-scale BMP efforts will be more effective than small individual measures but may be difficult to coordinate and fund. The hatchery can take its own steps to mitigate sedimentation through the use of upgraded radial or drum filters and settling tanks, which would also act as a preparation step to allow for water disinfection with UV Ozone systems.

The hatchery's current power losses throughout the year present a risk for using these updated technologies (RAS, chillers, UV Ozone systems, self-cleaning screens, etc.), which require reliable power. Installation of renewable energy sources in the form of solar panels, hydropower generator, or a biodigester could mitigate these power losses. A biodigester would also address the need for additional abatement of fish waste and reduce hatchery emissions associated with fish production.

Recommendations and Priorities:

- Water temperature must be addressed, and can be successfully addressed through the installation of chillers (chillers will be most efficient with reduced water needs as in with a RAS or pRAS) and shade cover structures
- Water availability due to water rights and low flows must be addressed, and installation of a RAS can help address vulnerability due to low flow, drought, and streamflow timing
- Pathogens must be addressed, and addressing water temperature will help immensely
- Power outages can be addressed through the installation of renewable energy sources such as solar and a biodigester
- Sedimentation should be addressed through additional filtration or settling infrastructure

Additional Discussion:

- Addressing water temperature will also minimize risks from projected increases to air temperature
- Use of a biodigester can also provide additional abatement for fish waste

4.3 Bandon Hatchery

Risk Analysis and Recommendations:

Bandon Hatchery faces risks to its operations from limited water availability. Competition for water from the hatchery's main intake sources already limit production at different times throughout the year, (during the summer exacerbating low flows, and during the fall when agricultural uses and groundwater pumping in the basin increase) and will continue to pose a growing problem unless significant efforts are made to resolve water rights issues. Communication among all water users in the basin is key, and relocation of upstream water users' points of diversion to a location downstream of the hatchery could help resolve water limitations at the hatchery. Since the hatchery's water use is mostly non-consumptive, this would allow both the hatchery and the upstream users to access the water needed to meet their demands. Additionally, climate change is projected to reduce streamflow during summer and fall with average reductions up to 17% in September for Ferry Creek and Geiger Creek, without taking competing water users into account.

The hatchery's water intakes are located in small reservoirs that are losing capacity as they fill in with more sediment over time. Ferry Creek Dam has damage to the spillway, and the ODFW has been presented options for its future (Foundation Engineering Inc, 2014). Rebuilding the dam, adding a sediment sluice, and dredging the reservoir are potential options in addition to relocating water withdrawals from upstream users that will prolong the useful life of this reservoir. The uncertainty of the dam and its spillway creates uncertainty for the hatchery's water intake on Ferry Creek and should be considered with future plans.

The installation of a RAS or pRAS system would help to alleviate issues related to low flow and limited water availability, whether due to water rights, drought, or climate change-induced changes in streamflow timing and magnitude. Such a system will require significant initial and ongoing investment, but incorporating this technology could allow the hatchery to continue with its current production into the mid-century and beyond. It could also allow an increase in production with the addition of a supplemental Fall Chinook program, which would require upgrades and resealing (or replacement) of existing raceways and ponds. A RAS system requires reliable electricity, so the hatchery should consider installing renewable energy sources such as solar or hydro power, or a biodigester that would also reduce emissions due to fish production. However, such an investment may be too expensive for Bandon Hatchery that has lower production goals and already struggles with limited water availability in the watershed.

The hatchery could also conduct well tests for groundwater, as previous tests and the large number of local groundwater users in the area suggest that groundwater could be a supplemental water source. However, groundwater levels across the state tend to be decreasing and experiencing larger depth-to-water values over time, so the incorporation of groundwater into production should be approached with caution.

The hatchery faces unique risks from wildfire because of its extensive construction made of wood in its operational infrastructure, as well as the heavily vegetated surroundings. Earthquakes are a risk due to the earthen Ferry Creek Dam, which would benefit from upgrades or rebuilding of the dam.

Recommendations and Priorities:

- Resolving limited water availability due to water rights is crucial for continued hatchery operations
- Installation of RAS can address risks to production posed by decreased water availability, drought, and low flows, even in the face of increased summer production
- Wildfire and earthquakes will remain a risk and should be considered in regards to renovating the dams and buildings, increasing defensible space, and upgrading technology

Additional Discussion:

- Installation of RAS to address water availability can also make the use of chillers more feasible to manage water temperature, though Bandon does not currently face issues with high water temperatures

4.4 Cole Rivers Hatchery

Risk Analysis and Recommendations:

Cole Rivers Hatchery has ongoing risks to operations in the form of limited power supply. The hatchery must have a reliable source of power to maintain its hatch house. A new power line will be installed in the near-future, and the hatchery should consider the addition of renewable energy sources as a backup or primary electricity source. The hatchery's large open-air footprint provides the ideal setting for a large-scale solar installation, which can easily provide enough power for the hatchery (and potentially provide annual paybacks from selling excess energy to the local power grid). Solar energy would ensure reliable power to the hatchery as well as cut down on greenhouse gas emissions generated on the hatchery's behalf from the hatchery's power provider.

Climate change is projected to change the timing of peak runoff on the Rogue River, up to two months earlier which will decrease the magnitude of summer flow by up to 40% in a natural flow environment. However, Lost Creek Lake will largely mitigate the hatchery from the impacts of these projected changes. Coordination and communication with USACE, the managing entity of these reservoirs, is essential to ensure sufficient water availability during low flow time periods as well as to prevent flooding of the hatchery in times of increased high flows. A RAS or pRAS system would also address potential risks of limited water availability due to low flow and drought by improving efficiency of production water use at the hatchery. By reducing water needs for existing production, the hatchery could consider raising additional fish, such as summer full-time production for Rock Creek Hatchery's fish. Expanded production would require the installation of additional raceways and water, the latter of which would be addressed by a RAS. Given the stable water supply at Cole Rivers Hatchery, a RAS system would likely only be needed if the hatchery were to continue production for Rock Creek Hatchery or take on additional production for a different hatchery.

The open-air concrete hatchery infrastructure is accompanied by a risk of rising water temperatures. Shade covers on the raceways can keep rising water temperatures in check, as well as increase fish health by providing shelter from the sun and thus preventing sunburn (and any subsequent infections due to lowered immunity to pathogens). A RAS or pRAS system could ensure that any rising water temperatures can be actively decreased through the effective use of chillers. Cool water temperatures would help minimize fish thermal stress and pathogen outbreaks and thus provide healthier fish.

Cole Rivers Hatchery is in a strong position compared to other hatcheries given its stable water supply and cool water temperatures.

Recommendations and Priorities:

- Restoring reliable power to the hatchery without need of generators is crucial. In addition to the new electricity line being installed, the hatchery can ensure plentiful renewable energy through installation of solar panels
- The hatchery should maintain good working relations with USACE, who manage the upstream reservoir and water source, to ensure that release schedules reflect adequate streamflow for hatchery production even in the face of changing precipitation and natural streamflow timing
- Installation of RAS will also address risks from low flows, drought, and streamflow timing
- Shade cover for the raceways can help mitigate rising water temperatures, reduce algal growth, and prevent sunburn on fish

Additional Discussion:

- Installation of RAS to address water availability can also make the use of chillers more feasible to manage water temperature, though water temperature is not considered to be an issue for Cole Rivers
- RAS installation is not crucial so long as USACE operating plans maintain streamflows and water temperatures to meet salmonid needs, but could allow the hatchery to host production on behalf of other hatcheries

4.5 Leaburg Hatchery

Risk Analysis and Recommendations:

Leaburg Hatchery has ongoing risks due to water temperature. Mean water temperatures at the hatchery intake remain within a reasonable range for salmonids even through the summer, and are projected to reach a mean around 16°C in 2045. However, this temperature threshold poses a problem for the hatchery due to its obligations to discharge water below 16°C. Maximum water temperatures at the intake during the summer will be higher than that threshold; the hatchery must ensure it takes measures to actively cool warm incoming waters and prevent any additional heating of the water as it passes through the hatchery operations. Shade covers can help limit water temperature increases due to solar radiation and have the added benefit of preventing sunburn to fish and thus improving their health (and reducing subsequent infections due to lowered immunity to pathogens). Active cooling of waters that are already too warm when they reach the hatchery will require the use of chillers, which are most effective on smaller volumes of water. Installation of a RAS or pRAS system in combination with a chiller can reduce water needs for production and allow more effective chilling. Keeping water temperatures lower can also help limit pathogen outbreaks, especially those strains that thrive at higher temperatures (see Appendix for list of thresholds and temperature preferences).

Pathogens are already an existing issue at the hatchery. The hatchery can limit worsening of outbreaks through maintaining cool water temperatures and also through effective disinfection of incoming water. UV Ozone systems can be effective at decreasing incoming pathogen loads and work best when fine sediments are filtered out first, which would require the installation of additional settling and drum or radial filtration capabilities to maximize UV effectiveness.

Reduction of water needs through a RAS system would also mitigate against increasing threats of streamflow magnitude changes, increasing low flows, and drought. The upstream network of reservoirs is largely expected to mitigate low flow conditions and changes in streamflow timing for the hatchery, though this mitigation is dependent on discharges that provide at least minimum environmental flows throughout the year. Groundwater could provide a potential supplement for water needs and for cooling small volumes of water; updated groundwater testing should be conducted before integrating groundwater into production, as groundwater levels have generally been decreasing in the area where data is available.

A RAS system requires reliable electricity, as does the existing self-cleaning screen system at the intake. The hatchery could ensure power for a RAS and chiller system, as well as reduce greenhouse gas emissions due to its power provider and fossil-fuel backup generator, by installing renewable energy in the form of solar panels, mini hydropower, or a biodigester, which would also eliminate emissions due to waste from fish production.

Recommendations and Priorities:

- Water temperature can be addressed through the installation of chillers (chillers will be most efficient with reduced water needs as in with a RAS or pRAS) and shade cover structures
- Pathogens must be addressed and can be addressed in part through the use of UV Ozone to treat incoming water. Cooler water temperatures from a chiller will help mitigate against pathogens that prefer warmer water
- Water availability due to changes in precipitation and low flows must be addressed, and installation of a RAS can help address these vulnerabilities, in addition to maintaining good relations with USACE who manage the upstream network of reservoirs

4.6 Oak Springs Hatchery

Risk Analysis and Recommendations:

Oak Springs Hatchery faces risks to water availability from the combined impacts of drought and competing water uses in the basin, particularly groundwater pumping that has the potential to disrupt its water source from springs. Projected changes in streamflow timing and magnitude of nearby rivers along with surface water withdrawals will likely have some impact on the springs as well. The hatchery already reuses water up to three times throughout the hatchery operations process; no further reuse of water is possible without additional treatment, disinfection, and conditioning in between uses.

A RAS or pRAS system could reduce production water needs and in doing so mitigate against potential low flows or limitations in water availability. A RAS system requires consistent, reliable electricity, and the hatchery has ample opportunities to supplement its existing onsite hydropower generator with additional hydropower, solar power, biodigester, and potentially wind power, which would first require further monitoring.

Additional water rights could potentially be obtained to Deschutes River water, but pathogen loads would increase, including *C. shasta* which currently has no cure. The use of this river water in production would require extensive disinfection such as a multistep process including sand filtration, UV Ozone, chlorination, and subsequent dechlorination.

Watershed conditions (steep hillslopes, erodible soils) combined with a single entry road to reach the hatchery will continue to pose a risk in limiting access to (or egress from) the hatchery. Surrounding scrub, shrub, and herbaceous land cover increase wildfire risk and emphasize the importance of access.

Recommendations and Priorities:

- Water availability due to water rights and low flows must be addressed, and installation of a RAS can help address vulnerability due to drought, streamflow timing, and changes in precipitation
- Watershed conditions pose hazards for landslides, with fewer ways for the hatchery to adapt

Additional discussion:

- Installation of RAS to address water availability can also address risks related to water temperature and pathogens, especially if Deschutes River water is ever considered as a water source

4.7 Conclusions

A risk assessment was completed for six fish hatcheries operated by the ODFW examining vulnerabilities under current and future conditions given the impacts of climate change. The risk assessment identifies the most significant risks at each hatchery and presents adaptation measures that can be implemented to reduce the vulnerability of the hazard at each hatchery. A significant and holistic investment in upgrading hatchery technology can reduce potential impacts due to major climate change effects in Oregon streams and allow ODFW to continue to raise healthy salmonids into the mid-century and beyond. This risk assessment serves as a framework for applying to other hatcheries in ODFW’s portfolio and as a resource to document a need for additional resources to continue to meet its purpose over the next 50 years.

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Rock Creek Hatchery Infrastructure and Upgrade Assessment

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Submitted to Oregon Department of Fish and Wildlife

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Purpose of Report

The purpose of this report is to present an assessment of current conditions for Rock Creek Hatchery, a state hatchery in Oregon that suffered extreme losses in the Archie Creek Fire in September 2020. These vulnerabilities include natural hazards such as low flow, sedimentation, and climate change impacts, and structural and organizational issues including water rights, power and fuel, and financial. A ranking of the risks for each identified vulnerability is presented, along with possible solutions and alternatives. The intent of this document is to facilitate the rebuild of the hatchery and its operations, enabling it to fulfill its mission as part of the ODFW hatcheries system, while updating and modernizing procedures and infrastructure to reflect changing needs based on climate and program priorities.

There are several alternative scenarios presented in this document involving the rebuild and refurbishment of Rock Creek.

1. The "do-nothing" scenario, which requires no further rebuilding at Rock Creek. All production goals at Rock Creek would be suspended, with returning adult salmonids frequently collected and transported to other hatcheries.

2. Rebuild Rock Creek to attain its full production goals with improvements. This rebuild requires addressing problems with infrastructure, energy use and emissions, and elevated water temperatures in the surrounding basins.

3. Rebuild Rock Creek to attain partial production goals, shifting all summer operations to other hatcheries. A reasonable nearby hatchery alternative is Cole Rivers Hatchery, though it faces its own current challenges on top of those associated with expanding production.

The majority of this assessment addresses specific solutions to vulnerabilities and challenges faced by the hatchery as part of a full or partial rebuild.

1. Background

1.1. Description of Rock Creek Hatchery

Rock Creek Hatchery is a state-run fish hatchery managed by the Oregon Department of Fish & Wildlife (ODFW). It is situated on approximately 26.5 acres of land at the confluence of Rock Creek and the North Umpqua River near Idleyld Park, Oregon, and has been in place since 1925 with a period of closure and reconstruction in the 1970s (ODFW 2020a).

Figure 1.1. Rock Creek Hatchery location shown as fish symbol near the confluence of Rock Creek and North Umpqua River upstream of Idleyld Park.

The hatchery plays a role in conservation and harvest programs for Chinook and Coho Salmon, and Steelhead and Rainbow Trout, with differing responsibilities for collection, spawning, incubation, and rearing throughout the year for various life stages of the respective salmonid species, as detailed in the Hatchery Management Plan (2020). The annual production goal of the hatchery is the release of around 130,000 lbs of juvenile fish. In addition to collecting adults for broodstock, there are 1,000 lbs of adult fish that go towards fulfilling tribal obligations and 200-300 additional fish for local food banks.

The hatchery has also contributed to environmental education in Douglas County by providing upwards of 15 tours a year.

Its water sources are Rock Creek and the North Umpqua River, with North Umpqua water being pumped in during Rock Creek's low-flow summer months. The surrounding area averages variable amounts of precipitation between 40-100 inches annually (FEMA 2020) with the majority of that falling during the fall and winter months. The surrounding watershed is mostly forested, with a small percentage of the land covered in impervious surfaces in the form of roads or buildings (NLCD 2019).

Prior to the Archie Creek Fire in 2020, the hatchery had a holding pond, an abatement pond, 16 concrete raceways, 7 troughs, 300 vertical incubators, 2 fish passage ladders, and fish trap facility, as well as 5 residential homes for hatchery managers, workers, and their families, and an educational facility Rock-ED; the condition of all the aforementioned infrastructure at that time was considered "good" except for 4 raceways in "poor" condition. However, the widespread, intense fire caused substantial damage to the hatchery's infrastructure and the surrounding watershed.

1.2. Impacts of the Archie Creek Fire

The Archie Creek Fire started on September 8, 2020, and was contained two months later after burning 131,596 acres in Douglas County, Oregon (FEMA 2020). This fire burned particularly hot with high severity (FEMA 2020, USFS 2022a) and heavily impacted the Rock Creek watershed, the lower parts of which experienced burns of up to 100% of the watershed.

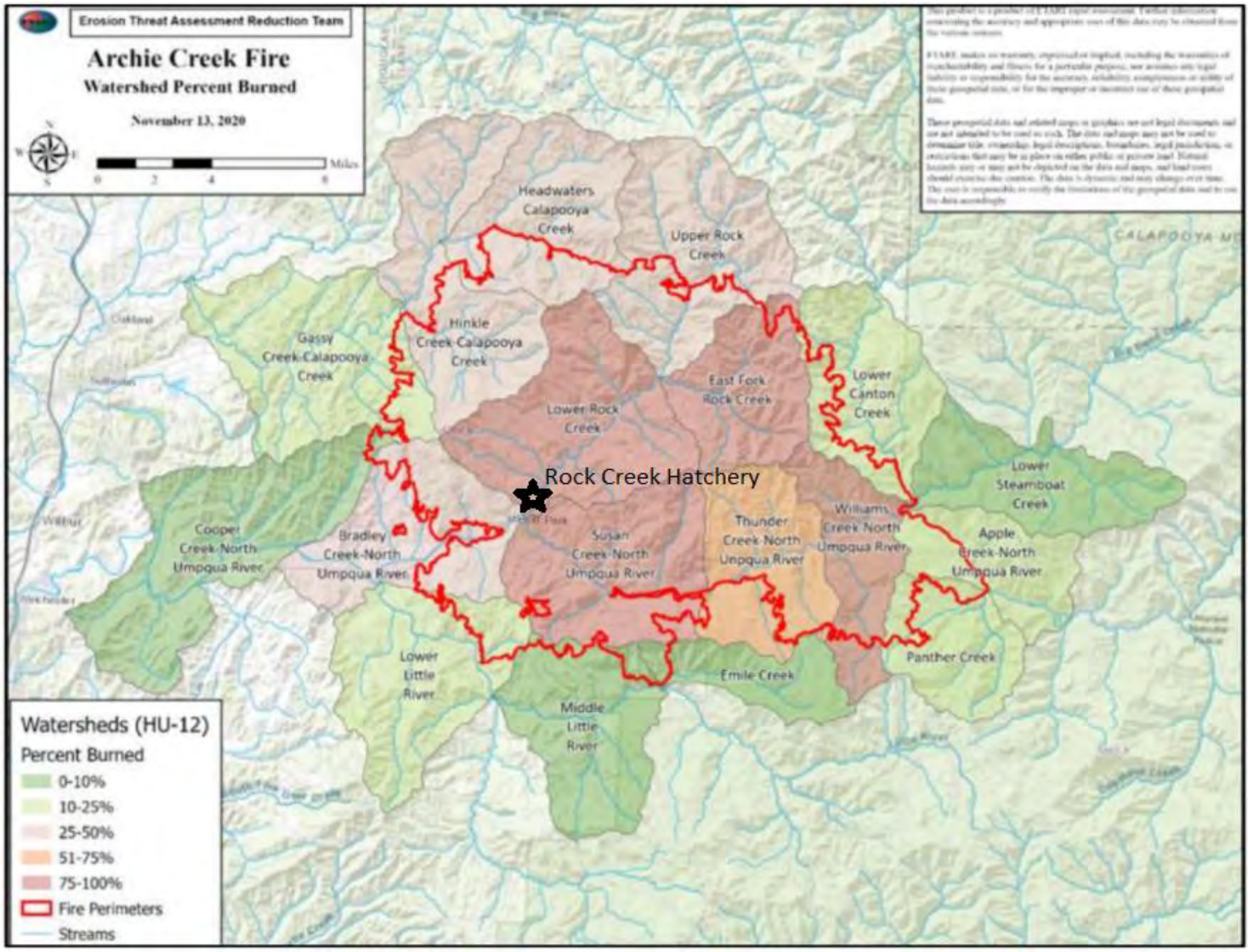

Figure 1.2. Watershed percent burned during the Archie Creek Fire, modified from FEMA 2020. Darker red areas such as those around the hatchery show 75-100% burn areas.

The following image showcases the extent of the fire's deforestation as seen in satellite imagery (ESRI 2022). The image from March 2021 clearly shows the outline of the Archie Creek Fire, six months after the fact; the burn's extent is brown and starkly different from the surrounding green landscape, despite being a forested area.

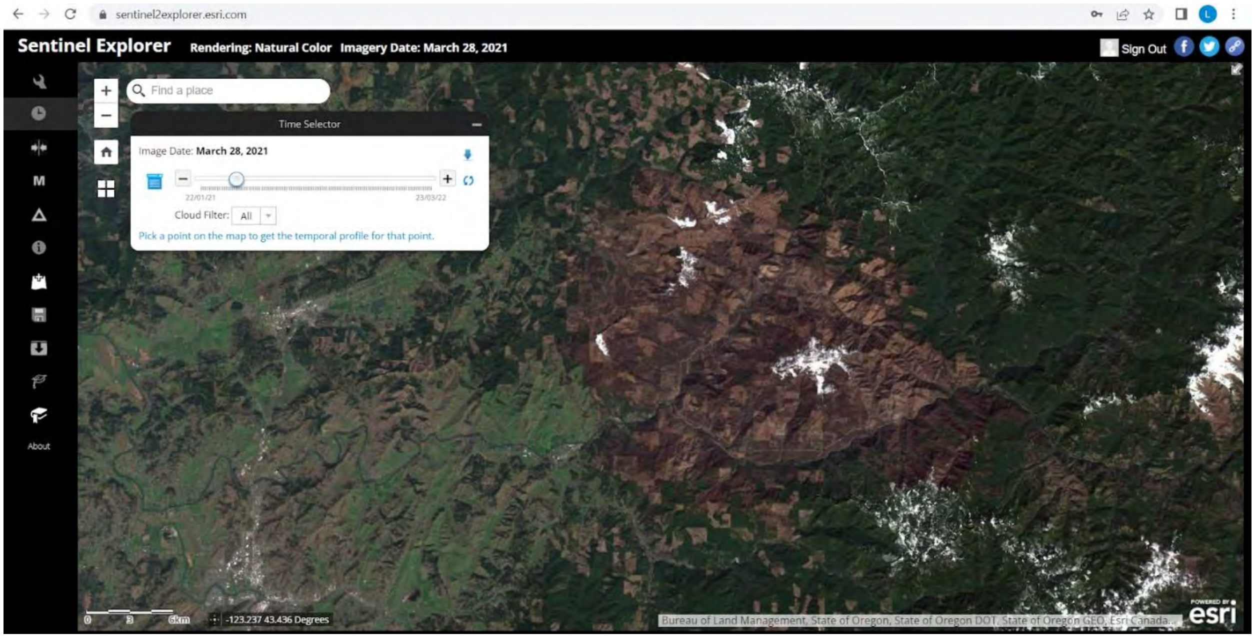

Figure 1.3. Satellite imagery of Archie Creek Fire burned area in March 2021.

The riparian zone of Rock Creek upstream of the hatchery was largely shaded in the past, but the fire effectively opened up the stream by burning every tree, most of which are being removed by logging companies.

Figure 1.4. Burned trees along North Umpqua River (left) and Rock Creek (right) riparian zones in April 2022, with burned trees in background hillside areas already logged.

High soil burn severity and the loss of vegetation increased erosion risk substantially in Rock Creek and its tributaries (FEMA 2020). The hydrologic response of the Rock Creek watershed for 2- and 5-year return interval peak flows is anticipated to be a 1.5-1.6 magnitude increase in runoff as a result of the fire, based on regional regression equations. The vegetation is estimated to take 2-3 decades to recover from the most intense burns, which could result in higher streamflow amounts during precipitation events until sufficient vegetation recovers.

To speed up the pace of recovery, the US Forest Service has begun the arduous task of replanting in the North Umpqua Basin, as part of a 10-year strategic plan to address wildfires (USFS 2022a, USFS 2022b). The help of community partners and organizations such as the National Forest Foundation, the Arbor Day Foundation, Douglas County, several tribes, Pacific Power (PPL), and Douglas Timber Operators, and additional funding from such sources as the Bipartisan Infrastructure Law will hasten this vegetation recovery process.

1.3. Impacts on Rock Creek Hatchery

Pre- and post-fire photos of Rock Creek Hatchery confirm the severity of the burn in terms of devegetation of the surrounding area.

Figure 1.5. Pre-fire photos from ODFW, photo on left accessed from KQEN 2022, photo on right directly from ODFW.

Figure 1.6. Post-fire photos from Dan Meyer, accessed from KPIC 2022, with final photo directly acquired from ODFW.

The fire affected the hatchery infrastructure in a somewhat piecemeal fashion, notably leaving the wooden RockED educational center and wooden picnic pavilion completely untouched, while destroying buildings on the eastern half of the property. The following diagram shows the areas of the hatchery that were entirely burned and those parts that were left standing. The intake structure on Rock Creek remains standing and stable due to its solid concrete build, but the equipment inside, including computers and wiring associated with the fish viewing window used to count fish returns, was destroyed. Concrete raceways are still standing and able to contain fish.

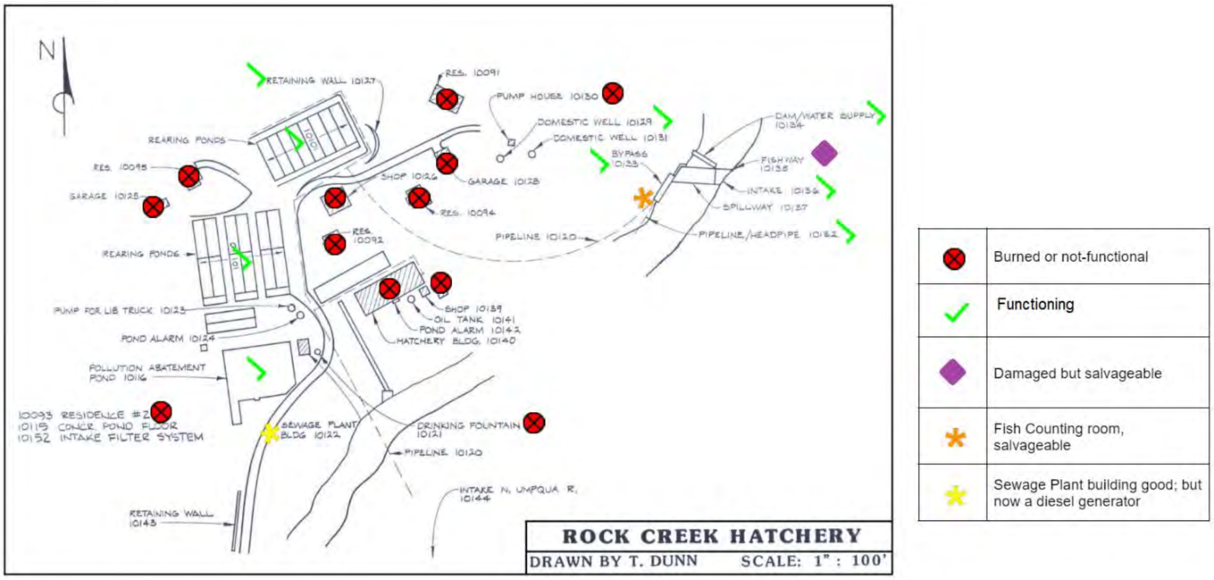

Figure 1.7. Diagram modified from Hatchery Management Plan 2020, with burned infrastructure denoted as red circles and functioning, standing infrastructure marked as green checkboxes.

Figure 1.8. Structures remaining after the fire, plus additional temporary structures, as of April 2022.

Figure 1.9. Intact raceway holding returned adult fish, with visible debris slides beneath the access road as of April 2022.

Figure 1.10. Viewing window by dam and fish passage with burned wiring and computer and video equipment used in fish counting.

Figure 1.11. Intact structures in background with footprints of burned, removed residence and hatch house in foreground.

The remainder of this document addresses specific solutions to vulnerabilities and challenges faced by the hatchery as part of a full or partial rebuild of operations.

2. Vulnerabilities and Alternatives

In this report we document the existing vulnerabilities to the Rock Creek Hatchery, which have been informed by meetings with ODFW staff, site visits, and a literature review. The vulnerabilities are outlined below categorized as operational, environmental, or pathogen.

- Operational
  - Infrastructure improvements
  - Destabilization of surrounding area and watershed
- Environmental (Water quality and quantity)
  - Low flow
  - Groundwater availability
  - Water rights availability
  - Increased water temperature
  - Sedimentation
  - Dissolved oxygen
  - Other water quality parameters
  - Contaminants from the Archie Creek Fire
- Pathogens
  - Disease conditions related to climate change elements

The following table details a qualitative vulnerability rankings system based on severity of impact to production based on current conditions and likely future trends of the respective condition. The severity of impact to production categories has the following descriptions:

- No impact to production: This identified potential vulnerability currently poses no risk to hatchery operations at Rock Creek. Production levels will be met even if this factor isn't addressed, or will not be negatively affected by doing this.
- Minor impact to production: This identified vulnerability poses some risk to meeting production goals, though goals are still likely to be met.
- Moderate impact to production: This vulnerability poses a risk to meeting production goals; if this vulnerability is not addressed, goals will not be met, reduced returns will be likely, and operations could begin to suffer.
- Major impact to production: This vulnerability poses a risk to meeting production goals; if this vulnerability is not addressed, goals will not be met and operations will be untenable without addressing. There is anticipated loss of fish life and reduced returns, and possible loss of human life.

Future trend categories include the following:

- Improving: Condition is expected to improve, or problematic condition is likely to lessen in frequency or extent.

- No trend: Condition is not trending towards worsening or improving.
- Slight worsening: Condition is expected to slightly worsen over the coming decades, or problematic condition is likely to increase in frequency or extent.
- Severe worsening: Condition is expected to noticeably worsen over the coming decades, or problematic condition is likely to substantially increase in frequency or extent.

Table 2.1. Vulnerability ranking matrix

Severity (down) and Trend (right)	Improving	No trend	Slight worsening	Severe worsening
No impact	Very Low risk	Low risk	Low risk	Moderate risk
Minor impact	Low risk	Moderate risk	Moderate risk	Moderate risk
Moderate impact	Moderate risk	High risk	High risk	**Very high risk**
Major impact	High risk	High risk	**Very high risk**	**Very high risk**

2.1. Operational Challenges

2.1.1. Necessary improvements to infrastructure

Vulnerability ranking: **Very high risk**

The Archie Creek Fire caused direct damage to hatchery infrastructure, including buildings, trucks, and residences, and indirect damage to the hatchery by destabilizing the surrounding steep hillslopes. Additionally, 4 vintage concrete raceways were already listed in the hatchery's management plan as being in poor condition due to their age (ODFW 2020a).

2.1.1.1. Alternatives and recommendations

A large portion of the hatchery's infrastructure will require rebuilding or repurchasing to attain full or even partial production capacities. Various components of the property could be upgraded during this rebuild process, including the incorporation of alternative energy sources.

2.1.1.2. Rebuild damaged buildings

The hatchery property and facilities are undergoing valuation for insurance and FEMA claims as well as an archaeological study over the entire premises; both of these studies will be completed in Summer 2022, and the latter will determine the extent of possible rebuilding due to allowable locations on the property (ODFW 2022). This assessment is written with the assumption that rebuilding will be allowable on any part of the property, but especially over the existing raceways.

The concrete infrastructure on the premises (raceways, intake structure with fish ladder) survived the fire, as did the educational center. Gravity-fed raceways not only survived the fire but allowed adult fish in them to survive 10 days before transport to Cole Rivers. Garages and storage rooms that were burned have largely been replaced with temporary prefabricated structures. All the residences were destroyed and have not been replaced yet.

Crucial infrastructure for restoring basic hatchery operations includes replacing pumps and rebuilding the hatch house and all its associated equipment. Fish trap equipment located at the dam allowing for the sorting of wild fish from returning hatchery fish needs to be repaired, and the counting window at the intake needs to be refurbished and rewired.

Initial insurance valuations of damaged or destroyed infrastructure list a replacement cash value total of $7.5 million, which is the cost of rebuilding the 5 residences, intake facility, equipment garage, and hatch house to pre-fire standards. A similar rebuild of a hatchery in the Walla Walla basin in Washington cost $21 million (CUJ 2020, CBBulletin 2021). The Walla Walla hatchery rebuild is an upgrade to an existing hatchery facility, adding capacity for egg incubation, early juvenile rearing, grow-out rearing, administrative facilities, a shop and office, a visitors' center, and three new residences, adding production goals of hundreds of thousands of spring Chinook smolts on top of existing adult salmon production.

Other recent hatchery build costs include a $16 million new salmonid hatchery in Northeast Oregon (construction that was ultimately deferred) (CBFish 2006) and a $4-7 million proposed sucker hatchery at Klamath Falls (GOVTRIBE 2021). Previous costs associated with upgrades of the Rock Creek facility include a $5 million fish ladder installation in 2013 and $600,000 raceway upgrade in 2015 that split two aging raceways into four (Hatchery International 2013, KCBY 2015).

Onsite housing is a benefit that can help with staff retention and is required to provide quick response to emergencies. Residences should be rebuilt as operations increase back to normal production levels to support staff required to live onsite; each residence can be expected to cost between $600,000-$750,000 based on insurance valuations.

2.1.1.3. Fire suppression system

To aid in creating a defensible space zone and protecting infrastructure from future fires the hatchery might encounter, a fire suppression system could be installed that automatically triggers based on surrounding temperatures and utilizes onsite water in conjunction with an external sprinkler system. Installation costs of this sprinkler system could be upwards of $30,000-60,000 to cover areas around all the hatchery's infrastructure (HomeGuide 2022). The near-complete burning of all vegetation on the previously lush, forested surrounding landscape will provide less fuel for future fires until new plantings grow sufficiently large.

2.1.1.4. Digester

The hatchery has a functioning abatement pond to treat fish waste, pollutants, and nutrients, and it undergoes quarterly testing and reporting to the Department of Environmental Quality (DEQ). While no improvements are necessary in order to meet water quality obligations, replacing the abatement pond with a biodigester could provide treatment as well as a potential source of energy when combined with a carbon capture system. Such a biodigester system was recently deployed as an aboveground system for a cost of $80,000 at a 100 metric ton tilapia farm in British Columbia (Sistema 2020).

An anaerobic biodigester microgrid system for a hog farm that included 20 kW solar panels, a 100-kW diesel generator, a 185-kW biogas generator, a 250 kW/735 kWh battery system, and a controller had capital costs between $550,000 to $650,000. Annual operating and maintenance costs are approximately $25,000 with revenue from annual electricity sales of $56,000. Such an electricity amount would be sufficient to power Rock Creek Hatchery based on its 2019-2020 energy use and could be used locally instead of being sold back to the local utilities (EPA 2012, Biocycle 2018), though in reality Rock Creek Hatchery would not generate this much energy because it does not generate as much waste as the farm, which produces 10,000 gallons of pig manure daily. Estimates from a Norwegian salmon farm using waste from 9 million smolts are that a biodigester could produce 500,000 kWh per year (Salmon Business 2019); Rock Creek's potential outputs would be reduced accordingly, based on its having over a magnitude lower of fish.

With estimated greenhouse gas emissions of 0.791 kg CO2e (carbon dioxide equivalent) per kg production in fish production, Rock Creek Hatchery had 47,000 kg (47 tonnes) CO2e from fish waste. These emissions accounted for 3% of the ODFW system total of 1,351 tonnes CO2e in 2019-2020, and could be reduced by the biodigester setup and turned into usable electricity.

2.1.1.5. Solar panels

Rock Creek Hatchery used a substantial amount of energy in 2019-2020 (ODFW 2021a), second to Irrigon Hatchery in energy use out of all the state hatcheries, largely for the use of pumps. New pumps will provide better efficiency than old ones from before the fire. Even assuming resumption of full production with minimal efficiency improvements in pumping, the high energy demands could potentially be met through a solar panel installation on the property. The use of solar energy to supply some or all of the hatchery's energy demands supports the ODFW's Climate and Ocean Change Policy that aims to become carbon neutral by the mid-21st century. Additionally, renewable options such as solar power could prevent catastrophic losses in the face of future power cutoffs, such as those suffered during the Archie Creek Fire. During the fire, electricity was shut off to the surrounding area, leaving the hatchery's pumps to run solely off of generators, which ran out of fuel after two days, leading to the death of hundreds of thousands of juvenile fish.

Rock Creek Hatchery received an estimate of up to $75,000 for installation of a 23kW solar system; without substantial energy-efficiency improvements in the pumps used onsite, a larger solar installation would be required to take on the bulk of the electricity requirements.

Table 2.2. Details about solar energy estimates and costs

Description	Value
Energy Use for Rock Creek Hatchery (2019-2020)	683,188 kWh (ODFW 2021a)
Average monthly energy use	56,932 kWh
Estimated average peak sun hours for Rock Creek based on geography	4-5*
Solar system required to fully power hatchery	400-600 kW*
Price for 100kW system	$130,800** (not including possible federal solar tax credit of up to 26% through 2022)
Space required for 100kW system	6,500 sq ft.**
Price for 150kW system	$170,400**
Payback time period	3-5 years*** 9-12 years*

*(UnboundSolar 2022)

**(SunWatts 2022)
*** (InfiniteEnergy 2022)

With electricity at an estimated cost of $0.10 per kWh, energy costs for Rock Creek Hatchery would have been around $68,000 annually. With a grid tie-in that covers 1/4 of the electricity needs, that electricity cost would be reduced by $17,000. With a 150kW tie-in system for $170,000, electricity savings would equal the grid installation and capital costs after approximately 10 years. A system covering 100% of the hatchery's 2019-2020 energy use would need to be 400-600kW, with an estimated cost for a full 436kW grid-tie system being $600-700,000 (UnboundSolar 2022). Pacific Power (PacifiCorp) is the electricity provider for Rock Creek Hatchery and allows customers to have solar-generation systems up to 2 MW connected to the grid.

Annual maintenance costs would be relatively small, requiring panel cleaning and inspections, some of which could be done by hatchery staff. Inverter replacement could be required after the first 10-12 years, at a cost of $8,000 or more per inverter. The hatchery's raceways are a prime location for solar panel installation, with over 50,000 square feet of open-air concrete channels. See the section on artificial shade cover for additional installation details and benefits.

Battery storage to account for periods of poor weather or night-time operations when solar is not available can be sized to account for different levels of redundancy. Running on battery power for prolonged periods of time is not recommended due to the high energy needs of the hatchery's pumps and the current relatively high cost and limited storage capacity of batteries, though battery technology continues to improve rapidly.

Table 2.3. Sample battery costs

	Storage capacity	Price
Batteries and battery banks	10.8 kWh	$8,100 (EcoFlow 2022)
	32 kWh	$29,000 (Unbound Solar 2022)
Battery + inverter full system	13.5 kWh	$15,600
	40.4 kWh	$34,800 (+ $1,000 shipping and DIY or electrician installation, excludes cost of wiring and conduits) (SunWatts 2022)

With an estimated 291.8 g of CO_2e per kWh, Rock Creek Hatchery's annual electricity usage amounts to 200 tonnes, or 6% of ODFW system-wide electricity. Installation of solar power to take on some portion of that electricity, would reduce the CO_2e tonnage proportionally, with a

150 kW system that meets ¼ of the electricity needs having a respective reduction in CO2e of 50 tonnes.

According to Pacific Power 70.5% of their 2020 standard power supply comes from fossil fuels (2022). Additionally, the Oregon Department of Environmental Quality estimated that Pacific Power's average emissions per megawatt hour produced are 0.636 tonnes of CO2e per megawatt hour, which is higher than the US EPA estimates used in the ODFW greenhouse gas inventory (DEQ 2022). This higher emissions rate would mean that Rock Creek's annual electricity usage contributes an estimated 434.5 tonnes of CO2e. Installation of solar power would be that much more important in this situation, reducing the CO2e tonnage proportionally, with a 150 kW system having a respective reduction in CO2e of 108 tonnes of CO2e.

2.1.1.6. Micro-hydro power

The hatchery has several potential locations for local or micro-hydro power installations. The first is located at the old fish ladder structure along Rock Creek, and the second is on the hatchery effluent pipe that spills water from the hatchery into the river. These two locations present sufficient challenges to rival their benefits: the old fish ladder is located against a steep slope with an unstable hillside and is not always submerged throughout the low flow summers, and has a head drop of only 20 feet. The second location is within the 100-year floodplain and would require a prolonged study for possible approval. Due to the low power potential, unstable hillside, highly variable flow and additional cost of constructing a new intake and laying new pipelines, the old fish ladder location was not pursued further.

Two estimates for different micro-hydro generators located at the hatchery effluent outlet were made. The intention is to install a micro-hydro power generator at the outlet of the hatchery effluent pipe. This location is reported to have 55 feet of head and consistently provides between 25-30 cfs of flow from the hatchery, providing an estimated 100 kWh of power, or up to 876,000 kWh annually. This would exceed the 683,188 kWh annual power requirement of the hatchery (ODFW 2021a). Estimated cost for both systems was around $400,000 for 90-100 kW generator and necessary inverter and control systems. This comes out to an estimated cost of $4,000-$4,450 per kWh generated. With electricity at an estimated cost of $0.10 per kWh, energy costs for Rock Creek Hatchery would have been around $68,000 annually.

Assuming the system completely covers the required annual energy usage, it would take approximately 6 years for the generator to pay for itself. Both units have an estimated lifespan of 30 years. This means over its lifetime a micro-hydro generator would save the hatchery an estimated $1.6 million dollars in electricity costs. This benefit does not consider the potential for selling power back to local utility companies if the generator exceeds energy requirements of the hatchery. Also, if the generator supplies all of the hatchery's power, then it will be eliminating 200 to 434.5 tonnes of annual CO_2e emissions due to power usage (depending on emissions factor used as discussed above).

Table 2.4. Quotes for hydropower setup

	Canyon Hydro	InPipe Energy

Generator Model	Custom Built: Cross flow gear turbine	In-PRV: Pressure recovery system
Power Output	90-100 kWh	90-100 kWh
Estimated Cost	$400,000	$350,000-$400,000
What's in the box?	Generator & necessary equipment for energy inversion and unit control	Generator & necessary equipment for energy inversion and unit control
Additional Requirements	Power house to cover unit (25' x 25')	Utility box for controls and power hook up
Expected Maintenance	First 10 years, low: oiling, greasing etc. Post 10 years, medium: replace worn parts	First 10 years, low: oiling, greasing etc. Post 10 years, medium: replace worn parts
Life Expectancy	30-years	30-years
Company Location	Deming, Washington	Portland, Oregon
Source	CanyonHydro 2022	InPipeEnergy 2022

2.1.1.7. New truck fleet

A replacement for the 2,300 gallon stainless steel recirculation tank freightliner lost to the fire has already been ordered (but has faced a significant delay due to ongoing supply chain issues).

As trucks reach the end of their useful lifespan and require replacement, electric trucks would be a reasonable consideration for new equipment. Modern electric trucks can provide the torque and towing capacity required for hatchery operations, as well as provide sufficient range to cover potential runs between Rock Creek and Cole Rivers or Bandon hatcheries, which are each approximately 100 miles away. The following table details sample costs of current and soon-to-be-available pickup truck models.

Table 2.5. New truck purchase example models and costs

Vehicle	Cost
2022 Ford F-150 XLT (gasoline)	$43,840 (4x4 option with tow package, estimate from manufacturer)
2022 Ford F-150 (hybrid)	$45,000
2022 Ford F-150 Lightning (electric)	$43,634 (eligible for up to $10,000 in rebates, $7,500 federal and $2,500 state) (IRS 2022)
2022 Ford F-150 Lightning upgraded XLT	$74,994 (up to $7,500 federal rebate)
Extended battery range for truck	$10,000 (increase from 250 miles per charge to ~300 miles)
2024 Chevrolet Silverado EV	$39,900 estimated (available Fall 2023, plus costs for towing package, at ~400 miles per charge)
Charging station (charge in ~8 hours, Ford)	$1,310 (requires dedicated 100A electrical circuit and installation by electrician)

Fuel savings from switching to electricity could more than cover any differences in cost that an electric truck might have initially. A fleet of 10 vehicles could spend around $1500 less each month using electricity as fuel. A single vehicle in use for 100,000 miles could potentially spend $15,000 less in electric fuel costs than in gas or diesel fuel over the course of its lifetime (based on costs for each as of April 2022).

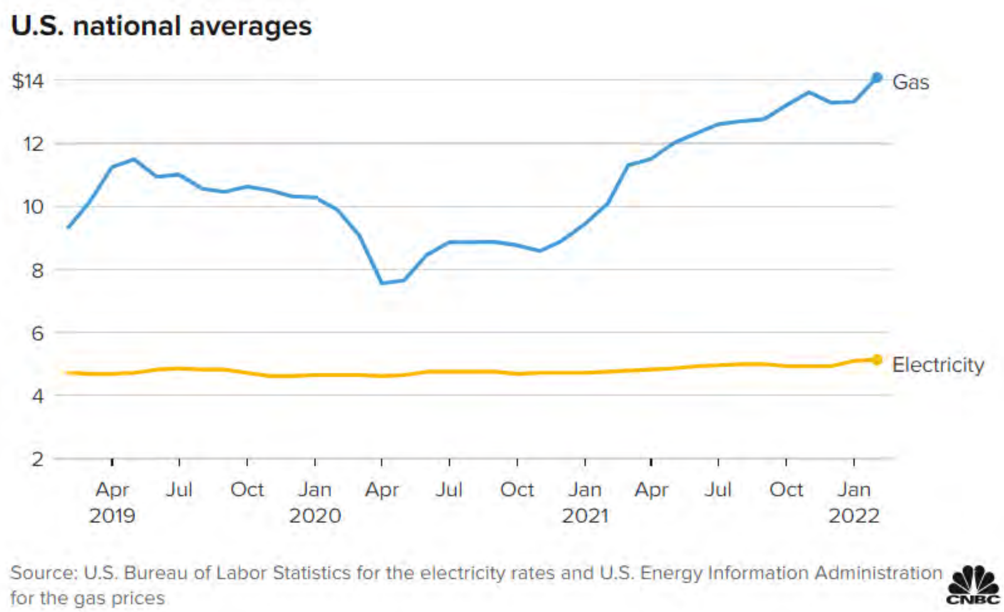

Figure 2.1. Graph comparing cost of gas vs. electricity for 100 miles (3.9 gallons of gas vs. 34.7 kWh) (CNBC 2022).

Table 2.6. Estimates of fuel costs

Vehicle type	Fuel efficiency	Fuel unit costs****	Monthly fuel cost driving 1000 miles / month	Total Fuel Costs for 100,000 miles
Ford F-150 (gasoline)	21 mpg*	$5.267 / gal	$250.81	**$25,080**
Ford F-150 (diesel)	27 mpg**	$5.402 / gal	$200.07	**$20,007**
Ford F-150 (hybrid)	25 mpg	$5.267 / gal	$210.68	**$21,068**
Ford F-150 Lightning (electricity)	2.2 miles per kWh***	$0.105 / kWh	$47.73	**$4,773**

*as low as 13 mpg reported at (EPA 2022)
** According to manufacturer for 2021 model
*** EPA unofficial estimates
**** Fuel cost estimates as of March 30, 2022 for West Coast minus California from (EIA 2022). Electricity costs based on Level 1 at-home costs from (EnergyBot 2022); Level 2 and 3 are faster and generally cost more.

With the increasing presence of charging stations and relative ease of adding at-home charging stations, electric trucks have the range necessary to go between these hatcheries as well. The hatchery could install its own charger onsite; a slower Level 2 charger requires a dedicated 240-volt 50-amp outlet and 200-amp panel upgrade, at an estimated cost of $1,500-$4,500 depending on electrician rates, while the cost of a fast DC charger would be at least $28,000. In place of installing its own chargers, the hatchery could instead choose to invest in additional battery power for its trucks and assume that market demand will drive additional charging station installations that can be utilized, especially since purchasing and obtaining these large electric freighters will likely have a long wait time.

Alternatives to privately-owned and operated charging stations include the use of public EV charging stations. The West Coast Electric Highway has plentiful stations, with numerous DC Fast charging stations in Oregon, which could refuel a Ford F-150 Lightning in as little as 45 minutes, depending on the kW of the charger (though a faster charge generally has higher electricity prices) (West Coast Green Highway 2022). The Oregon coast and I-5 have the highest density of charging stations across the state, and additional charging stations are likely to come online in the next several years, particularly as the State works on passing legislation banning the sale of gasoline-powered vehicles by 2035.

Electric freight is quickly becoming a viable possibility. Many electric lorries are already available and in use in Europe, and such trends are catching on in the US. Companies such as Telsa and Volvo have begun production of heavy-duty and freightliner trucks in the US, with rising demand from delivery companies such as UPS and Amazon to electrify their truck fleets. Companies such as BYD that have supplied electric buses in the US have expanded production to include heavy trucks. A low-end estimated cost for Tesla trucks is $150,000, with available and pre-production makes and models of other trucks and tractors costing up to $300,000 (PGE 2021).

There are incentives from car companies, federal, and state entities to invest in these electric fleets. Large rebates across various states, particularly California, will encourage market growth for these electric trucks. Improving battery technology with decreasing prices will help decrease these initial costs in subsequent models; additionally, end-of-life battery recycling continues to improve rapidly such that the environmental benefits of EV is not outweighed by the waste caused by used batteries. Additionally, the ride is expected to be quieter (6 decibels lower in the cab than in its diesel-based version according to Volvo) and smoother, even while carrying a payload of 40,000 pounds, which can improve the welfare of drivers (and potentially transported fish, though such an idea is only speculation at this point).

CO_2 emissions from hatchery vehicles can be a significant contribution to a hatchery's total emissions. The following table compares proposed vehicle alternatives per mile emissions rate.

Table 2.7. Estimate CO_2 emissions from Vehicles

Vehicle type	Fuel efficiency	CO_2 Equivalents per Gallon****	CO_2 Equivalents per Mile	Miles driven per Tonne CO_2e Released
Ford F-150 (gasoline)	21 mpg*	8.81 kg CO_2e/ gallon gasoline	0.42 kg CO_2e/mile	2,300 miles/tonne CO_2e
Ford F-150 (diesel)	27 mpg**	10.24 kg CO_2e/ gallon diesel	0.38 kg CO_2e/mile	2,600 miles/tonne CO_2e
Ford F-150 (hybrid)	25 mpg	8.81 kg CO_2e/ gallon gasoline	0.35 kg CO_2e/mile	2,800 miles/tonne CO_2e
Ford F-150 Lightning (electricity)	2.2 miles per kWh***	0.2918 kg CO_2e/ kWh used 0.636 kg CO_2e/ kWh used$^{\Omega}$	0.13 kg CO_2e/mile 0.29 kg CO_2e/mile	7,600 miles/tonne CO_2e 3,400 miles/tonne CO_2e

*as low as 13 mpg reported at (EPA 2022)
** According to manufacturer for 2021 model
*** EPA unofficial estimates
**** kg CO_2e per gallon taken from Table 5 in ODFW 2021a
Ω assuming vehicles charged by PacifiCorps power supply from ODEQ estimates

2.1.1.8. Shifting hatchery production to other facilities

The fire killed hundreds of thousands of juvenile fish, but 700 spring Chinook and Summer Steelhead adults were able to be transferred to Cole Rivers with only about 3 fish lost en route (NRToday 2022b). The relocation efforts required 7 tanker trucks and took place 10 days after the fire, when hatchery employees could again safely access the facilities.

Partial production at other hatchery facilities could alleviate the operational stresses on Rock Creek instead of requiring full standalone operations, particularly in the summer months when Rock Creek has historically struggled with elevated water temperature.

Expected fish losses due to transport are typically low, though the effects of transport on longterm survival can be variable from year to year and are likely dependent on environmental factors in the watershed including temperatures (Clemens et al. 2009, Sutphin and Hueth 2015, Geist et al. 2016, Kock et al. 2021). Good water quality throughout transport, maximum stocking density thresholds, best management practices to minimize stress including the use of salt, and a recovery period prior to release can improve survival chances of salmonids in the wild.

Increased time spent in external transport by juveniles might impact adult migration (Keefer et al. 2008). Cole Rivers Hatchery is relatively close to Rock Creek, which would minimize fish time spent in transport, and has the capability to raise the fish, but it has its own separate challenges that would need to be addressed for the hatchery to take on growout operations for Rock Creek's fish.

Costs to transport fish to this alternative hatchery, which is around 100 miles away from Rock Creek Hatchery, can be estimated accordingly. Based on current equipment, current fuel prices, estimated fuel efficiencies, and maintenance costs (FreightWaves 2022), the total trip cost of equipment and fuel for each transport truck would be around $190.

Table 2.8. Estimated costs for fish transport between hatcheries

Description	Value
Trip distance	100 miles each way
Fuel prices (diesel)	$5.40 per gallon
Loaded truck fuel efficiency	6 mpg
Unloaded truck fuel efficiency	8 mpg
Approximate fuel costs per round trip	$157.50
Additional maintenance costs	$0.17 per mile
Approximate maintenance costs per round trip	$34
Total cost per trip	$191.50

A 2,300 gallon tank (completely filled) at stocking densities of 24 g/L and 48 g/L could hold 553 lbs of fish and over 1,100 lbs of fish respectively, with minimal additional losses due to the higher stocking density (Sutphin and Hueth 2015). Based on Hatchery Management Plan goals for numbers and weights of Fall and Spring Chinook, Rainbow Trout, and Winter Steelhead at release, relocating Rock Creek's stock at the higher stocking density would require over 100 truck loads to transport nearly 125,000 lbs of fish, at a cost of $21,000. This cost represents the relocation of these fish from an external hatchery back to Rock Creek for acclimation and release. The initial relocation of Rock Creek’s stock would be much lower than this (lower total pounds of younger fish), so the overall round-trip relocation costs for these fish would be less than $42,000. Coho were not included in this relocation calculation, as they should not require over-summering, but if Coho production were moved to other locations for growout as well, the costs would increase accordingly for the additional 3,000 lbs at release.

A similar round-trip using an electricity-fueled freightliner shows a potential cost of $37.58 for electric fuel (based on Level 1 electricity costs of $0.105 per kWh; estimated fuel efficiencies of 0.65 miles per kWh for an unloaded truck and 0.49 miles per kWh for a loaded one, based on ratios of efficiency for lighter-weight trucks between diesel and electric) for a round-trip cost of $72 in fuel and maintenance (assuming similar maintenance costs).

The ODFW greenhouse gas emission inventory uses emission factors of 10.24 kg CO_2e/gallon of diesel fuel and 291.8 g CO_2e/kWh of electricity. Using these numbers and those above related to fuel efficiency, greenhouse gas emissions could be reduced on a per-round trip basis by 0.2 tonnes, using electric freightliners in place of diesel ones. Weekly trips would add up to a reduction of 10 tonnes of CO_2e over the course of a year.

Cole Rivers operations

Cole Rivers Hatchery was able to accommodate Rock Creek's adult fish in the aftermath of the Archie Creek Fire and continues to raise juvenile spring Chinook and Summer Steelhead from those adults that return to Rock Creek, which are collected and transported to Cole Rivers once a week. Cole Rivers is a facility consisting mostly of open-air concrete structures and is unlikely to suffer direct fire damage, in fact having previously served as an emergency shelter during other fires. However, the hatchery remains vulnerable due to its electricity situation; it has been running solely from generator power for the past year. A new power line restoring its electricity is scheduled to be completed by Fall 2022, but until that time, the hatch house is entirely dependent on twice-a-week fuel deliveries. If fuel trucks are ever unable to access the hatchery, Cole Rivers risks losing a million juvenile fish due to the inability to pump water to them. Cole Rivers' extensive open space with 87 exposed raceways would be ideal for a solar power installation, which could provide reliable power for the facility and shade for fish and workers in a location that can reach air temperatures above 100°F during summer.

While Cole Rivers currently has enough space and water available to raise a relatively small number of adults from Rock Creek, handling all of Rock Creek's growout in addition to the normal Cole Rivers production would require the building of new raceway and hatch house infrastructure. Cole Rivers has 87 raceways, but these raceways are constantly in rotation to meet existing production goals. There is 53,000 square feet of unused space near the raceways and abatement pond at the south end of the complex, as well as 48,000 square feet near the main building that is currently occupied by recirculation tanks. Additionally, existing raceways could be resurfaced to be made more efficient, addressing water losses and leakage as well as algae buildup.

Obtaining additional water for new fish and raceways could prove problematic, as Cole Rivers is already utilizing most of its allotted water, and the Rogue River basin is already fully allocated during the summer months. See section on Water Rights for further discussion. Recirculation could reduce the amount of additional water required but must be paired with adequate filtration and disinfection systems such as UV, as high loads of pathogens and disease can be worsened with recirculation instead of single-pass flow systems. Cole Rivers does not suffer from high water temperatures in the way that Rock Creek does but still experienced increased numbers of copepods on Rainbow Trout that were held in recirculation tanks for temporary operations, highlighting the importance of water treatment in addition to temperature control.

Expanded operations would also require the relocation of Rock Creek staff or hiring of additional staff to take on new duties related to the additional fish. Staff retention has notably been an issue at the hatchery, with limited onsite housing available. The creation of new onsite subsidized housing could attract new staff.

2.1.2. Erosion and destabilization of surrounding area

Vulnerability ranking: **Very high risk**

The Erosion Team Assessment/Reduction Team (ETART) assessment from FEMA conducted after the Archie Creek Fire presents warnings of high potential for landslides and debris flow in the area, with major impacts to the hatchery facilities and buildings, access roads, and nearby culverts. The document also warns of the possibility of erosion under the footing of Rock Creek Bridge.

Figure 2.2. Photos of Rock Creek Hatchery showing potential debris flow and landslide areas considered a high risk due to destabilized soils and erosion potential (FEMA 2020).

Figure 2.3. Picture of intact raceways and ultraviolet (UV) ozone system in front of Rock Creek Road, April 2022. The small ozone structure with the green roof is the same one shown in the above pictures from the FEMA report, with burned trees removed and the road more visible, along with visible debris slides at the road level.

The hatchery is considered highly likely to experience damaging debris flow in rain events in excess of 1in/hr due to its steep adjacent slopes and being located on the toe of an active landslide area. The Statewide Landslide Information Layer for Oregon (SLIDO) shows the Rock Creek Hatchery in a “Very High” landslide risk category (ODGMI 2022).

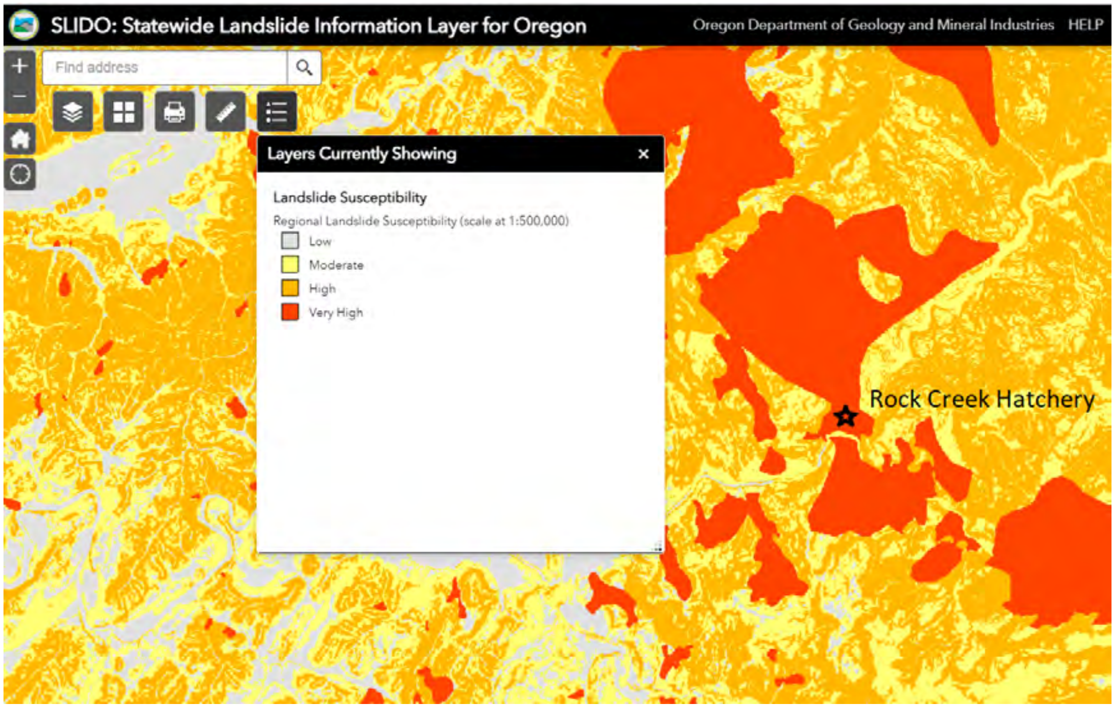

Figure 2.4. SLIDO landslide risk with Rock Creek Hatchery marked in a "Very High" zone for landslide susceptibility.

These risks will likely increase over the next several years as the roots from burned, dead trees on the steep surrounding hillslopes lose their hold in the soil. New plantings in the area will require years to decades to begin stabilizing the slopes again. The access road leading into the hatchery is developing cracks, with visible slides of loose material on the supporting hillside below the road.

2.1.2.1. Alternatives and recommendations

There are a number of steps the hatchery could take to secure operations against these potentially increasing risks due to unstable hillslopes.

2.1.2.2. Communication and alert systems

Alert systems regarding fire are in place and effectively alerted hatchery staff to various levels of response during the Archie Creek Fire. A similar system for landslides and hillslope failures could be put in place with monitoring agencies and emergency management personnel. Creation of such a system would require communication and coordination with county and emergency management contacts.

2.1.2.3. Frequent monitoring of landslide potential

ODFW should frequently engage with agencies at the state and federal level that specialize in geohazards and landslides, with the latter groups conducting ongoing monitoring of the area for stability and safety. Landslide monitoring equipment is available in several different forms, including traditional integrated turnkey engineering equipment and low-cost remote sensor networks. Integrated engineering equipment can easily range from $8,000-80,000, with more expensive options typically being easier to deploy with more sophisticated yet user-friendly software and drawing data from multiple sources and types of sensors. Such an integrated system could include the following instrumentation: inclinometers, piezometers, soil moisture sensors, tilt meters, extensometers, rain gauges, crack meters, laser scanning, and data loggers, and is offered by brands such as Encardio, Slide Minder, Leica, and Trimble.

Low-cost sensor network setups pair many individual sensors with a centralized control station that monitors parameters and sets off an alarm when any parameter surpasses a pre-set "problem" threshold. While the cost of equipment is cheaper for these sensor networks, substantial time investment (and knowledge) is required from the end-user in its deployment and continued use. An example of a network of low-cost sensors was deployed in Sitka, Alaska to monitor landslides at a cost of $940 per node and $165 per hub, with 6 nodes and 2 hubs covering areas several kilometers apart, and the project provided step-by-step open source directions for creation and installation of such a network (Chu et al. 2021).

2.1.2.4. Engineering inspections

Douglas County owns the hillsides and road that surround the hatchery and should conduct engineering studies on the road, with the potential to preemptively brace the area or install supports before the road slumps off, as well as studies of the hillside and its erosion potential and safety risks.

An engineering firm provided an inspection in October 2020 and noted cracked, sagging pavement along Rock Creek Road. The inspection results observed that erosion and runoff could flow to the hatchery from the steep slopes along the north edge of the property but judged that there was sufficient space between the hillslopes and hatchery facilities to prevent runoff and debris from reaching infrastructure.

2.1.2.5. Frequent inspection and debris removal on water intakes

The hatchery should conduct frequent inspection and debris removal on water intakes. Hatchery staff already do this, and the current drum filter may be sufficient in its current capacity.

Improved bar screen and trash rake technology can provide frequent automated removal of debris without manual intervention from hatchery staff. Screens and individual parts can sell for as low as several thousand dollars up to tens of thousands of dollars, but installation costs increase the overall capital investment. A flood management district near Portland installed updated automated Lakeside Muhr trash rakes that reduced cleaning time to 5 minutes instead of an hour (StormH2O 2022). A WWTP in Washington, Indiana retrofitted their 12-foot intake screens with the same Lakeside technology at a cost of $750,000 (Filtsep 2021).

Estimates for installation of 4 different systems on Parker Dam (which handles water volumes of up to 2,000 times that of Rock Creek) ranged from $900,000 to $1.6 million for equipment plus estimated construction costs of $3-4 million (Wahl, Christensen, and Grush 2008). Other companies that sell trash rakes and biologically-friendly screens include Siemens and Atlas Polar, with prices for a 900 cfs turbine project in Rhode Island ranging from $180,000 to $250,000 (Cook 2009). Ongoing maintenance costs are estimated to be minimal and include regular oiling of machinery.

2.1.2.6. Berm or debris diversion structures

To protect lives and structures on the hatchery property, the hatchery could build berms or diversion structures at the base of the hillside so that in case of a hillslope failure, damage to the property can be minimized. The size, siting, and materials of these berms should be determined based on results of engineering and landslide risk assessments of the surrounding hillslope and road. Costs could range from as low as $2 per linear foot of topsoil to more than $70 per cubic yard of large riprap materials (Minnesota Stormwater Manual 2020). The more expensive riprap materials could be used to provide a more permanent solution, both along the west and north sides of the property to protect from debris flow but also to create a fire buffer along the eastern side of the property.

2.1.2.7. Alternate access to hatchery

An old access road to the hatchery is located off Highway 138 by the confluence of Rock Creek and the North Umpqua River. It is currently blocked off with a concrete barrier and highway guard rails, is likely too narrow for modern trucks to use, and would require maintenance to remove fallen trees and brace the steep hillside. The costs of opening and widening this road would be immense, and further study would be required to verify the road's usability. However, it could provide alternate access to the hatchery in the situation that the current main access road closes due to road construction, failure, or flooding, with the potential to be widened through extensive hillside engineering.

Figure 2.5. Example of rocky hillslope lining access road (left). View of narrow access road through chainlink fence, with hatchery roof visible in the distant right side of the image (right).

Figure 2.6. Blocked access from highway (left). Concrete barrier blocking access to old road from highway (right).

2.1.2.8. Revegetation of hillslopes and surrounding watershed

Restabilizing the surrounding watershed through revegetation is an important goal being undertaken with partnering agencies. The process of reestablishing vegetation will be an ongoing effort; efforts by Rock Creek hatchery management to plant 1,500 trees in 2021 were met with heavy losses due to a dry year with low precipitation. Douglas County replanted the hillside with new trees every 15-20 feet in 2022. These partnered efforts should be expanded on throughout the watershed until new vegetation is reestablished.

2.2. Environmental Constraints (Water quality and quantity)

2.2.1. Low flows

Vulnerability ranking: Moderate risk

Rock Creek Hatchery had a volume capacity of nearly 127,000 ft^3 before the fire and used up to 33 cfs of water at its maximum in Water Year 2020. It is allocated withdrawal rates of 30 cfs from Rock Creek and 25 cfs from North Umpqua River, with water from the North Umpqua pumped in during the summer months when Rock Creek experiences low flows (ODFW 2020a, Oregon Water Availability Reporting System 2022).

The following chart shows the water used in Water Year 2020, the last year of the hatchery's normal operations prior to the Archie Creek Fire (ODFW 2020b). Rock Creek serves as the main source of water from the months of November through May, with a nearly full switchover to

North Umpqua water in June through October. Though the permitted use on the North Umpqua is for withdrawals of up to 25 cfs, the hatchery only used a maximum withdrawal rate of 20 cfs in October 2019. Water permitted from an additional creek on the property is used for domestic and irrigation purposes at an amount less than 0.1 cfs.

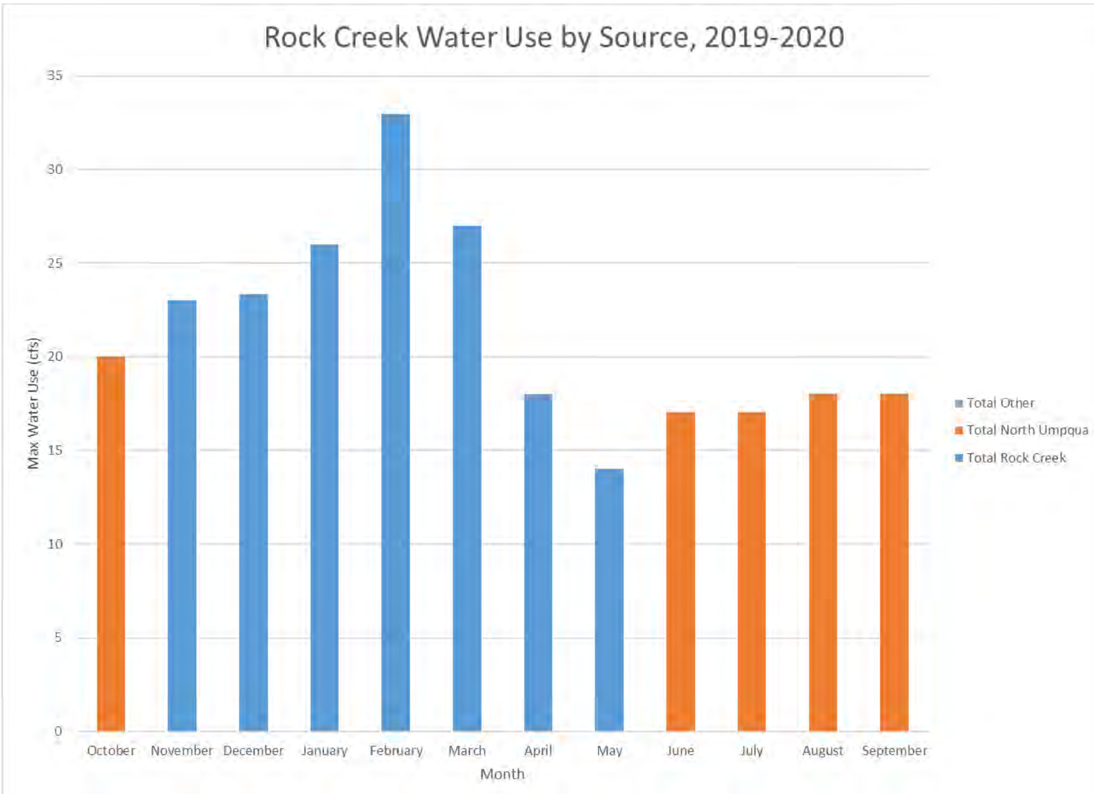

Figure 2.7. Water use by hatchery in 2019-2020, by source.

Rock Creek currently provides enough water to supply operational needs during the winter months but does not provide sufficient flow in the drier summers. The North Umpqua currently supplies enough water for the hatchery's summer requirements. Future trends in the winter availability of water are projected to include higher precipitation and streamflows, which would ensure sufficient streamflow from Rock Creek during that time. Devegetated watersheds will also result in elevated streamflows during precipitation events (FEMA 2020).

The USGS gage at Rock Creek was reestablished after the fire in 2021 and has been recording the temperature and streamflow since that time (USGS 2022a). Streamflow data for the site is also available from the 1950s-1970s (not shown), and mean daily values from that time period are not significantly different from the 2021-2022 data. Low streamflows in Rock Creek are linked with higher temperatures, with both occurring in the dry summers, creating compounding stressors on hatchery operations and fish health.

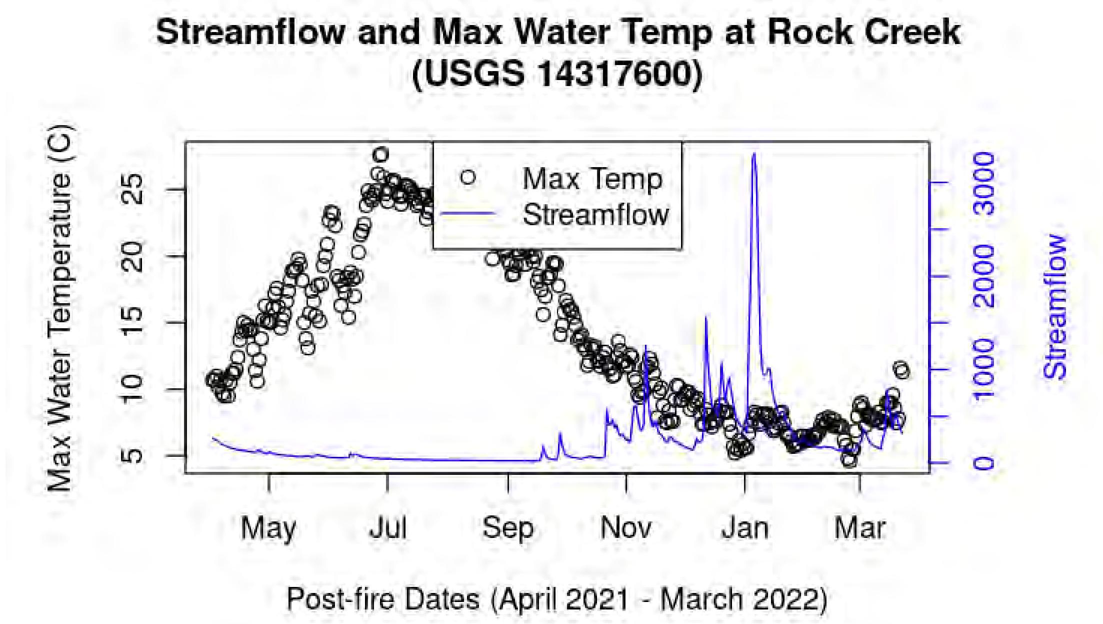

Figure 2.8. Maximum temperature and streamflow values at Rock Creek gage from Spring 2021 onwards.

Trends for nearby water bodies may help determine historical and long-term trends for Rock Creek. The following streamflow graph is for Steamboat Creek, which is located upstream along the North Umpqua River from Rock Creek; this creek was not affected by the Archie Creek Fire but experienced burns from the Jack Creek Rough Patch fire complex in its upper watershed. It has continuous streamflow gage data available since the 1980s, and the trends in streamflow since then show a very slightly decreasing trend line over time (USGS 2022b).

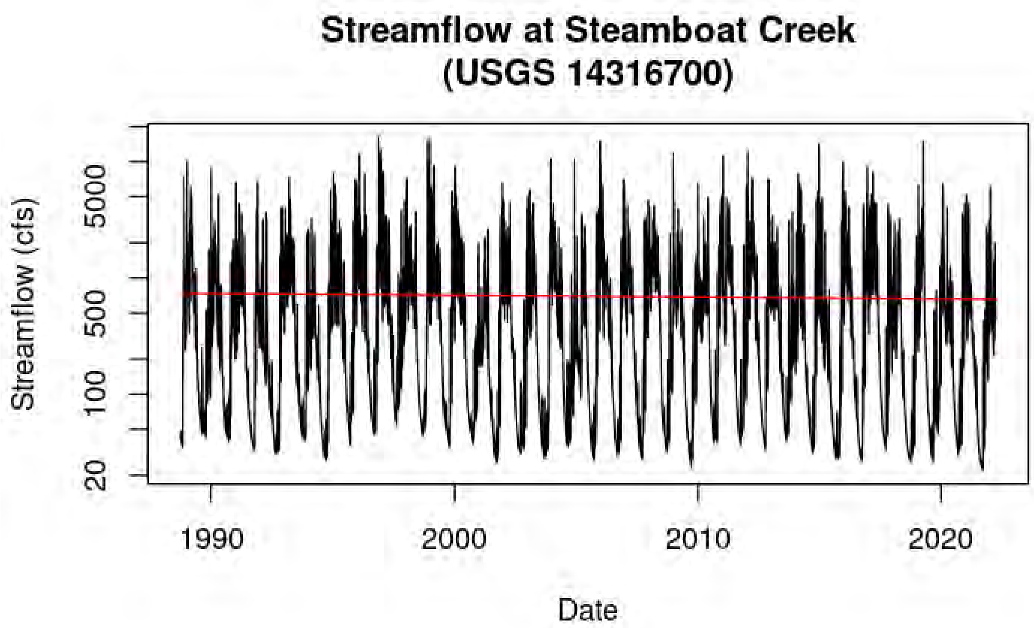

Figure 2.9. Streamflow at nearby Steamboat Creek gage since the 1980s, with regression trendline in red.

The following streamflow graph shows Rock Creek streamflow (blue) alongside Steamboat Creek (red), both experiencing low flows in summer 2021. Rock Creek follows a similar discharge pattern to Steamboat Creek but often with slightly lower discharge amounts.

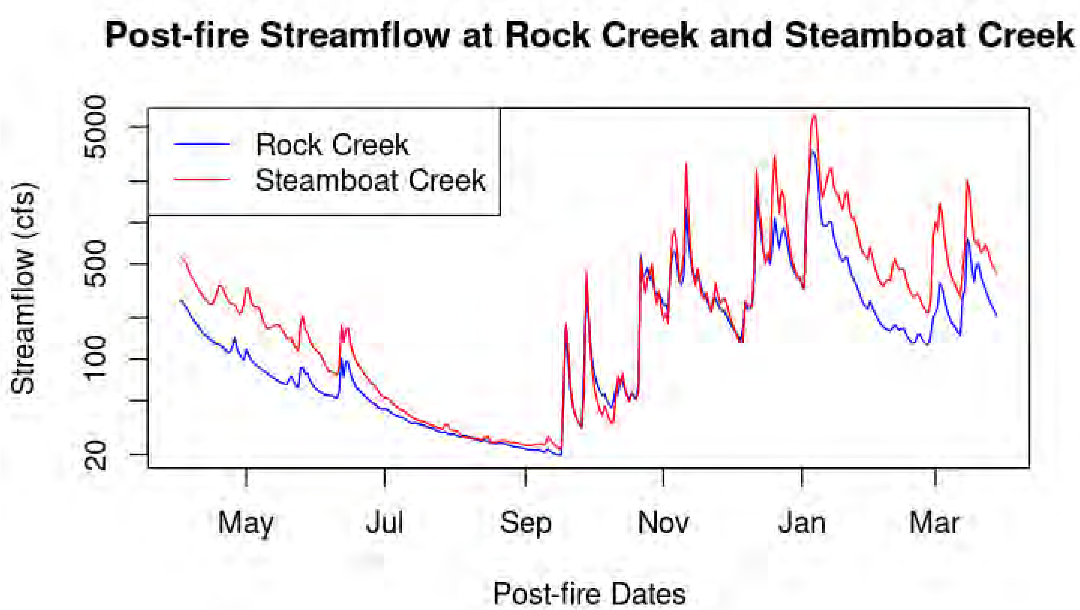

Figure 2.10. Rock Creek and Steamboat Creek streamflows since Spring 2021.

Despite the peaks in streamflow for winter 2021-2022, various observational and predictive datasets show large parts of Oregon, including the Umpqua basin, as being in prolonged drought. The USGS WaterWatch data shows the area experiencing lower than normal streamflows in the Rock Creek and North Umpqua River basins (USGS 2022c). NOAA's NCEP predicts a persistent drought due to the inability of the region to make up for previous deficits in precipitation (NWS 2022).

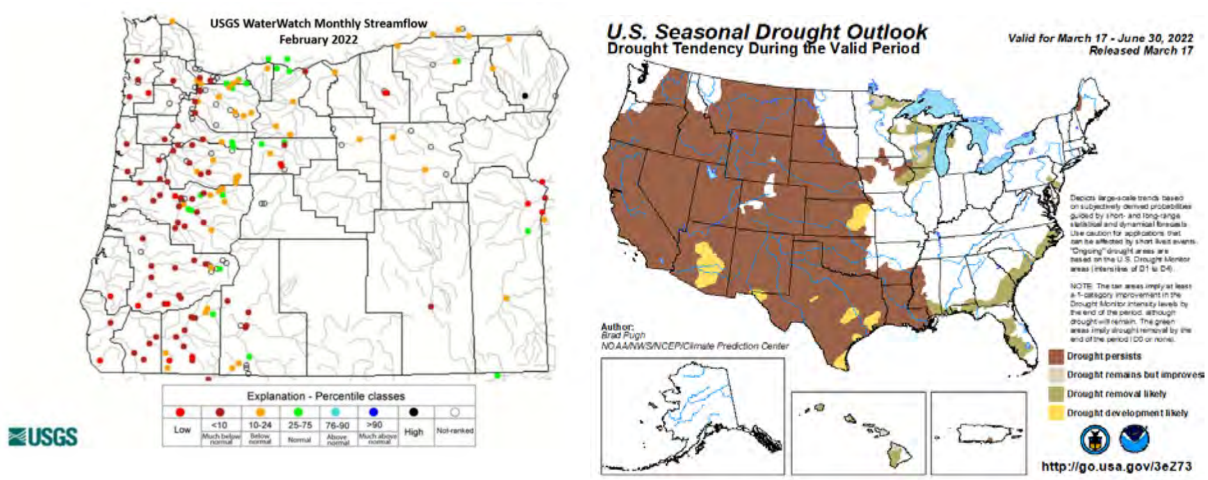

Figure 2.11. USGS WaterWatch streamflow percentiles in February 2022, when the area should be receiving some of its highest precipitation of the year (left). NCEP drought outlook showing predictions of persisting drought for most of Oregon through Summer 2022 (right).

Based on a number of considerations, the University of Nebraska-Lincoln's Drought Monitor shows the North Umpqua and Rock Creek area to be in a D2 "Severe Drought," which can include such impacts as crop and pasture failures, water shortages, and possible imposition of water restrictions (UNL 2022). The current Palmer index from National Integrated Drought Information System (NIDIS) as of March 2022 confirms drought conditions, indicating extreme drought in the North Umpqua Basin based on soil moisture conditions (NIDIS 2022).

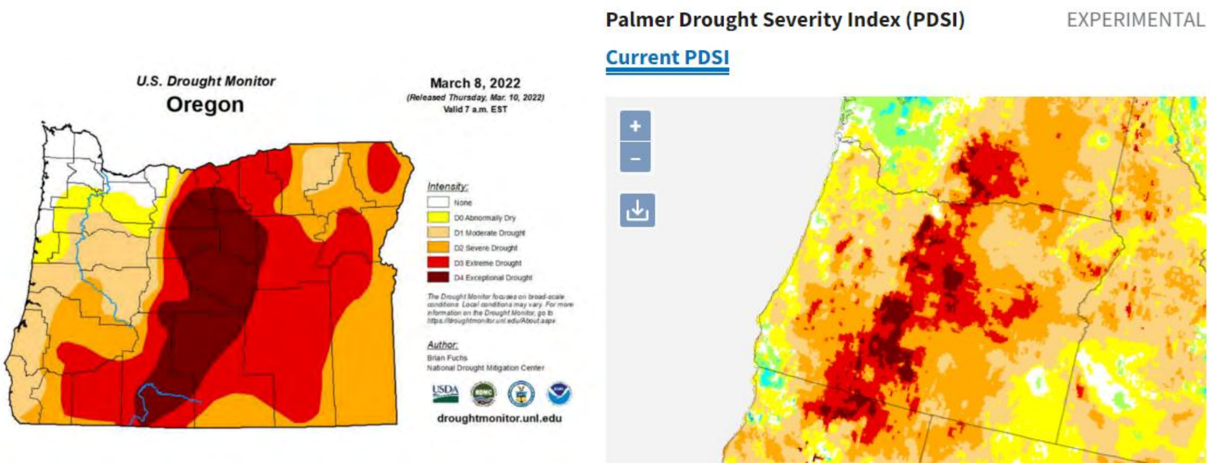

Figure 2.12. Drought Monitor showing Severe and Extreme Drought for areas near the Umpqua basin (left). Palmer Drought Index showing extreme drought (shades of red) areas near the Umpqua basin (right).

The amount of precipitation required to pull the region out of drought would be substantial. NOAA's Drought Reduction Tool shows precipitation amounts of >12" to ameliorate drought in the basin of interest (NOAA 2022).

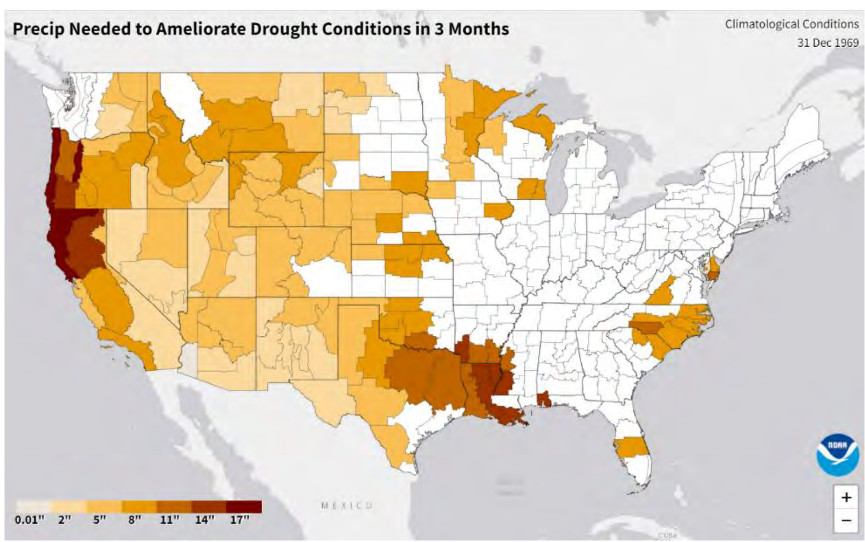

Figure 2.13. Precipitation required to ameliorate drought conditions, with areas near the Umpqua basin requiring around a foot or more.

Variable and decreasing snow amounts will continue to contribute to the prolonged drought of the area, as noted in the following snow graphics showing the North Umpqua River having received only 64% of the anticipated snow for the year in March 2022 based on the 30-year median value (NWS 2022) and 82% of the anticipated snow up to April 2022.

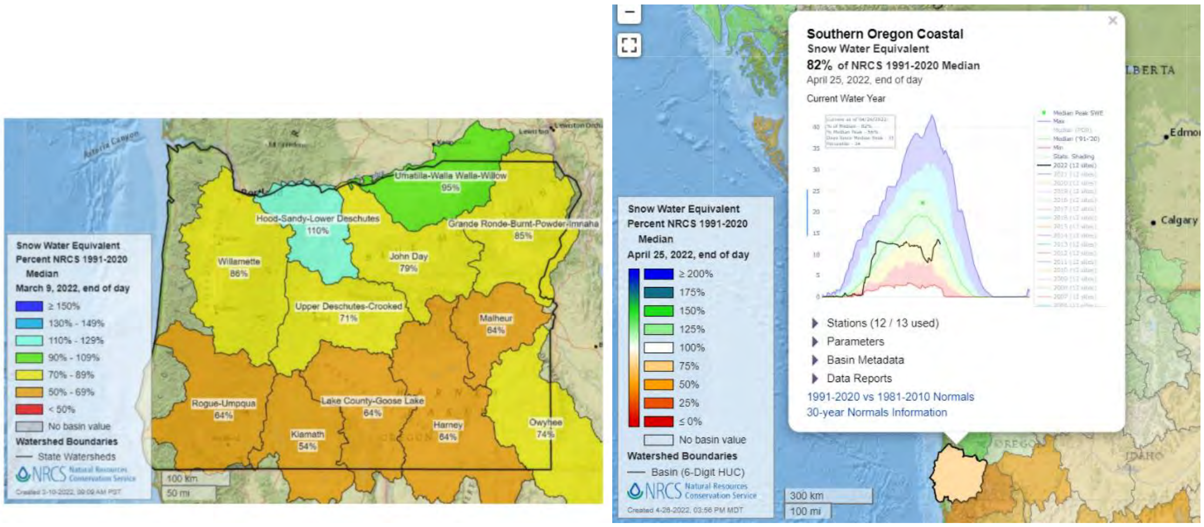

Figure 2.14. Snow water equivalent in March 2022 showing lower than normal snow amounts having fallen in the Umpqua area (left). After a late April snowstorm, the area is still only at 82% SWE compared to historical normals (right).

Observed precipitation and temperature data shows that the area experienced lower precipitation than normal for the January-February timeframe and higher mean temperature during that time (NWS 2022).

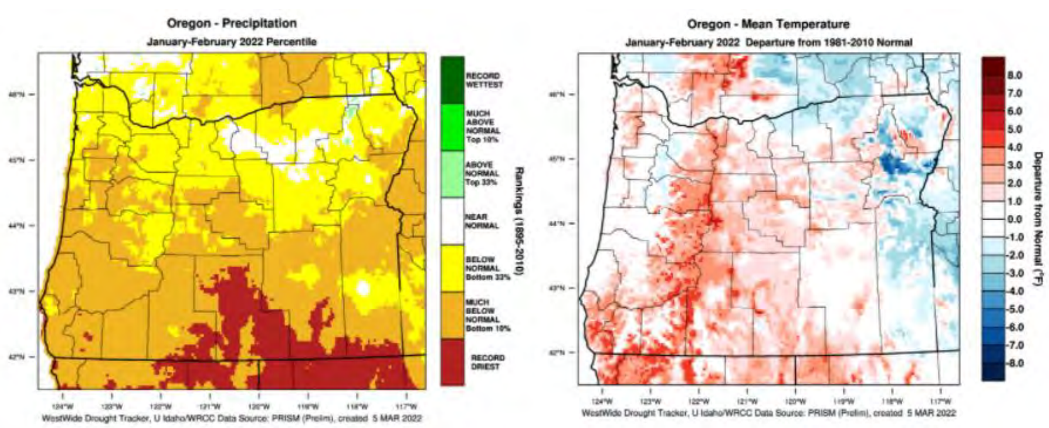

Figure 2.15. Precipitation and Mean Temperature for January-February 2022 showing much below normal precipitation amounts and higher temperatures.

Surface water predictions from the ODFW for years up to 2080 show average monthly decreasing streamflows in the North Umpqua, as well as decreasing summer flows and increasing minimum flows in the fall projected from the USFS work with the VIC model (Sawaske 2021). The surface water report noted that changes in North Umpqua summer flows could be due in part to water management practices at infrastructure upstream in addition to climatic factors.

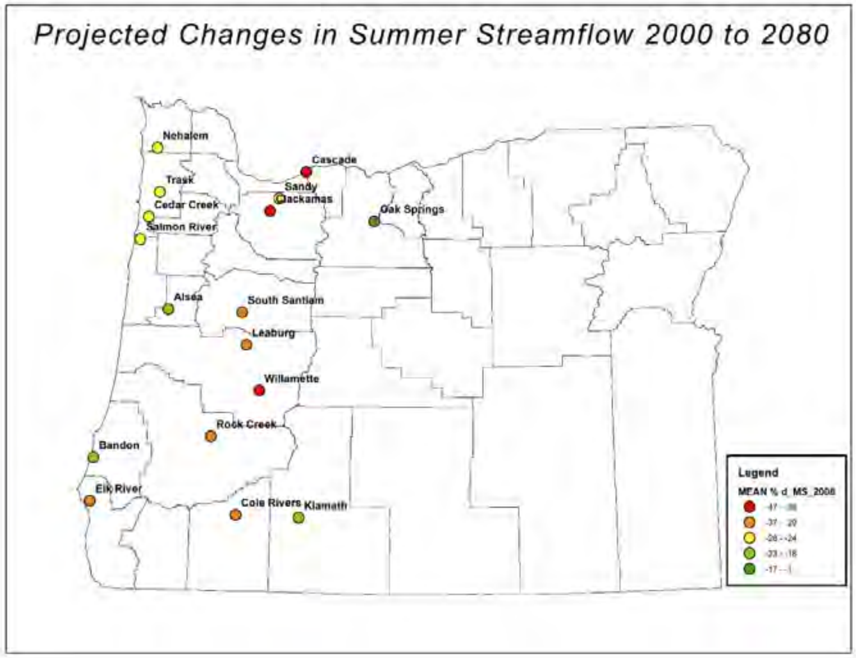

Figure 2.16. Projected changes in streamflows between 2000 and 2080 at state hatcheries, with Rock Creek Hatchery projected to experience significantly lower streamflows by 2080.

These myriad data sources all point to the trends of the Rock Creek and North Umpqua River basin as being likely to experience reduced streamflows in the hotter summer months over the coming decades, though they currently support operational needs.

2.2.1.1. Alternatives and recommendations

Due to likely decreases in streamflows and water availability over several decades, especially during drier, warmer summer months, investment in water-reducing and water quality-improving infrastructure is an important consideration for the future of Rock Creek Hatchery, as a supplement to its senior water rights in the Umpqua basin (see section on Water Rights for further discussion).

2.2.1.2. Recirculation

RAS

Recirculation Aquaculture Systems (RAS) can reduce water use with recycling rates of up to 99%. Water is continuously recirculated through a system and replaced at regular intervals to account for water losses due to evaporation and removal of waste buildup in tanks. Maintaining water quality is of the utmost importance in such a system. Use of RAS technology requires sediment filters to remove particulates, biological filters (with special attention to ammonia treatment), aerators and oxygenation, oxidation and disinfection, pH and water chemistry control, chillers (and a well-insulated building), and circulation pump. RAS setups are more dependent on oxygenation and water quality filtration systems than traditional flow-through ones, and a single point of failure could cause large losses. Setups also take longer than single-pass systems, as the nitrifying biofilter requires weeks to months for beneficial microbes to colonize the filter substrate. Even with close attention, water quality in RAS systems is generally worse than pass-through systems but is still sufficient for fish rearing; the more frequent the removal of waste and the less densely the system is stocked, the better quality the water in the RAS will be (Isla 2008).

Economies of scale benefit RAS setups, with larger RAS setups being more cost-effective per kg of fish. Capital costs are a significant portion of RAS setups (Engle et al. 2020). Example costs from an Atlantic salmon RAS setup are available for 3 production levels with the following components: RAS with dual-drain culture tanks, radial flow settling tanks, microscreen filtration, fluidized sand biofiltration, cascade aeration for carbon dioxide stripping, low head oxygenation for oxygen addition, ozonation, and water chilling (Bailey and Vinci 2020). Costs per kg of the 1,200 MT (metric tons) production level is around $43. This production level is the lowest one in the example study and is still a magnitude higher than the entire pounds out of Rock Creek Hatchery in a given year, so based on this economy of scale, the costs of such a system for Rock Creek's maximum output would likely be much higher per kg. Assuming the same capital costs as the 1,200 MT system per kg, however, Rock Creek's former goal of 130,000 lbs (59 MT) of fish per year would have capital costs of $2.5 million.

A 220,000 MT facility is under construction in Miami for $350 million ($1,591/MT). A RAS system to be built on a defunct pulp mill in northern California is estimated to cost $100 million, with around 10% of that amount going into site remediation and preparation (Chase 2021). A 5,000 tonne, $90 million dollar salmon farm project is in the works in the arid UAE (Evans 2019). These costs equate to $18,000/MT.

Lower capital cost examples do exist, with an 80-tonne steelhead RAS facility in British Columbia that was constructed for $1.1 million, which is more comparable to Rock Creek Hatchery’s production levels and location.

An Atlantic salmon farm with a capital cost of $54 million for 3,300 MT of salmon had operation & maintenance costs of $4.37/kg, including a total of 5,460 kWh of electricity based on the system build ($0.33/kg) (Liu et al. 2016). These estimates are in line with other averages for recirculating systems that have estimated O&M costs around $4 per kg of fish, with half of that going towards feed, 16% to labor and management, 8% towards electricity, and 6% to oxygen and bicarbonate (Vinci et al. 2022). Using these values per kg, Rock Creek would have O&M costs of $260,000, and could increase electricity usage by 30% over its current baseline.

Each RAS unit in a study of Atlantic salmon and disease used 0.8m^3 for various stocking densities, from 453 g per unit up to 4,721 g (~10lbs) (Mota et al. 2022). A study of partial RAS setups at Hagerman National Hatchery used stocking densities six times higher than the Mota studies. Based on the more conservative Mota densities, Rock Creek's total capacity of 130,000 lbs would use a total volume of 10,400 m^3 with an exchange rate of 20% daily (2,080m^3 or 549,478 gallons) at the highest stocking rate for a daily average inflow rate of 0.85 cfs. At the lower stocking rate, Rock Creek’s production would require a total volume of 104,000 m^3 with an exchange of 3% daily (3,120m^3) for a daily inflow rate of 1.3 cfs.

Such rates are in line with anticipated 90%+ recycle rates of RAS systems (with some such as Veolia's RAS2020 boasting recirculation rates up to 99.5%). Even with extensive disinfection systems in place, disease outbreaks are possible and can be more intense than in flow-through systems. Biological filtration systems are more prone to failure due to some pathogen treatments, with treatments such as formalin potentially having negative effects on nitrifying bacteria.

Wastewater and waste products are concentrated in RAS systems, which would provide excellent input to a biodigester. The biodigester (or solar or hydro power) could then be used to offset additional electricity needs.

pRAS

An alternative to implementing a full RAS system is the implementation of a partial RAS system (pRAS), which reuses less water than a full RAS system and typically does not require as much careful maintenance of water quality because the water gets flushed out and refreshed more periodically. Such a system can provide a good balance between water reuse, cost, required maintenance, and fish health. Due to diminishing intake water availability, Hagerman National Fish Hatchery in Idaho began implementing a multi-year phased implementation of a partial RAS system. Hagerman had 66 steelhead raceways in use and intends to replace them with lower water-using pRAS setups. The ultimate production goal is over a million Chinook and 270,000 Steelhead in RAS systems that reuse 95% and 70% of intake water at flows of 0.5 cfs and 3 cfs, respectively. The phases start at 50% reuse water with lower numbers of fish and progressively increase that reuse and numbers of fish in the system over several years' of system buildout.

The hatchery reported on 5 years' worth of trends in the fish in use in these RAS trials. The first year reported RAS fish as having higher body lipid percentage than raceway fish, which can cause delayed emigration from freshwater and possibly impact post-release survival rates but is a result of feed type and amount and exercise strategy. Future years of smolts showed improvements in lipid percentages with improved flow velocities in the tanks and changes in diet and feeding. Over the period of several years hatchery staff appear to have been able to optimize RAS rearing such that pRAS fish do not have statistically different body conditions on release from their raceway counterparts. However, one of these later years shows pRAS fish as having smaller body mass, which could effect post-release survival. The use of a RAS system likely produces fish which can be just as healthy as raceway fish but requires careful attention to water quality, fish growth and feeding, and fish exercise.

2.2.1.3. Filtration

With lower water volumes of summer water sources to dilute pollutants, filtration of available water will become more important in the existing single-pass flow-through raceway setup. Filtration will be of the utmost importance if a RAS system is deployed. Filtration systems that are included in the RAS systems described above include sand filters and membrane filters. Both are effective components at removing algae and microbes, respectively, and can help UV systems work more effectively by removing fine particles.

Rock Creek currently uses drum filtration as well as UV and ozone treatments. The UV ozone system in place treats 2 raceways and could be expanded with an additional 5-6 units to cover the remaining raceways even without installation of a RAS. Staff training will be required to safely use the UV ozone system. Commercial-grade UV filters capable of flow rates up to 52,500 gph are available at costs starting at $10,000 per unit (Aqua Ultraviolet 2022). Lamps, quartz sleeves, and seals require replacement every 1-2 years. A 240-Watt UV-Ozone inline system capable of treating flow rates up to 7,200 gph per unit costs $3,172 each.

Examples of full-system costs to hatcheries include the following two scenarios (Fish Site 2010). A closed vessel system for a 3,000-gpm TrojanUVLogic treatment setup required $228,708 in capital costs with $11,242 annual maintenance and operating costs. A 5,000-gpm open vessel system for a different hatchery using a 48-lamp TrojanUV3000Plus cost $328,400 with annual operating costs of $15,456. Rock Creek Hatchery would require a system with costs greater than the latter setup if it were to treat its maximum withdrawal amounts and to add ozone treatment.

2.2.1.4. Relocation of fish to hatcheries with higher streamflows

Several hatcheries are anticipated to have future streamflows similar to what they are currently. Summer operations could be relocated to these other hatcheries, requiring numerous tanker truck trips, coordination with the receiving hatchery, and possible relocation of staff. See previous section on relocating fish and hatchery operations for further discussion.

2.2.1.5. Revegetation and restoration of watershed

Revegetation of the Rock Creek and North Umpqua watersheds will gradually help restore flow regimes, with lower peak flows and more gradual release of water to streams as the soil recovers from the intense burns. While this restoration cannot address lower overall water availability to streams in the summers from precipitation, it can mitigate the current post-fire impacts.

2.2.2. Groundwater availability

Vulnerability ranking: Low risk

Rock Creek Hatchery constructed 4 different wells in the 1970s and 1980s (OWRD 2022c). One of these wells was a test well, and the remaining 3 produced yields of 1, 12, and 12 gpm with the stated intention of being for domestic use. The higher yield wells had a depth to water of over 180 feet, found below approximately 50 feet of sand, gravel, and clay, with the remainder below that being basalt. In the lower Rock Creek watershed there are approximately 34 wells, constructed between the years of 1961-2021; the majority produce yields below 10 gpm.

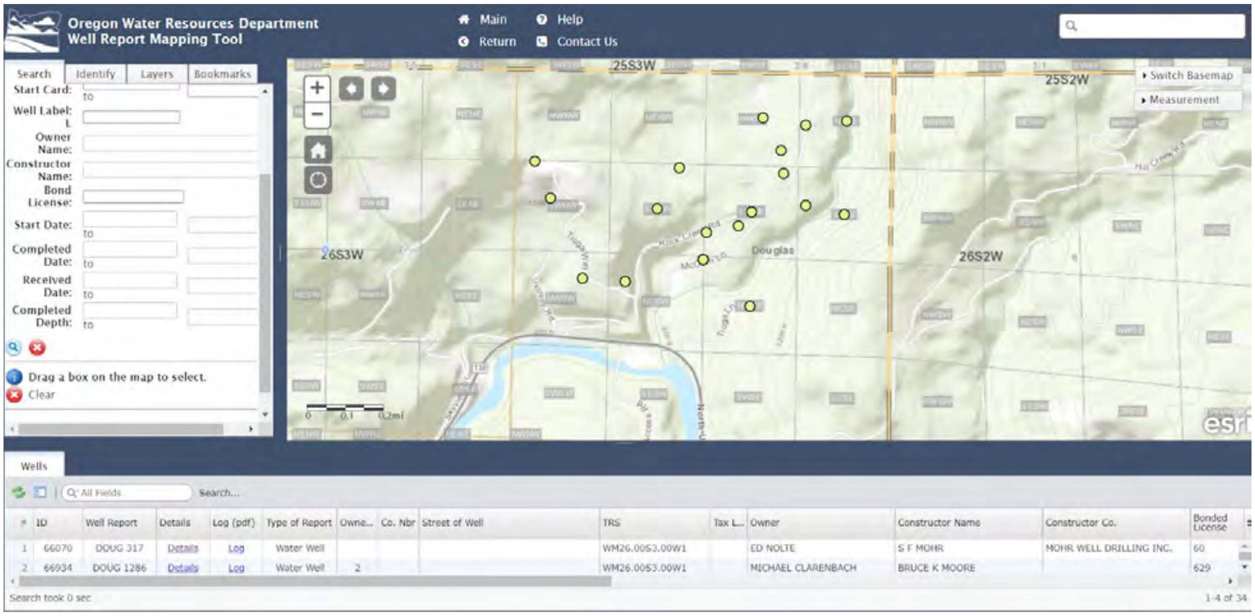

Figure 2.17. Wells in the proximity of Rock Creek Hatchery.

USGS Groundwater Watch as of late March 2022 shows below normal groundwater conditions in the areas of south Oregon nearest to the Umpqua Basin (USGS 2022d).

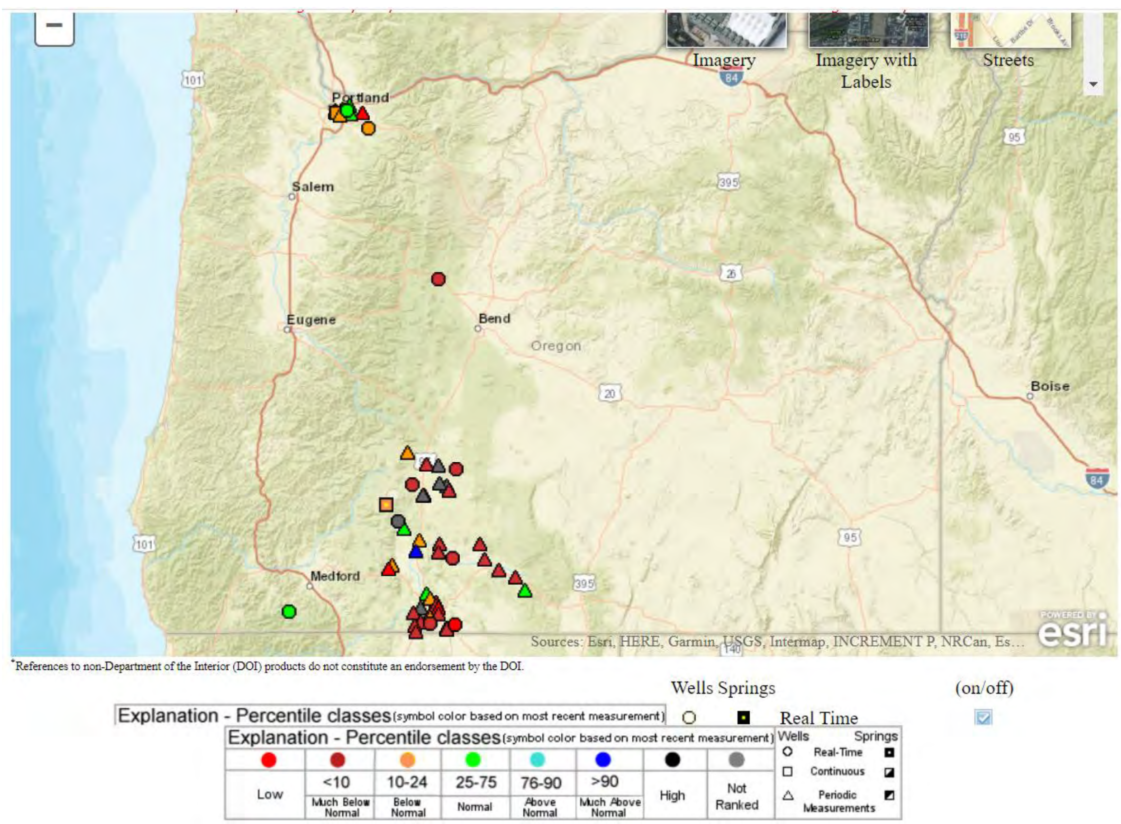

Figure 2.18. USGS GroundwaterWatch showing a number of below normal groundwater levels at wells in southern Oregon.

Rock Creek Hatchery does not currently utilize groundwater in its operations. Many groundwater wells across the southwestern portion of Oregon are at much below normal levels, and the wells constructed at the hatchery in the past produced yields too low for fish production needs, so it would be unnecessary to attempt to use groundwater directly for Rock Creek's operations. See section on water temperatures for a discussion in indirect groundwater usage.

2.2.2.1. Alternatives and recommendations

None necessary.

2.2.3. Water rights and availability

Vulnerability ranking: Low risk

Permits to increase the hatchery's surface water withdrawal allocations from Rock Creek were issued in 1923, 1928, 1936, and 1947, and from North Umpqua in 1976 (OWRD 2022a). The hatchery sold its rights to an additional 7 cfs of North Umpqua withdrawals to Douglas County, showing a history of having sufficient water for operations. Due to the age of the permits, the hatchery is unlikely to lose access to North Umpqua River due to the principles of prior appropriation and the hatchery's seniority in the North Umpqua basin, even if the North Umpqua experiences reduced streamflows to the point of requiring water use restrictions (OWRD 2022b). Water availability during winter months from Rock Creek is not projected to be a problem, with the potential for increasing winter flows. However, the North Umpqua does not have any remaining available summer flow and is projected to have decreasing summer flows, so the hatchery should operate under the assumption that there will not be any possibility of expanded operations in the low flow summer months (OWRD 2022a).

The value of Rock Creek Hatchery's water rights now and into the future is substantial; new allocations for water withdrawal are difficult to obtain across the state, and most streamflow in summer months is fully allocated. In the early 2000s, South Umpqua water was worth $85 per acre-foot in a 5-year lease bought by Oregon Water Trust. At that price point, withdrawal of 30 cfs for the hatchery would equate to 21,700 acre-feet per year, which would cost $1.8 million on a similar 5-year lease in 2003 dollars.

The value of water rights is expected to increase with decreased availability and increased scarcity. Prices for water rights will vary based on locations, sellers' water uses and perceived opportunity costs, seniority, and lease length (Butsic and Netusil 2004). The buying and approval process for new water rights, when available, and transfer process for changes to existing rights can take up to several years (Barter, Bellis, and Smith 2017). As such, Rock Creek Hatchery's established senior water rights in the North Umpqua basin will be invaluable in the ability to restore any hatchery operations onsite in both the immediate future and longer-term.

2.2.3.1. Alternatives and recommendations

None necessary. Even if summer operations at the hatchery are reduced, ODFW should consider utilizing at least some portion of the North Umpqua water rights so that those rights are not taken away after 5 or more years of disuse.

2.2.4. Increased temperatures

Vulnerability ranking: **Very high risk**

The North Umpqua River Basin has had a Total Maximum Daily Load (TMDL) in place since 2006 for temperature (ODEQ 2006). Rock Creek and the North Umpqua River segments near Rock Creek Hatchery are on the 303(d) list as impaired streams for failing to meet the thermal requirements for both core cold water habitat (16°C) and spawning habitat for salmonids (13°C). High temperatures for this area are a familiar phenomenon; Rock Creek hatchery temporarily closed in the 1970s due to high temperatures and low streamflows that required facility reconstruction (ODFW 2020a).

Modeling information from an ODFW climate study shows potential increases of 1.5°C by 2040 and 2.5°C by 2080 (Dunn 2021).

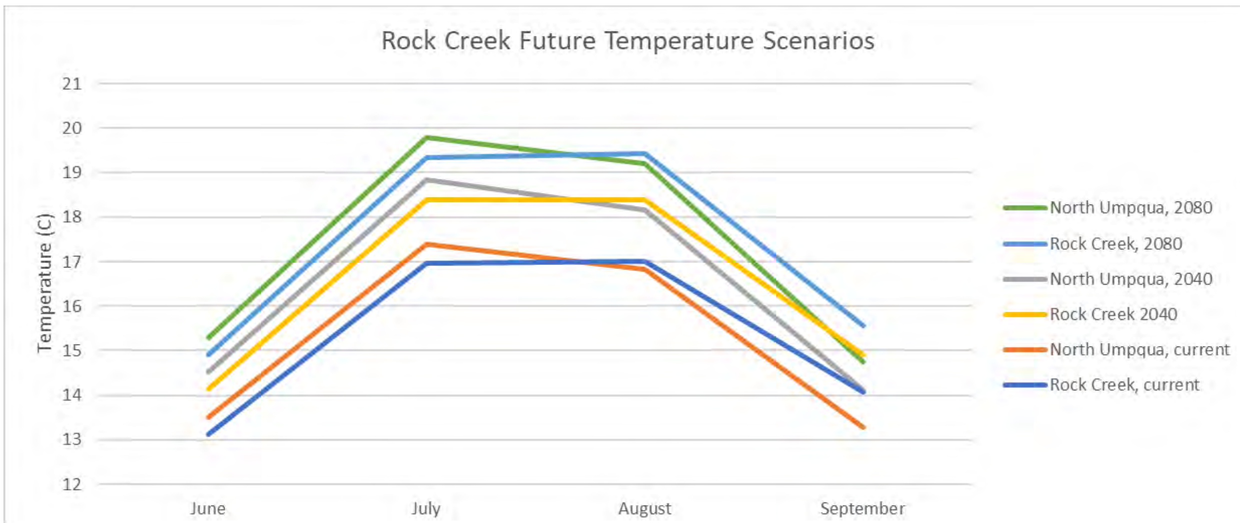

Figure 2.19. Rock Creek temperature scenarios comparing current temperatures to those modeled for 2040 and 2080.

Rock Creek's temperatures before the Archie Creek Fire already reached problematic maximums during the summer months, as seen in this dataset from 2016-2017 that includes daily minimum and maximum temperatures and a green line denoting biologically-based temperatures necessary for salmonid health.

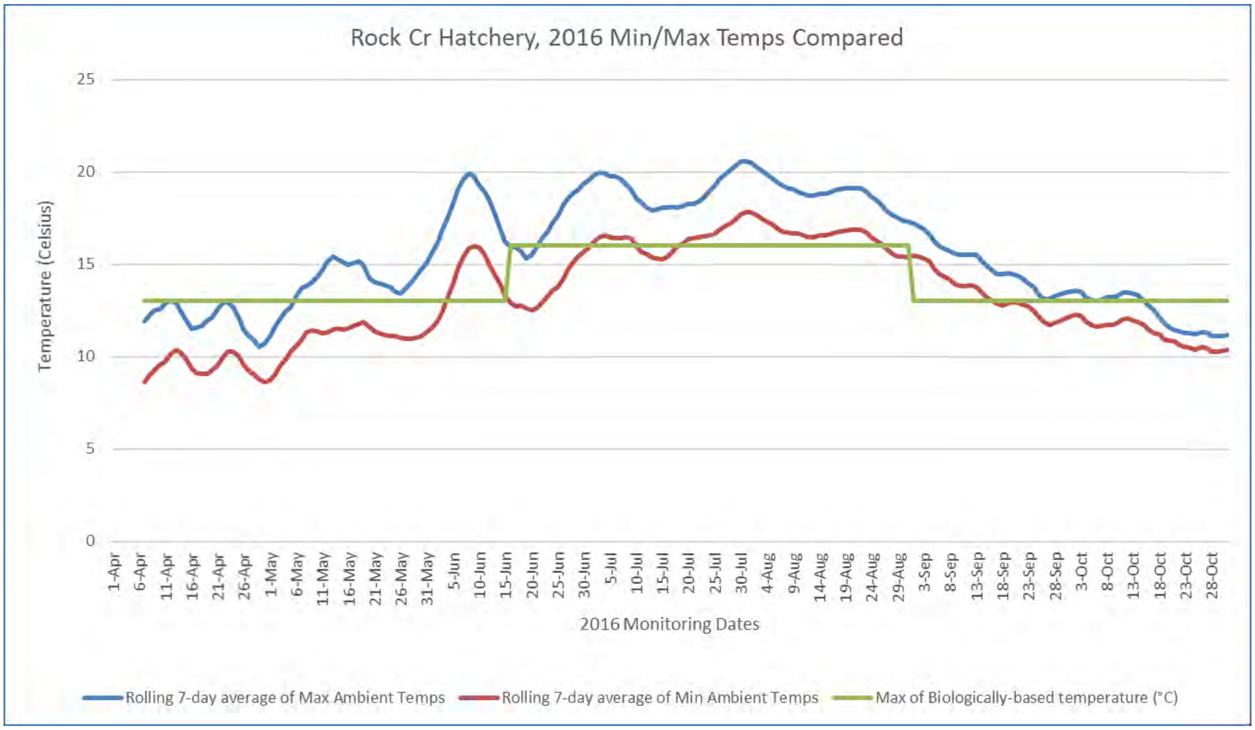

Figure 2.20. Modified from temperature data for 2016-2017 for Rock Creek Hatchery (ODFW 2016).

The restored USGS gage at Rock Creek shows this trend to have been in place in 2021-2022 as well, with single-day summer maximum temperatures reaching upwards of 28°C and with a daily mean above 20°C for all the summer months.

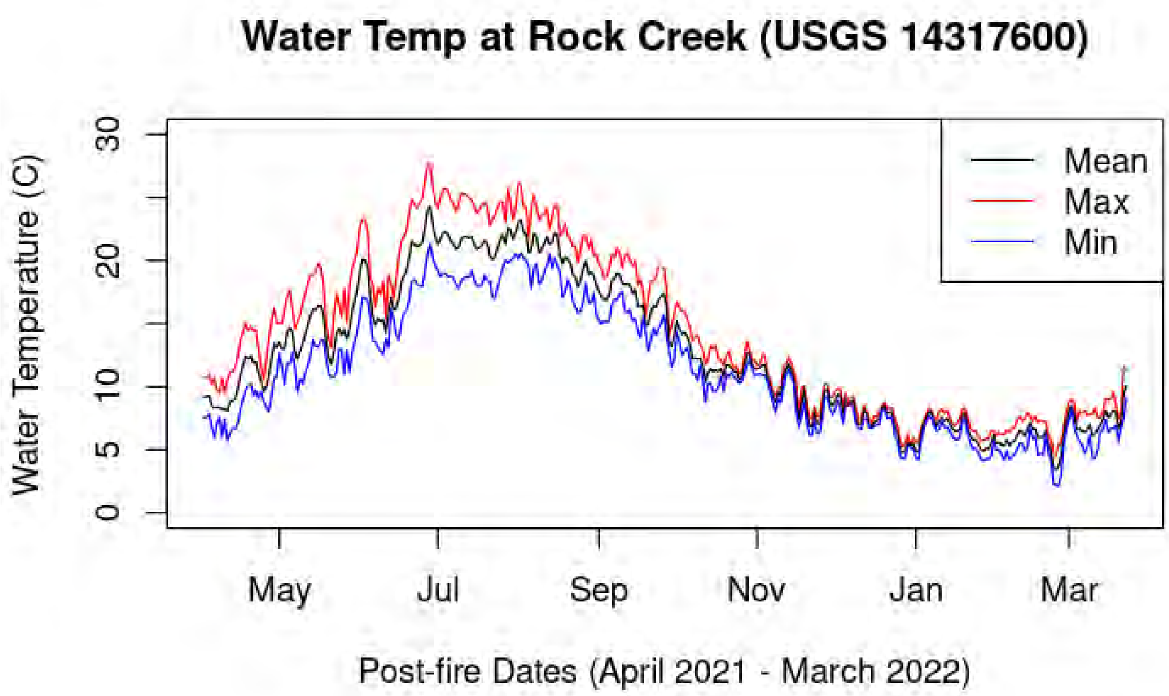

Figure 2.21. Water temperatures at Rock Creek gage from April 2021 onwards.

To get an idea of how those temperature trends vary from before the fire, Rock Creek temperature data can be compared to the North Umpqua River, which has had its water temperature recorded at a USGS gaging station since 2007 (USGS 2022e). Summer temperatures are higher in post-fire years than the years immediately preceding the fire, and there is an increasing trend over the dataset.

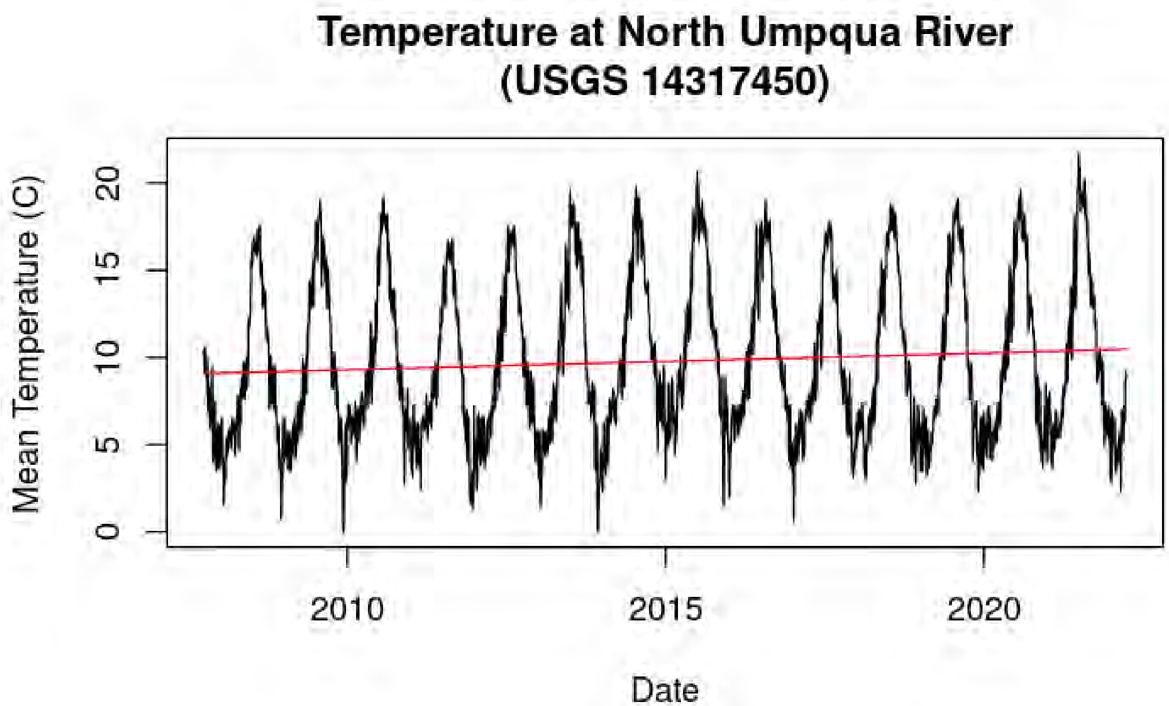

Figure 2.22. Temperatures at North Umpqua River near Rock Creek since 2000s.

Rock Creek's thermal regime tracks the North Umpqua's, so the trends in the North Umpqua are likely applicable to Rock Creek, with elevated daily mean temperatures long before the Archie Creek Fire. A similar trend can be seen in the temperature data at USGS gage 14318000 for the Little River, a tributary to the North Umpqua downstream of Rock Creek (not shown), reinforcing that the entire Umpqua basin is experiencing rising temperatures.

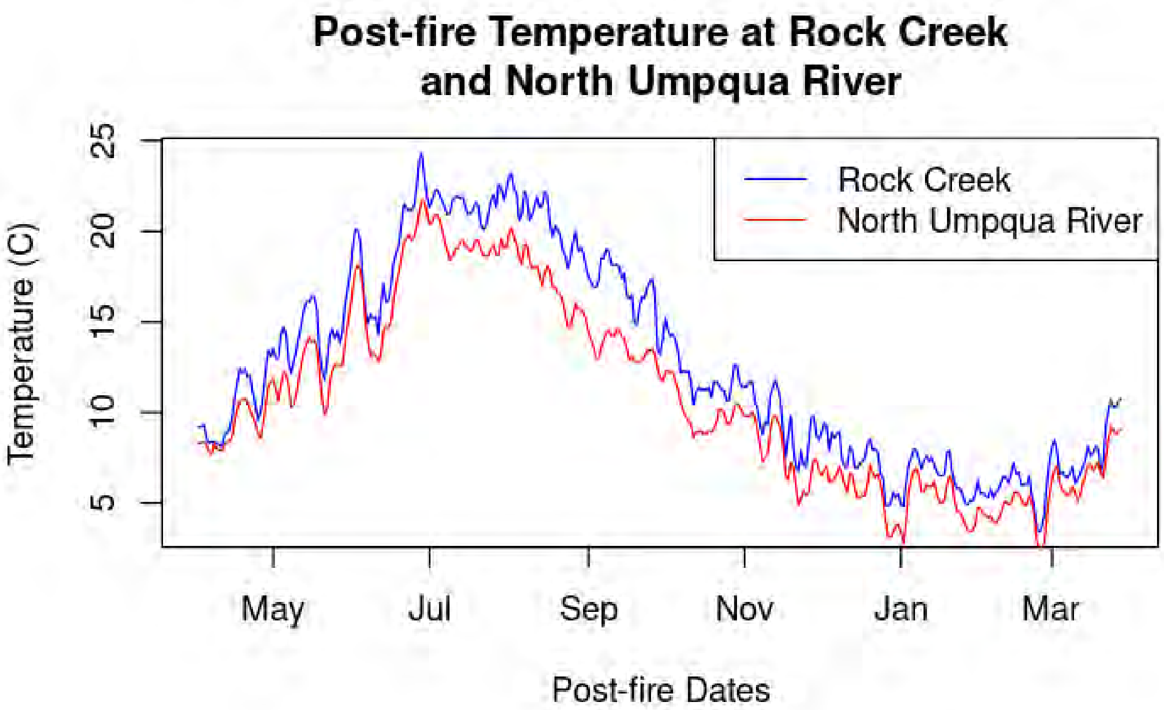

Figure 2.23. Temperatures at Rock Creek and North Umpqua since April 2021.

The Archie Creek Fire placed this area on a worst-case trajectory for temperature as vegetation in the watershed and riparian cover regenerate over the next decades. Temperatures can be expected to stay elevated in areas that were already experiencing increasing thermal stress with an intact riparian buffer.

Salmonids are particularly sensitive to higher temperatures. The lethal temperatures for general salmonids at various life stages can be found in the following table, with slight variation between different species (modified from Carter 2008). It is important to note that these listed temperatures reflect constant, chronic (greater than seven days) exposure to these temperatures with no break. These thresholds are the collated results of numerous studies, many done in controlled laboratory conditions that lack the spatial and temporal heterogeneity of temperatures in real streams with diurnal variations (which provide space and time with lower temperatures).

Additionally, increased water temperatures in the wild can equate to lower dissolved oxygen and a subsequent decrease in invertebrates and food sources, which does not reflect a hatchery setting in which fish can be fed until they are satiated. Furthermore, these temperatures do not reflect the degree of adaptability that has been exhibited within different salmonids, particularly with regards to acclimation. Populations even within the same species have exhibited tolerances for water temperatures varying by several degrees, based on their geography, the temperatures of the waters in which they typically migrate, and periods of acclimation to higher temperatures (Myrick and Cech Jr. 2005, Farrell et al. 2008).

Because of these additional factors, it is possible to find salmonid populations thriving even in areas where water temperatures reach the high 20s (°C). These listed lethal temperatures are general guidelines, but they still point to potential trouble within the North Umpqua River basin as temperatures rise, especially for migrating and wild salmonids during the summer.

Lethal Temperature Thresholds

Lethal Threshold[1] (°C)			
Life Stage	**Steelhead**	**Chinook**	**Coho**
Adult Migration and Holding	24	25	25
Juvenile Growth and Rearing	24	25	25
Spawning, Egg Incubation, and Fry Emergence	20	20	20

[1] The lethal thresholds selected in this table are generally for chronic exposure (greater than seven days). Although salmonids may survive brief periods at these temperatures, they are good benchmarks from the literature for lethal conditions.

Figure 2.24. Lethal temperature thresholds for salmonid life stages at chronic exposure (modified from Carter 2008).

The gage at Rock Creek recorded maximum temperatures above the listed lethal threshold for adult and juvenile Steelhead, Chinook, and Coho Salmon for several days in the 2021 summer months, though they were not back-to-back or chronic, and mean temperatures were below the lethal threshold. Temperatures mid-May through mid-September were generally above 20°C.

As the hatchery draws water from North Umpqua River during the summer rather than from Rock Creek itself, conditions for fish within the hatchery were a little better in terms of inflowing water temperatures. North Umpqua River temperatures were generally a few degrees lower than Rock Creek during this period, and the daily mean stayed below 20°C except for 1-2 weeks in the early part of the summer. However, temperatures reached daily maximum temperatures over 20°C most days between June and August. As noted above, the summer temperatures in the basin have shown an upward trend and are likely to see that trend continue.

Not all species represented at the hatchery are affected to equal degrees by these high temperatures due to the timing of their life stages. The earliest of the Fall Chinook adults arriving between August and November, with peak spawning in October, could be subjected to high temperatures within the North Umpqua basin in the August time frame. Late-arriving Spring Chinook collected between April and June could face high temperatures in June. Adult Rainbow Trout are subject to high temperatures when they are collected during the summer, as are the majority of juveniles which are released at the end of the summer.

Coho adults are unlikely to experience high temperatures, with the earliest arriving at the end of September, and smolts released in early April. Likewise, Winter Steelhead adults are collected from January to May and should not face high temperatures. Summer Steelhead were vulnerable to high temperatures, being released in April and in returning from June to November, but this program has been stopped at Rock Creek Hatchery.

Juveniles that over-summer for the various species prior to their releases would benefit from cooling of hatchery water during the hottest summer months.

2.2.4.1. Alternatives and recommendations

Due to the clearly increasing stream temperatures, devegetation of cooling cover, and the potential thermal stress on fish and decrease in fish health, addressing temperatures in the Rock Creek and North Umpqua streams is imperative.

2.2.4.2. Artificial shade cover

Rock Creek has already begun using shade cloths over some of its raceways, and the fish, which are prone to sunburn, are said to appear "happier" in the shaded sections. The amount of riparian vegetative cover and the shade it provides is especially important in controlling temperatures in smaller, shallower streams without much groundwater input (Cristea and Janisch 2007, Johnson and Wilby 2015, Sparrow 2018). Artificial shading has been used with varying success on decreasing stream temperatures, with some streams having their temperatures decreased by up to several degrees C (Ebersole 2007, Fink 2008, Anderson 2017). Substrate likely plays an important role on the thermal regime, with bedrock streams having higher maximum daily temperatures and larger daily ranges compared to streams with alluvial deposits and gravel substrate, possibly linked to hyporheic exchange and increased hydraulic residence time (Johnson 2004).

Artificial stream shading (experimental reach) located at Lost Creek restoration site Portage County, WI.

Figure 2.25. Example of 70% shade cover on creek in Wisconsin (Anderson 2017).

Speelyai Hatchery in Washington used sprinklers to create makeshift shade for Spring Chinook, but saw losses on average of 17% annually. The hatchery installed shade covers in an A-frame style over raceways and saw a reduction in brood mortality, down to around 7% annually. Fish appeared to be less stressed and had move room to spread out over all the shaded areas, and shade covers reduced algal growth and predation, though these covers make it more difficult to move hoses and pipes around and reduce visibility across the hatchery property.

An advantage of shade cloth is that it can be partial opacity and only block a portion of incoming sun, but it could require maintenance or replacement especially as a result of storm events. An advantage to a hardened cover would be that solar panels could be housed on the roof to provide electricity for the hatchery. Both options could provide immediate reduced maximum temperatures in the raceway, possibly up to several degrees C since the raceways are similar to bedrock stream with no groundwater inputs or hyporheic exchange to temper higher temperatures. Both options also have the potential to reduce algal growth by limiting sunlight.

Table 2.9. Shade option example costs

Design Option	Size	Cost per unit
Custom cloth industrial hatchery covers	10’x10’ with open sides (Weatherport 2022)	$1,653 (plus delivery); up to 500 units to cover 50,000 square feet for a total of $826,000
90% bulk shade cloth	32-foot by x feet cloth (Greenhouse Megastore 2022)	$17 per foot; up to 1500 units for a total of $25,500 (hardware already available to attach shade covers)
Prefabricated hardened roof shade structure	Prefabricated solar pergola, custom sizes and designs but pricing shown for 10’x10’ without solar panels (West Bay Energy 2022) (see section on solar power for additional discussion)	$1500; up to 500 units to cover 50,000 square feet for a total of $750,000
	Prefabricated carport, 24’x25’x6’ (from Alans Factory Outlet)	$2,744.50 each; up to 83 units to cover 50,000 square feet to for a total of $228,000

The raceways provide more than adequate area for a solar installation, so covering the entire available space is not necessary from an electricity-generating standpoint. Partial shade cover could still provide cooling, shaded habitat, and solar power at a lower cost than what is listed in the table. However, shaded cover of water in the raceways can only mitigate heating occurring on the Rock Creek property and will not help decrease water temperatures in the surrounding basin.

2.2.4.3. Engineered cooling and chillers

Water chilling systems could be used to reduce the high summer water temperatures within the hatchery. A chilling system would need to be installed so that water coming into the hatchery is chilled before it enters the raceways.

Current surface water withdrawal rates

It is estimated that it would take up to 5,625 tons of cooling to reduce an incoming 30 cfs of water to within biological acceptable limits (FPL 2022). Within the industry a rough estimate of the cost of installing a new chilling plant is between $1,500 and $1,800 per ton of required cooling. This means a rough estimate cost of installing a new cooling plant at Rock Creek could be between $8.4 million and $10.1 million. The plant would also significantly increase the electricity requirements at the hatchery. There are two companies that make chillers powerful enough to meet the demand at Rock Creek, Carrier and York. Both systems are custom designed for the site conditions and project requirements and would require the construction of a building to house the system. Quotes for these systems are currently in progress.

Table 2.10. Chiller Systems

	AquaEdge® Water-Cooled, Custom-Design Centrifugal Chiller 17DA	Titan™ OM Custom Design Centrifugal Chiller
Company	Carrier	York
Chilling Capacity	5,500 Tons	5,500 Tons
Source	Carrier 2022	York 2022

Recirculating system surface water withdrawal rates

Incoming surface water flows to a RAS system would have substantially lower cooling needs. With incoming flows of 1.3 cfs, summer cooling of North Umpqua River surface water could require 3 million BTUs/hr or 250 tons, to cool water to 20°C from a high of 25°C. (This maximum temperature is higher than current North Umpqua max temperatures but is within easy reach in the coming decades. Refreshing water during the coolest parts of the night could lessen the necessary temperature change but would require a chiller that could chill larger volumes of water at once, increasing the chiller tonnage and thus capital costs.) Such needs for a chiller are still large but realistic, with new 50-ton chillers available from $45,000 per unit and 200-ton chillers from $180,000. These chillers typically run on a 460/480V 3-Phase power supply and are comprised of refrigerant, compressors, fans, condensers, evaporators, and water pumps. Air-cooled chillers have an anticipated lifespan of 15-20 years but are cheaper to build than water-cooled chillers that have a lifespan of up to 30 years. Chillers run at maximum efficiency at around 75% of capacity and thus should be sized up when possible.

Annual O&M costs include cleaning tubes, with estimated annual costs for a 200-ton chiller plant of $122,400. Air-cooled chiller power costs for a 1200-ton chiller in the San Francisco area as of 2018 were estimated to be $0.05 per ton-hour (Sharma and Anand 2018). Similar power cost estimates for a 250-ton chiller system for Rock Creek running 24/7 for 3 months of the year (June-August) would produce a cost of $25,000 for the electricity to run the chiller over a small volume of recirculating water. Based on current North Umpqua River temperatures, the chiller could actually run less frequently, reducing power and maintenance costs.

With withdrawal rates such as those required by a RAS, cooling needs would be significantly reduced, and chillers could reasonably be used to cool water.

2.2.4.4. Groundwater and geothermal

Greater utilization of colder groundwater during summer could compensate for the anticipated increases in warmer surface water temperatures. Leavenworth National Hatchery in Washington faced a similar situation to Rock Creek Hatchery, in raising salmon in waters with elevated temperatures. The national hatchery began a study to see if temperatures of warm inflow waters were significantly lowered by percolating warm effluent through the ground to recharge wells (Wenachtee World 2015). Based on initial results, six of the seven wells tested appeared to effectively lower water temperatures enough such that the recharged groundwater could be used for hatchery operations.

Based on well data in the Rock Creek area, groundwater temperatures are 58°F (14°C) or lower (as low as 53°F in one well test), but the depth to water could be over 180 feet through basalt, and groundwater yield near the hatchery does not appear to be sufficient to meet production needs as a replacement for warmer surface water. If groundwater were to be mixed in with the surface water at current withdrawals, a single 10 gpm well would not be able to cool the inflow supply by even half a degree F. Due to the quantity of groundwater required to cool surface water any noteworthy amount and estimated well withdrawal rates in the area, the use of groundwater for cooling at the Rock Creek Hatchery is only plausible in conjunction with recirculation systems.

With the use of a RAS system with inflows of 1.3 cfs and groundwater temperature of 14°C, 0.6 cfs of groundwater would be required to cool 0.7 cfs of surface water from 25°C to 20°C. These groundwater requirements are still higher than yields in the surrounding area (with individual well tests yielding 0.02 cfs at the hatchery several decades ago). Smaller ratios of groundwater to surface water would be required with lower maximum surface water temperatures and could be mixed in only during those hottest weeks during the summer, reducing groundwater needs further. However, with general groundwater levels being below normal in southern Oregon, developing new practices at Rock Creek Hatchery that depend on groundwater for mixing and cooling of surface water should be approached with caution.

Regardless of whether groundwater itself were used in operations, the constant lower temperatures underground could be used to cool surface water through the use of geothermal systems or deep-well injection technology.

The use of geothermal cooling on Rock Creek Hatchery's pre-fire withdrawal rates is not recommended due to the magnitude of Rock Creek's cooling needs at its maximum summer withdrawal rate. The amount of underground loops and subsequent land necessary to provide sufficient cooling and removal of BTUs from the system would be in the scope of acres or hundreds of vertical boreholes, and would likely end up overloading the receiving grounds with such heat that the system would no longer function after a certain point.

Even if all the land on the Rock Creek facility were available for use in installing a geothermal system, initial installation costs would be incredibly expensive. Rock Creek's cooling needs at a maximum summer withdrawal flow rate of 25 cfs with a necessary temperature change of from 25°C to 20°C equates to 61 million BTUs/hr or 5,000 tons, as noted in the section about chillers, which would require initial costs of over $39 million based on average installation costs of $7,500 per ton (NREL 2022).

Incoming surface water flows to a RAS system would have substantially lower cooling needs but would still require a sizable investment for a geothermal system. With incoming flows of 1.3 cfs, summer cooling of North Umpqua River surface water could require 3 million BTUs/hr or 250 tons. A geothermal system for these recirculation volumes would have an installation cost of at least $1.2 million and would require thousands of feet of drilling for underground loops and boreholes.

A geothermal system must be sized with careful considerations to the maximum anticipated temperatures in the region over the coming decades, because once in place, their capacity cannot be adjusted like chiller systems.

2.2.4.5. Novel materials

A novel material that arose out of a Stanford-based research project has been used to develop cooling systems for commercial centers, in particular data centers that are notorious for their energy use and constant need for chilled water (Stanford Engineering 2017, SkyCool Systems 2022). This material is deployed in the form of flat panels on roofs, which cool a circulating liquid without electricity and experience reduced temperatures up to 8°C below ambient temperature. The cooled liquid can then be used to improve the efficiency of an existing chiller unit. The company is seeking partners for pilot deployments as they seek to prove the technology on a larger scale. These materials could be combined with afore-mentioned solar system and shade setups to cool water that enters the hatchery.

Even in addressing temperatures of waters in the hatchery, waters in the surrounding North Umpqua basin are generally too warm during summer months and continue to increase in temperature. Fish released to places like Cow Creek or those adults returning during warm months will have to contend with temperatures that can approach lethal thresholds for adult salmonids. Artificial covering on all the streams in the North Umpqua basin is both impossible and ecologically unsound; vegetation regrowth, substrate and large woody debris additions to streams, and creation of coldwater refugia is the only option for those watersheds on such a large scale.

Released and returning fish will have to cope with those conditions if they spend any time in the surrounding river basins, regardless of how the hatchery manages its own water temperatures internally, so holistic full-watershed restoration practices must be taken on in addition to any hatchery-internal temperature mitigation if hatchery and wild native fish are expected to survive in the watersheds during the summer months.

2.2.4.6. Revegetation in watershed

See previous recommendations for reestablishing vegetation in the watershed, which could take decades to see full regrowth and reestablishment of shade cover.

2.2.4.7. Increased wood in streams

The addition of large woody debris to streams creates beneficial habitat for fish. Logging companies in the watershed are already intentionally setting aside a portion of the burned trees for addition to streams. Rock Creek Hatchery worked with forestry partners in the past to donate trees for addition to streams, and multiple organizations including ODFW and the Bureau of Land Management are actively working to incorporate dead trees and large woody debris into the North Umpqua basin streams.

Figure 2.26. Burned trees along Rock Creek marked with yellow fish symbols for instream use in April 2022.

2.2.4.8. Restoration of streams for increased coldwater refugia

Rock Creek has substantial coldwater refugia, but increasing water temperatures in the basin necessitate the creation of as much salmonid-friendly habitat as possible. In addition to large woody debris being added to streams, partnering agencies working in the North Umpqua and Rock Creek such as the US Forest Service, Douglas Timber Operators, and Bureau of Land Management could consider adding gravel and cobble to streams in addition to large woody debris to increase habitat and potential hyporheic exchange at the stream bottom that can provide opportunities for water to cool.

2.2.4.9. Relocation of fish to other facilities

Relocation of fish to different hatcheries to prevent temperature-related losses during the summer months is an option that would not require infrastructural changes at Rock Creek Hatchery. See previous recommendations of relocating fish to other hatcheries for discussion about challenges and costs.

Relocation of fish does not address the elevated temperatures that returning adults will experience in the North Umpqua basin even if they are to be collected and transported elsewhere. Hatchery fish could be sorted out at the Winchester Dam and transported to different hatcheries before they progress too far upstream in the North Umpqua, but this earlier sorting would require staffing at the Winchester Dam and also does not address temperature problems in the North Umpqua that would jeopardize wild salmonids, e.g., returning Summer Steelhead.

It is likely that some amount of watershed best management practices can be implemented to mitigate against the worst effects of temperature increases, but as many practices as possible will need to be utilized in conjunction to see noteworthy results and prevent lethal temperatures to salmonids in the coming decades.

2.2.5. Sedimentation

Vulnerability ranking: Moderate risk

Because the Rock Creek watershed experienced such high soil burn severity and vegetation loss, there is increased potential for erosion and sediment delivery to the stream that ultimately supplies the hatchery.

The Rock Creek and North Umpqua USGS gages record turbidity data, which can serve as a proxy for sedimentation in the basin. The maximum turbidity rates in the North Umpqua exhibit a decreasing trend over time but are also variable on an annual basis. Higher turbidity during the 2021-2022 time period corresponds with time periods of higher flows, which makes sense in a post-fire erosion-prone area. Rock Creek exhibits the same amount of turbidity or higher as the North Umpqua, and this turbidity difference is visible at the confluence, with Rock Creek's water appearing browner as of April 2022.

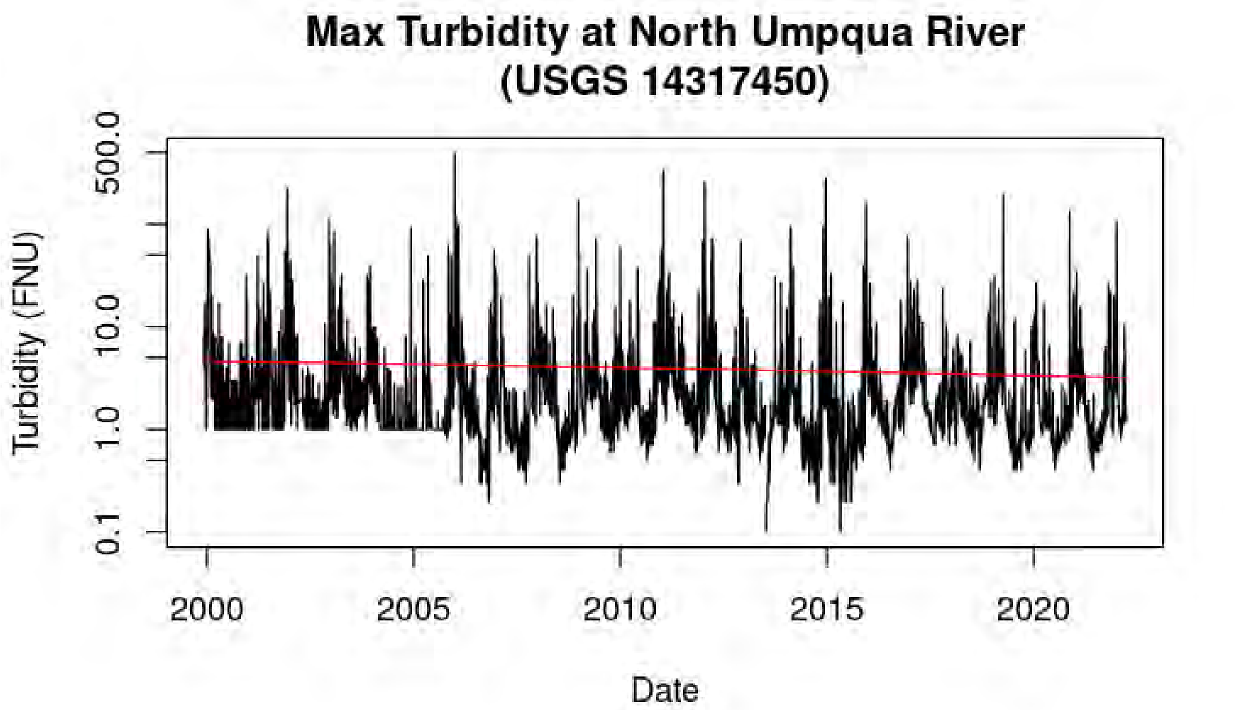

Figure 2.27. Maximum turbidity at North Umpqua gage since 2000s.

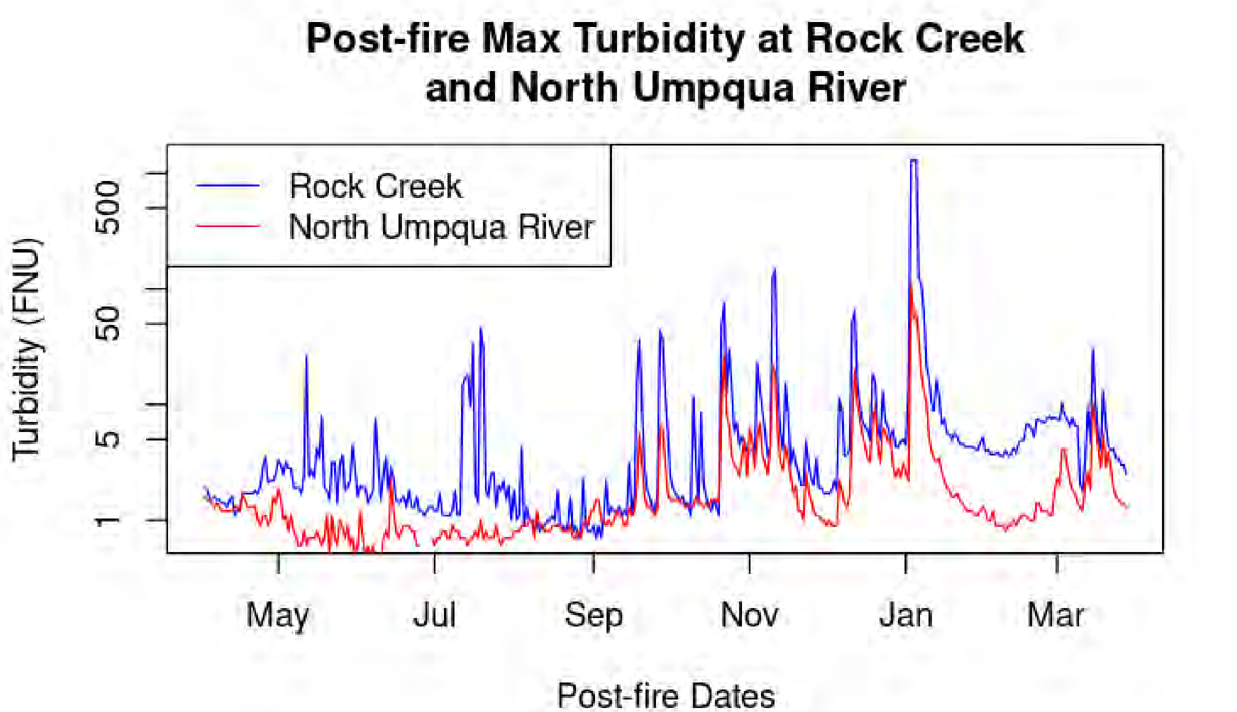

Figure 2.28. Turbidity at Rock Creek and North Umpqua gages since April 2021.

2.2.5.1. Alternatives and recommendations

As the watershed experiences flux over the next few decades, with burned trees falling or being removed and new trees growing from revegetation efforts, Rock Creek will likely continue to see elevated sediment loads and turbidity levels in association with precipitation events.

2.2.5.2. Increased frequency of inspection and debris removal

Without frequent cleaning of screens, water intakes and the fish ladder could become clogged with sediment and debris. Hatchery staff already frequently inspect and clean intake screens and infrastructure.

2.2.5.3. Settling tank

A settling tank could be installed on the premises to allow incoming sediments to settle out before use in production. This tank could be combined with a UV ozone system for maximizing water quality. A possible location for a settling tank could be along the trail area between the main hatchery facilities and the observation deck and would require installation of a level pad and tank setup.

To allow a settling time of 90 minutes at maximum withdrawal rates, total storage of up to 1.2 million gallons of water storage would be required (King County 2016). Lower-end sample costs for a series of tanks to hold this capacity are $2,000 per flocculation tank (plus overseas shipping), capable of treating up to 300 cubic meters per hour and thus requiring up to 10 to fully treat all incoming water (Alibaba 2022). Other sources for settling tanks, including higher-quality and used ones, could require initial capital costs of hundreds of thousands of dollars (Business Wire 2013, HomeAdvisor 2022, Machinio 2022).

2.2.5.4. Revegetative planting throughout watershed

Revegetation and planting are already ongoing within the watershed and will be important in stabilizing hillsides and mitigating sedimentation and soil loss during precipitation events. See previous recommendations for reestablishing vegetation in the watershed, which could take decades to see full regrowth and reestablishment of hillslope cover.

2.2.6. Dissolved oxygen

Vulnerability ranking: Low risk

A general summary of dissolved oxygen concentrations and their effects on non-embryonic and non-larval life stages can be seen in the following table (modified from Carter 2008).

Dissolved oxygen concentrations and their effects on salmonid life stages other than embryonic and larval

Level of Effect	Water Column DO (mg/L)
No Production Impairment	8
Slight Production Impairment	6
Moderate Production Impairment	5
Severe Production Impairment	4
Limit to Avoid Acute Mortality	3

Source: USEPA 1986a

Figure 2.29. Dissolved oxygen thresholds for salmonids (modified from Carter 2008).

Dissolved oxygen (DO) in Rock Creek since 2021 has had a daily mean value >8 mg/L, with daily minimum values closer to 7 mg/L in July and August. Based on these recorded values and assuming that DO does not exhibit a decreasing trend over time, Rock Creek should be sufficiently oxygenated to support salmonids without detriment to fish health. (Such trends should continue to be monitored, as DO typically declines with increases in temperature.) Additionally, a UV ozone water treatment system is already in place that increases the dissolved oxygen onsite.

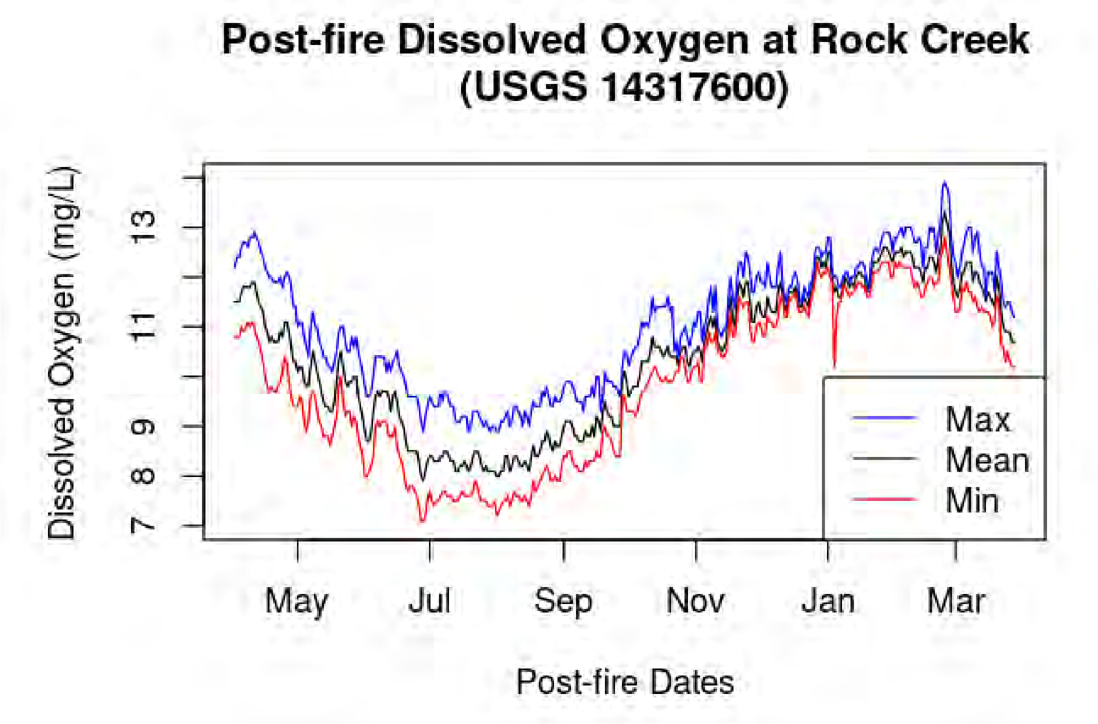

Figure 2.30. Dissolved oxygen at Rock Creek gage from April 2021 onwards.

2.2.6.1. Alternatives and recommendations

None necessary.

2.2.7. Other water quality parameters

Vulnerability ranking: Low risk

pH values less than 5 and greater than 9 are problematic ranges for fish (Carter 2008). Rock Creek's recorded values since 2021 are greater than 6.5 and below 9 and thus do not appear to require mitigation but should continue to be monitored over time.

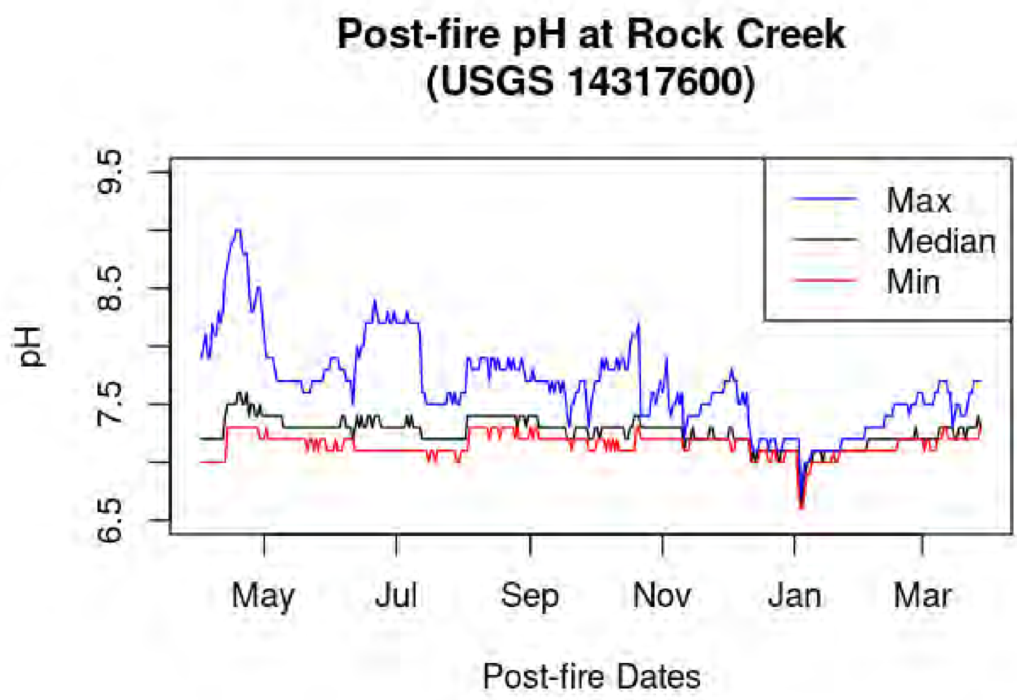

Figure 2.31. pH at Rock Creek gage from April 2021 onwards.

Specific conductance values are a direct measure of electrical conductance of a water body and serve as a proxy for the amount of specific salts and pollutants in water. Total Dissolved Solid values are required to be less than 500 mg/L for the Umpqua Basin to support salmonids (ODEQ 2022), which converts to nearly 800 uS/cm. The values measured in Rock Creek are far below this threshold, staying below 100 uS/cm in the 2021-2022 time span.

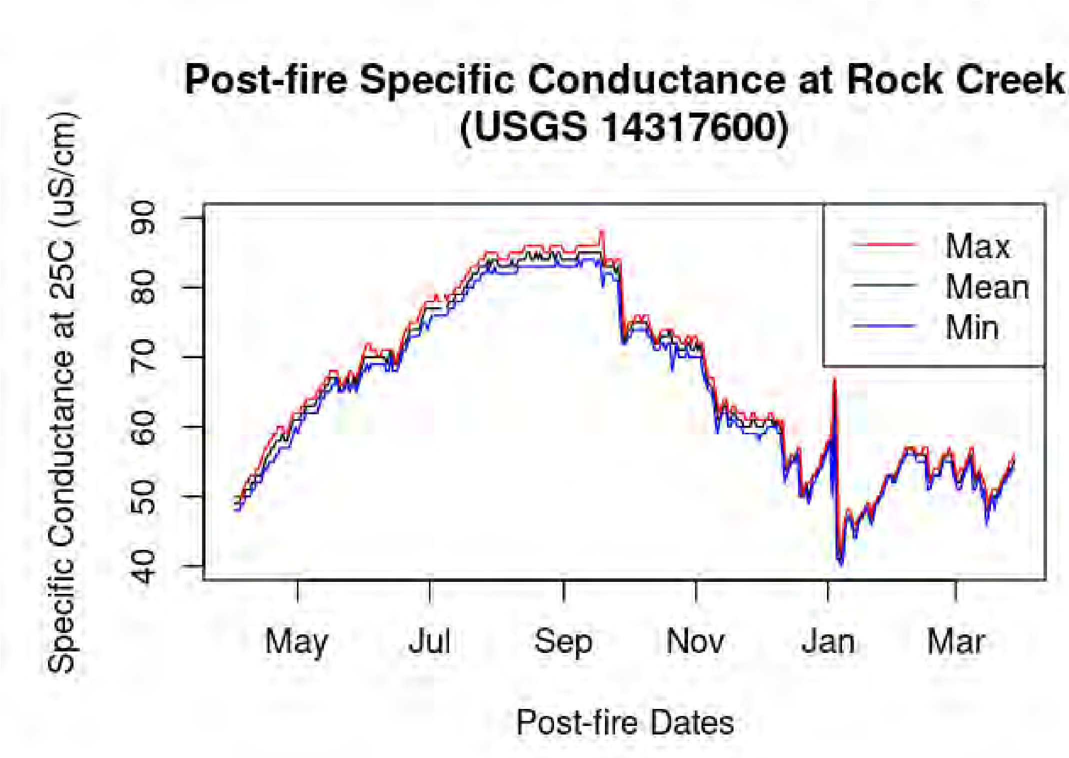

Figure 2.32. Specific Conductance at Rock Creek gage from April 2021 onwards.

2.2.7.1. Alternatives and recommendations

None necessary.

2.2.8. Contaminants from burned debris

Vulnerability ranking: Low risk

The state DEQ did extensive testing around the site after the fire during removal of burned materials and did not report any noteworthy problems. Burned buildings have all been removed down to the foundation level.

2.2.8.1. Alternatives and recommendations

None necessary. Hatchery staff should stay in communication with the DEQ about any discoveries of persistent or hazardous chemicals found in the watershed that could make their way into Rock Creek's water supply.

Table 2.11. Environmental vulnerability summary

Vulnerability	Impact	Solutions
Low flow conditions	The facility requires 25 cfs during summer months to maintain operations.	• Ensure water rights are not infringed upon • Reestablish watershed vegetation to increase

		percolation and recharge • Install a RAS recirculation system to recycle water and reduce water needs • Relocate operations during summer
Increased water temperature	Fish health suffers due to consistently warmer water temperatures in the summer months. Facility ideally needs water to stay below 20°C during Jun-Sep.	• Install chillers • Install additional shade cover • Reestablish watershed vegetation • Increase in-stream habitat and coldwater refugia • Relocate operations during summer
Water rights and availability	The facility needs to ensure it receives its full allotment of water rights if the facility is to resume normal operations.	• Ensure water rights are not being infringed upon by upstream users
Water quality	Sediment loading while watershed and riparian vegetation reestablishes is likely to be elevated during precipitation events.	• Reestablish watershed vegetation • Frequent cleaning of intake filters and screening • Install settling tank or pond

2.3. Pathogens

2.3.1. Disease conditions related to climate change elements

Vulnerability ranking: High risk

Rock Creek has experienced rising temperatures since long before the Archie Creek Fire and at the same time was known for its high load of pathogens and disease, dating back since at least the 1970s and 80s.

The transmission rates of fish parasites and pathogens are expected to increase with increasing temperature (Mallick and Panigrahi 2018). Rising river temperatures lead to increased infection rates and disease progression in the freshwater stage of salmonids life history (Kocan et al. 2009; Marcogliese 2001; Udley et al. 1975; Wedemeyer 1996) which can also impact adult survival to spawning grounds or hatchery facilities. At extreme levels, major mortality due to complications resulting from thermal stress may cause stock specific declines in the number of adult fish that return to hatchery facilities, thereby potentially limiting the availability of broodstock. Emigrating smolts may also face stress and physiological dysfunction due to increased river temperatures that could result in mortality prior to reaching the ocean (Clark et al. 2008).

In many pathogens, the rate of infection increases with warmer temperatures because of increased stress on the host (Fryer and Pilcher 1974; Fryer et al. 1976; Groberg et al. 1983; Karvonen et al. 2010; Kocan et al. 2009; Marcogliese 2001; McCullough 1999; Udley et al. 1975). Freshwater temperature increases can affect fish pathogens directly by altering their biological processes or indirectly by influencing the distribution and abundance of the fish they affect. On a population scale, temperature increases can alter the seasonal abundance, timing, and transmission efficiency of pathogens. On an organismal scale, temperature changes can affect the rate of pathogen replication inside the fish, the longevity of pathogen life stages outside the fish, the virulence of the pathogen, and the transmission of the pathogen among fish (Marcogliese 2001; Marcogliese 2008).

Many pathogens exhibit cycles of seasonal abundance, with highest levels occurring during warmer months. Warming temperatures could result in earlier peaks and longer time periods of maximum pathogen abundance (Karvonen et al. 2010). In addition to becoming more prevalent, some pathogens become more virulent at warmer temperatures, resulting in an expanded and more severe time period of infectivity and disease (Karvonen et al. 2010; Kocan et al. 2009; Marcogliese 2001; McCullough 1999; Udley et al. 1975). Temperature may also differentially affect different aspects of pathogen infectivity; in the case of some parasites, shedding rates and the abundance of infective stages may be increased at warmer temperatures, but the longevity of those same life stages may be reduced, giving them less time to find and successfully invade a fish or another host (Foott et al. 2007; Marcogliese 2008).

Thermal stress coupled with hatchery overstocking are synergistic stressors that impair fish immune systems, leaving them more vulnerable to disease (Rebl 2020). Because lower rearing density can also decrease the transmission of ectoparasites and penetrating endoparasites, it could be an efficient tool in ecological disease management. Reduction of fish density could be used in prevention of some diseases such as Columnaris especially if water temperature is high (Suomalainen et al. 2005).

Disease outbreaks at Rock Creek Hatchery pose great operational challenges (ODFW 2016a; ODFW 2016b; ODFW 2017), with Rock Creek hatchery fish having experienced every pathogen that has been in the state hatchery system at some point. A summary of diseases that have occurred at the Rock Creek Hatchery are shown in the table below.

Table 2.12. List of pathogens that have been detected at Rock Creek in recent years, from ODFW's senior fish pathologist as of April 2022

Parasites	Spironucleus (Hexamita) Sanguinicola Ichthyopthirius Tetracapsuloides (Proliferative Kidney Disease)- transient Trematode worms

	Ichthyobodo (Costia) Chilodonella Tetrahymena Trichodina Copepods Nanophyetus Gyrodactylus Epistylis Ambiphrya Neascus Dermocystidium Nemaotde Apiosoma
Bacteria	Flavobacterium columnarae (Columnaris Disease) Flavobacterium physhcophilium (Cold water disease) Aeromonas septicemia Aeromonas salmonicida (Furunculosis disease) Pseudomonas fluorencens Yersinia ruckerii (Enteric Redmouth Disease) Renibacterium salmonunarum (Bacterial Kidney Disease)
Fungus	Internal fungus Phoma herbarum External fungus Saprolegnia
Virus	Infectious Hematopoeitic Necrosis Virus
Other, non infectious	Coagulated yolk disease Thiamine deficiency complex

These pathogens have different optimal thermal ranges in which they cause disease outbreaks in hatcheries, such that no time of year is inherently disease-free (Hanson and Peterson 2014). The following graphs show the difference in how disease and fish health vary throughout the year, based on health inspection data and disease case counts from Rock Creek Hatchery between 2017-2020. Those fish reported to be in healthy condition at the time of inspection had a high value in 2017, with a drop and steady rise in 2018, followed by decreasing values in 2020.

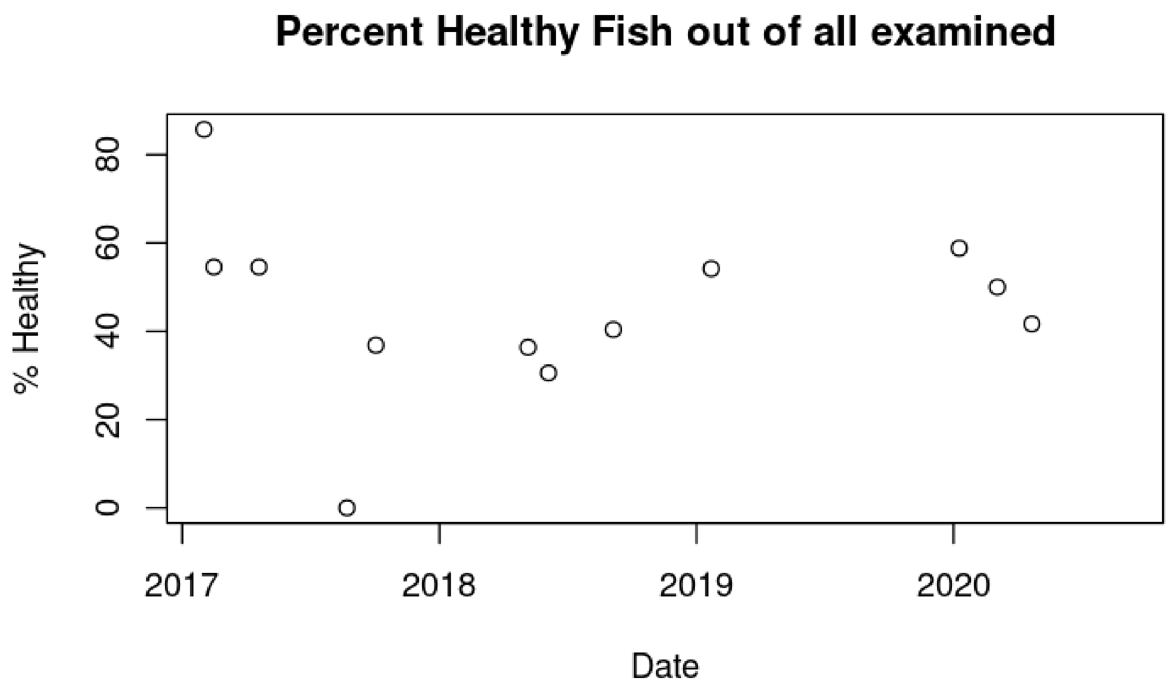

Figure 2.33. % Healthy fish out of those examined in monthly inspections from 2017-2020, where numbers of healthy fish were reported.

Examples of diseases with different prevalence are Columnaris and cold-water disease (CWD), both in the genus *Flavobacterium*. Columnaris cases spike in the warmer summer months, while CWD is present throughout most of the year.

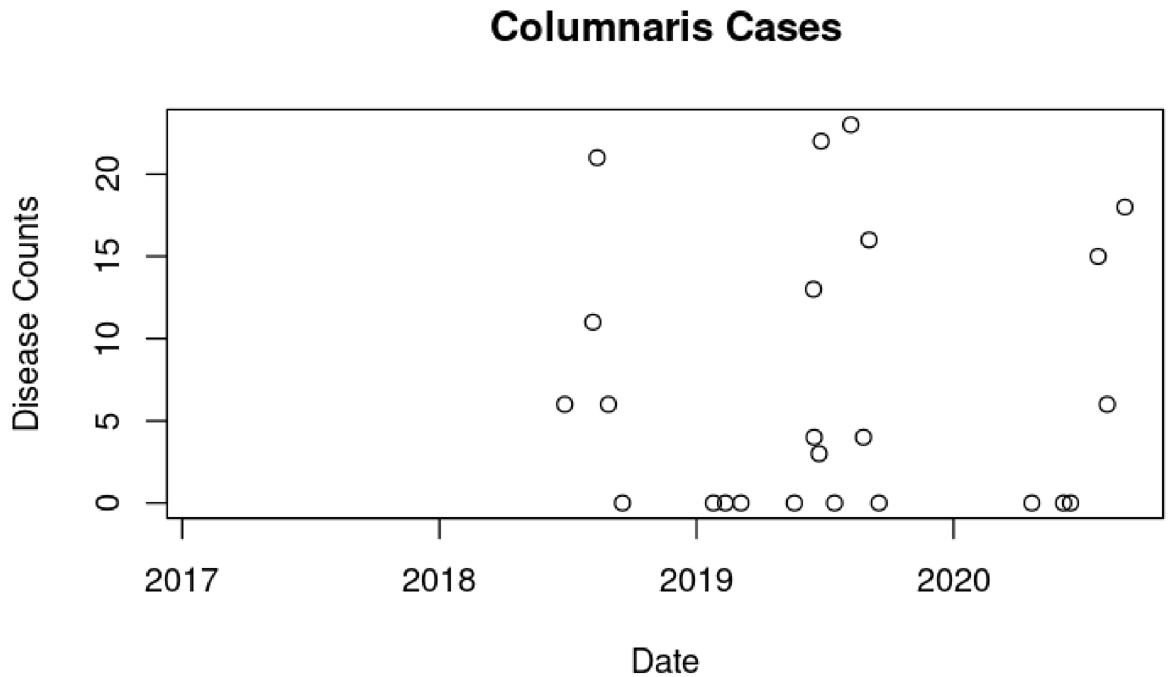

Figure 2.34. Columnaris case counts between 2017-2020.

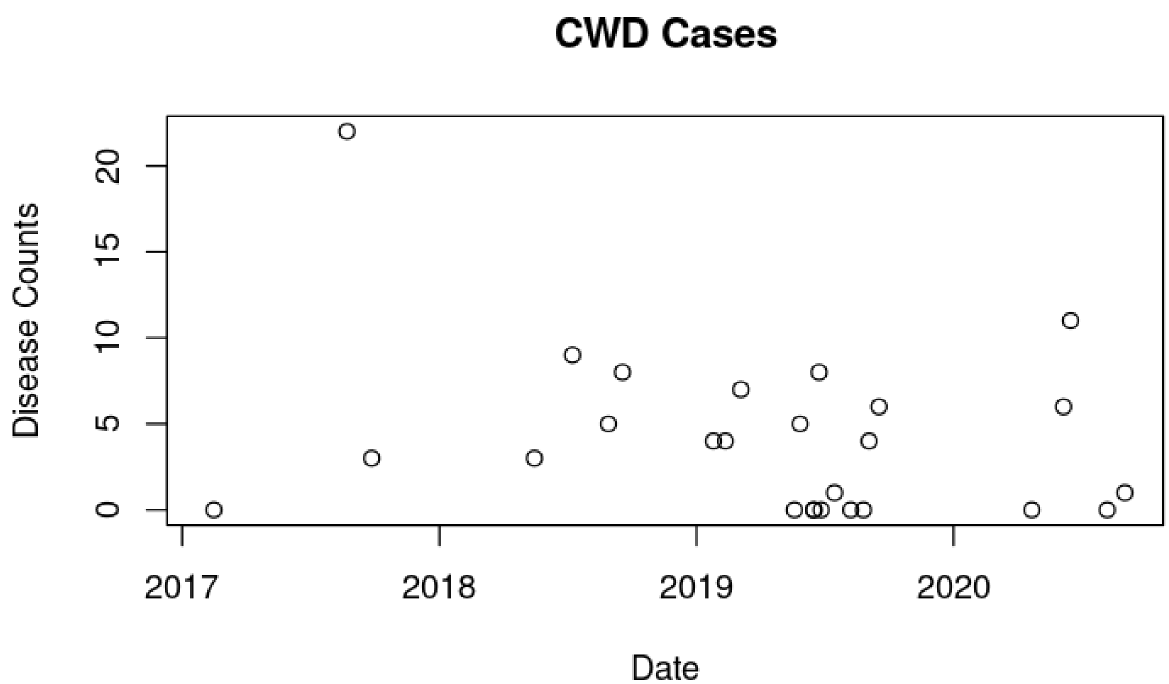

Figure 2.35. CWD cases from 2017-2020.

2.3.1.1. Alternatives and recommendations

Best management practices for minimizing stress to fish, stocking density, medication, and regular treatment and inspection of fish can be maximized in controlling disease impacts in hatchery fish by being paired with filtration, disinfection, and temperature control.

2.3.1.2. Stocking density

Reducing stocking density can improve fish health and survival. In a study done in Oregon (Kavanaugh and Olson 2014), rearing density had a significant effect on Steelhead growth, fin erosion, and adult survival. Winter Steelhead reared in low-density raceways (13.6 kg/m^3 at release) were significantly larger at release, larger at return, had significantly better dorsal fin condition, and had significantly greater smolt-to-adult survival rates than did those reared in medium (23.4 kg/m^3) and high (35.2 kg/m^3) density raceways.

2.3.1.3. Medications and treatment

General treatments are available for various diseases across salmonid species. Spring Chinook Salmon are treated for amoebic gill disease (AGD) and ich with formalin. BKD is treated with antibiotics aquamycin and erythromycin. Furunculosis and Columnaris are treated with oxytetracycline. Coho suffer from Cold Water Disease and Gill Amoeba. Cold Water Disease has been controlled substantially by insertion of vexar substrate in incubator trays and feeding of medicated fish "pills." Gill amoeba is successfully treated with Formalin. Coho have a very high resistance to *Ichthyophthirius multifiliis*, although the parasite is lethal to Steelhead. Steelhead suffer from Cold Water Disease and Gill Amoeba.

Rock Creek Hatchery already has an established set of medications and treatments it uses against pathogens. From the Hatchery Management Plan, antibiotics are used for control of bacterial diseases in adult brood fish via injection and administered orally as needed to juvenile fish, and formalin is added to water to control parasites and fungus in eggs and juveniles.

2.3.1.4. Regular inspections and examinations

The Hatchery Management Plan lays out general procedures set by ODFW for hatcheries including both reactive and proactive responses to managing disease, such as prompt removal of dead fish, necropsies, and dispensing appropriate treatment, as well as following best management practices for stocking based on density and flow rates. The plan also specifies those procedures followed by Rock Creek Hatchery. These procedures include regular monthly checkups of healthy and diseased fish, checkups before releases and transfers, regular whirling disease exams, and follow-ups on abnormal behavior or mortality rates.

2.3.1.5. Filtration and disinfection

In the hatchery, diseases can be controlled by the disinfection of the inlet water. The most common system is ultraviolet and ozone. UV lamps can be used to send out UV radiation having a sufficient dosage to inactivate microorganisms. Ozone gas (O_3), a very strong oxidizing agent produced by an ozone generator, can also be used in the hatchery for disinfection of water. Ozone can also reduce water turbidity, watercolor, organic carbon, metal ions and algae (Rehman et al. 2017). Disinfection is not selective between pathogens and beneficial microbial populations. Care should be taken for the doses applied and the location of the disinfection to avoid proliferation of opportunists within the system (Rurangwa and Verdegem 2014).

Rock Creek currently employs such a system, with one system in place that treats 2 raceways. This system could be expanded with 5-6 additional units to provide coverage for the remaining raceways.

2.3.1.6. *Temperature control*

See section on elevated temperature solutions. As Rock Creek Hatchery currently employs medication and UV ozone disinfection, temperature is a key component to reducing disease incidence.

3. Alternative overall management scenarios

This section presents several overall management scenarios that could be used for Rock Creek Hatchery operations now and into the future in order to address the previously described vulnerabilities.

Table 3.1. Vulnerability summary table for Rock Creek Hatchery based on current conditions and trends

Vulnerability	Ranking at Rock Creek Hatchery
Operations	Very High
Water temperature	Very High
Pathogens	High
Low flow	Moderate
Sediment loading	Moderate
Water rights and availability	Low
Other water quality parameters	Low

The following summaries discuss the overall potential scenarios for the future of Rock Creek Hatchery operations, how each scenario addresses the listed vulnerabilities, and associated costs of incorporating various recommendations.

3.1. Scenario 1: Do nothing

"Do nothing" and abandon production at Rock Creek Hatchery except for collecting returning adults and transporting them to other hatcheries.

In the "do nothing" scenario, Rock Creek would have operational costs of weekly transporting of returning adults. This scenario would fail to meet production goals. It would not attempt to address vulnerabilities to fish production due to infrastructure, increasing water temperatures, pathogens, low summer flows, or increased post-fire sedimentation, and water rights would not be affected.

A "do nothing" scenario due to lack of sufficient funds or failure to address Rock Creek's needs in a timely manner risks losing hundreds of thousands of salmonids from the Oregon waterways annually.

3.2. Scenario 2: Rebuild Rock Creek Hatchery with improvements

Rebuild Rock Creek Hatchery to accommodate year-round operations with improvements.

A full rebuild of the facility to include improved over-summering operations for rearing Fall and Spring Chinook, Winter Steelhead, and Rainbow Trout would require a substantial capital investment in rebuilding the facility and ensuring full-staffing. Fish health could be improved through the implementation of water cooling techniques focused only on water in the hatchery, such as chillers with recirculating aquaculture systems (RAS), shade coverings, and novel materials, and could include widespread efforts at watershed revegetation, which would also help stabilize the area and reduce future sediment issues. The hatchery could utilize green energy sources such as solar and hydropower to lessen emissions and increase independence from the electricity grid.

This scenario would allow for meeting production goals by addressing vulnerabilities in infrastructure and water temperature, which could in turn improve pathogen loads with cooler hatchery water temperatures. This scenario would also see improvements in sedimentation through addition of a settling tank and automatically-cleaning intake screens, additional UV ozone treatment for improving water quality, and limited issues with low flows due to the hatchery's senior water rights. This scenario is the most expensive but could allow Rock Creek Hatchery to fulfill its production goals onsite with the best results for fish and the environment. It could also allow the hatchery to reduce its greenhouse gas emissions in support of ODFW's carbon neutrality goals. At least partial funding is presumed to be available from finalized insurance valuations, as well as funding from several federal funding sources such as the new Bipartisan Infrastructure Law and the Inflation Reduction Act.

3.3. Scenario 3: Partial rebuild of Rock Creek Hatchery

Rebuild basic Rock Creek infrastructure and partially relocate operations from Rock Creek to another facility such as Cole Rivers Hatchery.

A partial rebuild of the facility involving other hatcheries in rearing and growout, particularly over the summer, could fulfill production goals and would require capital investment in the Rock Creek facility but without expensive cooling solutions, and would require additional staff members and infrastructure at other hatcheries such as Cole Rivers as well as truck transport of fish that would typically be reared at Rock Creek year-round including during the summer months.

Depending on the external facility, infrastructure vulnerabilities could increase or decrease (e.g., increased vulnerability due to power supply issues at Cole Rivers coupled with decreased vulnerability due to fire). Water temperatures are lower at these external facilities, and improvements in pathogens could be seen accordingly over time. Sedimentation vulnerabilities would improve due to low-sediment water sources (e.g., reservoirs) and surrounding watersheds not having experienced recent fires. Low flow vulnerabilities will likely stay the same or increase, depending on the particular facility in comparison to Rock Creek Hatchery, and water rights vulnerabilities will generally increase.

Building capacity for operations outside of Rock Creek could negate the need for operations at Rock Creek Hatchery at all, save relocating returning fish for spawning or acclimating fish for release (as in Scenario 1). However, building that capacity would necessitate obtaining the rights to additional water withdrawals, which could prove difficult or impossible and would take several years to establish at minimum. During that time, pre-fire production goal operations could continue in the rebuilt Rock Creek Hatchery.

3.4. Summaries of scenarios and how each addresses vulnerabilities

The following table provides a qualitative overview of how each of the presented overall scenarios addresses each individual vulnerability.

Table 3.2. Summary of alternative scenarios in addressing vulnerabilities and meeting production goals.

(+ means the scenario presents no problem or provides improving conditions related to the vulnerability, - means the scenario fails to address or worsens conditions related to a vulnerability.)

Scenario	Costs due to infrastructure and staffing	Ability to meet production goals	Vulnerability due to infrastructure	Vulner-ability due to water temps	Vulner-ability due to disease	Vulner-ability due to low flow	Vulner-ability due to sediment	Vulner-ability due to water rights
1. "Do nothing", no rebuild	+	-	-	-	-	-	-	+
2. Full rebuild with improve-ments	-	+	+	+	+	+	+	+
3. Partial rebuild with shared operations	-	+	+/-	+	+	+/-	+	-

The following two tables present the vulnerabilities, solutions, and costs for the different overall scenarios.

Table 3.3. Summary of vulnerabilities, solution, effects, and costs for "no rebuild" and "partial rebuild" scenarios

Vulnerability	Solution	Effect of Alternative of Vulnerability	Cost Estimate
No Rebuild			
Fish production	Truck transport of returning adult fish, weekly or as needed.	Not addressed/ More vulnerable	Less than $10,000

	Other hatcheries may not be able to meet fish production.		
Low flow	No treatment	Unaddressed	
Water temperature	No treatment	Unaddressed	
Disease/Pathogens	No treatment	Unaddressed	
Sedimentation	No treatment	Unaddressed	
Water Rights	No treatment	Unaddressed	
Rebuild for Full Operations with improved facilities			
Listed separately in Table 3.4 due to length			
Rebuild with Partial or Shared Operations			
Fish production	Return to pre-fire production volume, with production split across facilities	Addressed	$7.5 million, pending final insurance valuations, plus annual operating costs (staff, infrastructure, energy use)
Low flow	Transport fish to higher flow facility	Addressed	$21,000-$42,000 to transport fish between facilities
Water temperature	Transport fish to lower temperature facility	Addressed	
Disease/Pathogens	Possible improvements due to lower water temperatures	Addressed	
Sedimentation	Lower sediment due to water source	Addressed	
Water Rights	Possible water rights problems at other facilities	Unaddressed	

Table 3.4. Summary of vulnerabilities, solution, effects, and costs for Rebuild with Improvements

Solution	Effect on Vulnerability	Cost Estimate
Fish Production		
Basic facility rebuild costs	Return to normal fish production	$7.5 million, plus annual operating costs (staff, infrastructure, energy use)
Low Flow		
Maintain water rights to North Umpqua	Maintain senior rights to water during low-flow summers	
Water Temperature		

Shade cover	Help to reduce water temperature	$25,000+, depending on amount of raceways covered
Chiller	Help to reduce summer water temperature	$225,000 initial costs (when paired with RAS system) + $25,000 annual O&M, or $8 million+ without RAS system (Note: example costs for existing RAS systems typically incorporated the costs for some degree of chilling, filtration, etc.)
Geothermal cooling	Help to reduce summer water temperature	$1.2 million (when paired with RAS), or $39 million+ without RAS system
Novel cooling materials installation	Help chiller run more efficiently to reduce water temperature	Possible minimal costs to hatchery, assuming collaboration as part of pilot installation
Disease/Pathogens		
Additional UV ozone systems	Treat all incoming water	$3,000 per UV unit, or $328,000 for full UV ozone system with annual operating costs of $15,000 (Note: example costs for existing RAS systems typically incorporated the costs for some degree of chilling, filtration, etc.)
Sedimentation		
Berms, diversions against hillslides	Protect hatchery infrastructure from debris slides	$2 per linear foot of topsoil to more than $70 per cubic yard of large riprap materials
Watershed revegetation and restoration	Decrease sedimentation from upstream	Minimal cost to hatchery, assuming assistance from partnering agencies
Upgraded screens and trash rakes for inflow	More efficiently handle debris at inflow	$1000s – 10,000s for individual parts, up to $100,000s for installation and automation
Water Rights		
No issues currently		
Climate mitigation / Operational Improvement		
Electric truck fleet	Reduce fuel costs and dependence on fossil fuels	$43,000+ per lightweight vehicle with potential 100k miles lifetime savings of $15,000 in fuel, $150,000-300,000 for freightliners
Fire suppression system	Reduce damages from potential future fires	$30,000-60,000
Landslide monitoring system	Alert staff to landslide conditions	$1000s - $10,000s, depending on amount of DIY or turnkey setup
Biodigester	Treat fish waste and generate electricity	$80,000+ (example $550,000 with annual O&M costs of $25,000 and electricity revenue of $56,000)
Solar Panels	Generate electricity and reduce carbon emissions	$75,000 - 600,000 for 23kW - 436kW systems, with larger systems covering

		electricity costs and an anticipated 10-year payback period
Batteries for solar	Store electricity for emergency backup and reduce carbon emissions	Starting at $8,100 for 10.8 kWh battery, $35,000 for 40.4 kWh full system
Hydropower	Generate electricity and reduce carbon emissions	$350,000-400,000 for 90-100kW system, payback period 6 years
RAS Recirculation System	Reduce water volume needs and water temperature cooling needs	$1.1 million+ initial costs and estimated $260,000 annual costs (Note: example costs for existing RAS systems typically incorporated the costs for some degree of chilling, filtration, etc.)
Settling Tank	Remove sediment from inflows	$20,000+

3.5. Additional Steps for Carbon Neutrality

On March 10, 2020, Governor Kate Brown issued Executive Order No. 20-04, which mandated state agencies including the ODFW to reduce greenhouse gas emissions and prioritize actions that work towards those goals. Additionally, the executive order directed the Oregon Global Warming Commission to consider state carbon sequestration goals using the state's natural resources.

Graves et al. (2020) examined natural climate solutions (NCS) in Oregon and found that they could reduce emissions by 2.9 to 9.8 million metric tons (MMT) of carbon by 2050 with the largest reductions coming from deferred timber harvesting, reforestation of riparian lands, and replanting lands burned by wildfires. Other categories of emissions reductions include agricultural management. Restoration of tidal wetlands has a high carbon sequestration rate, but limited applicability in Oregon and thus contributes to a small portion (<1%) of Oregon's emissions reductions. Additionally, preserving existing forested lands accounts for large emissions reductions, but Oregon's land management conservation practices are already strong and thus limit the potential of this area to less than 5% of annual reductions (Graves et al. 2020).

Market Background

There is a growing market for carbon offsets as Oregon set carbon emissions goals and since California has started its cap and trade program in 2013. California's program was first targeted toward emissions in the electricity sector and then expanded to include the transportation sector. The annual carbon limit (or cap) is set in advance with an annual decline to help meet its emissions reduction goals. The program uses carbon offsets that can be bought by a group to meet its cap, up to 8% of compliance target (Environmental Defense Fund n.d.). The emissions allowances that are sold at auction fund the state's Greenhouse Gas Reduction Fund. For natural resources, these investments include wetland restoration, urban forests, fire prevention, and increased composting (C2ES 2022).

With Oregon Governor Brown's executive order, there will be immediate movement by the Department of Environmental Quality (DEQ) to develop climate mitigation scenarios, establish emission targets and identify who will be regulated, develop a trade system (or not), and determine how much of an emissions allowance can be met by carbon offsets. (Sickinger 2021).

Solutions

The Nature Conservancy and the American Forest Foundation have developed a program to help small landowners with forested land to participate in carbon offset program, called Family Forest Carbon Program (FFCP). A second program called the Forest Carbon Co-op is targeted to medium-sized forest owners to engage in carbon markets (The Nature Conservancy 2020).

Finite Carbon is a private company based in Pennsylvania that provides a market for carbon offsets in the form of privately-owned forested areas. They recently received a $5 million investment from BP, the oil and gas company, showing the expected future growth of forest management in reducing carbon emissions (Dezember 2020).

The ODFW could offset their largest emissions via the areas recommended by Graves et al. (2020), namely deferred timber harvesting, reforestation of riparian lands, and replanting lands burned by wildfires. These efforts would build on the agency's large-scale ongoing land preservation efforts that provide immense amounts of carbon sequestration. The agency could support grant programs that help privately-owned forested lands become a part of carbon trading solutions.

4. Conclusions

Rock Creek faces high risks to its operations in the form of fire-damaged infrastructure in need of replacement; possible landslide risk and hillslope failure on the surrounding terrain and access road; elevated and increasing water temperatures in the basin; and high loads of pathogens and disease, in part due to elevated water temperatures. Possible moderate risks in the coming decades could include lower water availability in the summer months (or conflict to uphold water rights) and increased sedimentation, requiring extra filtration and filter maintenance, with low risks related to other water quality parameters.

Continuing to uphold Rock Creek's contributions to the salmon population of Oregon requires significant investment in one of several different possible scenarios to address the highest risks to production. The "do nothing" scenario abandoning production at Rock Creek Hatchery is the least expensive scenario but risks the loss of hundreds of thousands of juvenile and tens of thousands of adult salmonids from the Oregon waterways annually. Rebuilding Rock Creek to full or partial production requires significant capital investment and annual operating costs but with the payoff of restoring production goals.

The highest cost option of **rebuilding and upgrading Rock Creek Hatchery could meet all production goals with lower environmental impacts**; such an option would require significant capital investment beyond insurance payoffs for rebuilding but could **provide healthier fish with**

a lower carbon and water footprint. In particular, the installation of a RAS system to reduce water needs could protect against potential threats of low flow and allow for the use of chillers to provide healthier temperatures for fish.

The option to shift production to other hatcheries would require less capital investment and annual operating costs at Rock Creek Hatchery, but could incur significant costs in upgrading other facilities and increase risk to production due to vulnerabilities at the other facilities. Supporting production *in situ* at Rock Creek Hatchery would be the most beneficial to the hatchery system as a whole by providing more locations that can care for fish, rather than fewer. This analysis does not consider the larger integrated system or climate response which might find even more preferential treatment towards rearing at Rock Creek, pending further analysis of water rights and availability in light of changing climate scenarios at other hatcheries including Cole Rivers.

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