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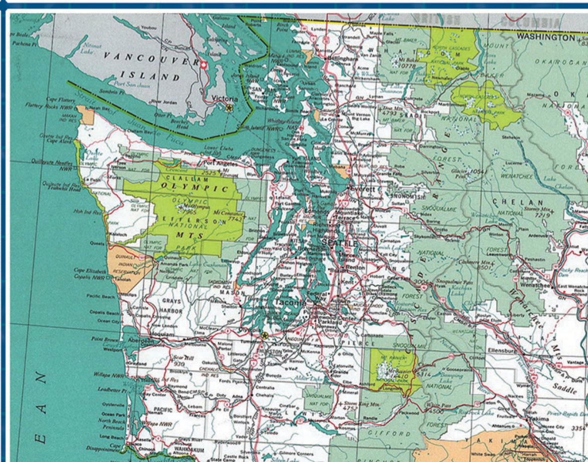
# Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA



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# Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA

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# Abstract

The South Fork Nooksack River (South Fork) is located in northwest Washington State and is home to nine species of Pacific salmon, including Nooksack early Chinook (aka, spring Chinook salmon), an iconic species for the Nooksack Indian Tribe. The quantity of salmon in the South Fork, especially spring Chinook salmon, has dramatically declined from historic levels, due primarily to habitat degradation from the legacy impacts of various land uses such as commercial forestry, agriculture, flood control, and transportation infrastructure. Segments of the South Fork and some of its tributaries exceed temperature criteria established for the protection of cold-water salmonid populations, and were listed on Washington State's Clean Water Act (CWA) 303(d) list of impaired waterbodies. High water temperatures in the South Fork are detrimental to fish and other native species that depend on cool, clean, well-oxygenated water. Of the nine salmon species, three have been listed as threatened under the federal Endangered Species Act (ESA) and are of high priority to restoration efforts in the South Fork—spring Chinook salmon, summer steelhead trout, and bull trout. Growing evidence shows that climate change will exacerbate legacy impacts. This qualitative assessment is a comprehensive analysis of climate change impacts on freshwater habitat and Pacific salmon in the South Fork. It also evaluates the effectiveness of restoration tools that address Pacific salmon recovery. The objective of the assessment is to identify and prioritize climate change adaptation strategies or recovery actions for the South Fork that explicitly include climate change as a risk. The Beechie method (Beechie et al. 2013), with some adaptation to the South Fork watershed, was used to provide a systematic, stepwise approach to analyzing climate change impacts in the South Fork, including evaluation by climate risk (focusing on temperature, hydrologic, and sediment regimes), per salmonid species (emphasizing ESA-listed species), and per restoration action. The South Fork watershed was divided into twelve analysis units, including five reaches of the South Fork and seven subbasins. Restoration actions evaluated are those that address legacy, ongoing, and future climate change impacts within each reach and subbasin. We found that the most important actions to implement to ameliorate the impacts of climate change in the South Fork watershed are riparian restoration, floodplain reconnection, wetland restoration, and placement of log jams. Most of these actions are already being implemented to varying degrees, but the pace and scale of implementation will need to be increased by explicitly addressing barriers to implementation. This will require substantial planning including a watershed conservation plan, project feasibility assessments, agency consultation, landowner cooperation, stakeholder involvement, and funding. The qualitative assessment's findings will inform development of the CWA South Fork temperature TMDL Implementation Plan, updates to the ESA Water Resource Inventory Area 1 (WRIA1) Salmonid Recovery Plan, and other land use and restoration planning efforts.

# Foreword

The U.S. Environmental Protection Agency (EPA) Region 10 and EPA's Office of Water (OW) and Office of Research and Development (ORD) have launched a Pilot Research Project to explore how projected climate change impacts could be considered in the implementation of a Clean Water Act (CWA) 303(d) temperature Total Maximum Daily Load (TMDL,) and influence restoration actions in an Endangered Species Act (ESA) Salmonid Recovery Plan. The Pilot Research Project uses a temperature TMDL being developed by Washington's Department of Ecology (Ecology) for the South Fork Nooksack River (South Fork) in Washington, as the pilot TMDL for climate change vulnerability analysis. An overarching objective of the Pilot Research Project is to support the goals and priorities of EPA's climate adaptation plans.

A range of projected climate change impacts from the Intergovernmental Panel on Climate Change (IPCC) Scenarios were evaluated as a *risk assessment* to thoroughly consider plausible futures of potential impacts to salmonids.

The project consists of two separate research assessments:

The qualitative assessment (this report) is a comprehensive analysis of freshwater habitat for ESA salmon restoration in the South Fork under climate change. The objective of the qualitative assessment is to identify and prioritize climate change adaptation strategies or recovery actions for the South Fork that explicitly include climate change as a risk.

The quantitative assessment (in press, EPA/600/R-14/233) provides a comparison of QUAL2Kw modeled stream temperatures, including riparian shading, with and without climate change for the 2020s, 2040s and 2080s. A range of projected climate change impacts from a high, medium, and low impact scenario are analyzed for each time period. This assessment discusses and considers the relevant CWA water quality standards developed to protect beneficial uses, including cold-water fisheries.

Together, these two assessments identify comprehensive actions to protect CWA beneficial uses (salmon habitat) and ESA recovery goals under potential climate change.

Stakeholder outreach and tribal engagement is considered a critical element of this project. Workshops, webinars, and working interdisciplinary teams have been utilized throughout the life of this project. The result is actionable science and, with the participation of scientists, environmental practitioners and decision makers, supports the co-production of knowledge for climate change adaptation.

**Foreword by**

One EPA Team:
EPA Region 10
EPA Office of Water
EPA Office of Research and Development

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# List of Abbreviations

| | |
|---|---|
| 7-DADMax | Highest 7-day average of the daily maximum temperatures |
| 7-DADMin | Highest 7-day average of the daily minimum temperature |
| 7Q10 flow | 7-day average flow with a 10-year recurrence frequency |
| 7Q2 flow | 7-day average flow with a 2-year recurrence frequency |
| BMP | best management practice |
| cfs | cubic feet per second |
| CIDT | Core Interdisciplinary Team |
| CIG | Climate Impacts Group |
| CMER | Cooperative Monitoring, Evaluation, and Research Committee |
| CMIP3 | Coupled Model Intercomparison Project 3 |
| cm/s | centimeters per second |
| CREP | conservation reserve enhancement program |
| CWA | Clean Water Act |
| DHSVM | Distributed Hydrology Soil Vegetation Model |
| DPS | Distinct Population Segment |
| Ecology | Washington State Department of Ecology |
| ELJ | engineered log jam |
| EPA | U.S. Environmental Protection Agency |
| ESA | Endangered Species Act |
| ESU | Evolutionarily Significant Unit |
| FFR | Forest and Fish Rules |
| FPA | Washington State Forest Practices Act |
| GCM | Global Climate Model *or* General Circulation Model |
| HMZ | historic migration zone |
| in | inches |
| IPCC | Intergovernmental Panel on Climate Change |
| IRPP | Instream Resource Protection Program |
| km | kilometer |
| LWD | large woody debris |
| Mg/L | milligrams per liter |
| MPG | major population group |
| NEP | National Estuaries Program |

| | |
|---|---|
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NTU | nephelometric turbidity units |
| NWIFC | Northwest Indian Fisheries Commission |
| ORD | EPA Office of Research and Development |
| OW | EPA Office of Water |
| PDO | Pacific Decadal Oscillation |
| PNW | Pacific Northwest |
| PSP | Puget Sound Partnership |
| QUAL2Kw | The Washington version of a river and stream water quality model (QUAL2K) that is in turn a modernized version of EPA's older QUAL2E model |
| RM | River Mile |
| RMAP | road maintenance and abandonment plan |
| SFRB | salmon recovery funding board |
| TMDL | Total Maximum Daily Load |
| USDA | U.S. Department of Agriculture |
| USFS | U.S. Forest Service |
| USGS | U.S. Geological Survey |
| VIC | Variable Infiltration Capacity hydrologic model |
| VIDT | Virtual Interdisciplinary Team |
| WAC | Washington Administrative Code |
| WAU | Watershed Administrative Unit |
| WDFW | Washington Department of Fish and Wildlife |
| WDNR | Washington State Department of Natural Resources |
| WMP | Watershed Management Project |
| WRIA | Water Resource Inventory Area |
| WSDOT | Washington State Department of Transportation |

# Acknowledgements

We acknowledge and thank the Nooksack Indian Tribe as the primary authors of this assessment, including: Oliver Grah, Water Resources Program Manager; Treva Coe, Habitat Program Manager; Mike Maudlin, Forest and Fish Specialist/Geomorphologist; Ned Currence, Fisheries/Resource Protection Program Manager; and Jezra Beaulieu, Water Resources Specialist. The Nooksack Indian Tribe led the qualitative assessment as they shared authorship of the current Water Resource Inventory Area (WRIA) 1 Endangered Species Act (ESA) Salmon Plan Recovery Plan, they have substantial local knowledge of the South Fork watershed and fish habitat, and are key implementers of recovery actions. We also want to acknowledge and thank the Core Interdisciplinary Team (CIDT) that was formed to support the Nooksack Indian Tribe in authorship of the qualitative assessment. CIDT team members include: Steve Klein, Project Leader, U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD); Jon Butcher, Principal Hydrologist, Tetra Tech; Hope Herron, Climate Change Specialist, Tetra Tech; and Tim Beechie, Supervisory Research Fish Biologist, National Oceanic and Atmospheric Administration (NOAA) Fisheries, who served as Technical Advisor.

We also want to acknowledge and thank the Peer Reviewers (Britta Bierwagen, EPA ORD; Lisa Crozier, NOAA Fisheries; Kip Killebrew, Stillaguamish Tribe of Indians; David Peterson, U.S. Forest Service; and Crystal Raymond, Seattle City Light) of this report for their many suggestions and comments that resulted in a much improved product.

Lastly, we want to acknowledge and thank the Virtual Interdisciplinary Team (VIDT) for continued involvement and helpful comments during the life of this project. Members of the VIDT include representatives from EPA Region 10, Washington Department of Ecology, EPA ORD, Lummi Nation, WRIA 1 Salmon Recovery and Watershed Management staff teams, as well as attendees from the project stakeholder workshops: *Restoring Salmon Habitat for a Changing Climate In The South Fork Nooksack River, WA* workshop, which was held in Seattle, Washington, June 2012 and the *EPA Region 10 Climate Change and TMDL Pilot* workshop, which was held in Bellingham, Washington, January 22 and 23, 2013, cosponsored by EPA and the Nooksack Indian Tribe.

# Executive Summary

The South Fork Nooksack River (South Fork) is located in northwest Washington State and is home to nine species of Pacific salmon, including Nooksack early Chinook (aka, spring Chinook salmon), an iconic species for the Nooksack Indian Tribe. Segments of the South Fork and its tributaries are identified as being impaired by elevated temperature on Washington's 2010 Clean Water Act (CWA) 303(d) list. These segments exceed the temperature criteria established to protect aquatic life uses for the support of cold-water salmonid populations. High water temperatures in the South Fork are detrimental to fish and other native species that depend on cool, clean, well-oxygenated water. Populations of Nooksack salmon, especially Nooksack early Chinook, have dramatically declined from historic levels. Growing evidence shows that climate change will exacerbate legacy impacts to temperature, hydrologic, and sediment regimes of the South Fork.

The Total Maximum Daily Load (TMDL) program, established by Section 303(d) of the CWA, is used to establish limits on loading of pollutants from point and nonpoint sources necessary to achieve water quality standards. One important use of the TMDL is to bring impaired waters back into compliance with water temperature criteria established for the protection of cold-water fisheries as a primary designated use of the South Fork. The U.S. Environmental Protection Agency's (EPA) Region 10, Office of Research and Development (ORD) and Office of Water (OW), the Washington Department of Ecology (Ecology), and the Nooksack Indian Tribe have launched a Pilot Research Project to explore how projected climate change impacts could be considered in the implementation of a CWA 303(d) temperature TMDL and influence restoration actions in an Endangered Species Act (ESA) Salmonid Recovery Plan. The Pilot Research Project uses a temperature TMDL being developed by Ecology for the South Fork in Washington, as the pilot TMDL for climate change vulnerability analysis. However, the collaborative framework and coordinated research components developed as part of the Pilot Research Project have provided the opportunity to focus more directly on the impact of climate change, primarily increased stream temperatures, on salmon that inhabit the river. Therefore, the pilot also provides the opportunity to move beyond the South Fork temperature TMDL and assess how climate change might influence salmon recovery plans, including ESA recovery plans.

This qualitative assessment is a comprehensive analysis of climate change impacts on freshwater habitat and Pacific salmon in the South Fork. It also evaluates the effectiveness of restoration tools that address Pacific salmon recovery. The objective of the assessment is to identify and prioritize climate change adaptation strategies or recovery actions for the South Fork that explicitly include climate change as a risk. The qualitative assessment's findings will inform development of the CWA South Fork temperature TMDL Implementation Plan, updates to the Endangered Species Act (ESA) Water Resource Inventory Area 1 (WRIA 1) Salmonid Recovery Plan, and other land-use and restoration planning efforts. A companion document, the quantitative assessment, compares projected increases in stream temperature with the thermal tolerances and requirements of various salmonids to inform the CWA TMDL numeric cold-water temperature water quality standard (Butcher et al. 2016).

This qualitative assessment used a stakeholder-centric involvement process that benefited from the engagement of knowledgeable scientists and informed lay-persons alike. The stakeholder process has included several stakeholder involvement events to date (i.e., nine workshops, meetings, webinars) and will include additional opportunities for stakeholder engagement to refine this assessment and present key findings. It is hoped that the qualitative assessment will serve as a pilot project whereby the methods can be applied to other drainages with similar species, limiting factors, and restoration planning, including the Middle Fork and North Fork Nooksack rivers.

The qualitative assessment methodology is based on *Restoring Salmon Habitat for a Changing Climate* (Beechie et al. 2013). In that paper, Beechie et al. present a methodology to provide a systematic, stepwise approach to analyzing climate change impacts; we refer to that methodology herein as the Beechie method.[1] The qualitative assessment applies the Beechie method to the South Fork context, including evaluation per climate risk, per salmonid species, and per restoration action.

The qualitative assessment evaluates historic conditions (or natural conditions in the South Fork temperature TMDL) and the changes, or legacy impacts, resulting from those conditions due to past land management. The cumulative effects of legacy impacts from timber harvest, flood control, transportation facilities, and conversion of forested land to agricultural uses in the South Fork have substantially altered the nature of the South Fork channel, floodplain, and watershed, and has resulted in degraded habitat conditions, including excessive stream temperatures and increased sediment loading, that threaten the survival of salmonids. Climate change has and will exacerbate those cumulative effects. Water temperature is highly correlated with air temperature. Recorded air temperature monitoring in the vicinity of the South Fork has suggested a 1.3 $^{o}$C increase from 1905 through 2010.

Modeling results presented in Section 5.1 (Evaluate Impacts by Climate Risk) show that climate change will have a significant effect on water temperature in the South Fork. South Fork water temperatures, without restoration of riparian shade, are projected to rise by amounts ranging from 3.5 to almost 6 °C during critical low-flow conditions by the 2080s; which could substantially impact fish and reduce the amount and quality of preferred salmon habitat. Table E-1 summarizes the distribution and severity of climate change impacts through the South Fork reaches and subbasins.

As part of this qualitative assessment, the potential magnitude of the impact that climate change could have on Pacific salmon species and life stages in the South Fork was evaluated (see Section 5.2 Evaluate Per Salmonid Species). Of the nine salmon species assessed, three salmon species have been listed as threatened under the federal ESA and are of high priority in the South Fork—spring Chinook salmon, summer steelhead trout, and bull trout. For all species, the life stages with the greatest potential to be impacted by the changing climate were during spawning and intra-gravel development stages, with high potential also recorded for several species during upstream migration/holding and rearing.

Salmon recovery actions and the ability of each action to ameliorate climate change effects were then evaluated (see Section 5.3 Evaluate Per Salmon Recovery Actions). Restoration actions were prioritized by reach and subbasins based on ability to ameliorate various climate change impacts and/or increase salmon resilience, and the potential effectiveness of each restoration action (see Table 5-8 and Table 5-9).

From a watershed scale perspective, channel conditions and legacy impacts today are directly related to intensive and extensive land management. Forestry dominates the watershed and timber harvest and logging road construction are likely the largest contributors to the legacy impacts. The South Fork temperature TMDL project has indicated that restoring the riparian zone of the mainstem of the South Fork alone is not enough to ameliorate excessive temperatures in the river. This strongly suggests that additional focus needs to be given to watershed-scale actions that will address both legacy impacts and future continued climate change.

The following is a list of possible actions that should be considered that address both legacy impacts and climate change:

Longitudinal Connectivity

- Evaluate feasibility of improving passage at South Fork River Mile (RM) 25 barrier and implement feasible projects.

[1] Tim Beechie is also a member of the core team involved in developing this report and provided guidance on application of the Beechie method to the South Fork.

**Table E-1. Distribution and Severity of Climate Change Impacts through the South Fork Reaches and Subbasins.**

<table>
<tr><th rowspan="2">Reach or Subbasin</th><th colspan="5">Climate Impact</th></tr>
<tr><th>Reduced Spring Snowmelt (percentSD+HL)</th><th>Elevated Summer Temperature</th><th>Reduced Summer Low Flow</th><th>Increased Winter Peak Flow</th><th>Sediment</th></tr>
<tr><td colspan="6">Reaches</td></tr>
<tr><td rowspan="5">1 (RM 0-14.3)</td><td rowspan="5">Moderate (43 percent of basin)</td><td>High (Currently exceeds 7-DAD Max lethal limit of 22 °C)</td><td rowspan="5">High (Potentially a reach that loses surface water to groundwater recharge)</td><td rowspan="3">High (Floodplain artificially confined and incised)</td><td rowspan="2">Moderate (Floodplain artificially confined and incised, loss of floodplain sediment storage)</td></tr>
<tr><td rowspan="9">High (Expected to exceed 7-DAD Max lethal limit under 7Q10 conditions with climate change)</td></tr>
<tr><td rowspan="2">Moderate (Rapid channel migration- increase in bank erosion)</td></tr>
<tr><td>Low (Floodplain unconfined)</td></tr>
<tr><td rowspan="2">Moderate (Floodplain naturally confined)</td><td rowspan="2">Low (Floodplain naturally confined/ channel migration limited)</td></tr>
<tr><td>2 (RM14.3- 18.5)</td><td>High (60 percent of basin)</td><td rowspan="6">Moderate</td></tr>
<tr><td rowspan="3">3 (RM 18.5-25.4)</td><td rowspan="3">High (66 percent of basin)</td><td>Low (Floodplain unconfined)</td><td rowspan="2">Moderate (Rapid channel migration)</td></tr>
<tr><td rowspan="4">Moderate (Floodplain naturally confined)</td></tr>
<tr><td rowspan="3">Moderate (Abundant stream-adjacent landslides and unstable slopes could increase sediment sources)</td></tr>
<tr><td>4 (RM 25.4-31)</td><td>High (73 percent of basin)</td></tr>
<tr><td>5 (Upstream of RM 31)</td><td>High (77 percent of basin)</td><td>Moderate (Expected to remain below lethal)</td></tr>
<tr><td colspan="6">Subbasin</td></tr>
<tr><td>Hutchinson</td><td>Moderate (18 percent of basin)</td><td>High</td><td>High</td><td>Moderate</td><td>Moderate</td></tr>
<tr><td>Skookum</td><td>High (67 percent of basin)</td><td>Moderate</td><td>Moderate</td><td>Moderate</td><td>Moderate</td></tr>
<tr><td>Acme Valley</td><td>Low (2 percent of basin)</td><td>High</td><td>High</td><td>Moderate</td><td>Moderate</td></tr>
</table>

| Reach or Subbasin | Climate Impact | | | | |
|---|---|---|---|---|---|
| | **Reduced Spring Snowmelt (percentSD+HL)** | **Elevated Summer Temperature** | **Reduced Summer Low Flow** | **Increased Winter Peak Flow** | **Sediment** |
| Plumbago and Deer | Moderate (29 percent of basin) | Moderate | Moderate | Moderate | Moderate |
| Edfro and Cavanaugh | Moderate (39 percent of basin) | Moderate | Moderate | Moderate | Moderate |
| Howard | High (55 percent of basin) | Low | Low | Moderate | Moderate |
| Upper South Fork | High (84 percent of basin) | Low | Low | Moderate | Moderate |

| Impact Potential | |
|---|---|
| (blue) | Low Impact |
| (yellow) | Moderate Impact |
| (orange) | High Impact |

Floodplain Reconnection

- Increase the pace of broader-scale floodplain reconnection projects by acquiring conservation easements or fee simple title to property in the floodplain or otherwise working with existing landowners to increase stewardship. In addition, work with land owners and develop plans that facilitate floodplain reconnection on specific parcels.

Restoring Stream Flow Regimes

- Enforce water rights and incentivize water conservation in the lower South Fork valley to the extent possible (e.g., water banking).
- Develop a groundwater-flow model coupled with a watershed model for the South Fork basin to evaluate future development/restoration scenarios to inform land use decisions and identify and prioritize floodplain wetland restoration projects.

Riparian Functions

- Continue to implement and expand the Conservation Reserve Enhancement (CREP) program through the lower South Fork and seek funding to extend 15-year lease terms and/or otherwise work to protect existing CREP buffers over the long-term.
- Increase opportunity and funding for riparian/wetlands protection and restoration along the lower South Fork through purchase of conservation easements, development rights, and/or fee simple title and/or working with landowners to foster stewardship.

Instream Rehabilitation

- Continue and increase the pace of instream restoration projects in high priority reaches of the South Fork that create cold-water refuges, increase effective shading, promote hyporheic exchange, reconnect floodplain channels, reduce redd scour, and create flood refuge habitat.

Planning

- Incorporate climate change into updates to *WRIA 1 Salmonid Recovery Plan* and development and prioritization of projects for Salmon Recovery Funding Board/Puget Sound Acquisition and Restoration Account funding.
- Develop a watershed management/conservation plan that facilitates the South Fork temperature TMDL implementation plan and comprehensively addresses the impacts of land management and climate change on the ecological health of the South Fork.

Monitoring, Research, and Adaptive Management

- Develop life cycle models for South Fork salmonid populations to identify limiting life stages and support quantitative assessment of climate change impacts on salmon recovery.

Most of these recommendations will require substantial planning, including a watershed conservation plan, project feasibility assessments, agency consultation, landowner cooperation, stakeholder involvement, and funding, if they are to be implemented in a manner that will effectively address the cumulative effects of legacy impacts and climate change on salmonids and ESA recovery. These parameters will require a substantial amount of time to work through and become effective. Thus, it is important that the recommendations presented above are considered and implemented in a timely fashion to support a climate-resilient ecosystem and ESA recovery.

# 1 Introduction

Global climate change affects the fundamental drivers of the hydrological cycle. Growing evidence shows that climate change will continue to have significant ramifications for the nation's freshwater ecosystems, as deviations from normal atmospheric temperature and precipitation patterns are more frequently recorded and are of greater magnitude across the United States (Bates et al. 2008; Karl et al. 2009). For example, stream temperature is projected to increase in most rivers under climate change scenarios, due in part to increases in air temperature, which, in turn, will adversely affect cold-water fish species such as salmon (Brekke et al. 2009). It is critical that watershed management, restoration and salmon recovery planning, regulatory, and voluntary approaches incorporate climate change science and understanding to ensure holistic and accurate analysis.

Segments of the South Fork Nooksack River (South Fork) and some of its tributaries were listed on Washington's 303(d) list of impaired waterbodies for temperature exceedances of water quality standards. Development of a total maximum daily load (TMDL) is required under the Clean Water Act (CWA) section 303(d) for impaired waters of the state. High water temperatures in the South Fork are detrimental to fish and other native species that depend on cool, clean, well-oxygenated water. The South Fork temperature TMDL addresses temperature impairment to designated uses including core summer salmonid habitat, char spawning and rearing, and salmonid spawning and incubation (Ecology 2016).

The U.S. Environmental Protection Agency's (EPA) Region 10, Office of Research and Development (ORD) and Office of Water (OW), Washington Department of Ecology (Ecology), and the Nooksack Indian Tribe have launched a Pilot Research Project to explore how projected climate change impacts could be considered in the implementation of a CWA 303(d) temperature TMDL and influence restoration actions in an Endangered Species Act (ESA) Salmonid Recovery Plan. The Pilot Research Project uses a temperature TMDL being developed by Ecology for the South Fork in Washington, as the pilot TMDL for climate change vulnerability analysis. However, the collaborative framework and coordinated research components developed as part of the Pilot Research Project have provided the opportunity to focus more directly on the impact of climate change on salmon that inhabit the river. Therefore, the Pilot also provides the opportunity to move beyond the South Fork temperature TMDL and assess how climate change might influence ESA recovery plans.

The Pilot Research Project is separated into two assessment processes: quantitative and qualitative. The quantitative assessment (Butcher et al. 2016) compares QUAL2Kw[2] modeled stream temperatures, including riparian shading, with and without climate change for the 2020s, 2040s, and 2080s. This effort involved comparing projected increases in stream temperature with the thermal tolerances and requirements of various salmonids, although upland land use and forest practices were not addressed in the quantitative assessment.

The qualitative assessment, this report, is a comprehensive analysis of climate change impacts on freshwater habitat and Pacific salmon in the South Fork, and an evaluation of the effectiveness of restoration tools. The objective of the assessment is to identify and prioritize climate change adaptation strategies or recovery actions for the South Fork that explicitly include climate change as a risk. The qualitative assessment findings will inform development of the CWA South Fork temperature TMDL

[2] QUAL2K is a one-dimensional river and stream water quality model intended to represent a well-mixed channel both vertically and laterally with steady state hydraulics, non-uniform steady flow, and diel heat budget and water-quality kinetics. QUAL2Kw is the Washington version of QUAL2K, that is in turn a modernized version of EPA's older QUAL2E model.

Implementation Plan, updates to the Endangered Species Act (ESA) Water Resource Inventory Area 1[3] (WRIA 1) Salmonid Recovery Plan, and other land use and restoration planning efforts. The recommendations in this report do not replace existing salmon recovery priorities, but could inform future updates to the WRIA 1 Salmon Recovery Plan and associated implementation and restoration strategy documents. The following salmon species were assessed: spring Chinook salmon (*Oncorhynchus tshawytscha)*, pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch)*, sockeye salmon (*O. nerka*), steelhead trout (*O. mykiss*), cutthroat trout (*O. clarkia*), and bull trout (*Salvelinus confluentus*).

The Nooksack Indian Tribe led the qualitative assessment, as they shared authorship of the current WRIA 1 ESA Salmon Plan Recovery Plan, and they have substantial local knowledge of the South Fork watershed and fish habitat. The Pilot Research Project has capitalized on the participation and involvement of key stakeholders in the South Fork watershed, particularly the Nooksack Indian Tribe, to ensure that the problem formulation, research activities, and ultimately, the findings and recommendations of the Pilot Research Project tasks will be relevant and implementable in the South Fork watershed. It is also hoped that, by developing and documenting a systematic approach to consideration of climate change in the South Fork watershed as a pilot project, the process will be more easily replicated in other watersheds with similar fish species, landscape settings, and limiting factors.

This qualitative assessment primarily focuses on voluntary habitat restoration and/or land management actions. It does not evaluate the effectiveness of regulatory best management practices (BMPs) such as those specified by the Washington State Forest Practices Act (FPA) and County regulations such as the critical areas ordinance and shoreline master program.

The qualitative assessment is organized into the following sections:

- Section 2: Overview of the WRIA 1 Salmonid Recovery Plan
- Section 3: Stakeholder Engagement
- Section 4: Qualitative Assessment Methodology
- Section 5: Qualitative Assessment
- Section 6: Next Steps
- Section 7: References

[3] The framework for watershed management in Washington is based on geographic areas known as Water Resource Inventory Areas (WRIAs). WRIA 1 includes the Nooksack River basin and several adjoining smaller watersheds, such as the coastal drainages of Dakota and California Creeks, as well as Lake Whatcom. For more information on WRIA 1 refer to: <http://www.co.whatcom.wa.us/publicworks/water/naturalresources/watershed.jsp>.

# 2 Overview of the WRIA 1 Salmonid Recovery Plan

The quantity of Nooksack River salmon, especially South Fork spring Chinook salmon, has dramatically declined from historic levels, due primarily to habitat degradation from the legacy impacts of various land uses such as commercial forestry, agriculture, flood control, and transportation infrastructure. While salmon recovery planning in the Nooksack watershed was initiated in the late 1990s, efforts were energized when several salmonid species in Puget Sound were listed as threatened under the ESA in 1999. The Shared Strategy for Puget Sound (Shared Strategy) formed as a broad-based collaborative effort to build a practical, cost-effective recovery plan for Puget Sound. To that end, Shared Strategy catalyzed development of voluntary watershed-scale salmon recovery plans across Puget Sound, a regional nearshore approach, and an overarching *Puget Sound Salmon Recovery Plan* that summarized regional, cross-watershed strategies and actions and summarized the local chapters (Shared Strategy 2005). The combined *Puget Sound Salmon Recovery Plan*, together with a supplement prepared by the National Oceanic and Atmospheric Administration (NOAA) Fisheries, comprises the ESA recovery plan for Puget Sound Chinook. The *WRIA 1 Salmonid Recovery Plan*, adopted by the WRIA 1 Salmon Recovery Board in 2005, constitutes the WRIA 1/Nooksack watershed chapter of that plan.

The *WRIA 1 Salmonid Recovery Plan* is organized into the following sections:

- **Chapter 2: Goals.** Biological and general goals for salmon recovery in WRIA 1, including quantitative recovery goals for Nooksack spring Chinook populations.
- **Chapter 3: Background.** General watershed description and review and synthesis of the current knowledge on Chinook and bull trout populations.
- **Chapter 4: Limiting Factors.** Identification and prioritization of Nooksack Chinook limiting factors, including habitat, harvest, hatcheries, and hydropower. Includes identification of geographic priority areas.
- **Chapter 5: Strategies and Actions.** Recommendations for habitat-, harvest-, hatchery- and hydropower-related actions necessary to achieve recovery goals are presented in *Necessary Actions*.
- **Chapter 6: Implementation.** Includes monitoring and evaluation of salmon recovery efforts, a description of the decision-making structure, education and outreach components and preliminary funding estimates.

The *WRIA 1 Salmonid Recovery Plan (Plan)* articulated the watershed vision for the Nooksack River Basin: to recover self-sustaining salmonid runs to harvestable levels. At the time of plan adoption in 2005, the Puget Sound Chinook Evolutionarily Significant Unit and the Coastal/Puget Sound Bull Trout Distinct Population Segment (DPS) were listed as threatened under the ESA. Steelhead salmon were subsequently listed as threatened in 2007. Species priorities were encapsulated in the near-term (10-year) approach, which was specified thus:

- Focus and prioritize salmon recovery efforts to maximize benefit to North Fork/Middle Fork Nooksack spring Chinook and South Fork Nooksack spring Chinook salmon.
- Address fall Chinook through adaptive management, focusing in the near-term on identifying hatchery- versus naturally-produced population components.
- Facilitate recovery of WRIA 1 bull trout by:

  - Implementing actions with mutual benefit to both spring Chinook salmon and bull trout, and
  - Removing fish passage barriers in presumed bull trout spawning and rearing habitats in the upper Nooksack River watershed.
- Address other salmonid populations by:
  - Protecting and restoring salmonid habitats and habitat-forming processes throughout WRIA 1 through regulatory and incentive-based programs (which is the focus of this qualitative assessment), and
  - Encouraging and supporting voluntary actions that benefit other WRIA 1 salmonid populations without diverting attention from spring Chinook recovery.

A Near-Term (10-year) Action Plan[4] was developed to assist in the prioritization and implementation of near-term recovery actions in the Nooksack River Basin. These actions include the following:

(1) Restore passage at major spring Chinook salmon barriers.

(2) Restore the Nooksack spring Chinook salmon freshwater habitat.

(3) Integrate salmon recovery into floodplain management planning.

(4) Integrate salmon recovery into regulatory updates.

(5) Establish a South Fork Nooksack spring Chinook salmon hatchery population rebuilding program.

(6) Establish new instream flows in WRIA 1.

(7) Protect and restore estuarine and nearshore areas.

(8) Protect and restore functioning riparian and water quality conditions, and reconnect isolated habitat in lowland tributaries and independent tributaries to the Fraser River and Strait of Georgia.

(9) Continue to manage harvest and harvest-oriented hatchery programs so they do not impede recovery.

Restoration guiding principles, strategies, and priorities were presented in the *WRIA 1 Salmonid Habitat Restoration Strategy,*[5] which guides restoration project development and ranking for Washington State Salmon Recovery Funding Board funding allocations to WRIA 1. The strategy informs implementation of actions 2, 7, and 8 above, although the geographic priorities were and continue to be the Nooksack River Forks (i.e., primarily action 2; WRIA 1 SRB 2016). Due to the critically low quantity of both Nooksack spring Chinook salmon populations, projects expected to benefit Chinook abundance and productivity in the near term are emphasized. Restoration priorities for WRIA 1 Salmon Recovery Funding Board and Puget Sound Acquisition and Restoration funding are updated annually and have evolved since plan adoption to the current restoration strategy matrices in use (WRIA 1 SRB 2016). The current WRIA 1 restoration strategy does not address the impacts of climate change on salmon habitat and fish survival. Such updates provide an opportunity to emphasize inclusion of climate change-ready restoration actions into restoration planning. The current high priority (i.e., Tier 1) strategies in the South Fork include the following voluntary actions:

- Construct log jams to form deep complex pools: cool-water inflow areas (River Mile [RM] 0-20.6).
- Construct log jams to form deep complex pools: other areas (RM 0-20.6).

[4] Included as Appendix B, WRIA 1 Salmonid Recovery Plan (WRIA 1 SRB 2005).
[5] Included as Appendix E, WRIA 1 Salmonid Recovery Plan (WRIA 1 SRB 2005).

- Set back or remove riprap embankments (RM 0-10.9).
- Lower artificial levees to native bank/floodplain elevations (RM 7.2-8.6).
- Relocate river-adjacent infrastructure outside the 100-year erosion hazard area (RM 7.2-8.6).
- Reconnect floodplains (RM 20.6-22 and other reaches if applicants provide sufficient justification).
- Acquire properties necessary to facilitate restoration (RM 0-12.8).
- Acquire properties at risk of degradation to protect high-quality habitat and habitat-forming processes (RM 8.6-20.6).

Progress to date for Chinook salmon habitat restoration in the Nooksack River Basin includes detailed habitat assessment and restoration planning for 78 miles of the Nooksack forks, construction of 227 log jams, acquisition of 758 priority acres within the historic migration zone, and restoration of 300 feet of passage at Canyon Creek. Design work has also been advanced for reconstruction of the Middle Fork diversion dam to facilitate fish passage. Through 2014, 17 restoration projects have been completed in the South Fork and 136 engineered log jams constructed. The general objectives associated with the restoration projects completed to date include forming pools, increasing complex woody cover, and creating temperature refuges; more recent project designs incorporate floodplain reconnection as an objective.

Due to the very small sizes of the two early Chinook populations, the *WRIA 1 Salmonid Recovery Plan* focuses on immediate benefits to the abundance and productivity of the populations and does not consider potential impacts of climate change on the South Fork, and thus, the effectiveness of restoration actions under a changing climate. The goal of the qualitative assessment is to provide a species biology and ESA recovery context to the South Fork TMDL that focuses on compliance with water quality criteria associated with the designated beneficial uses, and more importantly, incorporates climate change risk into salmon recovery planning in the South Fork.

# 3 Stakeholder Engagement

The Pilot Research Project is structured as a stakeholder-centric process. Stakeholder outreach and engagement is considered a critical element of the qualitative assessment, as WRIA 1 technical staff are the most familiar with salmonid populations, watershed processes, and habitat conditions, and stakeholder engagement in project activities makes it more likely that the findings and recommendations will be embraced and ultimately implemented. Stakeholder engagement activities and key outcomes for this qualitative assessment are identified below in chronological order.

1. Stakeholder Workshop, hosted by EPA Region 10. Seattle, WA. June 2012.

The Pilot Research Project was launched by EPA Region 10 in a workshop held on June 25, 2012, in Seattle, Washington. The objective of the workshop was to solicit input from key stakeholders on the project goals and activities. Specific workshop objectives were developed to meet both the regulatory and research objectives. Sixty-six attendees participated in the Climate Change TMDL Pilot and temperature TMDL workshop, including 38 in-person attendees and 28 virtual attendees via GoToMeeting. These stakeholders provided valuable insight into problem formulation and have been instrumental in the project accomplishments achieved to date.

2. Stakeholder Engagement and Project Scoping Facilitation meeting, hosted by Washington's WRIA 1 Watershed Management and Salmon Recovery staff teams. Bellingham, WA. October 4, 2012.

The purpose of the meeting was to brief the WRIA 1 Salmon Recovery and Watershed Management staff teams on the Pilot Research Project and to solicit input on issues, concerns, and opportunities to improve the scope and effectiveness of the project. There were 12 meeting attendees.

The key outcome of the October 2012 meeting was that the WRIA 1 Salmon Recovery team agreed that consideration of potential climate change impacts in the South Fork and the effects on salmon recovery efforts was important. The team recommended implementing the qualitative assessment as a rapid-prototype pilot. Specifically, these recommendations included: (1) developing an assessment methodology based on *Restoring Salmon Habitat for a Changing Climate* (Beechie et al. 2013), and (2) leaving open the possibility of another follow-on project to "refine the assessment methodology" and/or "scale to a larger landscape," possibly for the entire Nooksack River Basin or WRIA 1.

3. Stakeholder Engagement and Project Scoping Facilitation meeting, hosted by the Nooksack Indian Tribe. Bellingham, WA. January 22 and 23, 2013.

The purpose of the meeting was to (1) identify measured climate change trends and projected future climate change; (2) understand how historic and current landscape watershed processes impact salmonids and aquatic habitats in the South Fork, evaluate current conditions, and identify existing restoration tools; and (3) support development of the step-by-step methodology for the qualitative assessment in the South Fork by review and application of the Beechie (Beechie et al. 2013) method for evaluation of salmon recovery strategies in the face of climate change in the South Fork. Thirty-two participants attended the two-day meeting.

The meeting was interactive, with workshop participants *working the problem* by applying the Beechie methodology to each of the South Fork stream reaches and identifying points of agreement and knowledge gaps. The key outcome was that participants agreed to form an interdisciplinary team to help review and provide feedback as the qualitative assessment proceeds.

4. Formation of the Core Interdisciplinary Team (CIDT) in February 2013.

Per the recommendation of the January 2013 Stakeholder Engagement and Project Scoping Facilitation meeting, six key stakeholders agreed to serve as the CIDT to develop the qualitative assessment. The stakeholders include four staff of the Nooksack Indian Tribe Natural Resources Department, several of whom are among the primary authors of the *WRIA 1 Salmonid Recovery Plan* and associated implementation documents (3 Year Work Plans, Restoration Strategy Matrices), Tim Beechie, and Steve Klein. The Nooksack Indian Tribe is a key implementer of recovery actions, and staff—specifically, Oliver Grah, Treva Coe, Mike Maudlin, and Ned Currence—agreed to lead technical CIDT activities.[6] Jezra Beaulieu of the Nooksack Indian Tribe provided technical support. Tim Beechie of NOAA served on the CIDT as the primary author of the Beechie methodology, used by the qualitative assessment to incorporate climate change considerations into recovery actions. Steve Klein of EPA ORD served on the CIDT as the project manager of the Pilot Research Project. Tetra Tech provided facilitation and technical support for the CIDT, but staff are not considered stakeholders.

The CIDT met regularly via conference call (beginning in February 2013 through report completion in August 2016) to provide input and oversight of development of the qualitative assessment. The CIDT identifies the need for, and serves as the coordinating arm for, engagement of the larger Virtual Interdisciplinary Team (VIDT) and broader stakeholder meetings.

5. Commitment to form the VIDT in February 2013.

The interest to form a VIDT to provide broader input to the qualitative assessment was identified during the Stakeholder Engagement and Project Scoping Facilitation meeting; and commitment to form the VIDT was made in February 2013. While the CIDT met virtually and in person on a regular basis, the VIDT convenes as necessary to provide review and comment of the qualitative assessment. The VIDT consists of members of the WRIA 1 Salmon Recovery and Watershed Management staff teams, as well as other relevant EPA Region 10 staff. There are approximately 50 members of the VIDT. Members of the VIDT included representatives from EPA Region 10, Ecology, EPA ORD, Nooksack Indian Tribe, Lummi Nation, WRIA 1, as well as attendees from the January 2013 workshop held in Bellingham, WA, and other interested parties.

6. VIDT Webinar on the Proposed Methodology for Evaluating Climate Change on Endangered Species Act Recovery Actions, co-sponsored by EPA ORD and the Nooksack Indian Tribe on November 20, 2013.

The goal of the webinar was to solicit input from the VIDT on the proposed methodology for conducting the qualitative assessment. Forty members of the VIDT participated in the webinar. After hearing the webinar presentations, the majority of attendees agreed that the proposed methodology is adequate for the qualitative assessment.

7. VIDT Webinar on the Qualitative Assessment Findings, co-sponsored by EPA ORD and the Nooksack Indian Tribe on May 19, 2015.

The second VIDT webinar was held to present the methodology, findings, and recommendations of the qualitative assessment. As a rapid-prototype pilot, it is hoped that the qualitative assessment will serve as a pilot project whereby the methods can be applied to other drainages. The webinar sought to obtain valuable stakeholder input on the process and recommendations of the qualitative assessment as the team

[6] Tim Beechie, Supervisory Research Fish Biologist, NOAA Fisheries, served as Technical Advisor and Steve Klein, EPA ORD, served as Project Leader. The Nooksack Indian Tribe served as lead authors, including: Oliver Grah, Water Resources Program Manager, Treva Coe, Habitat Program Manager, Mike Maudlin, Forest and Fish Specialist/Geomorphologist, Ned Currence, Fisheries/Resource Protection Program Manager, and Jezra Beaulieu, Water Resources Specialist.

works to move from research demonstration to scaling up to a more comprehensive program. The VIDT endorsed the qualitative assessment approach and recommendations, as well as the need to scale to other watersheds such as the Middle and North Forks.

8. WRIA 1 Salmon Recovery Staff Team Briefing, Bellingham, WA, August 6, 2015.

Treva Coe, Nooksack Indian Tribe, briefed the WRIA 1 Salmon Recovery Staff Team on the findings of the Draft Final Qualitative Assessment. The meeting provided an opportunity for the staff team to ask questions and further discuss the draft findings.

9. WRIA 1 Program Coordination Management Team Briefing, Bellingham, WA, November 9, 2015.

Treva Coe and Oliver Grah, Nooksack Indian Tribe, and Steve Klein, EPA, briefed the WRIA 1 Program Coordination Management Team on the findings of the Draft Final Qualitative Assessment. The meeting provided an opportunity for the management team to ask questions and further discuss the draft findings. Particularly, the issue of prioritizing restoration options and importance of scaling to other watersheds was discussed. There were 24 atteendees.

# 4 Qualitative Assessment Methodology

The qualitative assessment methodology is based on *Restoring Salmon Habitat for a Changing Climate* (Beechie et al. 2013). In that paper, the authors grouped restoration actions according to the watershed processes or functions they attempt to restore, and then, based on evidence from peer-reviewed literature, classified them as either likely or not likely to ameliorate a climate change effect on high stream flows, low stream flows, and stream temperatures.

Beechie et al. (2013) have developed a series of guiding questions that form an overarching framework for how to consider climate change impacts alongside restoration planning. The primary question is "Do climate change predictions alter restoration plans?" To answer that question, a subset of guiding questions needs to be considered:

1. What habitat restoration actions are necessary for recovery of local salmon populations?
2. Do future stream flow and temperature scenarios alter the types of habitat restoration actions that are necessary for recovery?
3. Does the restoration plan or action ameliorate a predicted climate change effect on stream flow or temperature?
4. Will the restoration plan or action increase habitat diversity and salmon population resilience?

A decision tree for following these guiding questions for a salmon restoration plan is presented in Figure 4-1.

Impacts of climate change will vary among rivers and will include several different climate change risks (e.g., increase in temperature, decrease in base flow, increase in peak flow, and increase in sediment loading and transport). In turn, the risks to salmonid populations could vary according to salmonid species (e.g., impairing optimal temperature thresholds according to life cycle), season, and/or location within the river system. The first step in applying the Beechie method is for practitioners to determine the geographical extent of the climate change assessment. Considerations when determining the geographic extent of the assessment include the resources available to conduct the assessment, data availability and coverage, and units used for planning efforts to date.

To systematically consider the possible effects of climate change but also account for variability of impacts, the Beechie method has been applied to a manageable scale of evaluation: river reaches. The mainstem South Fork was divided into five reaches based on river miles: RM 0–14.3 (floodplain; impaired TMDL reach); RM 14.3–18.5 (canyon); RM 18.5–25.4 (core Chinook spawning); RM 25.4-31 (confined areas); and RM >31 [mostly U.S. Department of Agriculture (USDA) and U.S. Forest Service (USFS) administered lands]. The contributing watershed was divided into seven subbasins based on these reach breaks and the contribution of larger tributaries. Figure 4-2 shows how the South Fork was divided for the analysis.

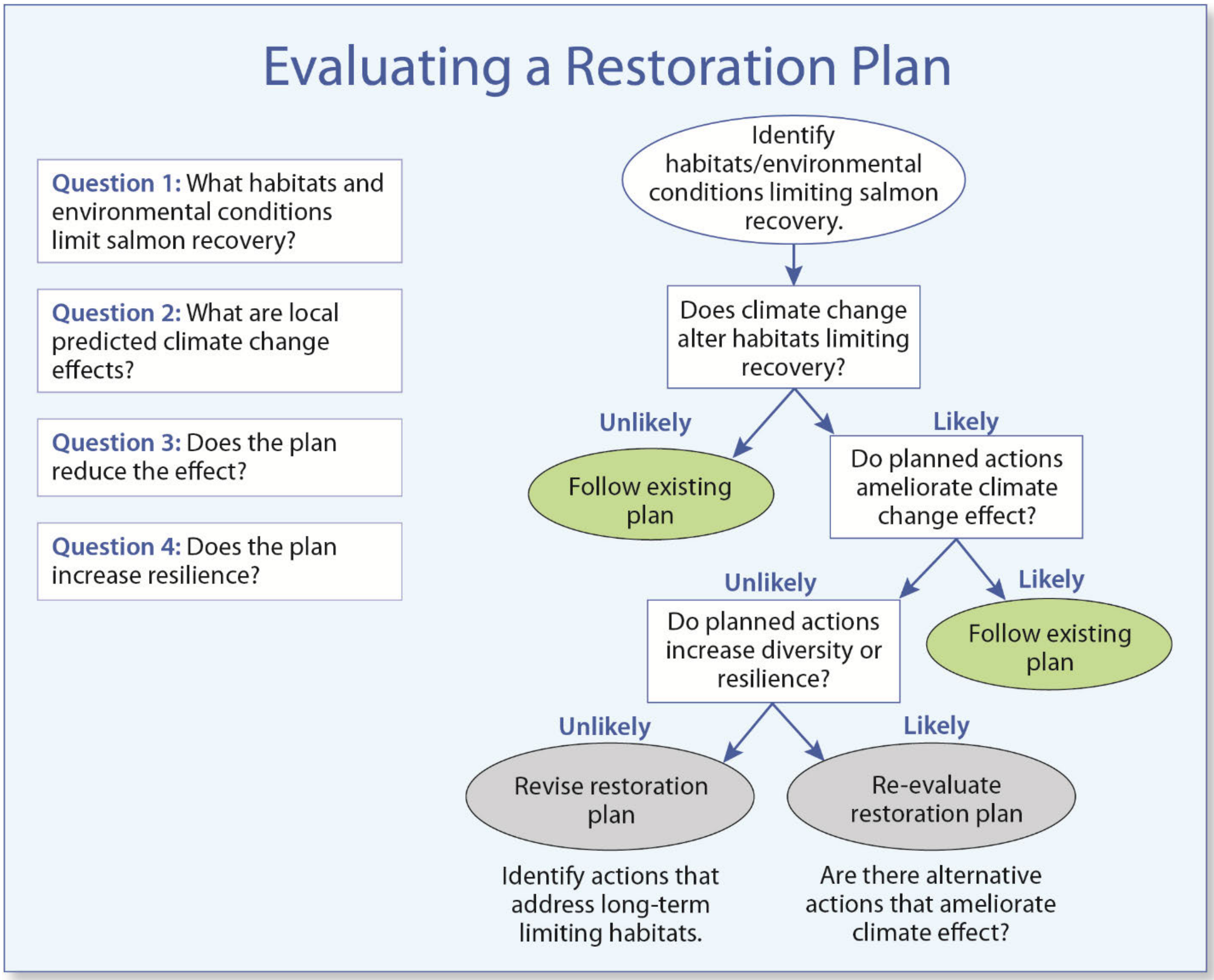


**Figure 4-1. Decision Tree for Evaluating a Salmon Restoration Plan for Climate Change Considerations. From Beechie et al. 2013.**

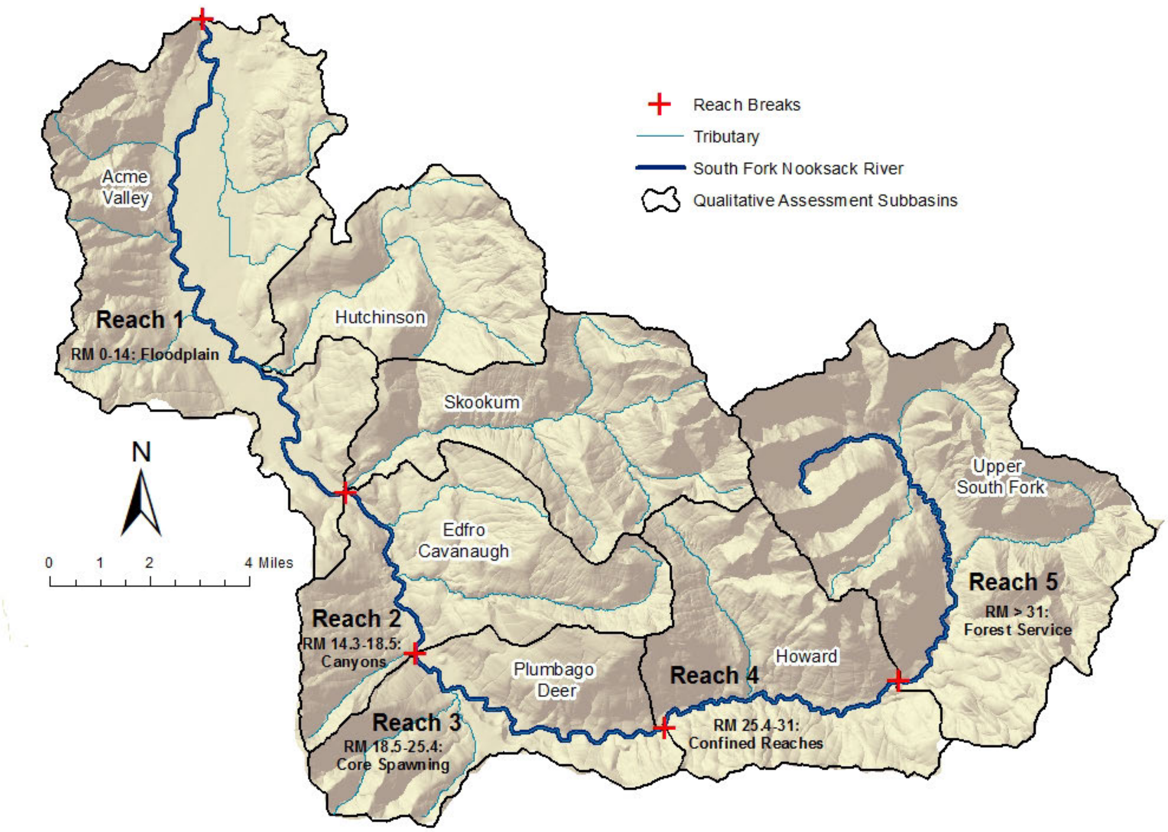


**Figure 4-2. River Reach Breaks and Subbasins for the South Fork Qualitative Assessment.**

<u>Assessment Reach #1 - RM 0-14.3: TMDL Impaired Reach</u>

The lowest reach of the South Fork flows through a broad alluvial valley that is dominated by agricultural land use (Figure 4-3). Historically, this unconfined valley was the area where wood and sediment delivered to the channel upstream was deposited, forming a branching river system with abundant logjams and a well-connected floodplain with extensive wetlands. This section of the river was the first to be impacted by land use changes, beginning with land clearing in the 1860s for agriculture and shingle bolts. The floodplain was almost entirely cleared and burned by the early 1900s and logjams removed from the channel to allow for wood transport down the river. The loss of logjams and vegetation from the banks of the river and increased sediment loading led to rapid channel migration and widening by the 1930s, and subsequent bank armoring to protect eroding farmlands. Cumulatively the effects of land clearing, channel cleaning, bank armoring, and increased sediment loading since the 1930's have led to channel incision and floodplain abandonment through much of the lower 14.3 miles of the river. Although incision has led to channel deepening, the wide active channel area still exists, thereby reducing the effectiveness of riparian shading.

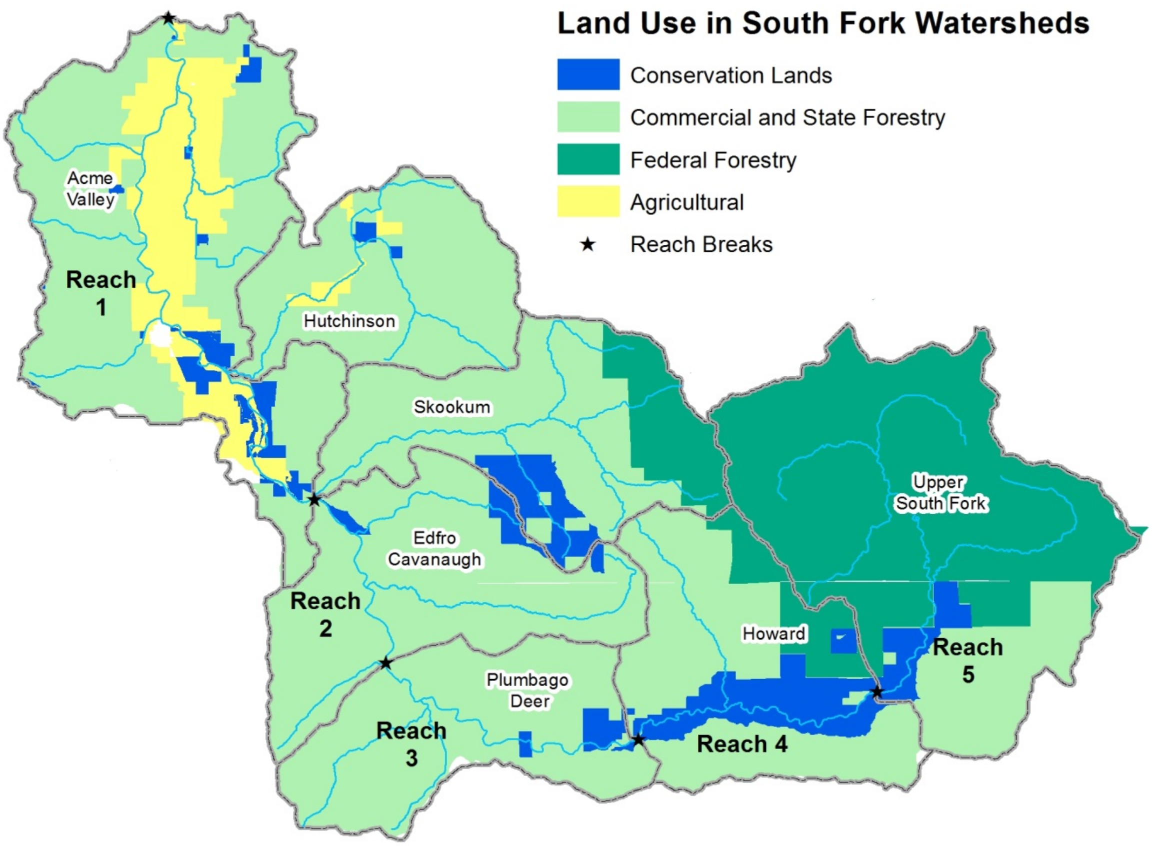


**Figure 4-3. Generalized Land Use in the South Fork Watershed and Subbasins.**

Some of the likely impacts on hydrology and water quality as a result include increased water temperature, increased sediment delivery to the channel, increased sediment transport rate, stream incision, and general loss of the natural streamflow regime (faster runoff times, higher peak flows, lower low flows). In addition to legacy impacts, climate change will impact the watershed further, especially RM 0-14, by increasing water temperatures, decreasing baseflows, increasing peak flows, and altering sediment dynamics with a likely increase in sediment loading and transport. To protect riparian and floodplain habitat and facilitate habitat restoration, land acquisition has been a high priority in the lower South Fork. The acquisition has allowed for wetland creation, floodplain channel restoration, and extensive riparian planting, while making substantial portions of the floodplain available for floodwater storage.

Assessment Reach #2 - RM 14.3-18.5: Canyons

The segment of the South Fork from RM 14-18.5 has a more confined morphology dictated by bedrock valley walls and erosion-resistant terraces. Channel migration has been very low through the historic period in this reach. Most of this segment is in its natural condition with ample riparian cover and serves as a conduit for sediment. There are no barriers, roads, or rip rap that interfere with flow. Currently much of this reach is industrial forest land and managed under Washington State Forest Practice Rules, which require site-potential buffers along the river.[7] Property acquisition to provide long-term protection for the reach has been the focus of restoration activities. Habitat restoration opportunities are limited by poor construction access.

Assessment Reach #3 - RM 18.5 – 25.4: Chinook Core Spawning

The unconfined sections of the river in this section represent the core spawning areas for South Fork spring Chinook and have been the focus of instream habitat restoration since the 1990s. This reach of the river is bordered by a mix of industrial forest lands and conservation property. Riparian zones are recovering from past forest practice activities that harvested the majority of the riparian zone of the South Fork. Several large deep-seated landslides occur along the channel in this reach, episodically contributing large amounts of fine sediment to the river. Four engineered logjam projects have been completed and design is ongoing for several more projects. The focus of the restoration has been on creating high quality holding habitat for adults, with a newer focus on trying to reverse the trend of channel incision in the reach. Extensive sediment reduction work has been completed by forest landowners and restoration partners in this reach. Riparian restoration has been ongoing for approximately 15 years and is expected to continue.

Assessment Reach #4 - RM 25.4 – 31: Confined Reaches

A partial passage barrier marks the break between this reach and the downstream core spawning area. In the early 1990s, Seattle City Light acquired a corridor along the South Fork from RM 25 to the USFS border, near RM 33. The channel is sinuous and intermittently anastomosing in some reaches with occasional large gravel bars. Erosion resistant terraces of fluvial and glacial deposits slow the channel migration rate through much of the reach. Deep-seated landslides occur in glacial deposits that line the channel and the upland portions of the watershed, as well as a large bedrock landslide at RM 31 along the right bank of the channel. Past land use activities have likely exacerbated the glacial deep-seated landslides, as groundwater recharge areas were not protected by the Forest and Fish Rules (FFRs) until the last decade. In addition to the deep-seated landslides, there are abundant shallow-rapid landslides that have delivered sediment to the channel. These slides generally occur on steep, convergent slopes and are often related to land use activities, such as timber harvest or road construction.

Assessment Reach #5 - Upstream of RM 31: USDA-USFS

This section of the river lies above the anadromous barrier at RM 31. Much of the watershed above RM 31 lies within land administered by the USFS and is currently protected by the North West Forest Plan. Forest roads are limited on USFS property, but a lack of funding for maintenance has led to several places where road failures have impacted aquatic resources. The South Fork downstream of the USFS boundary is bordered by property acquired and preserved by Seattle City Light as mitigation for dams on the Skagit River. These areas have been a focus for forest road abandonment, infrastructure removal, restoration, and riparian planting. Beyond the mitigation property, lands are managed for industrial forestry and are

[7] The Washington State Forest Practices Rules (Title 222 WAC) establishes standards for forest practices such as timber harvest, pre-commercial thinning, road construction, fertilization, and forest chemical application. In July 2001, Washington adopted new forest practice measures commonly referred to as the "Forests and Fish Rules." These new Washington rules are the result of the 1999 Forests and Fish Report (FFR) and the resulting Salmon Recovery Act of 1999 (sometimes referred to as the Forest and Fish Law). The Washington State Forest Practices Habitat Conservation Plan (FPHCP) (also known as the Forest and Fish HCP) was approved in 2006 by U.S. Fish and Wildlife Service and NOAA Fisheries to meet the requirements of ESA as well as the CWA. For the purposes of this report, we use the term "forest practices" as those used to meet the current Washington State Forest Practice Rules and FPHCP. For more information on Washington State Forest Practices Rules, refer to: <http://www.dnr.wa.gov/programs-and-services/forest-practices>. For more information on Washington Forest Protection Association, refer to: <http://www.wfpa.org/forest-policy/environmental-law/>.

subject to the FFRs, which require buffering of all fish-bearing streams and portions of non-fish bearing streams. A substantial number of higher hazard forest roads have been abandoned by the landowner in this reach of the river. While no instream habitat projects have been completed or are planned in this section of the river, efforts focused on watershed and riparian restoration and sediment reduction are expected to continue.

This assessment uses secondary data as described in the Quality Assurance Project Plan, *EPA Region 10 Climate Change and TMDL: Qualitative Assessment* (USEPA, 2014). The core data for this assessment is based on three published reports: 1) *Restoring Salmon Habitat For A Changing Climate* (Beechie et al. 2013); 2) *Quantitative Assessment of Temperature Sensitivity of the South Fork Nooksack River Nooksack River under Future Climates using QUAL2Kw, EPA/600/R-14/233* (Butcher et al., 2016); and 3) *WRIA 1 Salmonid Recovery Plan* (adopted by the WRIA 1 Salmon Recovery Board in 2005). Limitations on use of these data are stated in this assessment. Other published and unpublished reports are used as secondary data and cited throughout this assessment. Unpublished data is attributed to the organization [federal, tribal, state, local and non-government organizations (NGOs)] that was responsible for the collection of the data and these references conform with their organization's policies and procedures to ensure data quality (e.g., Quality Management Plans and Standard Operating Procedures). Anecdotal information or assumptions used in sensitivity analysis are clearly cited in this assessment and best professional judgement by natural resource professionals, including the Nooksack Indian Tribe and other government organizations (federal, tribal, state, local) is necessary and desirable to synthesize data and present informed conclusions.

# 5 Qualitative Assessment

The qualitative assessment methodology is based on *Restoring Salmon Habitat for a Changing Climate* (Beechie et al. 2013). In that paper, Beechie et al. present a generalized framework for evaluating and updating salmon recovery plans in the context of climate change; we refer to that methodology herein as the Beechie method.[8] Applying the method requires some adaptation and customization (i.e., adaptive management) based on the local technical information and recovery planning context. For example, at early scoping meetings in WRIA 1 for this qualitative assessment, local stakeholders expressed the desire to understand the magnitude of climate change impacts relative to legacy (i.e., the impacts of past land uses, such as commercial forestry, agriculture, flood control structures, and transportation infrastructure) and ongoing land use impacts.

Climate change is a significant additional stressor on freshwater salmonid habitat that exacerbates the cumulative impacts of past land use practices (forestry, agriculture, flood control). Legacy impacts of past land use practices are still evident on the landscape today and include reduced riparian shade, channel simplification and bank hardening, lack of large woody debris, and sources of sedimentation to the river channel. Furthermore, it is likely that these land uses have also altered the hydrologic and temperature regimes of the South Fork.

We consider past (historical), current (existing) and future (climate change) habitat conditions to evaluate ESA recovery actions in the South Fork. These assessments provide the information needed to determine which restoration actions are needed and where, and to develop a restoration strategy for the basin. We use four process-based principles to guide development of the restoration strategy and support sustainable recovery of salmonid populations: 1) target root causes of habitat and ecosystem change; 2) tailor restoration actions to local potential; 3) match the scale of restoration to the scale of physical and biological processes; and 4) clearly define expected outcomes, including recovery time (Beechie et al. 2010).

The following sections apply the Beechie method to the South Fork, including evaluating legacy impacts and the impacts by climate risk, salmonid species, and stream reach.

## 5.1 Evaluation of Impacts by Climate Risk

### 5.1.1 Existing Conditions and Changes from Historic Conditions

Existing habitat and water quality conditions in the South Fork watershed are well documented.[9] Evaluating historic conditions [or natural conditions as discussed in the draft South Fork temperature TMDL, (Ecology 2016)] and the changes from historic conditions is more difficult as there is limited information on conditions that existed at the onset of settlement in the 1860s. The use of the term *historic conditions* is analogous to *natural conditions,* which is defined in the Washington Water Quality Standards as water quality that was present before any human-caused polluton (173-201A-020 WAC). In the case of the South Fork, these are the conditions of the watershed that occurred prior to European development. Changes that have occurred in the watershed since then arise from three types of factors, only one of which is due to *changing* climate:

[8] Tim Beechie is also a member of the core team involved in developing this report and provided guidance on application of the Beechie method to the South Fork.
[9] For example, refer to *WRIA 1 Limiting Factors Report (Smith 2002)*, *WRIA 1 Salmonid Habitat Restoration Strategy (2005)*, South Fork reach assessments/restoration plans.

1. Anthropogenic impacts, or legacy impacts, from such land uses as timber harvest throughout most of the watershed, conversion of forestland to agriculture on the lower valley bottomlands, and channel and floodplain alterations, including agricultural drainage, flood control levees and dikes, transportation facilities, and hardened river banks;
2. Natural variability in climate; and
3. Non-stationary changes in climate (i.e., climate change).

Evaluating the impacts of these factors, which interact with one another, and distinguishing the impacts of each individually is difficult. Historical data are limited to General Land Office maps and notes, and limited photographs and oral and written accounts. Simulation models can be used to estimate watershed conditions prior to these impacts [i.e., *natural conditions* as discussed in the draft South Fork temperature TMDL (Ecology 2016)]. More recent observations are potentially affected by both land management and climate trends. Further, the natural climate of the Pacific Northwest (PNW) is subject to long-term cycles such as the Pacific Decadal Oscillation (PDO) that are superimposed on any underlying trend of change in the climate system. Fish populations in the PNW have always been exposed to these natural climate cycles, so these factors should not be considered a new risk; however, underlying climate change does pose an enhanced risk, or cumulative impact, to salmonids, which is the focus of this qualitative assessment.

#### 5.1.1.1 Temperature

Water temperature is critical to the health of salmon populations, and high temperatures during the summer are especially limiting. Water temperature in the watershed has been monitored at multiple locations by the Nooksack Indian Tribe since 2000. Longer monitoring records from the US Geological Survey (USGS) and Ecology are available at a few stations going back to 2001. The USGS temperature station at the Wickersham gage (12209000) operated continuously from July 2001 to September 2008; however, it was moved downstream a short distance to the Saxon Road bridge after 2008 (watershed area 103 square miles and 129 square miles, respectively). The year round average water temperature in the South Fork at Wickersham was 7.28 ºC, with a range from 0.1 to 23.5 °C. The highest 7-day average of daily maximum temperatures or 7DADMax, which is the metric for stream temperature criteria, averaged 20.85 °C across these eight years, with the highest value of 22.96 °C being recorded in 2004.

The distribution and availability of cold-water refuges may mitigate the impacts of elevated temperatures on salmonids. Fish detect differences in temperature of <0.1 °C and can thermoregulate through movement to thermal refuges, which can occur at spatial scales ranging from microhabitats to entire river basins (Torgerson et al. 2012). Cold-water refuges are defined as "those portions of a water body where… or when the water temperature is at least 2 °C colder than the daily maximum temperature of the adjacent well-mixed flow of the water body" (ODEQ 1995, as cited in Torgerson et al. 2012). Many tributaries in the chinook zone (i.e. downstream of RM 31) provide cold-water refuge from high temperatures in the South Fork. In 2013, 7DADMax temperatures in the South Fork ranged from 19.5 °C at RM 25.0 to 22.2 °C at RM 0.9 (Nooksack Natural Resources 2014); in contrast, 7DADMax temperatures in monitored tributaries were 16.1 °C (Deer Creek), 9.8 °C (Fobes Creek), 11.6 °C (Hutchinson Creek[10]), 16.9 °C (McCarty Creek), 18.6 °C (Hardscrabble Creek), and 16.8 °C (Black Slough). Similarly, in 2014, 7DADMax temperatures ranged from 19.0 °C (RM 25) to 22.2 °C (RM 0.9) in the South Fork (Nooksack Natural Resources 2014) and were 15.8 °C in Skookum Creek.[11] Cold-water refuges have also been documented in the South Fork in a log-jam-formed pool at the mouth of Hutchinson Creek and in side channels, braids, blind channels, and backwaters likely fed by groundwater seeps and/or hyporheic upwelling (Nooksack Indian Tribe, unpublished data). Gendaszek (2014) also documented cold-water

[10] https://fortress.wa.gov/ecy/eap/flows/station.asp?sta=01C070
[11] http://waterdata.usgs.gov/wa/nwis/dv?referred_module=sw&site_no=12209490

refuge during daytime in a log-jam formed pool in the South Fork; the temperature anomaly was attributed, at least in part, to thermal stratification.

Water temperature is largely driven by a combination of air temperature and solar radiation input. Increases in stream temperature are expected where riparian shade, including both mainstem and tributary shading, has been reduced by human activity. Increases in temperature would also occur if air temperatures have increased. While long-term records of water temperature do not exist, it is known that riparian shading has been reduced from its natural condition and that air temperatures have been gradually rising (approximately 1 ºC over the last 100 years). This may indicate a climate-related increase in summer water temperatures of about 0.67 °C during that period (Isaak et al. 2011[12]).

Like most watersheds in the PNW, the conditions prior to European settlement (i.e., historic or natural conditions) have been extensively modified by human activity. European settlement of the Nooksack River basin occurred in the 1860s and 1870s and was accompanied by timber harvest and extensive snag and log jam removal in the river (Collins and Sheikh 2004). Most of the native forest at lower elevations had been logged by 1900, and portions of the land on the alluvial bottomlands of the river were converted to agriculture, accompanied by extensive ditching and draining of wetlands. At higher elevation portions of the watershed, private commercial forestry lands, and public lands in the South Fork watershed, clear cut logging apparently started in earnest in the 1950s, peaked in the 1960s and 1970s and then began a steady decrease (Lentz 2006). These activities substantially altered the nature of the South Fork channel and watershed, and the riparian vegetation that provides shade and other functions to both the mainstem and tributaries.

Under current Forest Practices Rules, stream buffers vary by landowner type, stream characteristics, and site potential for tree growth. Washington State Trust lands, administered by the Department of Natural Resources (DNR), are subject to a Multi-species Habitat Conservation Plan (HCP). The plan requires buffering all streams that are greater than two feet wide, and those less than two feet wide “where necessary” to meet the objectives of the plan. All fish-bearing waters receive a buffer that is as wide as the 100-year site potential tree height, or 100 feet, whichever is greater. These streams also receive an additional 50-100 foot wind buffer (depending on stream type) when there is at least a moderate potential for windthrow. Non-fish bearing streams receive a 100-foot buffer. The State Lands HCP further requires leaving buffering of avian habitats, wetlands, and unstable slopes. Additional deciduous trees are left scattered or clumped within the harvest unit. The HCP also requires that two-thirds of DNR-managed lands in the rain-on-snow zone to be hydrologically mature. The “rain-on-snow” zone is defined in the HCP as an elevation zone where it is common for snowpacks to be partially or completely melted during rainstorms several times during the winter (DNR 1997).

Private forestlands managed by large industrial landowners are subject to the requirements of the Forest Practices HCP and are governed by the state Forest Practices Rules. These rules use a site potential tree height-based stream protection strategy, with requirements that vary by water type[13] (e.g., whether or not streams/water bodies are used by fish, and whether or not streams experience perennial or seasonal flow). The water type classifications include:

- Type “S” (shoreline) - streams and waterbodies that are designated shorelines of the state.

[12] Isaak et al. (2011) report across multiple sites that the summer average water temperature increases in a ratio of about 0.67:1 relative to the average change in air temperature.
[13] For additional information on DNR Forest Practices Water Typing refer to: <http://www.dnr.wa.gov/forest-practices-water-typing>.

- Type "F" (fish) - streams and waterbodies that are known to be used by fish, or meet the physical criteria to be potentially used by fish. Fish streams may or may not have flowing water all year; they may be perennial or seasonal.
- Type "Np" (non-fish) - streams that have flow year round and may have spatially intermittent dry reaches downstream of perennial flow.
- Type "Ns" (non-fish seasonal) - streams that do not have surface flow during at least some portion of the year, and do not meet the physical criteria of a Type F stream.

Buffer requirements for type S and F streams vary with streamsize but include a minimum 50 foot no-harvest buffer on each side of the stream. Type Np buffers include 56-foot circular buffer around sensitive areas (perennial initiation points, springs, confluences) and 50-foot no-harvest buffers along: (a) 500 feet of type Np streams greater than 1000-feet in length; (b) 300 feet or 50 percent of length (whichever is greater) on type Np streams between 300 and 1000 feet in length; or (c) the entire length of type Np streams less than 300 feet in length.[14] There are no buffers required on type Ns streams; however, Ns streams do require a 30 foot equipment limitation zone to limit exposed soil to no more than 10 percent of the surface area.

As with the State Lands HCP, unstable slopes are also buffered. The combined effects of these buffers can lead to nearly continuous buffers for perennial streams, such as is seen in the Sygitowicz Creek subbasin (Figure 5-1), although they may have variable maturity and shade effectiveness. Small forest landowners owning parcels that are 20 contiguous acres or less are exempt from the riparian buffers rule, as long as the owner of the parcel does not own a cumulative total of more than 80 acres. Instead, these landowners can either follow the FPRs in place prior to 1999, or work with the DNR to establish an alternative management plan for the riparian portion of the harvest area. In fact, both large and small landowners may propose site specific alternate plans which are reviewed by multidisciplinary teams and must be approved by DNR as providing equal protection to riparian functions. These result in a wide variety of riparian prescriptions.

USFS-administered lands are governed by the Northwest Forest Plan. Virtually all of the federal land in the South Fork watershed is Congressionally Withdrawn, Administratively Withdrawn, Riparian Reserve, or Late Successional Reserve, leaving only 67 acres (0.27 percent of the federal land in the watershed) of Matrix land where timber harvest could occur. There has been no timber harvest on federal lands in the South Fork since the 1990s when 30 acres were harvested (Lentz 2006).

Riparian buffers on non-forest lands are regulated by Whatcom County's Shorelines regulations and critical areas ordinance. These require no net loss of ecological function. The buffers are 150 feet for Shorelines of the State (mean annual flow of 20 cubic feet per second [cfs] or more), 100 feet for other fish-bearing streams (current, presumed, or historic use), and 50 feet for all non-fish streams. Many of the landowners of agricultural streams in the South Fork watershed have enrolled in conservation programs, such as the Conservation Reserve Enhancement Program, that provide incentives to reforest the riparian zone.

[14] A helpful guidance document that describes buffer rquirements is *A Simplified Guide to Forest Practices Rules in Washington State*, which can be found online at: <http://file.dnr.wa.gov/publications/fp_fpi_complete.pdf>.

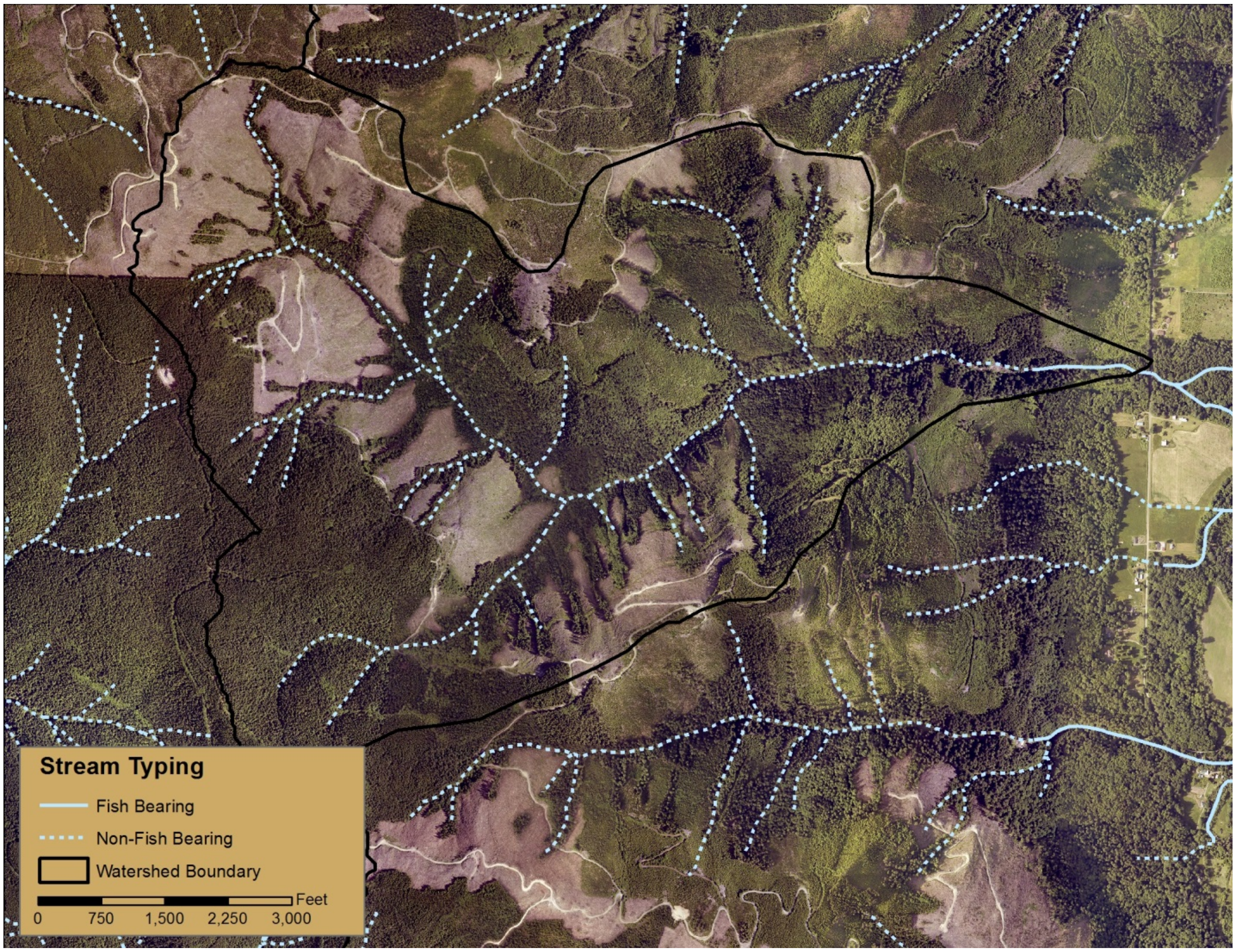


**Figure 5-1. Stream and Unstable Slopes Buffering in the Sygitowicz Creek Subbasin, a Tributary to the South Fork near RM 4.**

In addition to long-term cycles (muti-decadal) of climate variability such as the PDO, there are shorter cycles of climate variability that affect stream temperature. Typical low-flow conditions or 7Q2 (average once every two years) and critical low-flow or 7Q10 (average once every ten years) are expressions of climate variability that affect salmonid survival and population resilience (Table 5-1).

Reduction in shade along the mainstem South Fork due to timber harvest and land use changes was evaluated in the draft South Fork temperature TMDL (Ecology 2016). Ecology's modeling scenarios provide estimates of what is achievable assuming 100-year site index conditions. Results for TMDL Scenario 5 (7Q10) suggest that the full restoration of assumed system potential shade associated with tree height and buffer width associated with the 100-year site index would lower the highest 7DADMax water temperatures by 2 °C or more as compared to current conditions TMDL Scenario 3 (7Q10) (Table 5-1).

Note that the draft TMDL numbers river reaches by kilometers (rather than river miles) downstream of the confluence with Wanlick Creek. Separate results are summarized above and below reach 28 because different water temperature criteria apply in these two regions. TMDL reach 28 corresponds approximately to RM 18, the downstream end of the confined area in reach 2 (Table 5-1).

**Table 5-1. TMDL Modeling Scenario Results for Typical Low-flow and Critical Low-flow Conditions in the South Fork (Butcher et. al. 2016).**

| TMDL Scenario | Condition | Maximum Stream Temperature (°C) (averaged across select reaches) | | | | |
|---|---|---|---|---|---|---|
| | | All Reaches | RM 0-13 | RM 14-17 | RM 18-30 | RM 31+ |
| *Typical Low-flow Conditions (7Q2 flows; 50th percentile air temperature)*[b] | | | | | | |
| 1 | Current Conditions: 7Q2 | 19.0 | 19.7 | 19.1 | 18.7 | 17.6 |
| 2 | 100-yr System Potential except on developed land: 7Q2 | 16.9 | 17.7 | 17.0 | 16.6 | 15.2 |
| *Critical Low-flow Conditions (7Q10 flows; 90th percentile air temperature)*[c] | | | | | | |
| 3 | Current Conditions: 7Q10 | 21.0 | 22.0 | 21.3 | 20.8 | 18.5 |
| 5 | 100-yr System Potential except on developed land: 7Q10 | 18.7 | 19.8 | 19.0 | 18.4 | 16.0 |
| 6 | 100-yr System Potential everywhere: 7Q10 | 18.7 | 19.7 | 19.0 | 18.4 | 16.0 |

*Notes:*

[a] From the headwaters to RM18, the summer water quality criterion is 12 °C. For RM 18 to the mouth, the water quality criterion is 16 °C. 7Q2 flow is the lowest 7-day average flow that occurs on average once every 2 years.

[c] 7Q10 flow is the lowest 7-day average flow that occurs on average once every 10 years.

Mean annual air temperatures for the watershed under current conditions range from 8 to 9 °C at lower elevations and 4 to 7 °C at higher elevations (USGS 2000). Atmospheric temperatures in the PNW also show a rising trend beneath large year-to-year variability. There are not long periods of air temperature measurements in the South Fork watershed, but measurements are available at nearby Clearbrook, WA (within Whatcom County but in the Sumas watershed) back to 1903 (GHCND Station USC00451484, elevation 19.5 meters). Air temperature at this station has increased by about 1.3 ºC per century over the period of record (Figure 5-2).

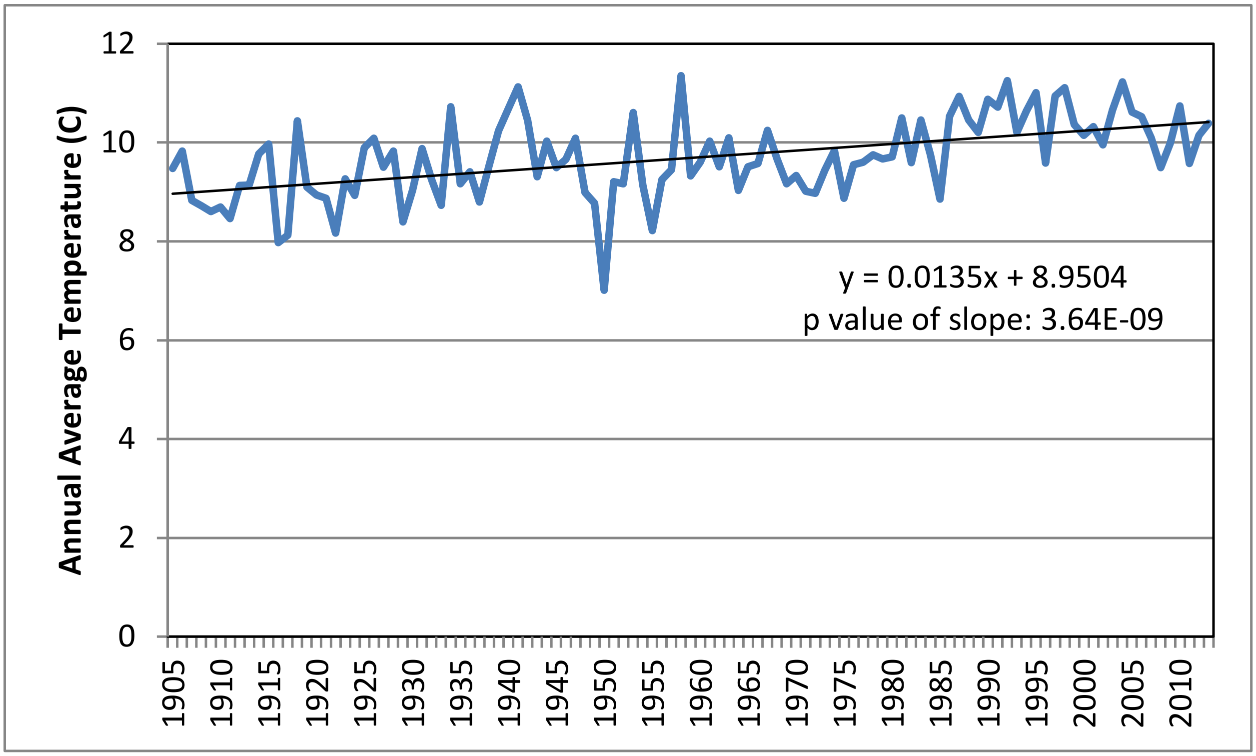


**Figure 5-2. Annual Average Air Temperature Trend at Clearbrook, WA**

More generally, Mote (2003a) found that records from 1920 to 2000 indicate an increase in annual average temperature of 0.91 °C in the maritime PNW, with a much larger increase of 1.83 °C in the winter months (January – March period). Revised estimates in Mote and Salathé (2009) estimate the observed increase in atmospheric temperature in the PNW between 1900 and 2000 to be 0.8 °C. Hamlet and Lettenmaier (2007) showed that increases were larger for the daily minimum temperature than for the daily maximum temperature, and that the greatest increases occurred in the winter months; however, in the PNW, the daily minimum temperatures increased by 1 °C or more during the summer months as well.

For the South Fork watershed, estimates of historic air temperature change can be gleaned from the spatially interpolated air temperature estimates for 1915-2006 created as input to the University of Washington Climate Impacts Group's (CIG) climate modeling effort. These suggest increases for the South Fork greater than the regional average. Using an area-weighted composite of the CIG grid cells intersecting the South Fork watershed, the rates of change in air temperature are 1.16 °C/century for daily average temperature (close to the observed rate of increase at Clearbrook), 0.47 °C/century for daily maximum temperature, and 1.87 °C/century for daily minimum temperature.

Long-term continuous records of water temperature in the South Fork are not available; however, from the increasing trend in air temperature, it can be inferred that water temperatures have also increased. Isaak et al. (2011) report across multiple sites that the summer average water temperature increases in a ratio of about 0.67:1 relative to the average change in air temperature, suggesting the air temperature changes likely have led to a summer water temperature change on the order of 0.78 °C—in addition to any legacy impacts caused by changes in land use or reduction in stream shading. Future climate projections reported in the South Fork quantitative assessment (Butcher et. al 2016) suggest an even greater rate of change relative to air temperature in the future; however, this is due to the combined effects of increased air temperature, reduced flow, and changes in humidity.

###### 5.1.1.1.1 Sensitivity Analysis for Natural Conditions Estimate using Current Climate

In the draft TMDL, Ecology estimates the "natural condition" of the South Fork temperature regime utilizing readily available information such as buffer tree height associated with the 100-year site index. The critical 100-year "natural condition" scenario (Scenario 5 in Table 5-2) was chosen by Ecology as the TMDL natural condition scenario. However, the Nooksack Indian Tribe has noted that while the 100 year site index tree height averaged 160 feet, climax forest tree heights were thought to be historically greater, with the potential to reach 250 feet. Thus, Ecology also assessed the uncertainty of the Scenario 5 by assessing the temperature model's sensitivity to a number of environmental changes (Ecology 2016). These "sensitivity analysis" scenarios assess the effect of variations to the estimated natural condition based on data and analysis performed by the Nooksack Indian Tribe.

Four new scenarios were developed and modeled to evaluate the influence of different aspects of natural conditions; a fifth scenario was modeled to evaluate the combined impact and is considered by Nooksack Indian Tribe staff to best represent natural conditions (Table 5-2). These scenarios provide contrast to the *system potential* conditions assumed for Scenario 5 of the TMDL (Ecology 2016) and will inform development of the TMDL implementation plan and this qualitative assessment. Modeled natural condition scenarios are:

(1) Cooler headwater and tributary temperatures—assume tributary temperatures are 20 percent colder;

(2) Decreased natural channel width—channel plan view assumed to be consistent with the conditions encountered and as described in the 1890 Government Land Office surveys;

(3) Increased system potential vegetation height and riparian buffer width—assume vegetation height is consistent with average climax forest heights (250 feet) and effective buffer width 80 percent of that height;

(4) Enhanced hyporheic exchange—greater thickness of the stream gravels involved in hyporheic exchange; and

(5) The combined impact of all four alterations.

These scenarios involved modifying some of the parameters of the summer critical condition system potential vegetation model run under current climate (TMDL Scenario 5), which is based upon the following parameter inputs: $90^{th}$ percentile air temperatures and dew point with microclimate effect, 7Q10 flows for headwaters and tributaries with associated decreased channel bottom width, no clouds, shade based on system potential vegetation, and headwater/tributary temperatures set at or below the water quality criteria. Table 5-2 summarizes the results of the model runs for these variations on natural conditions considered in the draft South Fork temperature TMDL (Ecology 2016).

Each of the five scenarios or variations, including the combined natural conditions, resulted in decreases in stream temperatures during the critical summer low-flow times from the temperatures associated with the original Scenario 5 system potential model results. The results of this sensitivity analysis are important because they provide real contrast to those of Scenario 5. The additional variations or scenarios summarized above suggest that, under current climate conditions, restoring the South Fork to natural conditions (as simulated with the "Combined Natural Parameter Variations") could result in critical condition temperatures near water quality standards for the lower South Fork (RM18 to Confluence) in the long-term (e.g., 300-400 years). This is in contrast to the temperature predictions associated with the assumed system potential conditions in 100 years (i.e., 100-year site index).

**Table 5-2. Summary of Sensitivity Analysis for Natural Conditions Estimate using Current Climate.**

| Scenario/Variation | River Reach | | |
|---|---|---|---|
| | Headwaters to RM 18 | RM18 to Confluence | All Reaches Combined |
| **Water Quality Criteria (°C)** | 12 | 16 | 16 |
| **TMDL Original System Potential, Scenario 5** | 17.8 | 19.6 | 18.7 |
| **Cooler Headwater Tributaries (20 percent cooler)** | 16.9 | 19.0 | 18.0 |
| **Reduced Natural Channel Width** | 17.2 | 18.9 | 18.1 |
| **Increased Riparian Climax Tree Height and 80 percent Effective Buffer Width** | 16.7 | 18.2 | 17.5 |
| **Enhanced Hyporheic Exchange** | 17.8 | 19.3 | 18.6 |
| **Combined Natural Parameter Variations** | 15.1 | 16.4 | 15.8 |
| **% Change in Temperature with Combined Natural Parameter Variations** | -15.2% | -16.3% | -15.5% |

Adapted from the draft South Fork temperature TMDL (Ecology 2016).

#### 5.1.1.2 Flow

The general hydrology of the PNW is described as follows (Elsner et al. 2009):

> Small changes in temperature can strongly affect the balance of precipitation falling as rain and snow, depending on a watershed's location, elevation, and aspect. Washington, and the Pacific Northwest as a whole, is often characterized as having three runoff regimes: snow-melt dominant, rain dominant, and transient (Hamlet and Lettenmaier 2007). In snowmelt dominant watersheds, much of the winter precipitation is stored in the snowpack, which melts in the spring and early summer resulting in low streamflow in the cool season and peak streamflow in late spring or early summer (May-July). Rain dominant watersheds are typically lower in elevation and mostly on the west side of the Cascades. They receive little snowfall. Streamflow in these watersheds peaks in the cool season, roughly in phase with peak precipitation (usually November through January). Transient watersheds are characterized as mixed rain/snow due to their mid-range elevation. These watersheds receive some snowfall, some of which melts in the cool season and some of which is stored over winter and melts as seasonal temperatures increase. Rivers draining these watersheds typically experience two streamflow peaks: one in winter coinciding with seasonal maximum precipitation, and another in late spring or early summer when water stored in snowpack melts.

The South Fork watershed has a relatively small area of permanent snowpack and glacierets (a total area of about 270 acres); however, the hydrology under existing conditions is strongly influenced by fall-spring rainfall and rain-on-snow events, followed by a smaller hydrograph peak driven by higher elevation snowmelt in early summer. Under existing conditions, the higher altitudes of the South Fork are characterized as snow dominant, while the lower elevations are characterized as rainfall to transient rainfall-snowmelt driven.

Mote (2003a) reports generally consistent increases in precipitation for the maritime PNW with an average annual increase of 12.9 percent between 1900 and 2000, with most of the increase occurring in the winter and spring. However, April 1 snow water equivalent (SWE) is in contrast expected to decline

(Mote 2003b). These changes are expected to increase winter runoff, decrease spring snowmelt, and possibly result in lower summer low flows due to reduced spring infiltration coupled with potential decreases in summer precipitation. Increased air temperatures may also result in decreased summer low flows as evapotranspiration increases.

Long-term flow gaging of the South Fork has been conducted at the Wickersham gage (USGS 12209000) since May 1934—although unfortunately only partial-year records were collected from 1977-1995. Observations from 1915-2008 have an average flow of 713 cfs. The entire South Fork drainage area has an average annual discharge of 1,032 cfs based on Ecology data at gaging station 01F070 (WY 2004-2010) located on the left bank of the South Fork at the Potter Road Bridge crossing near the town of Van Zandt.

For temperature management, infrequent low flows that decrease resilience to heat inputs in the system are of particular interest. Curran and Olsen (2009) estimated that the 7-day average flow with a 2-year recurrence interval (7Q2) was 102 cfs and the 7-day average flow with a 10-year recurrence interval (7Q10) was 75.8 cfs.

The average monthly pattern of flow at Wickersham (Figure 5-3) shows dual peaks; one in the late fall and early winter as the rainy season kicks in and a higher incidence of rain and snow melt events, and a second lower peak in the period around May, associated with higher elevation snowmelt. The lowest flows typically occur in August and September. The pattern for 1996-2003 is similar to that of 1934-1964, but does show some possible differences, with the later period having higher flows in November and January, and slightly lower flows during the snowmelt period. Although the sample size for the recent period is small, this could reflect a small reduction in the area and depth of snow accumulation and therefore, quicker melt, and increased rainfall in the late-fall to early winter.

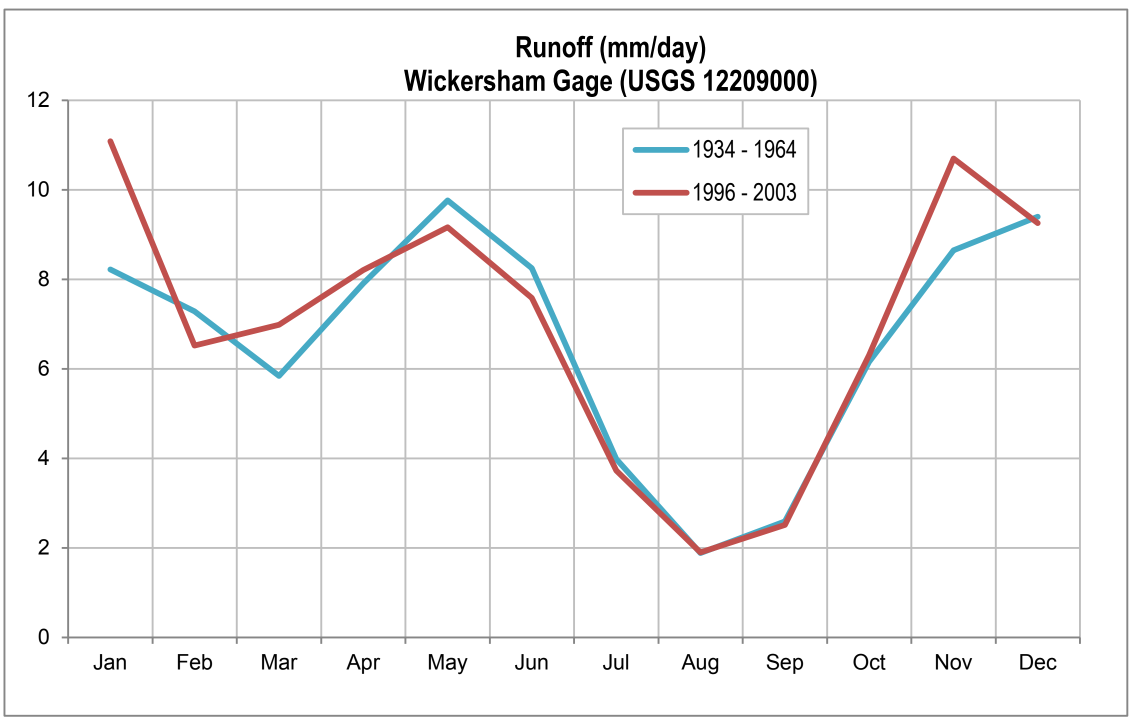


**Figure 5-3. Monthly Average Flow Depth at the Wickersham Gage.**

Consistent with Figure 5-3, the average annual flow at Wickersham (Figure 5-4; complete years only) shows little evidence of a significant trend: There is a positive coefficient on a regression of average annual flow against time, but this is mostly due to the low flows observed between 1935 and 1944 and the regression explains only a small part of the observed variability ($R^2 = 4.3\%$). Annual minimum 7-day average low flows (Figure 5-5) are shown for the whole period of record, as the summer period was monitored for all but one year. This shows periods of lower low flows around 1940 and 1990 that may in part be associated with natural decadal cycles in weather patterns, as the precipitation regime is closely tied to the PDO cycle, with less precipitation in positive phases of the PDO as reported by Baldwin et al. (2002) for the Olga 2SE station in the San Juan Islands (Figure 5-6). There is some suggestion of an increase in maximum daily average peak flows in recent years as shown in Figure 5-7; note that largest measured flows are shown as points for partial record years; these may not necessarily be the largest flow in the complete year.

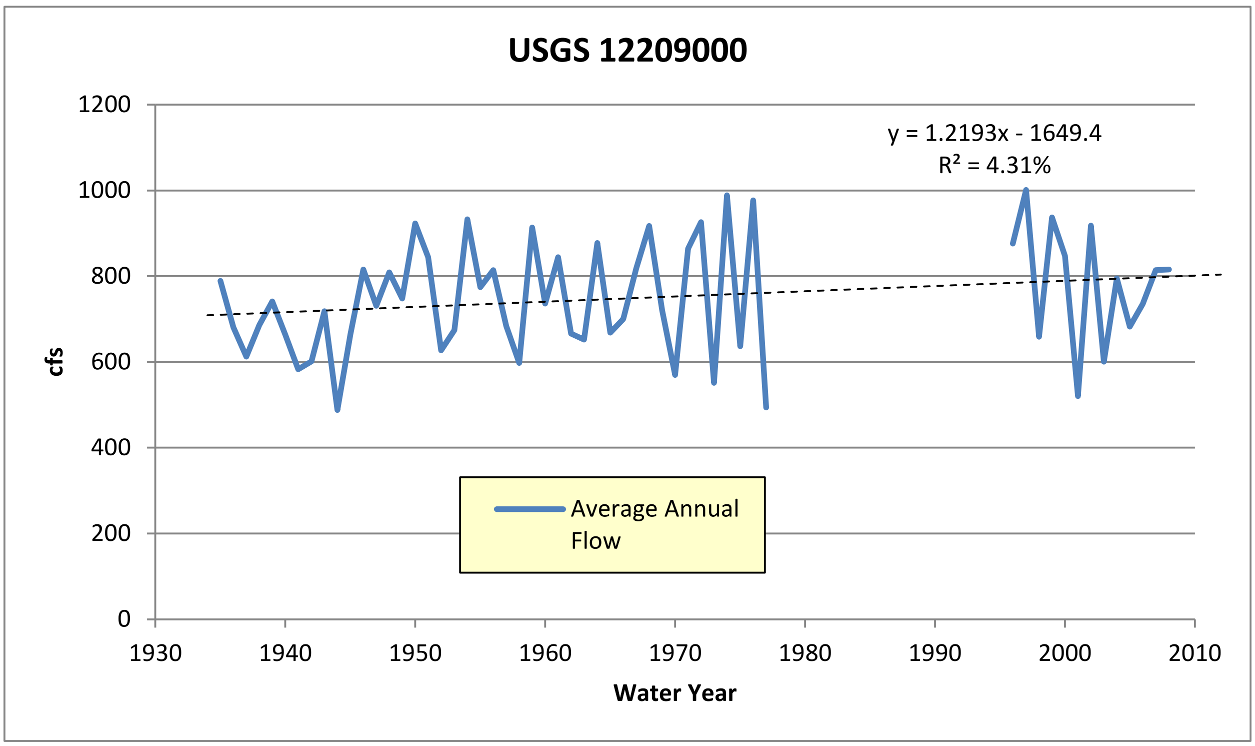


**Figure 5-4. Average Annual Flow at Wickersham.**

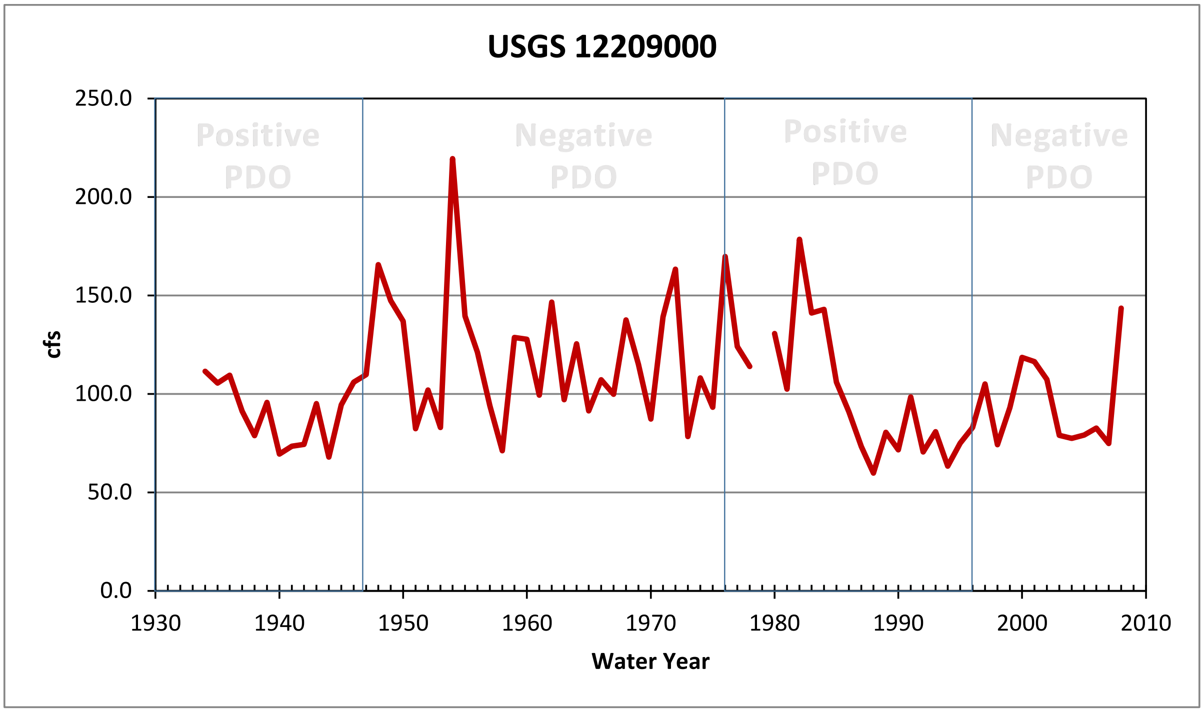


**Figure 5-5. Annual Minimum 7-day Low Flow at Wickersham.**

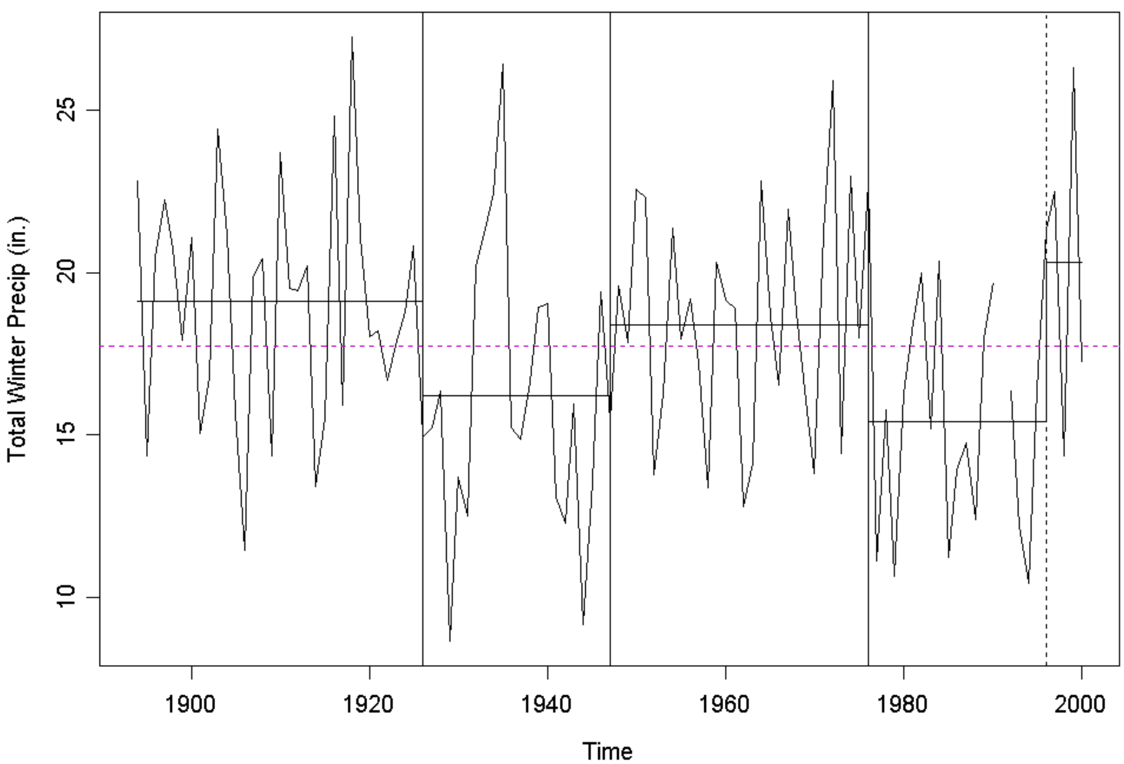


**Figure 5-6. Time Series of Olga 2SE Station Winter (Nov-Mar) Precipitation.**

Note: The Pacific Decadal Oscillation phase (vertical line), average precipitation for the phase (solid horizontal lines), and long-term average precipitation (dashed horizontal line) are shown (figure from Baldwin et al. 2002).

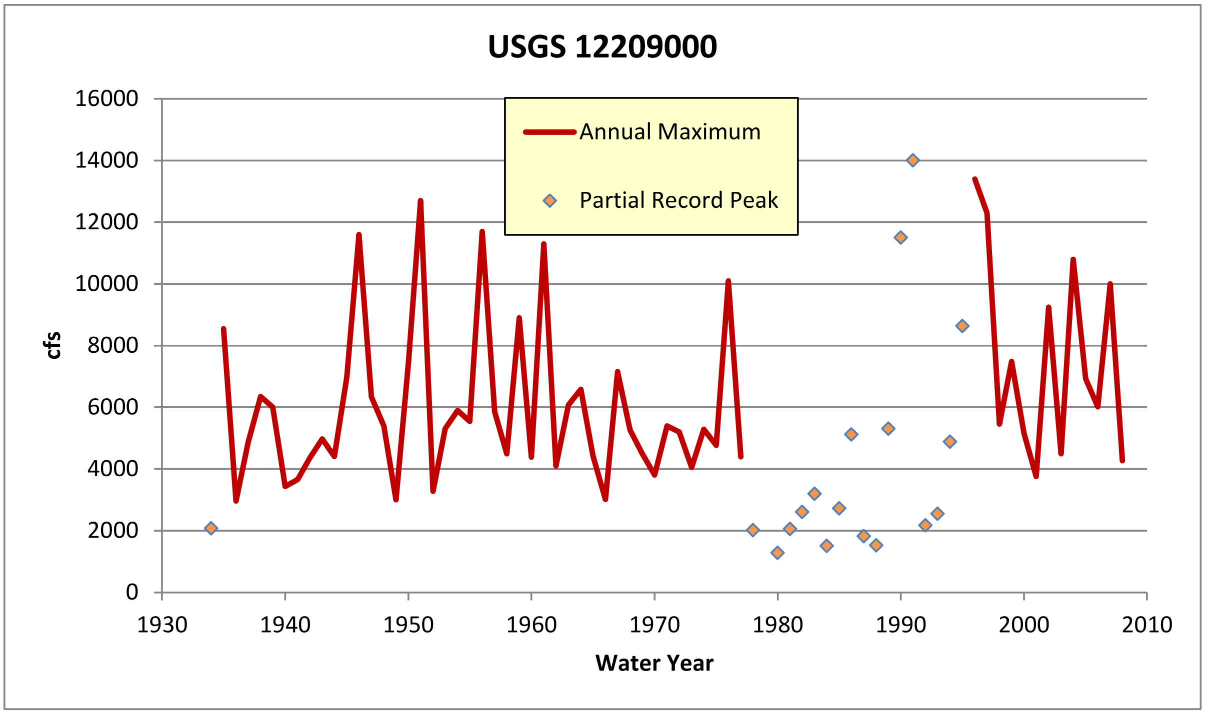


**Figure 5-7. Annual Maximum Daily Average Flows at Wickersham.**

Additional perspectives on longer-term trends in flow in the South Fork can be gathered by examining the output of the Variable Infiltration Capacity (VIC) model simulations conducted by CIG using historical interpolated climate data. CIG does not directly report South Fork flows at Wickersham, but these can be estimated by a spatially weighted average over the VIC model grid cells that intersect the South Fork watershed. The VIC model results provide a best estimate of the impact of climate forcing on hydrology in the South Fork; however, they do not account for any changes in land use over time in the South Fork watershed that may have increased flow through the reduction of mature forest cover. In addition, the VIC model was not calibrated to the South Fork. As described in the quantitative assessment (Butcher et al. 2016), the VIC results seem to provide a reasonable fit to summer low flows, but deviate from observed winter flows in the South Fork. Nonetheless, the VIC model results are likely valid in a relative sense and provide an additional line of evidence as to 20$^{th}$ century climate change impacts on hydrology in the South Fork.

Figure 5-8, Figure 5-9, and Figure 5-10 show, respectively, the VIC model predictions of annual average flow, minimum annual 7-day average low flow, and annual daily average peak flow at the Wickersham gage for 1915-2006. These are shown as area-weighted depths (in millimeters) over the watershed to focus attention on trends over time rather than the absolute magnitude of flow predicted by VIC (1 mm/d ≈ 9.2 cfs). Annual average flows show little evidence of a strong trend with time, although the linear trend has a slight increase. Seven-day average low flows were, on average, lower prior to 1948 than they have been since, but seem to have been elevated in the 1960s and 1970s compared to both earlier and later periods. VIC-predicted maximum flows appear to have declined until about 1950, but have subsequently increased.

In sum, both gaged and simulated flows in the South Fork show at most a limited response to changes in climate conditions between 1915 and 2006. There is likely a small increase in total flows and high flows, consistent with climate models, but a strong signal has not yet emerged.

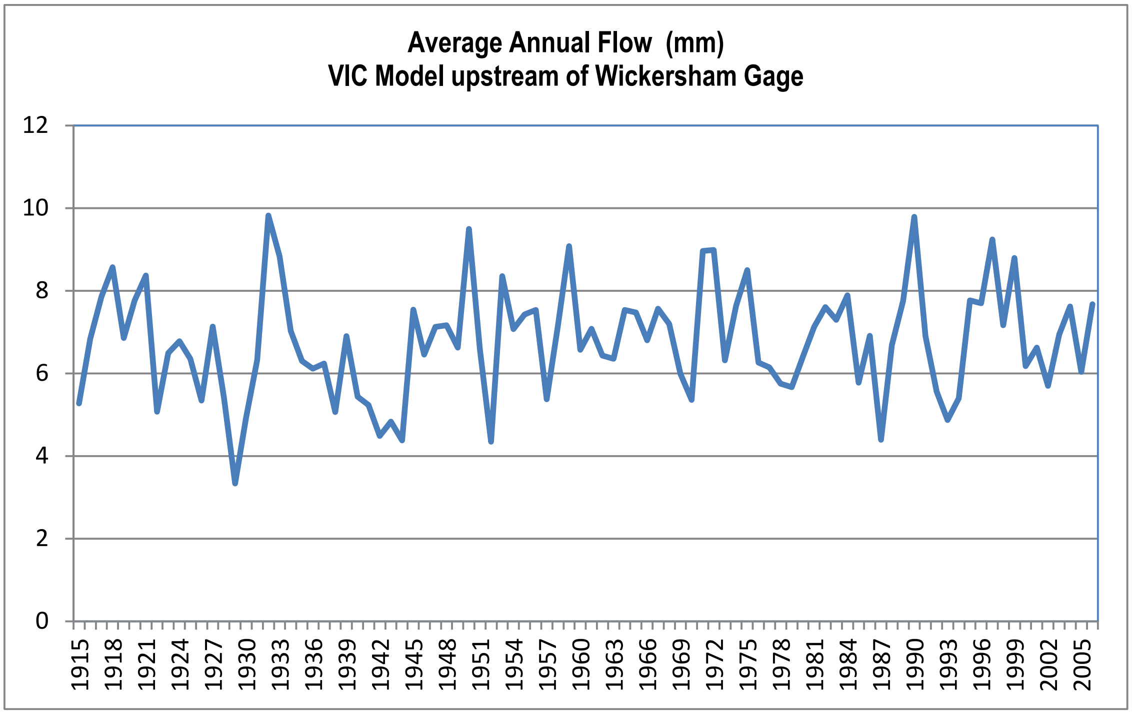


**Figure 5-8. VIC Model Predictions of Average Annual Flow Depth at Wickersham Gage.**

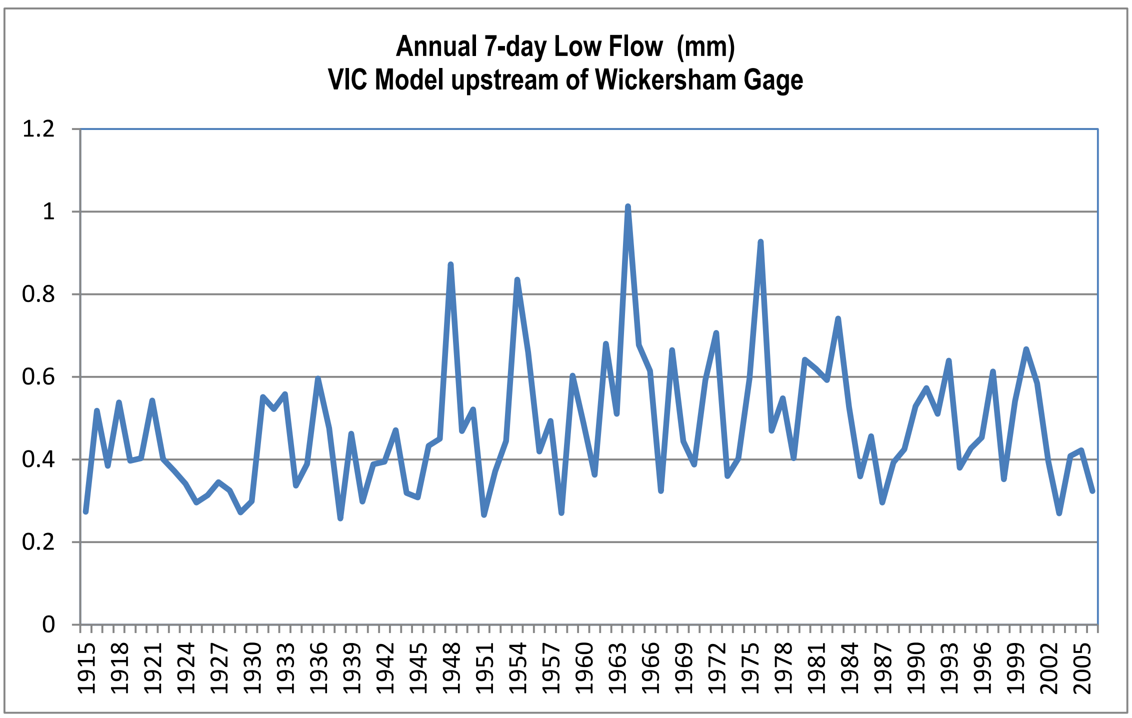


**Figure 5-9. VIC Model Predictions of Minimum Annual 7-day Average Low-Flow Depth at Wickersham Gage.**

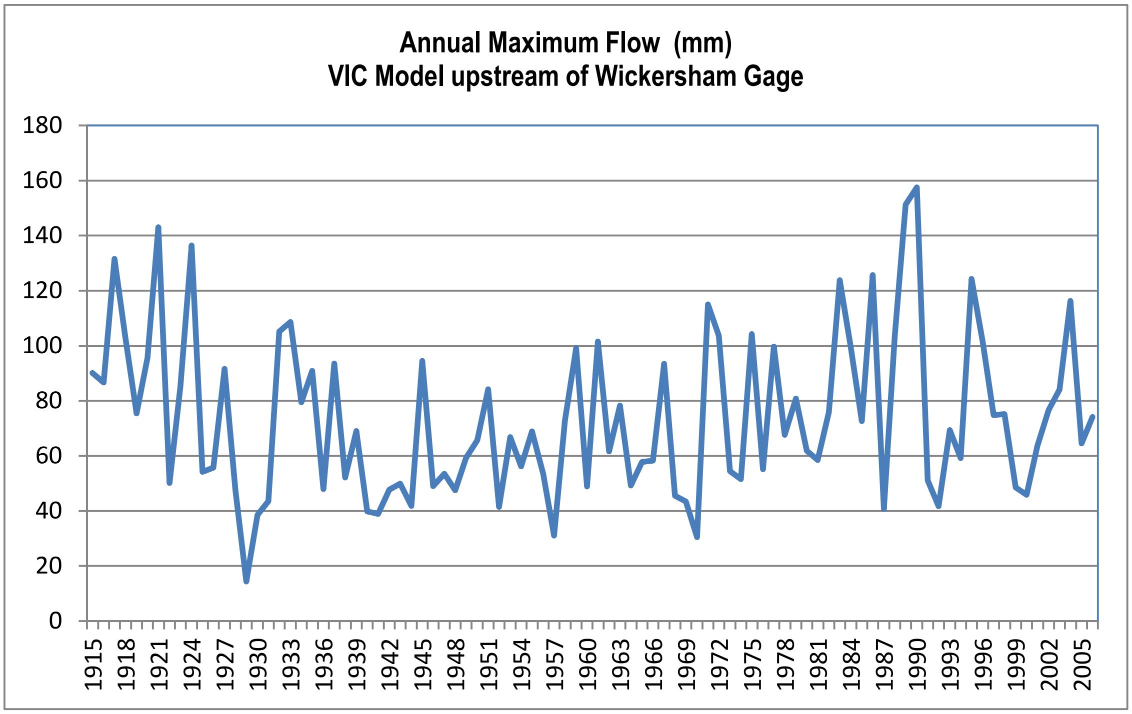


**Figure 5-10. VIC Model Predictions of Annual Maximum Daily Average Flow Depth at Wickersham Gage.**

### 5.1.1.3 Sediment

Due to the geology, climate, and physiography of the watershed, the Nooksack River watershed contributes the second largest sediment load per unit watershed area to the Puget Sound of the contributing river basins, delivering an estimated 1,400,000 tons of sediment per year to Bellingham Bay (Czuba et al. 2011). Estimates of sediment flux from the South Fork are estimated to be 519,745 tons per year based on an annual average discharge of 1032 cfs, although average values are difficult to discern because of the short period of sediment monitoring (NIT 2011). While the South Fork watershed likely has a high natural sediment load, sediment supply and transport in the South Fork have been significantly influenced by human activities. Clearing of channel-spanning log jams in the South Fork Valley, bank armoring, logging and clearing of riparian areas, and forest road construction have all been identified as likely causes of increased sediment supply (Soicher et al. 2006, Collins and Sheikh 2004, Maudlin et al. 2002, Watts 1996). The increase in sediment supply and transport due to human activities has contributed to changes in the channel and instream habitat conditions.

The South Fork watershed transitions from a more confined valley to an unconfined valley near RM 13. The wide floodplain and low gradient of the lowest 13 miles of the channel made this reach an area of sediment deposition, wood accumulation and channel migration (Sedell and Luchessa 1982). The large amounts of wood described in early accounts of the Acme Valley would likely have caused frequent channel avulsion and multiple low-flow channels across the floodplain (Collins and Sheikh 2004, Morse 1883). This is reflected in the 1890 Government Land Office Surveys of the channel, where the channel was narrower and more sinuous (~3,500 feet' longer), and 35 percent of the channel was multi-threaded and split with stable forested islands.

The South Fork is on the CWA Section 303(d) list for fine sediment (Ecology 2012). Recent measurements of fine sediments in potential spawning areas indicate moderate to high levels of fine sediments (<0.85mm) in the lower South Fork; of six sites sampled from RM 1.4 through 10.6, percent fine sediments was low in one site (10 percent, n=1, RM 10.15), moderate in two sites (RM 5.9: 15 percent, n=1; RM 10.6: 16 percent, n=1), and high in three sites (RM 1.4: 19 percent, n=1; RM 6.1: 20 percent, n=1; RM 9.2: 19 percent, n=1; Hyatt and Rabang 2003). Schuett-Hames et al. (1988b) observed that 37 percent of the usable spawning habitat in the South Fork was moderately embedded (25-50 percent embedded) and about 4 percent was >50 percent embedded. Hyatt and Rabang (2003) observed a slight downstream increase in fine sediments in spawning gravel samples through the South Fork.

High turbidities, which persist relatively late into the spring and early summer, are also a concern. During high-flow sampling in 2004/2005, Kopp (2005) measured higher turbidities and suspended solids in the South Fork (209.1 NTU; 264.6 milligrams per liter [mg/L]) than in either the North Fork (158 NTU; 120.7 mg/L) or Middle Fork (204.8 NTU; 182.1 mg/L). Soicher (2000) measured instantaneous turbidity at various locations during 1998 and 1999, including the South, Middle, and North Forks, as well as tributaries to the South Fork. The lower South Fork (Potter Road Bridge) had the highest measured turbidity, at 632 NTU, whereas maximum turbidity in the glacially turbid North and Middle Forks were 66 NTU and 36 NTU, respectively. Anecdotal observations indicate high turbidities, which limit spawn and snorkel surveying, can persist in the South Fork through mid to late summer. More recent continuous turbidity data show an average maximum of 348.04 NTU at Saxon Road (RM 13) from 2009 to 2013, and 311.3 NTU at Saxon from 20012-2013. Further downstream at Potter Road (RM 2) the river averaged a maximum turbidity of 300.6 NTU (2012-2013).

There are numerous mass wasting areas along the upper South Fork from ~RM 16.5 to RM 36 (Schuett-Hames et al. 1988b; Osbaldiston 1995) that are delivering or have the potential to deliver substantial amounts of fine sediment directly to the South Fork. Just one of these landslides was estimated to have delivered 210,000 cubic yards of fine sediment in three years to one of the most heavily used spawning areas in the South Fork (Abbe 1999). Such slides also visibly contribute to high turbidities in the South Fork, as evidenced from aerial flights over the South Fork (D. Huddle, Washington Department of Fish and Wildlife [WDFW], personal communication 2003). Most are deep-seated rotational features (e.g., earth slumps), although secondary shallow features occur within the larger deep-seated landslides. All of these slides are associated with unconsolidated glacial sediments, most notably glacial outwash and glacial lacustrine sediments. Although the landforms are natural, loss of large woody debris (LWD) roughness elements may lead to increased channel incision, oversteepening stream-adjacent valley walls, and increasing rates of landsliding and bank erosion. Further, historically abundant wood likely buttressed the toe of such landslides, reducing bank erosion rates. Channel widening and pool filling were documented in the mid-1980s in several tributaries and reaches of the mainstem channel (Schuett-Hames et al. 1988b, Schuett-Hames and Schuett-Hames 1984). Floodplain abandonment is evident throughout the watershed, likely resulting from an increase in sediment transport efficiency (Brown and Maudlin 2007, Soicher et al. 2006, Maudlin et al. 2002). Levees and channel incision have isolated the floodplain, causing fine sediment deposition in the channel rather than on the floodplain. Over one-third of the lower South Fork has been hydromodified; there is also evidence that the lower South Fork has incised (Maudlin et al. 2002). Potential causes of channel incision include loss of LWD roughness elements and artificial channel confinement.

Elevated mass wasting frequency due to forestry management practices has increased fine sediment supply to the lower South Fork. Kirtland (1995) estimated that landslides account for an estimated 72 percent of the sediment delivered to streams in the upper South Fork. Landslide inventories indicate that 81 percent of the 1216 landslides in the South Fork basin are shallow, rapid events that tend to deliver sediment to streams (Watts 1996, cited in Smith 2002). Most of the landslides are associated with forest management, with 37 percent related to clear cuts and 32 percent associated with roads (Cascade Environmental Services 1994, DNR 1998, Kirtland 1995, Watts 1996, Crown Pacific Limited Partnership 1999).

Surface erosion of forest roads increases fine sediment delivery to the lower South Fork. Average road density in the South Fork subbasin is high at 3.38 miles of road per square mile of watershed area; subbasins with high road density include Hutchinson Creek [(5.48 miles of road per square mile), Deer/Roaring/Plumbago Creeks (4.54 miles of road per square mile); Dye (3.98 miles of road per square mile), Skookum Creek (3.56 miles of road per square mile), and Cavanaugh Creek (3.56 miles of road per square mile); subbasins with moderate road density include Howard (2.84 miles of road per square mile) and Edfro Creeks (2.85 miles of road per square mile); D. Coe, Nooksack Indian Tribe, using DNR 2000 transportation and WRIA 1 basin shape files)].

### 5.1.2 Future Climate Risks

Projected future changes to the global climate system bring substantial risk to the management of the South Fork. Climate modeling studies are in general agreement that annual average surface air temperatures will likely rise on the order of 1 – 5 °C (about 2 – 9 °F) by 2100 throughout the U.S., depending on the future trajectory of greenhouse gas emissions (IPCC 2013). Climate models are likewise in general agreement that precipitation will increase at the global scale, but significant uncertainties remain concerning changes in precipitation amount and timing at the local to regional scales important to water managers (IPCC 2007, IPCC 2013, Karl et al. 2009). Rising air temperatures will increase the risk of high water temperatures. If flows decrease during critical summer periods, this could further amplify the impacts of higher air temperature on water temperature. Conversely, increases in high flows during the winter could wash out salmon redds and fry and destroy critical habitat.

An analysis of potential future climate in the South Fork and its impacts on water temperature and flow is provided in the quantitative assessment (Butcher et al., 2016) and is summarized here. The quantitative assessment is in turn based on work conducted by CIG at the University of Washington (Hamlet et al., 2010; Hamlet et al., 2013). The CIG focuses on the consequences of a changing climate in the PNW. Among their key products is the *Washington Climate Change Impacts Assessment* (Littell et al. 2009), a comprehensive assessment of the impacts of climate change on the State of Washington, which was developed under mandate of the Washington State legislature and recently summarized in Snover et al. (2013).

| WASHINGTON CLIMATE CHANGE IMPACTS ASSESSMENT: KEY FINDINGS |
|---|
| ▶ Increases in annual temperature of, on average, 2.2 °F by the 2020s, 3.5 °F by the 2040s, and 5.9 °F by the 2080s (compared to 1970 to 1992), averaged across all climate models. |
| ▶ April 1 snowpack is projected to decrease by 28 percent across the state by the 2020s, 40 percent by the 2040s, and 59 percent by the 2080s compared with the 1916 - 2006 historical average. |
| ▶ The Yakima basin reservoir system will likely be less able (compared to 1970 to 2005) to supply water to all users, especially those with junior water rights. |
| ▶ Rising stream temperatures will likely reduce the quality and extent of freshwater salmon habitat. |
| ▶ Due to increased summer temperature and decreased summer precipitation, the area burned by fire regionally is projected to double by the 2040s and triple by the 2080s. |
| ▶ Regional climate model simulations generally predict increases in extreme high precipitation over the next half-century, particularly around Puget Sound. |
| ▶ Climate change in Washington will likely lead to significantly more heat- and air pollution-related deaths throughout this century. |
| (Littell et al. 2009) |

The basis of the CIG climate change assessment is a common set of simulations using 21 global climate models (GCMs) from the Intergovernmental Panel on Climate Change (IPCC) *Fourth Assessment Report* and Coupled Model Intercomparison Project 3 (CMIP3). These models differ somewhat in their projections for the PNW. Mote and Salathé (2010) evaluated biases in the global-scale climate model predictions for the PNW. No single GCM was among the best performing five GCMs for prediction of both temperature and precipitation; likewise, no GCM was among the worst performing five for both temperature and precipitation. It is thus not appropriate to select a specific GCM based on its perceived prediction skill for the area; instead, the suite of GCMs is more appropriate for analysis of the potential ensemble range of future climates. The quantitative analysis therefore selected three climate models that are anticipated to produce the least warming of air temperature (model low-impact scenario), medium warming (medium-impact scenario), and highest warming (high-impact scenario).[15] These were evaluated at three time horizons through the 2080s.

#### 5.1.2.1 Temperature

The climate models predict a trend of increasing air temperature over the 21st century. By the 2080s, the average summer air temperature across the South Fork watershed is projected to rise by 2.81 °C to 6.31 °C (or about 5 to 11 °F), while the average winter air temperature is projected to rise by 2.44 to 4.28 °C (or about 4 to 8 °F; Figure 5-11).

Potential effects of changes in air temperature on the seasonal pattern of water temperature in the South Fork watershed were evaluated by fitting the logistic model of Mohseni et al. (1998) to simultaneous observations of air and water temperature collected by Ecology for the South Fork at Potter Road from 2003-2010. This model predicts water temperature response to changes in air temperature and does not consider other sources of impact, such as changes in flow or shading, but gives a reasonable indication of the potential range of seasonal changes, suggesting that average water temperatures in August could increase up to 6 °C by the 2080s under the high impact scenario if no actions are taken to mitigate the impacts (Figure 5-12).

Coupled with the air temperature changes, the climate models suggest a decrease in precipitation and an increase in dew point temperature during the critical summer period.

The combined effects of changes in climate and changes in summer low flow (see next section, 5.1.2.2) on summer water temperatures was evaluated through application of the QUAL2Kw model (Ecology 2003) that was calibrated for application to the South Fork as part of the TMDL effort. QUAL2Kw is a quasi-steady state model and is Ecology’s preferred tool for TMDLs. The model simulates hourly temperature and heat budget with hourly variations in input parameters and boundary conditions.

Because QUAL2Kw is a steady-state model, analyses are applied to critical conditions (e.g., high air temperature, low flow) rather than to continuous simulation. The TMDL analysis focused on 7Q10 low flows accompanied by 90$^{th}$ percentile 7-day air temperature. Under these conditions, large increases in the 7DADMax water temperature are predicted by 2080 if stream shading is left at current levels, with

[15] The full rationale for selection of climate scenarios is provided in Butcher et al. 2016. Seventy-nine climate scenario products from AR4 are available from CIG covering the South Fork watershed. These products incorporate a range of greenhouse gas emissions scenarios as interpreted through multiple GCMs. This project focuses on a limited subset of model results for the IPCC A1B emissions scenario. The A1B scenario is considered to provide a robust data set for a moderate emission scenario. Other IPCC emission scenarios predict greater warming, but there are only small deviations among scenarios until the latter half of the 21st century, and the range of models using the A1B scenario covers most of the A2 (high emission) scenario range through the 2080s. The upper bound of the suite of GCMs using the A1B scenario projects an average annual air temperature increase for 2080 that is only 0.6 °C lower than the upper bound from the A2 scenario. The selected models are CGCM3.1_t47 (low impact), CCSM3(medium impact), and HADGEM1 (high impact scenario).

temperatures increasing to above 23 °C throughout much of the length of the river (Figure 5-13). Restoration of system potential vegetation (tree heights associated with the 100-year site index) dampens the increase by about 2 °C in the TMDL scenario. There could be additional mitigation of water temperature increases through effective buffering on all tributaries to the South Fork, as was investigated in the additional natural conditions scenarios summarized above in Table 5-2. If system potential vegetation was in place it would be projected to protect against increases in 7Q10 temperature through the 2020s, but increases on the order of 2 °C are still expected by the 2080s, under the medium-impact climate scenario (Figure 5-14). It should be noted that the “combined natural parameters variations” scenario (referred to as “natural/restored”) suggested a 15.5 percent reduction in stream temperatures for the South Fork overall relative to the TMDL scenario (see Table 5-2).

Sensitivity analyses showed that the projected temperature increases are sensitive to dew point temperature and flow as well as air temperature and shade. The quantitative assessment also shows that more typical summer maximum conditions (7Q2 flow coupled with the median of the annual series of highest 7-day average maximum air temperature and system potential shade associated with tree height of the 100-year site index) resulted in less extreme temperature increases, with water temperatures remaining at or below 22 °C in all but the most downstream reaches of the river (Figure 5-15). Nonetheless, the high-impact GCM scenario still represents an increase of about 5 °C relative to the current conditions baseline for 7Q2 flows (about 8 °C relative to the natural/restored scenario associated with tree height of the 100-year site index) and would be associated with increased stress on salmon populations.

Figure 5-16 and Figure 5-17 compare 2080 projections of water temperature (using the medium-impact GCM) with current shade and natural/restored conditions. The natural/restored conditions are predicted to maintain temperatures near current conditions at both 7Q10 and 7Q2 flows.

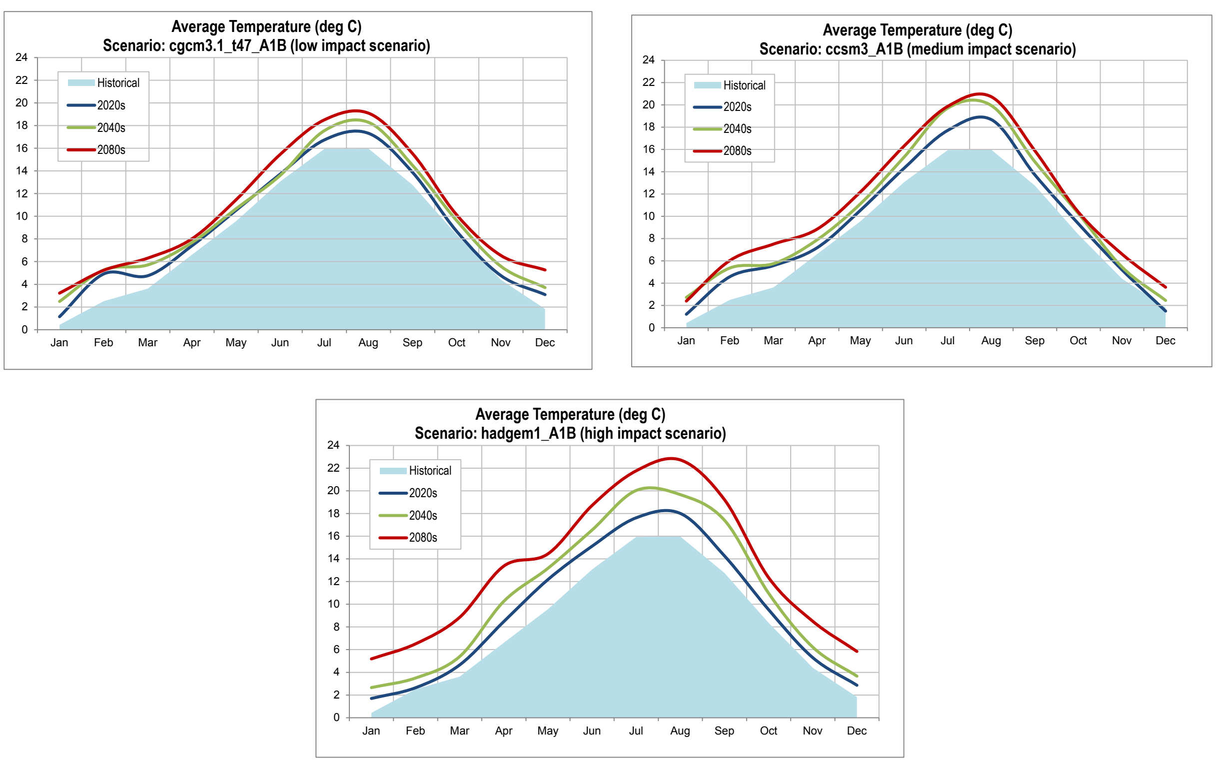


**Figure 5-11. Monthly Average Air Temperature in the South Fork Watershed for Low-, Medium-, and High-Impact Climate Scenarios (from Butcher et al. 2016).**
Note: Results shown are medians across the 25 CIG grid cells intersected by the South Fork watershed.

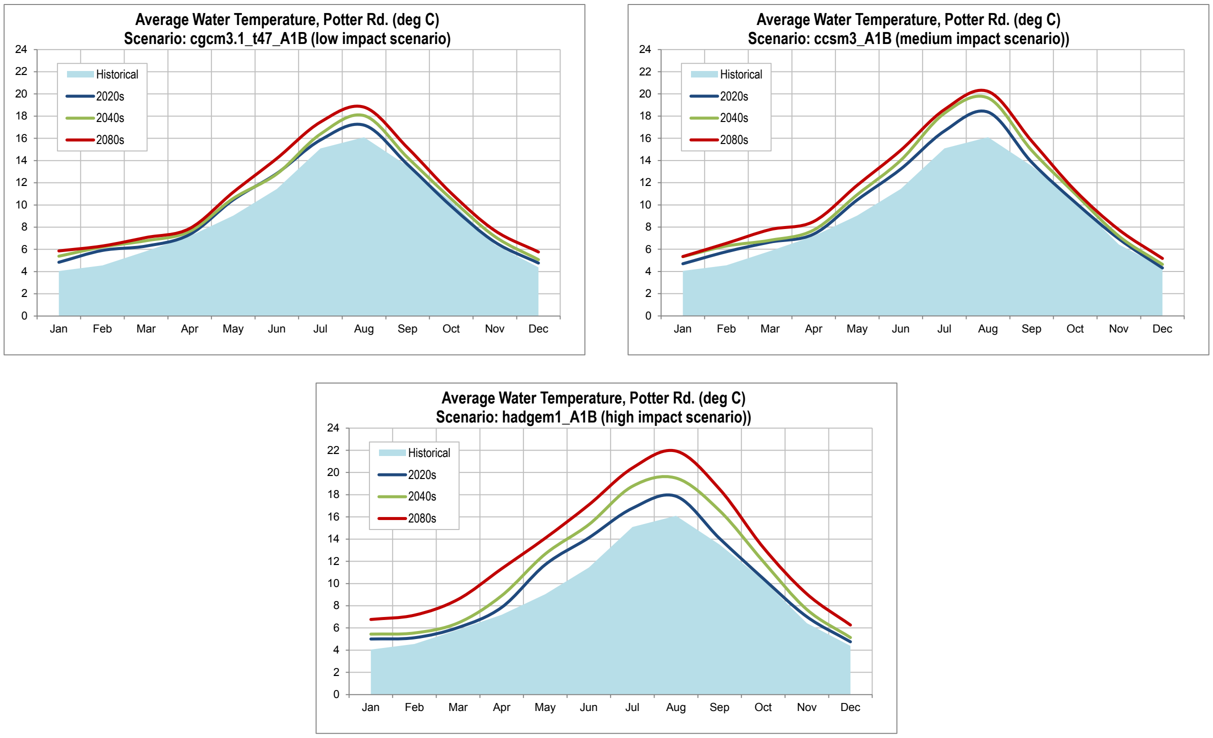


**Figure 5-12. Monthly Average Water Temperature in the South Fork at Potter Road Predicted by Mohseni Model for Low-, Medium-, and High-Impact Climate Scenarios.**

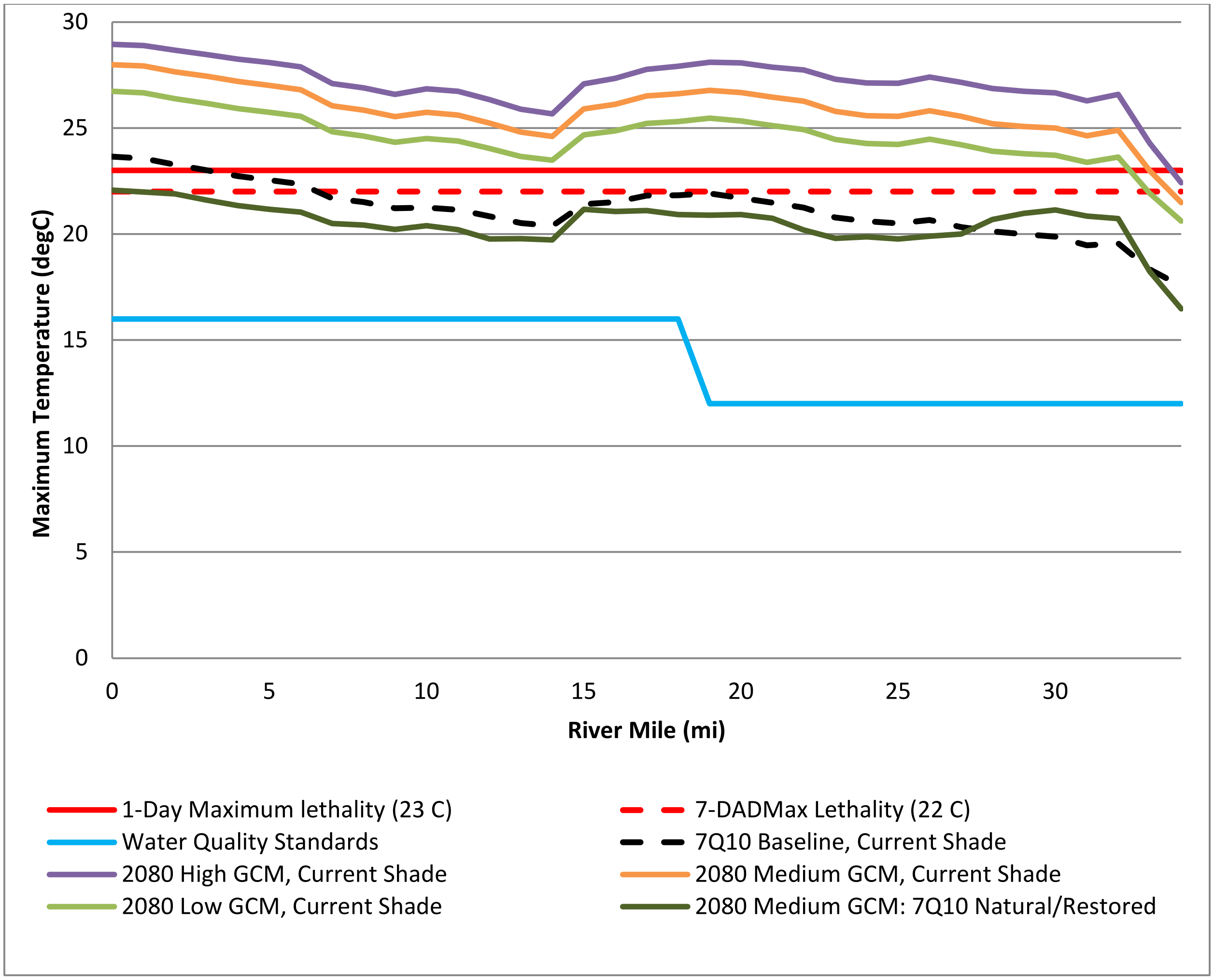


**Figure 5-13. Maximum Stream Temperature by River Mile for Existing 7Q10 flows, 90th Percentile Meteorology, and Current Shade); 2080 Conditions (High GCM, Medium GCM, and Low GCM) with Current Shade; and 2080 Conditions with Natural/Restored Conditions (adapted from Butcher et al. 2016).**

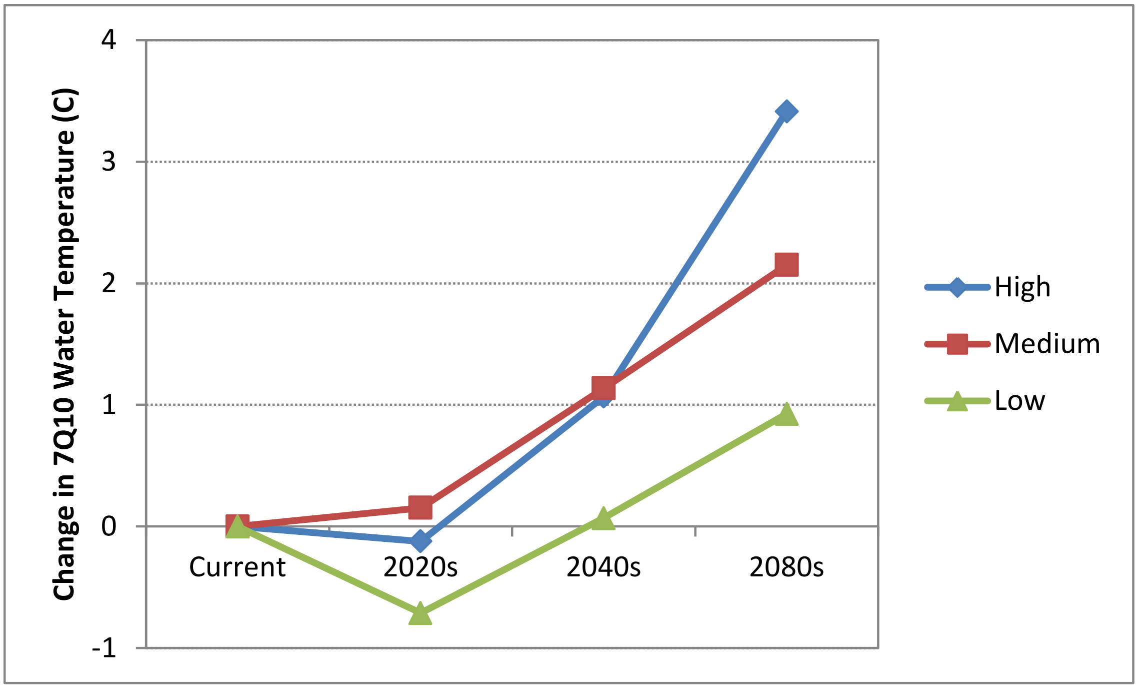


**Figure 5-14. Change in Spatially Averaged Maximum Water Temperature in the South Fork Mainstem at Critical Conditions for Future Climate Scenarios with System Potential Vegetation Compared to Current Climate and Vegetation (from Butcher et al. 2016).**

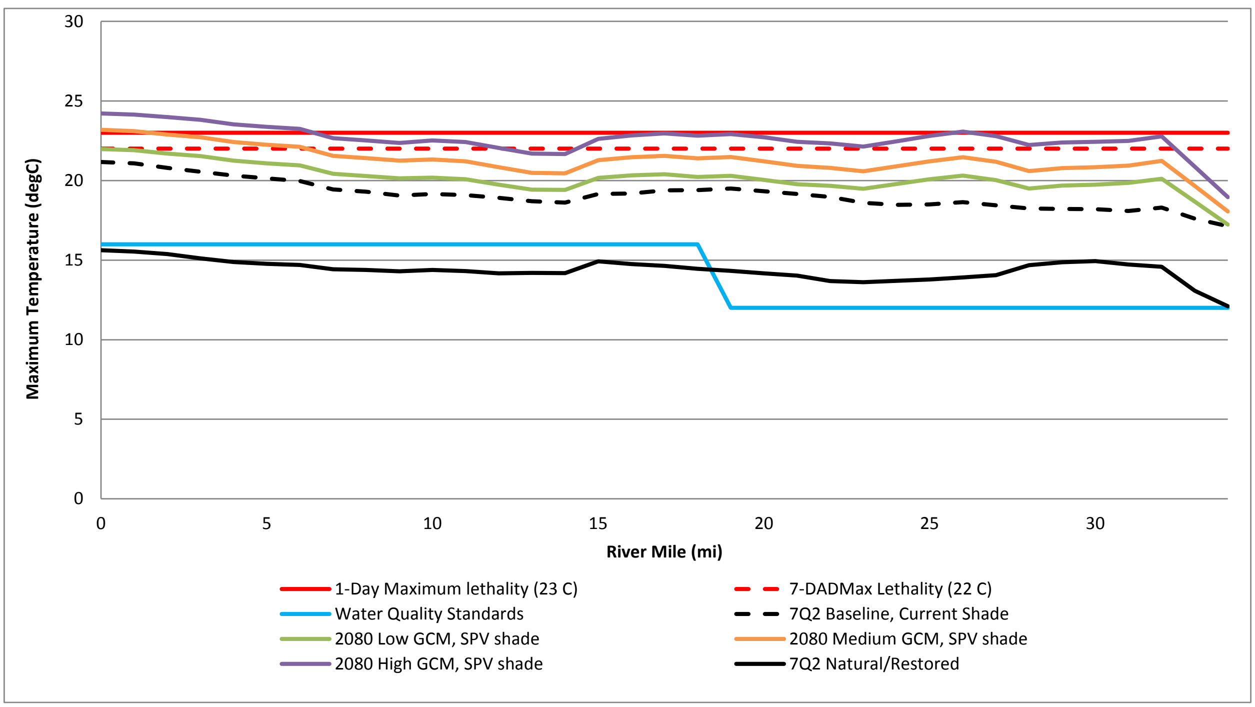


**Figure 5-15. Maximum Stream Temperature by Reach for 7Q2 flows and 50th Percentile Maximum Air Temperature with 100-yr System Potential Shade for 2080 High GCM, 2080 Medium GCM, and 2080 Low GCM.**

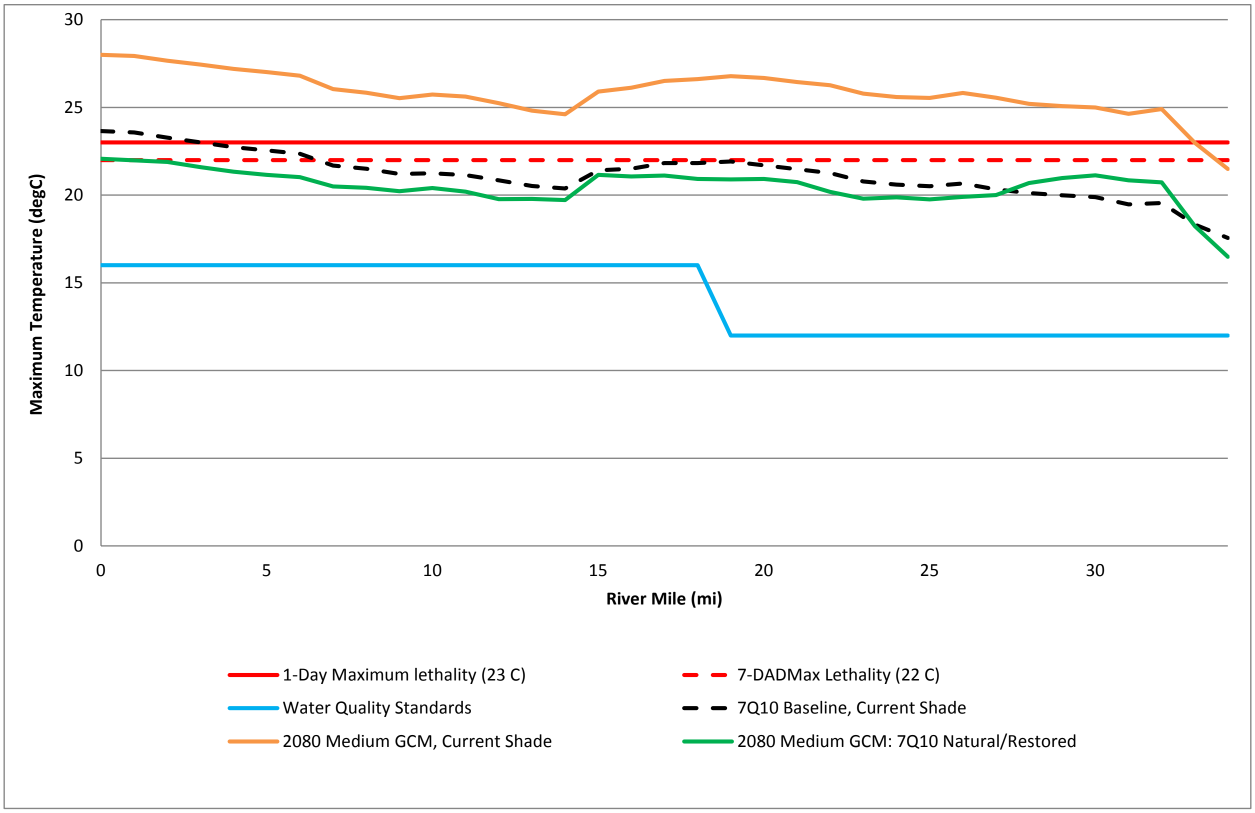


**Figure 5-16. Comparison of Projected Maximum Stream Temperature by Reach with Medium GCM and 7Q10 Flow for 2080 with Current Shade versus 2080 Natural/Restored Conditions.**

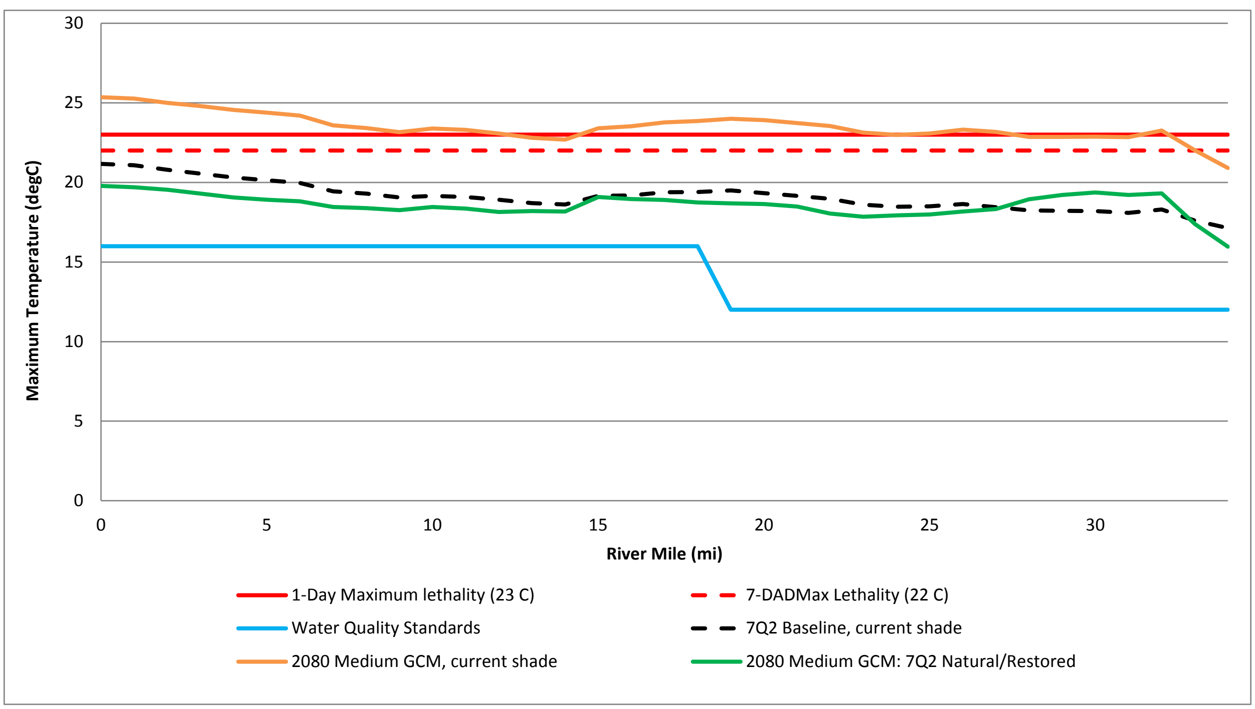


**Figure 5-17. Comparison of Projected Maximum Stream Temperature by Reach with Medium GCM and 7Q2 Flow for 2080 with Current Shade versus 2080 Natural/Restored Conditions.**

#### 5.1.2.2 Future Low-Flow Regime

VIC simulations suggest that total annual streamflow volume may increase throughout much of the PNW in the 2040s and 2080s (Elsner et al. 2009). However, summer flows are projected to decrease across most of the region, with a mean decrease of more than 30 percent by the 2080s (Wu et al. 2012).

The VIC model does not provide an exact representation of current flow conditions for the South Fork, although the fit is generally good for the critical late summer period. Therefore, mapping/extrapolation of CIG estimates to the QUAL2Kw domain is necessary. Specifically, the CIG output is applied using a change method in which the TMDL 7Q10 flow at the model headwaters and for all tributary and diffuse inflows is modified by the ratio of CIG estimates of low flows under current and future climate conditions.

The resulting ratios for tributary flow vary strongly by elevation, with greater reductions at higher elevations (which currently have the highest water yield) and larger fractional reductions for the 7Q2 than for the 7Q10 flow. For example, in the 2080s under the high-impact scenario, the predicted 7Q2 at the eastern ridgeline of the watershed is only 26 percent of the existing 7Q2 flow, while the baseflow of tributaries near the mouth of the South Fork remains at 90 percent of their existing 7Q2 flow. This reflects a shift away from snow-dominated runoff at high elevations.

The absolute decrease in 7Q10 flows from current to 2080s high impact is greatest at the mouth (where the model estimate declines from about 97 cfs to a range of 72-82 cfs, depending on the climate scenario). The relative decrease, however, is greatest at the headwaters (31 percent) and steadily shrinks toward the mouth, reflecting the smaller change in tributary inflows at lower elevations.

Murphy (2015) modeled changes in monthly median streamflow for the Nooksack River watershed using the Distributed Hydrology Soil Vegetation Model (DHSVM). Projected changes from historical (1950-2010) monthly median flows for August, when South Fork discharge is generally lowest, are -40 percent, -51 percent, and -57 percent by 2025, 2050, and 2075, respectively, under the RCP, or Representative Concentration Pathway, 4.5 (low greenhouse gas) scenario. Under the RCP 8.5 (high or "business as usual") greenhouse gas scenario, projected changes in August flows are even more profound: -41 percent, -56 percent, and -65 percent by 2025, 2050, and 2075, respectively.

#### 5.1.2.3 Future High-Flow Regime

Climate change may also lead to other changes in the hydrology of the South Fork. Most notably, higher elevation runoff is expected to shift from a snow-dominant to a transient regime, with a mix of rain and snow and snow melt occurring earlier in the year. A possible result in this regime shift is an increase in extreme high flows, which can cause salmon egg scour and loss. Indeed, Battin et al. (2007) predicted that climate-related changes in winter high flows would have a greater negative impact on salmon populations than changes in water temperature in the Snohomish basin.

The VIC model is not specifically calibrated for the South Fork and cannot be expected to provide highly accurate estimates of flood magnitude. Indeed, the model appears to have some weaknesses in its representation of historical spring high flows, as discussed in Butcher et al. (2016). However, it is appropriate to examine the model-projected relative changes in high flows to inform the potential magnitude of future changes. To do this, average flow depth (millimeters per day) was calculated for the weighted average of VIC grid cells intersecting the South Fork watershed, and the series of annual maxima for historic and future climate conditions was extracted. Estimates of peak runoff for various return periods were then calculated using the Gumbel Type I extreme value distribution (Maidment 1992).

Results shown in Table 5-3 suggest that the magnitude of floods of various recurrence intervals may increase from 4 to 39 percent. Interestingly, the low-impact (for temperature) climate scenario produces some of the largest projected increases in flood magnitude, with a 39 percent increase in the 2-year event and a projected 34 percent increase in the 25-year event by the 2080s. In contrast, the medium-impact scenario produces increases in flood magnitude of 10 to 17 percent, with no acceleration over time, and the high-impact scenario predicts only small changes in flood magnitude through the 2040s, but increases of 26 to 31 percent by the 2080s.

**Table 5-3. Projected Percent Change in Magnitude of Floods of Various Recurrence Intervals in the South Fork under Different Climate Change Scenarios (Butcher et al. 2016).**

| Global Climate Model | Recurrence | 2020s | 2040s | 2080s |
|---|---|---|---|---|
| CGCM3.1 (low impact) | 2-year | +23 % | +39 % | +39 % |
| | 10-year | +19 % | +32 % | +35 % |
| | 25-year | +19 % | +30 % | +34 % |
| CCSM2 (medium impact) | 2-year | +17 % | +16 % | +15 % |
| | 10-year | +12 % | +12 % | +12 % |
| | 25-year | +10 % | +12 % | +11 % |
| HADGEM1 (high impact) | 2-year | +5 % | +7 % | +31 % |
| | 10-year | +5 % | +5 % | +27 % |
| | 25-year | +5 % | +4 % | +26 % |

As an example, the empirical 10-year recurrence daily flow peak at the Wickersham gage, based on 1935-2008 monitoring, is 11,500 cfs. The range of projections for the 10-year flow in the 2080s is from about 12,900 to 15,500 cfs.

#### 5.1.2.4 Future Sediment

Sediment loads are likely to increase under climate change due to loss of soil-protecting snowpack, increased saturation of soils on steep slopes, increased frequency and magnitude of over-steepened slopes associated with valley glacier recession, increased entrainment and transport of sediment within the channels, and increasing intensity of precipitation events yielding more extreme peak flows. Flow and sediment modeling on the Skagit River has shown a possible six-fold increase in sediment load during the winter high-flow period by the 2080s (Hamlet and Grossman, in review). While the Skagit watershed is larger, more heavily glaciated, and contains multiple dams, the physical drivers in the Nooksack watershed are similar and it will likely experience a similar response to climate change. Increased sediment flux in the Nooksack will likely come as a result of several processes: increased streambank erosion, increased mass wasting, and increased surface erosion.

The channel shape and plan-form of the South Fork and its tributaries are expected to respond to increases in winter peak flow and more frequent high-flow events. Changes in channel width, depth, slope, grain size, bedforms, sinuosity and bed scour depth are all possible responses to increased frequency, magnitude and duration of flow. In the lower-gradient alluvial valleys of the South Fork and its tributaries, these changes will likely lead to an increase in bed and bank erosion. A partial sediment budget for the upper South Fork found that streambank erosion and undercutting of stream-adjacent unstable landforms was a dominant source (59 percent) of sediment to the river between 1967 and 1991 (Kirtland 1995).

Changes in mass wasting will likely occur in the South Fork in response to climate change. Increased precipitation and changes in evapotranspiration along with changes in the balance between, and the temporal distribution of, evapotranspiration and precipitation affect the hydrological regime of landslides, influencing their movement. Climate change scenarios for the Nooksack watershed suggest an increase in both winter precipitation and temperature over the next 75 years. These changes are likely to have a number of potentially contradictory impacts on different types of mass movement processes (Collison et al. 2000). For example, changes in evapotranspiration due to the projected 2-4 °C increase in winter temperature can offset the effect of increased precipitation on the groundwater level within the landslide. Landslides of different size and permeability react to changes in moisture balance at different time scales, making it important to understand changes in timing and frequency of rainfall in addition to changes in seasonal magnitude. Forecasting the consequences of climate change is made more difficult by the range of causes of landslides, from those triggered by water management on forest roads to natural deep-seated slides in glacial deposits that line the river valley.

Increased winter storm intensity will also increase the likelihood of unstable road-fill failures and failed stream crossings, triggering debris flows into tributary stream channels. In the Nooksack watershed, forest road failure has been a dominant mechanism for landslides (Watts 1996, Watts 1997, Watts 1998). In the Acme Watershed Administrative Unit (WAU), a subbasin of the South Fork watershed, approximately 43 percent of all landslides were associated with roads (Crown Pacific L.P. 1999). A more recent assessment of the Acme subbasin following the 2009 storm found a reduction in road-related failures from 43 percent to 12 percent of the total landslide sources, likely reflecting improved road maintenance requirements (Powell et al. 2010). The shallow-rapid landslides that are often triggered by road failures also have a higher likelihood than other types of slope failures of scouring channels and delivering sediment to lower gradient sections of the streams—often the most productive salmon habitat (Watts 1996). Once a channel has been stripped of its riparian vegetation and alluvium by a debris flow, it heats more rapidly and delivers warmer water to downstream areas (Snyder and Johnson 2006, Dunham et al. 2006). In the South Fork, tributaries are often an important source of cooler water to the mainstem, and many instream habitat enhancement projects focus on these tributary confluence areas as thermal refuges for migrating fish.

The expected increase in peak flow from the increased snow melt and intensity of precipitation will likely lead to an increase in turbidity and sediment flux for the watershed. While, increased evapotranspiration from higher winter temperatures may offset the increased precipitation that can trigger landslides, increased peak flow will likely increase bank erosion and undercutting of unstable landforms by the river. Increased sediment generation from forest roads is also possible due to increased road surface erosion and the increased likelihood of culverts and cross-drains failing. This increase in sediment sources will likely be coupled with an increase in sediment transport due to the projected ~11 percent increase in high-flow discharge by 2080.

Table 5-4 summarizes current conditions and projected potential conditions under climate change in the 2040 and 2080 timeframes.

**Table 5-4. Current Conditions and Potential Future Conditions for the South Fork under Climate Change.**

| Physical Parameters | Current Conditions | Future Conditions with Climate Change | |
|---|---|---|---|
| Timeframe | Variable | 2040 | 2080 |
| 7DADM (°C) | a) 18.4 b) 20.9 [1] | 24.5[2] | 25.1[2] |
| Mean annual flow (cfs) | 1032 [3] | +2.5% [4] | +6.2% [4] |
| Mean low flow (cfs) | a) 102 b) 75.8 [5] | -23% [6] | -34% [6] |
| Mean high flow (cfs) | 1,970 [3] | +12% [7] | +11% [7] |
| Sediment flux (tons/mi$^2$/year) | 38,872 [8] | +12% [9] | +11% [9] |
| Mean annual turbidity (NTU) | 35.7 [10] | +12% [9] | +11% [9] |
| Mean annual AT (°C) | a) 4-7 b) 8-9 [11] | +2.2 [12] | +3.0 [12] |
| Mean summer AT (°C) | 15.5 [12] | +3.3 [12] | +4.0 [12] |

| Physical Parameters | Current Conditions | Future Conditions with Climate Change | |
|---|---|---|---|
| Timeframe | Variable | 2040 | 2080 |
| Max summer AT (°C) | 23 [12] | 27.5 [12] | 28.1 [12] |
| Annual Precipitation (in) | 50-125 [11] | +1% [12] | +1% [12] |
| Summer Precipitation (in) | 5-7 | -39% [12] | -25% [12] |
| SWE (in) | 39.3-78.7 [13] | -46% [14] | -70% [14] |

[1] +Modeled results for a) *typica*l low-flow conditions (7Q2 flows; 50th percentile air temperature) and b) *Critical* low-flow conditions; (7Q10 flows; 90th percentile air temperature), for all reaches of the South Fork (Butcher et al. 2016).
[2] Spatially averaged 7Q10 maximum water temperature in the South Fork mainstem for future climate under the medium impact scenario (A1B) with existing shade (Butcher et al. 2016). See Butcher et al. (2016) for the high and low impact scenarios.
[3] Values based on Ecology data at gaging station 01F070 (WY 2004-2010) at Potter Road bridge (Kennedy and Butcher 2012). High-flow value indicates the 90th percentile flow.
[4] Total annual streamflow projections for the A1B scenario for Washington State, relative to the 1917-2006 time period (Elsner et al. 2010).
[5] Low flow values at the a) 7Q2 recurrence interval (Curran and Olsen 2009), b) 7Q10 recurrence interval (Butcher et al. 2016).
[6] Average change in summer low flows for Washington State relative to 1917-2006 (Snover et al. 2013).
[7] The VIC model's 25-year projected increased flood magnitude under the medium impact scenario CCSM2 (Butcher et al. 2016).
[8] Maximum Suspended sediment yield observed for South Fork River at Saxon on March 31, 2011 (NIT 2011).
[9] Changes in sediment flux are assumed to reflect changes in mean high-flow
[10] NIT turbidity data from 2009-2014 at Saxon Rd. Bridge.
[11] Annual air temperature for a) high elevations (>5000ft) and b) low elevations (<5000 ft.) and annual precipitation for the South Fork (USGS 2000).
[12] Values found using moderate warming scenario CCSM3_A1B. Values for summer are during June, July, and August (Butcher et al. 2016).
[13] Range in mean springtime SWE from Wells Creek Snotel (4030 ft.) to Middle Fork Snotel (4970 ft.) (Dickerson 2010).
[14] Average April 1st snowpack relative to 1916-2006 under medium emission scenario conditions (Snover et al. 2013).

### 5.1.2.5 Spatial Distribution of Impacts

The effects of climate change are expected to vary across the South Fork watershed. While climate modeling was not conducted at a scale that allows for evaluation of the effects at the subbasin scale, the watershed can be evaluated for the potential to respond to the expected changes in climate (Figure 5-18, Table 5-5). For example, reduced spring snowmelt was evaluated by the proportion of the watershed that is currently snow dominated or highland that could become part of the transient snow zone as a result of climate change. The most heavily impacted areas lie in the higher elevation zones in the Upper South Fork and Skookum Creek. Results from the loss of winter snow pack will be felt most severely in the upper reaches of the main stem where the majority of the watershed area lies above the transient snow zone.

Summer low-flow temperature modeling shows that the greatest impacts of increased air temperature on water temperature occur in the lower three reaches of the South Fork. These areas either currently exceed the 7-DAD Maximum lethal limit of 22 °C or will be expected to exceed this limit under the medium-impact climate change scenario. While no modeling has been completed for tributary streams, the greatest impact on water temperature is expected in the Hutchinson and lower South Fork subbasins, due to their lower elevation. Similarly, the impacts of potential lower summer flow is expected to have the greatest impact on attaining water temperature criteria in the lower elevation portion of the watershed. The mainstem South Fork through much of the Acme Valley (reach 1) loses surface water to groundwater recharge (Cox et al. 2005), further reducing low flows.

Increased winter peak flow is expected to be more strongly effected in reaches of the South Fork that have been impacted by artificial confinement to prevent erosion. Much of the valley has also incised into its floodplain during the historic period, further abandoning the floodplain surfaces. Sediment flux is expected to reflect the increase in peak flow, as sediment transport increases. Increases in bank erosion and potentially an increase in mass wasting could deliver more sediment to the channel in the steeper areas of the upper watershed and subbasins.

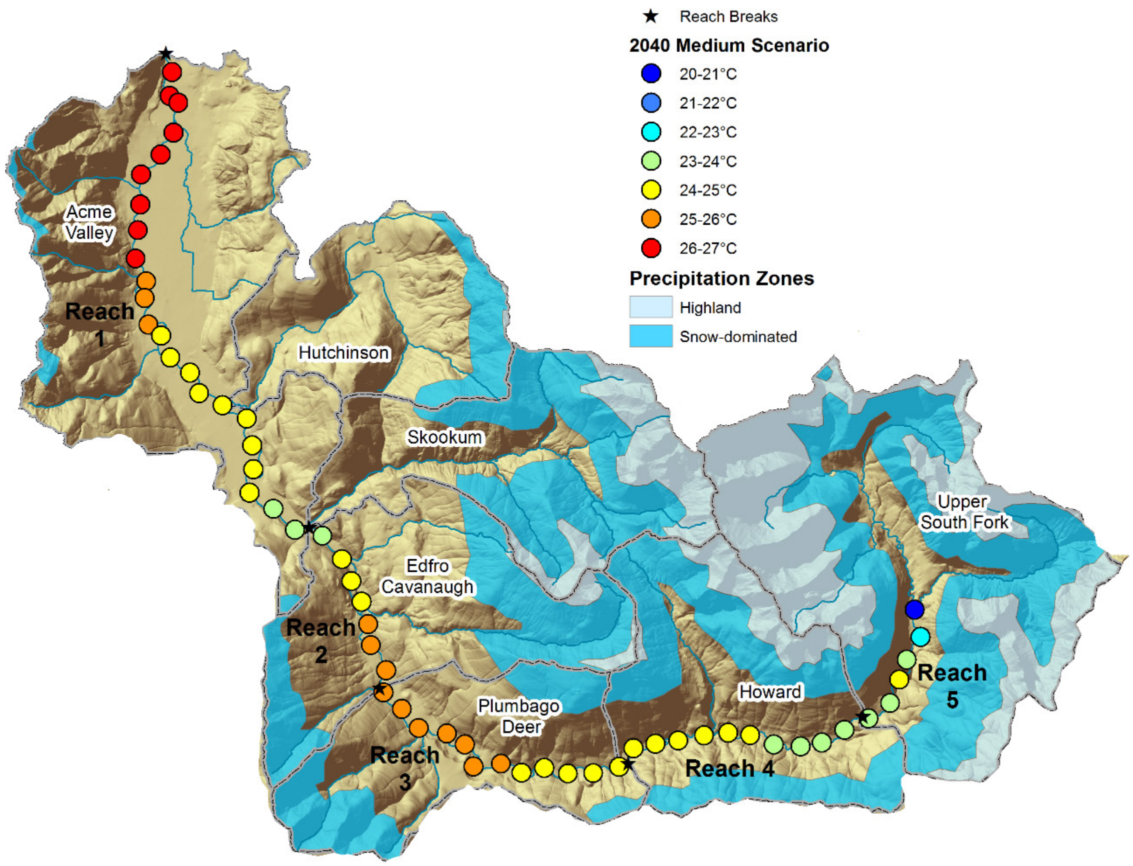


**Figure 5-18. Dots show QUAL 2Kw model nodes of the Maximum Stream Temperatures (7Q10 flows) along the mainstem South Fork Nooksack for 2040 (using a medium GCM), along with current snow-dominated precipitation zones based on elevation, climate, latitude and vegetation (DNR 1991). Not shown are the lower elevation “rain-dominated” and “rain-on-snow” zones in the watershed.**

**Table 5-5. Distribution and Severity of Climate Change Impacts through the South Fork Reaches and Subbasins.**

| Reach or Subbasin | Climate Impact: Reduced Spring Snowmelt (percentSD+HL) | Climate Impact: Elevated Summer Temperature | Climate Impact: Reduced Summer Low Flow | Climate Impact: Increased Winter Peak Flow | Climate Impact: Sediment |
|---|---|---|---|---|---|
| **Reaches** | | | | | |
| 1 (RM 0-14.3) | Moderate (43 percent of basin) | High (Currently exceeds 7-DAD Max lethal limit of 22 °C)<br>High (Expected to exceed 7-DAD Max lethal limit under 7Q10 conditions with climate change) | High (Potentially a reach that loses surface water to groundwater recharge) | High (Floodplain artificially confined and incised)<br>Low (Floodplain unconfined)<br>Moderate (Floodplain naturally confined) | Moderate (Floodplain artificially confined and incised, loss of floodplain sediment storage)<br>Moderate (Rapid channel migration- increase in bank erosion)<br>Low (Floodplain naturally confined/ channel migration limited) |
| 2 (RM14.3- 18.5) | High (60 percent of basin) | High (Expected to exceed 7-DAD Max lethal limit under 7Q10 conditions with climate change) | Moderate | Moderate (Floodplain naturally confined) | Low (Floodplain naturally confined/ channel migration limited) |
| 3 (RM 18.5-25.4) | High (66 percent of basin) | High (Expected to exceed 7-DAD Max lethal limit under 7Q10 conditions with climate change) | Moderate | Low (Floodplain unconfined)<br>Moderate (Floodplain naturally confined) | Moderate (Rapid channel migration)<br>Moderate (Abundant stream-adjacent landslides and unstable slopes could increase sediment sources) |
| 4 (RM 25.4-31) | High (73 percent of basin) | High (Expected to exceed 7-DAD Max lethal limit under 7Q10 conditions with climate change) | Moderate | Moderate (Floodplain naturally confined) | Moderate (Abundant stream-adjacent landslides and unstable slopes could increase sediment sources) |
| 5 (Upstream of RM 31) | High (77 percent of basin) | Moderate (Expected to remain below lethal) | Moderate | Moderate (Floodplain naturally confined) | Moderate (Abundant stream-adjacent landslides and unstable slopes could increase sediment sources) |
| **Subbasin** | | | | | |
| Hutchinson | Moderate (18 percent of basin) | High | High | Moderate | Moderate |
| Skookum | High (67 percent of basin) | Moderate | Moderate | Moderate | Moderate |
| Acme Valley | Low (2 percent of basin) | High | High | Moderate | Moderate |

| Reach or Subbasin | Climate Impact | | | | |
|---|---|---|---|---|---|
| | Reduced Spring Snowmelt (percentSD+HL) | Elevated Summer Temperature | Reduced Summer Low Flow | Increased Winter Peak Flow | Sediment |
| Plumbago and Deer | Moderate (29 percent of basin) | Moderate | Moderate | Moderate | Moderate |
| Edfro and Cavanaugh | Moderate (39 percent of basin) | Moderate | Moderate | Moderate | Moderate |
| Howard | High (55 percent of basin) | Low | Low | Moderate | Moderate |
| Upper South Fork | High (84 percent of basin) | Low | Low | Moderate | Moderate |

| Impact Potential | |
|---|---|
| (blue) | Low Impact |
| (yellow) | Moderate Impact |
| (orange) | High Impact |

# 5.2 Evaluation Per Salmonid Species

## 5.2.1 General Climate Change Impacts

Salmonids are particularly vulnerable to climate change because of their ectothermic physiologies and anadromous life histories that require migration through linear stream networks that are easily fragmented (Isaak et al. 2010). Climate change impacts on temperature, flow and sediment regimes could profoundly affect physiology, behavior, and growth of individuals; phenology, growth, dynamics and distribution of populations; structure of communities; and functioning of whole ecosystems (multiple authors, cited in Rieman and Isaak 2010), with increasing complexity and thus difficulty predicting impact at higher levels (Rieman and Isaak 2010). A summary of anticipated impacts by attribute is provided below:

*Increased temperatures*

- Temperature increases beyond physiological optima can be lethal or otherwise detrimental, depending on the rate of increase and the ability of salmonids to acclimatize or behaviorally respond by seeking out thermal refuges (Covich 1993). Sub-lethal effects include increased physiological stress, metabolic costs, and susceptibility to disease, which ultimately lead to reduced survival and/or reproductive success (McCullough et al. 2001). Species with extended freshwater rearing, like Chinook and coho salmon, steelhead and bull trout are especially vulnerable.
- Temperature increases may also lead to dissolved oxygen limitations, especially at summer low-flow, due to the reduced solubility of oxygen and higher metabolic rates at higher temperatures (Covich 1993 and Fisher et al. 1996).
- Warming may lead to increases or reductions in growth of juvenile salmonids, depending on the amount of food available, activity, and past conditions (Rieman and Isaak 2010). Growth suppression occurs if temperature increases without concomitant food availability increases, or if temperature exceeds physiological optima, and several studies have found reduced growth at higher temperatures (e.g., Bisson and Davis 1976; Brett et al. 1982, cited in Marine and Cech 2004; Marine and Cech 2004). Changes in growth rate may in turn affect timing of emergence, migration, and other critical life history transitions, as well as sexual maturation, potentially decoupling life history events from optimal conditions for emergence, spawning, and migration (Poff et al. 1997). Reduced growth rate during juvenile rearing is also associated with reduced marine survival (Beamish et al. 2009).
- High temperatures can create thermal barriers to migration (Sauter et al. 2001), affecting spawn timing and distribution.
- Shifts in temperature regimes will affect aquatic and riparian community structure and spatial distribution, including vegetation, aquatic invertebrates, and fish species. Such shifts may have negative consequences for food web dynamics, such as reduced prey availability and increased abundance and upstream expansion of warmwater fish competitors and predators (Isaak et al. 2010). Increased temperature has also been associated with increased predation risk (Marine and Cech 2004).
- Warming will increase the occurrence of some pathogens, especially *Flavobacterium columnare* (Columnaris), a pathogen associated with high temperatures (McCullough et al. 2001) that has been confirmed in pre-spawn mortalities of Chinook in the South Fork in August or September 2003, 2006, 2009, and 2013, and in pink salmon in 2003 and 2013 (Olson 2003a, 2003b, 2006, 2009, 2013a, 2013b). Corresponding maximum 7-day average of the daily maximum temperatures

in the lower South Fork (RM 1.8-3.5) during those same years were 23.1 °C (2003), 23.0 °C (2006), 23.8 °C (2009), and 22.1 °C (2013).[16]

- Temperature increases may induce earlier smoltification, which may decouple outmigration from high flows needed for fish to move quickly downstream. High temperatures may also impair smoltification itself (Marine and Cech 2004).
- High temperatures coupled with low summer flows may increase growth of filamentous algae, which could impair benthic invertebrate production (Bisson and Davis 1976). Substantial algal growth has been observed in the lower South Fork during summer low-flow.

*Loss of spring snowmelt reducing discharge*

- Reduced discharge in spring may reduce overall availability of habitat but increase suitable low-velocity fry habitat.
- Reduced velocities associated with reduced discharge may increase time of outmigration, thus exposure to predation, and thereby reduce smolt survival.
- Access to floodplain habitats may be hindered by reduced flows in late spring, especially in areas where incision has isolated the South Fork from its floodplain.

*Decreased summer/fall low flows*

- Lower stream flows will further increase water temperatures.
- Lower stream flows will reduce availability of holding and spawning habitat and juvenile oversummer rearing habitat. Low flows can also cause stranding.
- Lower summer stream flows may create temporary blockages to or delays in upstream migration, increasing pre-spawn mortality and reducing reproductive success (Beamish et al. 2009).

*Increased winter peak flows*

- Increased frequency and magnitude of peak flows will reduce egg-fry survival rates due to increased redd scour and channel shifting (Beamish et al. 2009; Mantua et al. 2010). Montgomery et al. (1996) found a tight relationship between egg burial depths and scour depths during the incubation period for chum salmon in two PNW streams, indicating that the populations are adapted to typical depths of bed scour in the streams and even small increases in scour depth could reduce egg survival.
- Changes in magnitude and frequency of peak flows effectively alter the disturbance regime, which may have profound implications for ecosystem processes (Rieman and Isaak 2010).
- Increased winter flows will reduce availability of slow-water habitats and displace rearing juveniles downstream of preferred habitats, increasing competition for limited rearing habitat (Mantua et al. 2010).

*Increased sediment load and flux*

- Increased fine sediments are associated with reduced egg-fry survival and benthic invertebrate production. High turbidities can either kill, injure, or modify the behavior of rearing and holding

[16] Data for 2003 and 2006 from: <https://fortress.wa.gov/ecy/eap/riverwq/station.asp?sta=01F070>; but only good for data through water year 2006; water years 2007 onwards have not been checked and the max 7dadm appear anomalously low. Data from 2009 from: Capuana, E. 2012. Nooksack River watershed Water Temperature Monitoring Program: 2009 Data. March 2012. Nooksack Indian Tribe, Natural Resources Department. Deming, WA. 48pp. Data from 2013 from: Nooksack Natural Resources (2014).

salmonids, resulting in increased mortality and/or reduced productivity of habitats. Potential impacts of elevated turbidities include (1) gill trauma and disruption of osmoregulation, blood chemistry, and reproduction; (2) reduction of feeding efficiency for juvenile salmonids, which are visual predators, thereby reducing growth rates; and (3) avoidance of habitats or delays in migration (Bash et al. 2001).

It is important to consider the pace of climate change and the ability of salmonids to adapt to that change. Although climate has been variable since the last major glacier retreat and salmonids have adapted to this variation, climate and stream temperature modeling of the various climate change scenarios suggest a more rapid change in the hydrology of western stream systems than that occurred prior to global industrialization. Fish adaptation can occur through phenotypic plasticity in life history, including habitat selection (e.g., thermal refugia) and timing of migration, although that plasticity may be generally constrained to historic ranges. Salmonids do have the capacity to rapidly colonize new habitats, so to the extent that climate change will affect the distribution and availability of critical habitats, salmonids may be able to exploit what emerges, assuming such habitat is suitable and accessible (multiple authors cited in Rieman and Isaak 2010). Salmonids may also adapt over time through natural selection—evidence indicates evolution can occur within 10 to 20 generations (40-80 years; multiple authors, cited in Rieman and Isaak 2010) – although there is uncertainty about climate change outpacing evolution rates.

### 5.2.2 South Fork Salmonids

There are nine species of Pacific salmonids that inhabit the South Fork. In general, these species are distributed in the South Fork from the mouth upstream to RM 20 or beyond, depending on species, and in tributaries. Table 5-6 summarizes the distribution of Pacific salmonid species in the South Fork and tributaries. Figure 5-19 summarizes the life stage periodicity and vulnerability to climate change impacts of currently unlisted species. More extensive discussion of hypothesized impacts to listed salmonids follows in this section. Monitoring of South Fork salmonid populations will be important to test the hypotheses presented below.

**Table 5-6. Distribution of Pacific Salmon Species in the Mainstem Nooksack River up-gradient Toward the Headwaters of the South Fork.**

| | | |
|---|---|---|
| **Chinook Salmon (early/spring-summer and late/fall spawn timing)** | South Fork Nooksack Early Chinook (early-timed) | Mainstem South Fork to RM31 and major South Fork Tributaries |
| **Pink salmon (mostly odd-year, some even-year spawners)** | | Mainstem South Fork to RM25 and major South Fork Tributaries |
| **Chum salmon (fall)** | | Mainstem South Fork to RM20 and major South Fork Tributaries downstream of RM 20 |
| **Coho salmon** | | Mainstem South Fork to RM25 and South Fork Tributaries |
| **Sockeye salmon (riverine)** | | Mainstem Nooksack River to RM25 and major South Fork Tributaries |
| **Steelhead (winter-run, summer-run)** | Nooksack River Winter Run, South Fork Nooksack River Summer Run | Mainstem South Fork and tributaries to RM 25 (winter-run), and to above RM38 (summer run) and major Upper South Fork Tributaries (summer-run) |
| **Cutthroat trout** | | Mainstem South Fork to RM 25 and South Fork Tributaries |
| **Bull trout (anadromous)** | Upper South Fork Nooksack River, Lower South Fork Nooksack River, Wanlick Creek | Mainstem South Fork and to above RM38 and cold-water South Fork Tributaries |
| **Dolly Varden (resident)** | | In Upper South Fork tributaries Bell Creek above falls and “Pine Creek” above steep cascades |

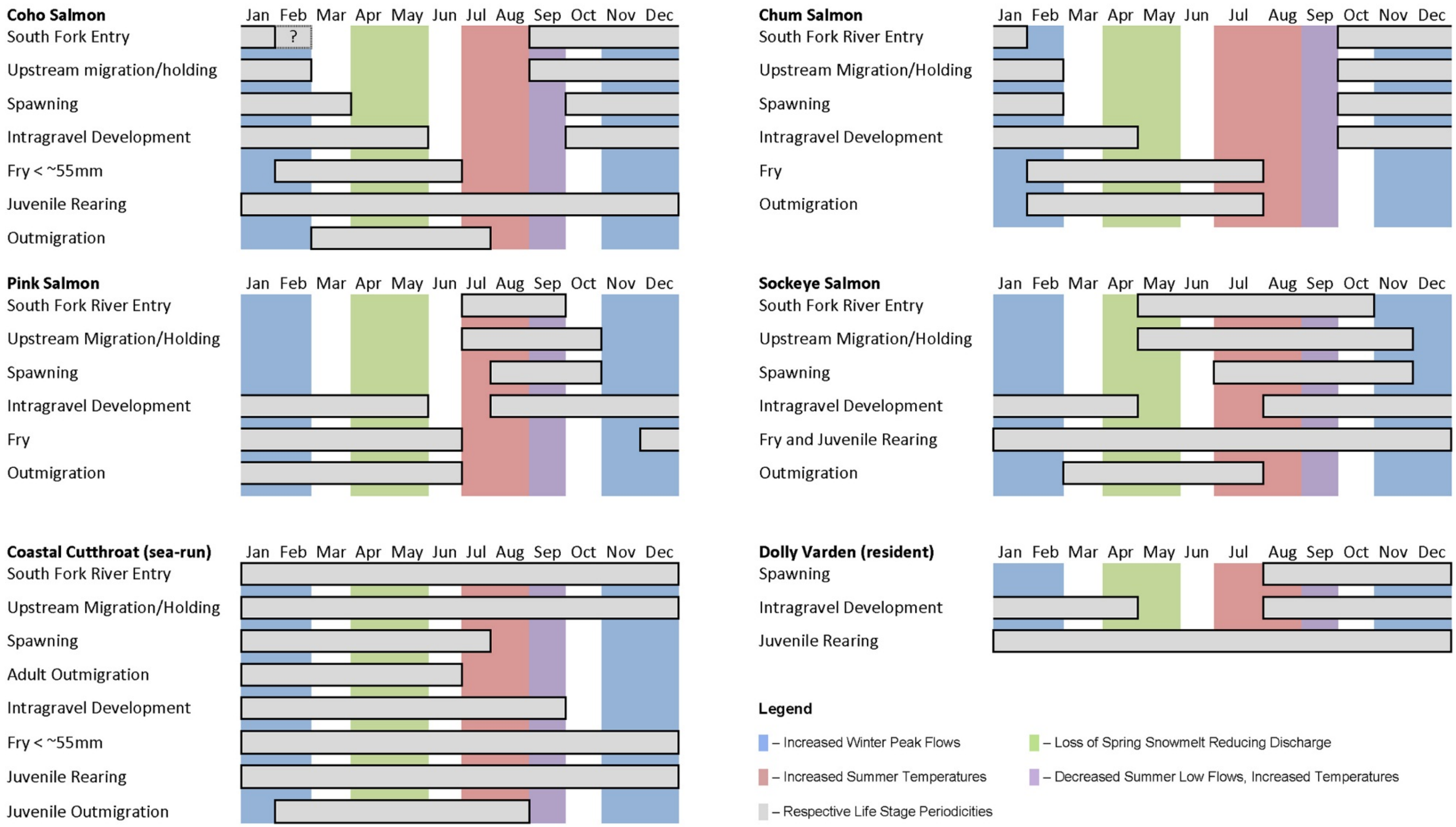


**Figure 5-19. Salmonid Life Stage Periodicity in the South Fork and Vulnerability to Climate Change Impacts. (Note: see Figures 5-21, 5-24, and 5-27 for similar figures for listed salmonids).**

## 5.2.3 Spring Chinook Salmon

### 5.2.3.1 Population Description

The South Fork Nooksack early (spring/summer) Chinook population is native, and NOAA's National Marine Fisheries Service (NMFS) describes them as essential for recovery of the threatened Puget Sound Chinook Evolutionarily Significant Unit (ESU) (64 FR 14308, March 24, 1999). Adult escapements continue to be very small, with less than 125 adults spawning per year between 2003 and 2013. In the late 1980s, the Skookum Creek Hatchery cultured native spring Chinook to augment the dwindling population. This appeared to have had little impact on adult returns, and supplementation was discontinued in 1993. A South Fork Nooksack spring Chinook population rebuilding program was restarted in 2007 with captive brood rearing of juveniles collected from the wild. Adult returns from releases to the South Fork from the spawned mature captive reared Chinook began returning to the basin in 2014. As a result of the fragile status and the unique and essential nature for this ESA-listed Chinook population, the South Fork has become the focus of strategic habitat restoration.

Chinook distribution extends to RM 31, although Sylvester's Falls at RM 25 constitutes a partial blockage (Figure 5-20). Most spawning occurs between RM 10 and RM 20.5. Scale analysis of returning South Fork Chinook adults indicates a relatively high percentage (38 percent) exhibited the stream-type life history strategy (long freshwater residence, smolt outmigration as yearlings) (PSTRT 2003). Scales from sampled spawners from 1999 to 2013 South Fork population Chinook also had a 38 percent yearling life history pattern (Co-manager unpublished data, compiled by Lummi Natural Resources). These data show a significant contribution of a stream-type life history strategy in the South Fork population and emphasize that freshwater rearing habitat, through both summer low-flow and winter high-flow periods, is important for South Fork Chinook (Figure 5-21).

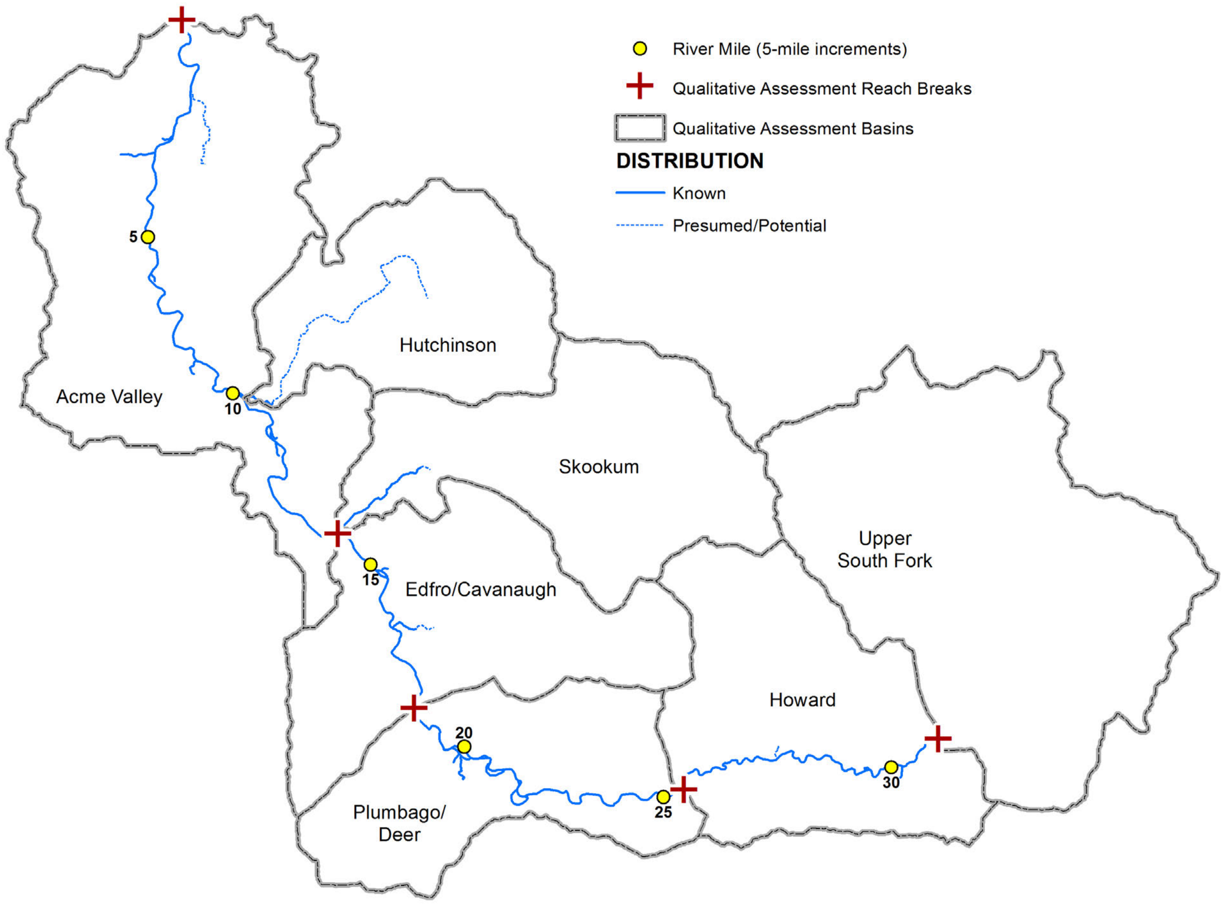


**Figure 5-20. Chinook Distribution in the South Fork Watershed and Subbasins (SSHIAP 2004)**

### 5.2.3.2 Climate change vulnerability

Spring Chinook salmon may be affected by climate change impacts throughout their life cycle (Figure 5-21). High stream temperatures and low flows during spring snowmelt and/or summer baseflow will impact river entry; upstream migration and holding, spawning, intragravel development, summer juvenile rearing, and outmigration. Increased winter peak flow will impact intragravel development, overwinter rearing, and outmigration. Although changes in hydrologic variability are not explicitly characterized in this qualitative assessment, a recent study found that variability in freshwater flows had a more negative effect on growth rate of 21 PNW Chinook populations (including South Fork Nooksack Chinook) than other climate signals evaluated, including PDO and North Pacific Upwelling indices), potentially because low flows restrict spawning to the center of the channel and high flows increase egg mortality (Ward et al. 2015).

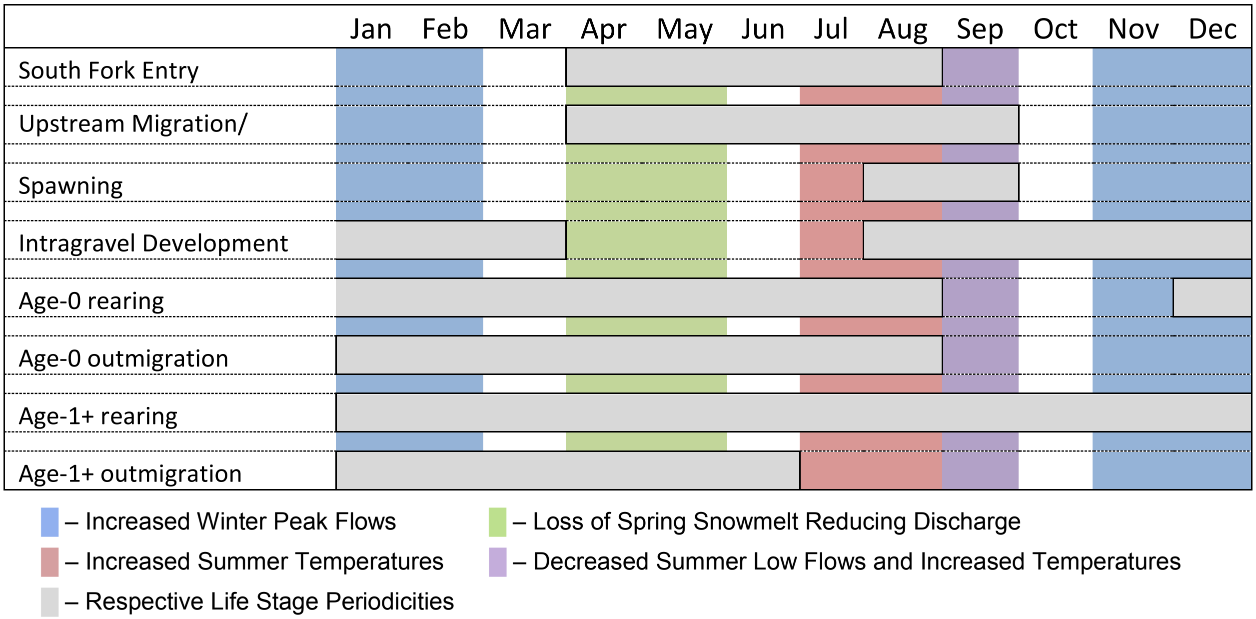


**Figure 5-21. Spring Chinook Life Stage Periodicity in the South Fork and Vulnerability to Climate Change Impacts.**

The upper incipient lethal threshold for juvenile Chinook is 25.1 °C (Brett 1952, as reported in McCullough 1999); adult salmonids appear to have lethal tolerances 2-3 °C cooler than juveniles (McCullough et al. 2001). Reach-averaged modeled temperatures for the critical conditions scenario (7Q10 flows[17], 90th percentile 7-day air temperature) under current conditions are 22.0, 21.4, 21.2, 20.2, and 18.9 °C for South Fork reaches 1-5, respectively. Assuming the 2080 medium emissions scenario, modeled critical conditions maximum temperatures are 26.4, 25.9, 26.2, 25.3, and 23.7 °C for reaches 1-5, which is above the lethal threshold for juvenile Chinook in all but reach 5. Restoring the South Fork to natural conditions will be important for spring Chinook persistence in the South Fork, and is estimated to reduce critical condition maximum temperatures (2080 medium emissions scenario) to 20.8, 20.8, 20.4, 20.4, and 19.4 °C, below the lethal threshold for juveniles (and likely adults), and less than current conditions. More normal conditions (7Q2[18] flows, 50th percentile 7-day air temperature) appear somewhat less dire. Modeled current maximum temperatures under normal conditions are 19.7, 19.1, 19.0, 18.3, and 17.8 °C for reaches 1 through 5, and 18.8, 18.8, 18.3, 18.6, and 18.2 °C with restoration to the natural conditions scenario. Impacts of increased water temperatures will also extend beyond the low-flow period; average monthly temperatures in the lower South Fork are expected to exceed optimal levels for incubation and early fry development, holding/spawning, and juvenile rearing for ~2, 3, and 4 weeks longer than historical conditions by 2020, 2040, and 2080, respectively (Figure 5-22). Higher temperatures may select for ocean-type (which smolt in days to months after emergence) over stream-type Chinook in the South Fork. Beacham and Withler (1991, reported in McCullough et al. 2001) found that mortality of stream-type and ocean-type Chinook reared at controlled temperatures for 16-18 days were similar, but the cumulative mortality curves differed, with stream-type Chinook and ocean-type exhibiting 70 percent and 3 percent mortality after 8 days (Beacham and Withler 1991, reported in McCullough et al. 2001). The authors suggested that ocean-type Chinook are better adapted to higher temperatures as they spend more time in coastal waters.

[17] 7Q10 flow is the lowest 7-day average flow that occurs (on average) once every 10 years.
[18] 7Q2 flow is the lowest 7-day average flow that occurs (on average) once every 10 years.

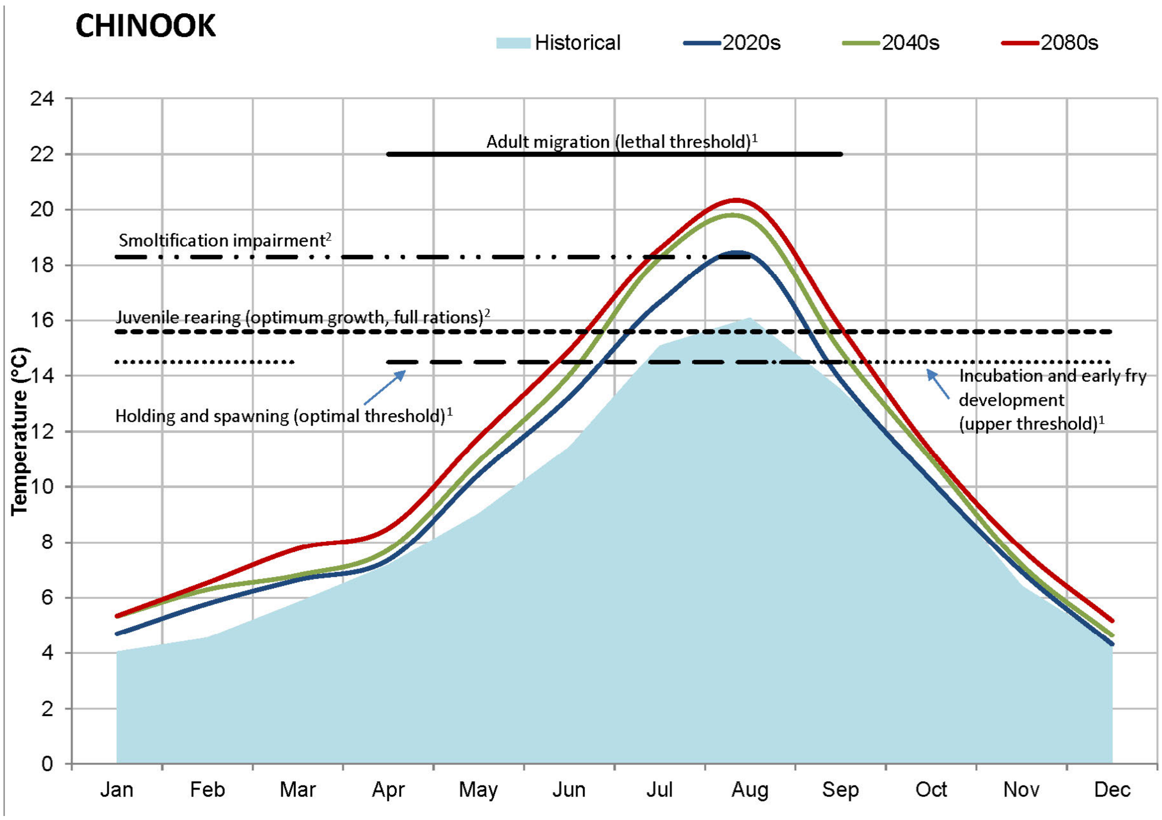


**Figure 5-22. Chinook Temperature Requirements and Periodicity by Life Stage, Compared with South Fork Monthly Average Water Temperature at Potter Road (ccsm3_A1B medium impact scenario). Temperature Requirements as Reported in [1]Beechie et al. 2013 and [2]McCullough 1999.**

#### 5.2.3.2.1 River Entry

Early Chinook enter into the South Fork between April and August and continue their upstream migration to their spawning areas. Increased summer water temperature in the mainstem South Fork during this period could delay river entry in the South Fork and result in bimodal period of entry, with fish entering either before the highest temperatures and holding through the warm water period, or holding below the South Fork confluence and entering shortly before spawning. Extended holding in the mainstem may also increase straying to the North and Middle Forks, thereby reducing spawning in the South Fork.

Although it is difficult to estimate the potential impact of climate change on sediment load throughout the Nooksack, increased fine sediment may also delay river entry (Bash et al. 2001), especially if frequency and magnitude of high turbidity events in the South Fork increase relative to those in the mainstem. Turbidities in the South Fork often exceed that in the mainstem Nooksack River; 43 percent of hourly turbidity measurements in the South Fork at Saxon Road bridge (RM 12.9) during river entry (April through August 2011) exceeded those in the mainstem—turbidities exceeded that in the mainstem from the beginning of April through May 6th of that year.

#### 5.2.3.2.2 Upstream Migration and Holding

Historical catch records in Bellingham Bay and the Nooksack River indicate that adult wild Chinook were present through most of the year. Early arrivals to the lower mainstem Nooksack River appeared to show up in February with a peak river entry in May to June. For a 1981 radio-tagging study of Chinook, fishing in the lower Nooksack River began in early April, and spring Chinook were caught the first week (Barclay 1981). Catch-per-unit-effort increased through mid-May, and the highest catch per day occurred the first week of June, after which fishing ended. Adult upstream migration of early Chinook occurs in four stages: river entry, upriver migration, holding, and spawning (Barclay 1980). Some spring Chinook that were radio-tagged in the lower mainstem Nooksack River in 1980 and 1981 moved directly upriver after tagging, while others remained in the lower mainstem, even moving back out to saltwater. After the Chinook were acclimated, they moved upriver at fairly uniform rates of 1.7 (1980) and 1.5 (1981) miles/day on average (range 0.97 to 3.7 miles/day) for a total of 30 to 40 days transit time to the Forks confluence (Barclay 1980, Barclay 1981). Based on this, the bulk of the spring Chinook population is expected to enter the South Fork between April and end of August. While few radio-tagged fish entered the South Fork, those individuals that did entered as soon as early June.

Early Chinook hold for long periods during the summer in freshwater prior to spawning. The 1980 and 1981 radio-tagging studies found that once migrating Chinook reached holding areas, migration dropped sharply (Barclay 1980, Barclay 1981). Some fish held in the same pool for two to four weeks. Schuett-Hames et al. (1988a) found the highest number and greatest volume of Chinook holding habitats occurred between RM 10 and RM 15. Prolonged holding in this reach is evidenced by records from earlier this century of local resident Tom Nesset catching Chinook in the reach through the month of June. It is also noteworthy that in 1921, a one-time survey of Hutchinson Creek in July recorded an adult Chinook, indicating that holding historically occurred in this tributary as well (Norgore and Anderson 1921). High temperatures will negatively impact upstream migration and holding of early Chinook. The lethal threshold for adult Chinook migration is 22 °C (as reported in Beechie et al. 2013), which is expected to be exceeded under critical conditions in all South Fork reaches by 2080 (medium emissions scenario). Modeling of restoration to the natural conditions scenario indicates maximum temperatures may be 1.2-2.6 °C below this threshold (2080, medium emissions scenario) during critical low-flow conditions and 3.2-3.8 °C below the threshold during normal low-flow conditions. Optimal holding temperatures for Chinook (14.5 °C, Beechie et al. 2013), however, are exceeded during normal and critical low-flow conditions currently, and climate change will increase both the magnitude and duration of exceedance of that threshold (Figure 5-22). It is estimated that average monthly temperatures in the lower South Fork will exceed optimal holding threshold for 2.5, 5, and 6.5 weeks longer than historical conditions in 2020s, 2040s, and 2080s, respectively (Figure 5-22). It is not uncommon under current conditions to have prespawn mortality of Chinook and pink salmon during and after periods of warm temperatures. Occasional necropsies by a NWIFC pathologist have found *Columnaris*, a pathogen associated with higher mortality at temperatures greater than 15 °C (Spence et al. 1996), to be the primary cause of death in some prespawn mortalities, including a Chinook and a pink salmon which were assessed in 2013. Increased temperatures would be expected to increase prespawn mortality levels from *Columnaris* above those already experienced. It is clear that the presence of temperature refuges will be very important in productivity of this lifestage.

Reductions in flows both early (due to reduced snowmelt) and late (due to reduced baseflow) may increase vulnerability to predation (including by humans), limit access, and further confine periodicity and distribution of spawning, especially in the upper reaches where the relative decrease will be greatest. Low flow can limit access to cooler water tributaries, like Hutchinson Creek and Deer Creek, as well as affect passability at partial barriers, such as RM 25, that limits access to cooler water areas of reach 4. Migration will be even more challenging for fish that enter the South Fork later, during the lowest flow period, due to thermal conditions. Together, these expected changes will likely further narrow the distribution of early Chinook to the mainstem of the river downstream of RM 25.

##### 5.2.3.2.3 Spawning

In the mainstem South Fork, Chinook spawning occurs from the confluence (RM 0) to RM 31. Sylvester's Falls at RM 25 constitutes a partial blockage, and spawn surveys indicate Chinook apparently do not get upstream of these falls every year (Figure 5-20). While steelhead and bull trout get upstream of RM 25 and RM 31, Chinook have not been recorded upstream of the RM 31 partial blockage. The spring

Chinook population spawns August through September, but primarily mid- through late September. From 1999 to 2001, 22.2 percent of the early Chinook redds recorded in the mainstem were located in the RM 8.6 to 12.9 reach (14.1 percent of the available habitat), and 66.7 percent of the tributary redds were located in Hutchinson Creek (RM 0.0-0.7). Only the mainstem reach from Larson's Bridge (RM 20.7) to RM 18.0 consistently supported a higher percentage of early spawning Chinook. Historically spawning abundance also peaked near the partial barrier at RM 25 and from here to the full barrier at RM 31, although spawning use of these areas has declined in recent years. It is unknown if this is a result of upstream habitat degradation, a very low population size, or the partial fish passage barrier present at RM 25. The majority of the early Chinook population currently spawns within two relatively short sections (RM 10-12.9 and RM 18-20.5) of the main channel of the South Fork, although spawning is distributed across all of the accessible area (Maudlin et al. 2002, Soicher et al. 2006, Brown and Maudlin 2007). These two sections represent the most upstream unconfined, low gradient sections of the river accessible and have historically been the most productive habitats in the watershed for early Chinook. Because of this lack of spatial diversity, the population is particularly vulnerable to habitat disturbance and water-quality impacts from climate change.

Beechie et al. (2013) report the optimal threshold (upper limit) for adult spawning as 14.5 °C. Summarizing the work of others, McCullough (1999) describes spring Chinook normally spawning as water temperatures decline from 12.8 °C to 4.5 °C and fall Chinook from 13.4 °C. to 5 °C. They conclude that 12.8 °C is an apparent critical temperature threshold for spring Chinook, and that declining temperatures afterwards are associated with the ability to complete spawning, have maximum long-term viability of eggs and alevins, and good and improving resistance to disease in adults and eggs. If high temperatures delay migrations and subject adults to high water temperatures in holding habitats, valuable energy is lost for spawning and defending redds, and reproductive success may decline. If spawning time is delayed three or more days in the early portion of the spawning period, survival to egg deposition stage should begin to decrease: in Atlantic salmon, as little as a 1-week delay in spawning after full maturation markedly reduces egg quality (de Gaudemar and Beall 1998, as cited by McCullough et al. 2001). Increasing water temperature in the core spawning areas could also force the redistribution of fish to lower productivity habitats in cooler tributaries or upstream. Reduction in low-flow discharge will further limit the useable area for spawning. Access to tributaries for spawning is currently flow-limited in most years, and a reduction in flow during the spawning period will likely make these areas inaccessible to migrating adults. This will also confine more of the spawning distribution to the mainstem channel, reducing resilience to catastrophic events. As flows during the spawning period diminish in the main channel, redds will be more concentrated in the remaining suitable areas where water is of an adequate depth and velocity to support Chinook spawning. The concentration of redds into a smaller wetted channel will increase the vulnerability of the population to disturbances, including floods from higher winter flows. The expected lower flow during the spawning period can also lead to the dewatering of redds of fish that spawn during late summer freshets, when temperatures also temporarily drop. The core areas for spring Chinook spawning are generally characterized by an unconfined channel, with redds commonly located along shallow channel margins, in pool tailouts, and in side channel areas where there is adequate discharge. These locations are susceptible to dewatering if spawning occurs during short freshets followed by drops in flow after the onset of spawning.

##### 5.2.3.2.4 Intragravel Development

Since the majority of the population currently spawns in the mainstem South Fork channel in two short reaches, increases in South Fork high flow will likely impact early Chinook incubation. Incubation losses are expected to increase as more redds are confined to the low-flow mainstem channel by reduced summer discharge, and then scoured to or below egg depths by increased winter peak flows. Increased bedload movement due to higher peak flows during incubation can also result in increased fill on top of redds, as well as lateral channel shifts away from redd locations (Hyatt 2007). Warmer temperatures during incubation could accelerate embryo development and lead to earlier emergence of juvenile

Chinook. Projected average temperature increases during the core incubation season (October through December) are 0.1 °C by 2020s, 0.6 °C by 2040s, and 1.0 °C by 2080s. A 1 °C increase in temperature can result in emergence ~18 days earlier than under historical conditions (historical base temperature 7 °C; McCullough 1999). Early emergence may expose emerging fry to higher flow and desynchronize emergence from springtime pulses in food availability. Survival-to-emergence may also be impaired by increased fine sediments and/or reduced dissolved oxygen concentrations associated with the fine sediment or higher temperatures.

#### 5.2.3.2.5 Juvenile Rearing

Fry are present over the general time frame of early February through early May (Wunderlich et al. 1982), suggesting a prolonged emergence period. More recent data recorded earlier emergence, as young-of-the-year juvenile Chinook were captured in the lower South Fork (RM 0.95) on December 7, 2001 (Nooksack Natural Resources, unpublished data). Distribution of rearing Chinook may vary between years depending on abundance of juvenile Chinook and other species, hydrologic conditions and resource availability (multiple authors, cited in Healey 1991). Small fry are expected to use channel margins, especially backwaters and areas with bank cover, and off-channel habitats (sloughs and side channels). Fry surveys conducted during the spring from 1994 to 1996 suggest a shift to off-channel habitats after emergence, especially in the South Fork (Castle and Huddle 1996). From March to June 1994, spring Chinook fry (34-45 mm length) were found in more than half of the spring seeps feeding into the South Fork between RM 15.1 and 29.8 (Castle and Huddle 1994). Minnow trapping surveys found Chinook in most floodplain habitats (Roos Slough in April, Nesset's side channel complex in September and November, Landingstrip Creek in March and May, and Rothenbuhler Slough in April) in the lower South Fork in 2001 (Naef 2002). Notably, snorkel surveys enumerated 438 juvenile Chinook in the side channel downstream of Nesset's Slough and 199 juvenile Chinook in a 300 meter-long reach in the floodplain portion of Hutchinson Creek, both during mid-September 2001 (Ecotrust, unpublished data), indicating heavy use of cooler, but more flow-limited habitats. In the South Fork, age zero plus Chinook were found throughout the sampled length (RM 0 – 20.6) during spring and fall, with patchy distribution during winter and summer (Coe 2005; see Figure 5-20). Densities were greater in the upper rather than in the lower South Fork (Coe 2005). Snorkel surveys during summer also indicate juvenile Chinook presence in South Fork tributaries: Hutchinson Creek, Skookum Creek, Cavanaugh Creek, Deer Creek, and Roaring Creek (Coe 2005). Juvenile Chinook were also observed during snorkel surveys of Black Slough and Todd Creek near their confluences with the South Fork.

Juvenile rearing is subject to the array of projected climate change impacts, from increased temperatures (affecting over summer rearing by stream-type life history Chinook), winter peak flows and associated sediment loads (early fry rearing, overwinter rearing) and decreased spring snowmelt and summer low flows (fry, parr rearing). The upper threshold of optimal temperatures for juvenile rearing (i.e., when optimum growth occurs at full rations) is 15.6 °C (McCullough 1999). QUAL2Kw modeling (see Section 5.1) indicates that threshold is exceeded currently during both normal (average 19.7 °C, 19.1, 19.0, 18.3, and 17.8 °C in reaches 1 through 5) and critical (average 22.0, 21.4, 21.2, 20.2, 18.9 °C in reaches 1 through 5) low-flow conditions throughout the South Fork. Further, climate change may increase the time by which average monthly temperatures in the lower South Fork exceed that threshold by 5.5, 7.5, and 8.5 weeks longer than historically by 2020s, 2040s, and 2080s, respectively (Figure 5-22). Increased summer water temperatures are expected to impact juvenile rearing, both through direct effects on physiology and behavior and indirect biotic effects that alter the abundance and distribution of predators and prey. This is expected to disproportionally affect survival of streamtype Chinook. When Nooksack Indian Tribe and Lummi Nation crews' beach seined juvenile Chinook 2009-2012 from the South Fork for broodstock for the captive brood hatchery population rebuilding program, mortalities were high if juveniles were seined at temperatures above 15 °C. To minimize mortalities, protocols were altered to only seining when temperatures were below 15 °C. Often temperatures began to exceed this criteria during the month of July. Increased water temperature may suppress growth, especially if food availability is limited due to changes in phenology and community structure, and if increases in fine sediments or algal production affect benthic invertebrate production. An increase in mortality from heat stress would be expected as well as behavioral changes as the fish seek refuge from the warmer South Fork water. The warmer water could lead to a redistribution of fish into lower quality cover and poorer habitat to escape the warm water. Reduced flow from cooler water tributaries, such as Black Slough and Hutchinson Creek, would likely reduce the summer rearing quality in the Acme Valley by reducing the availability of thermal refuges. Increased temperatures are likely to also increase prevalence of *Columnaris* disease in rearing stream-type Chinook.

The increases in winter peak flow will likely reduce availability of slow-water habitats and lead to an increase in outmigration during the winter period as fish are flushed from the South Fork. This may increase the proportion of South Fork Chinook that leave the watershed as smaller fry rather than as larger parr, which could lead to decreased survival.

The reduction in spring snowmelt could increase availability of low-velocity edge habitat for fry, increase migration time and thus vulnerability to predation for all spring and early summer outmigrants, and also limit access to floodplain habitats. It could also cause a shift to earlier outmigration of parr as the flow drops earlier in the year. These effects could inhibit freshwater rearing of juveniles and also lead to smaller fish entering the saltwater, where they would be at a competitive disadvantage and subject to greater predation in the nearshore compared to larger migrants. Warmer spring temperatures could offset this effect, by increasing the growth rate during the freshwater rearing period if enough food is present.

The reduction in summer low-flow discharge will affect habitat availability for yearling Chinook and could increase stranding of fish in isolated habitats. The loss of habitat area will likely lead to an increase in competition with other species for limited high-quality rearing space. Fish that prefer to rear in side channels and floodplain tributaries, which often are more diverse habitat than the mainstem channel, will be more susceptible to stranding as the flow drops and these channels become dewatered or disconnected. The loss of rearing space and direct mortality would likely impact yearling Chinook disproportionally, and possibly encourage a shift toward fry and parr outmigration. This shift again will lead to smaller fish entering the saltwater and may lead to increased predation and poor competition with large fish in the nearshore environment.

Increased fine sediment load may kill or injure, reduce feeding efficiency (since salmon are visual predators) or cause avoidance of habitats or delays in migration (Bash et al. 2001). It may also fill interstitial spaces in streambed substrate, thereby limiting potential temperature refuge from high temperatures (during summer) or low temperatures (during winter). In field and lab experiments, substantially more juvenile Chinook remained in sites to which larger substrate (cobble and rubble) had been added; emigration from study sites was high in areas lacking in suitable substrate (Bjornn 1971; Hillman et al. 1987). Entry into the substrate was correlated with stream temperatures declining to 4 to 8 °C. Chinook also appeared to select lower velocities in winter than in summer, avoiding velocities greater than 12 centimeters per second (cm/s) (Hillman et al. 1987).

#### 5.2.3.2.6 Juvenile Outmigration/Smoltification

Chinook salmon can outmigrate as fry (migrating to estuaries soon after emergence), as parr (rearing for weeks to months, prior to outmigrating to estuaries in spring or summer), or as yearlings. The smolt outmigration period for individual stocks and subpopulations of Chinook from the Nooksack is not well characterized, although Chinook outmigration generally occurs between December and mid-August. From 2013 data, it appears that South Fork population juveniles tend to smolt later in that period and tend to be larger fish (Lummi Natural Resources, unpublished data), although the sample size was small. While no yearling South Fork fish were caught that year, zero-age migrants were captured between mid-April and mid-August, with the bulk of the population passing the Hovander smolt trap near Ferndale on the mainstem Nooksack in July. The effects of climate change will vary between these three strategies and may later affect the relative proportion of Chinook outmigrating as fry, parr, or yearlings. Increased winter peak flows may displace more fry, increasing outmigration during winter floods, while lower velocities associated with decreased spring discharges may delay outmigration and increase vulnerability to predation. Increased summer water temperature could lead to an earlier outmigration for parr migrants and lead to smaller fish entering the nearshore. Warming may also impair smoltification, especially over the longer term (Figure 5-22).

### 5.2.4 Steelhead Trout

#### 5.2.4.1 Population Descriptions

The South Fork supports two populations of steelhead: South Fork Nooksack summer-run steelhead and Nooksack winter-run steelhead. Both stocks are native and wild. These populations are included in the Puget Sound steelhead DPS, which NMFS listed as federally threatened on May 11, 2007 (effective date June 11, 2007; 72 FR 26722). The populations are two of sixteen historic steelhead populations in the North Puget Sound Major Population Group (MPG), and two of 32 populations in Puget Sound. The South Fork is managed as a wild steelhead management zone. Recovery plans are not yet developed for Puget Sound steelhead, though recovery planning is underway.

Summer-run steelhead

Summer-run steelhead populations are uncommon in Puget Sound. The South Fork summer-run population comprises an important life history genetic reserve because it has not been supplemented with Lower Columbia River's Skamania strain summer-run steelhead, as has occurred for many other summer-run stocks in Washington. A recent genetic analysis found no hybridization of South Fork summer run steelhead with either hatchery winter run steelhead or hatchery summer-run steelhead stocks (Warheit 2014).

Summer-run steelhead are excellent migrating fish, and summer-run steelhead, as well as bull trout access habitat areas in the South Fork that are unavailable to other anadromous species. Summer-run steelhead are thought to mostly spawn in the upper South Fork, upstream of the partial passage blockage at Sylvester's Falls (RM 25). They also access habitat upstream of the partial blockage at RM 31 that appears to limit upstream use by spring Chinook (Figure 5-23). Summer-run steelhead spawning distribution is poorly understood, as the area is difficult to access in late winter, but spawning has been observed in Wanlick Creek and in the South Fork upstream of Wanlick Creek in March. Recently, spawning was confirmed in February too. At a minimum, this population utilizes the lower mainstem South Fork for upstream adult migration and adult holding, downstream migration as kelts (post-spawning adults that return to marine waters), and for rearing as smolts migrate downriver. It is unknown to what extent there is downstream movement of juveniles for rearing in the lower South Fork, though it likely occurs. There are no abundance estimates for summer-run steelhead, though the population is thought to number a few hundred individuals or less.

Winter-run steelhead

Nooksack winter-run steelhead are more common than summer-runs, and population escapement estimates have ranged from a low of 1,521 to a high of 1,901 adults from 2010-2014. The Nooksack River has been described as having one of the largest runs of winter-run steelhead in Washington, and was fifth in the state in steelhead catch in 1947 (Bradner 1950). The population declined, and the river had not ranked in the top 25 rivers in Washington for sport catch in the years leading up to 1984 (WDG 1984).

Winter steelhead utilize habitat downstream from summer-run steelhead and are thought to be limited by the partial blockage at RM 25 on the South Fork (Figure 5-23), perhaps attributable to lower metabolisms due to cooler water temperatures during their migration period. Winter-run steelhead spawn in the mainstem Nooksack River and all three forks, and in moderate size and larger tributaries to these areas. In 2013, the South Fork subbasin supported 28 percent of the population spawning. The mainstem South Fork had 31 percent of the total redds built in the forks and mainstem Nooksack River, and tributary spawning in the South Fork comprised 25 percent of the population's total tributary spawners. Hutchinson Creek is used to the falls located at RM 5.9, and from 2011-2014 this creek had the highest annual redd counts of any tributary in the Nooksack watershed (range 107 redds to 195 redds) (unpublished co-manager spawn survey data). In the South Fork subbasin, 48 percent of spawning occurred in the river in 2013, and 52 percent in tributaries. Hutchinson Creek had 66 percent of all South Fork tributary spawning. Redd densities are consistently appreciably higher in Hutchinson Creek than in the South Fork.

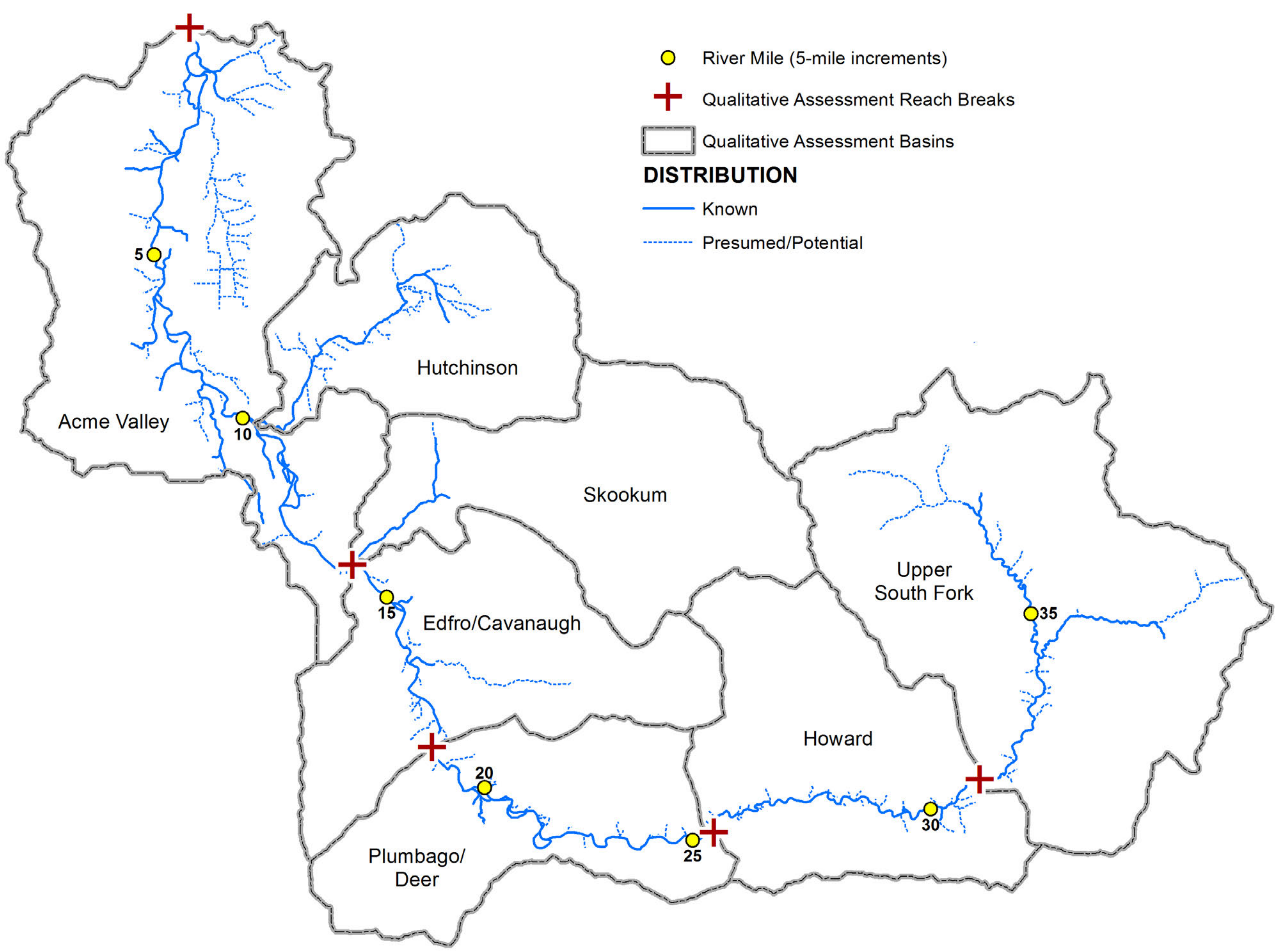


**Figure 5-23. Steelhead Distribution in the South Fork Watershed (SSHIAP 2004).**

### 5.2.4.2 Climate Change Vulnerability

Like Chinook, steelhead may be affected by climate change impacts throughout their life cycle (Figure 5-24). Increased summer water temperatures would affect summer steelhead adult upstream migration, adult holding, and juvenile rearing and winter steelhead adult kelt and juvenile outmigration, intragravel development, and juvenile rearing. Increased winter peak flows will affect both summer and winter steelhead holding, spawning, adult outmigration, intragravel development, and overwinter rearing for both summer-run and winter-run steelhead. Loss of spring snowmelt that reduces discharge will affect all life stages. Winter-run adult migration above the cascades located at RM 0.7 on Hutchinson Creek could possibly be affected by reduced spring discharge, as could summer-run migrations in the South Fork past partial barriers at RM 25 and RM 31.

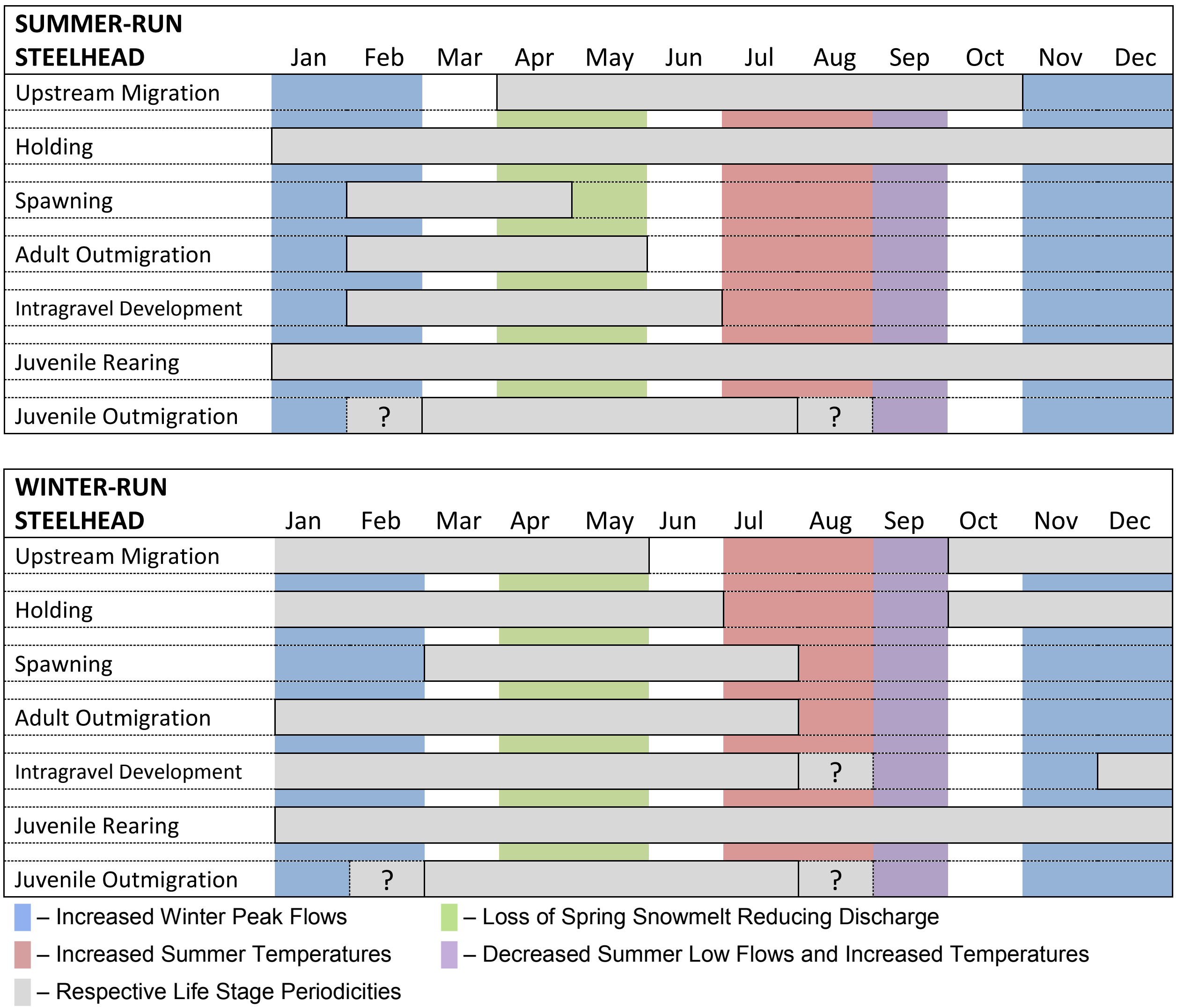


**Figure 5-24. Steelhead Life Stage Periodicity in the South Fork and Vulnerability to Climate Change Impacts.**

Steelhead are anadromous rainbow trout. The upper incipient lethal threshold reported in various studies for juvenile rainbow trout ranges from 25-26 °C, and adult thresholds may be 2-3 °C lower (McCullough 2001). Reach-averaged modeled temperatures for the critical conditions scenario (7Q10 flows, 90$^{th}$ percentile 7-day air temperature) under current conditions are 22.0, 21.4, 21.2, 20.2, and 18.9 °C for

South Fork reaches 1-5, respectively. Assuming the 2080 medium emissions scenario, modeled critical conditions maximum temperatures are 26.4, 25.9, 26.2, 25.3, and 23.7 °C for reaches 1-5, which is at or near the lethal threshold for juveniles in all but reach 5 and near the lethal threshold for adults in all reaches. Restoring the South Fork to natural conditions will be important for steelhead persistence in the South Fork, and is estimated to reduce 2080 medium emissions critical condition maximum temperatures to 20.8, 20.8, 20.4, 20.4, 19.4 °C, below the lethal threshold for juveniles (and likely adults) and less than current conditions. More normal conditions (7Q2 flows, 50$^{th}$ percentile 7-day air temperature) appear somewhat less dire. Modeled current maximum temperatures under normal conditions are 19.7, 19.1, 19.0, 18.3, and 17.8 °C for reaches 1 through 5, and 18.8, 18.8, 18.3, 18.6, 18.2 °C with restoration to the natural conditions scenario. Impacts of increased water temperatures will also extend beyond the low-flow period; average monthly temperatures in the lower South Fork are expected to exceed optimal levels for incubation and early fry development for approximately two, three, and four weeks longer than historical conditions by 2020, 2040, and 2080, respectively, and even longer for adult holding and spawning optimal thresholds, and exceed juvenile rearing optimal thresholds by 2040s and 2080s (Figure 5-24).

##### 5.2.4.2.1 River Entry

Puget Sound summer-run steelhead generally have river entry timing from May through October, and late winter spawning, so these fish have extended adult holding periods. Summer-run steelhead have been encountered and released in the lower Nooksack mainstem Chinook tangle net fishery in May and June. The fishery ends June 15. They are observed incidental to South Fork Chinook spawning surveys and during South Fork spring Chinook adult holding snorkel surveys. They have been caught in a former South Fork weir near RM 14 in July. Aggregations have been observed downstream of Acme in August snorkel surveys. This timing makes migrating and holding adults susceptible to climate change impacts similar to spring Chinook. Winter-run steelhead enter rivers from November through May, with spawning generally from February in low elevation tributaries through June in higher elevation settings. The timing of summer-run steelhead entry into the river may change as spring run-off is reduced by the loss of snowpack and warmer temperatures begin earlier in the year. The discharge conditions that enable passage beyond partial barriers at RM 25 and RM 31 are unknown, but spatial isolation from winter-run steelhead is likely very important to prevent hybridization with Nooksack winter-runs. Genetic results from South Fork Nooksack summer-run steelhead found one to be a hybrid with a Nooksack winter-run steelhead (Warheit 2014). Temperatures in excess of 22 °C constitute a thermal blockage (Beechie et al. 2013) and may delay river entry. Winter-run steelhead entry timing could be affected by lower spring stream flows and increased frequency of winter high-flow events.

##### 5.2.4.2.2 Upstream Migration and Holding

Summer-run steelhead enter the South Fork and migrate upstream to their spawning areas in the upper watershed; upstream of RM 25 and also upstream of the RM 31 partial barrier. Since these fish can enter the river as early as late spring, they hold for extended periods in the river before the on-set of spawning in February, rendering them vulnerable to elevated summer water temperatures and low flow during their migration and holding period. The optimal threshold for adult holding and spawning is 12.8 °C (Beechie et al. 2013), which is well exceeded under current and projected future critical and normal conditions, even with restoration to natural watershed conditions. Climate change will increase the length of time that optimal conditions are exceeded, which may result in delayed migration, an increase in heat-related bacterial infections and direct mortality from extended exposure. Low flow and high temperatures may limit their access to spawning areas in the upper river, and increase competition with early Chinook and bull trout for mainstem holding in the lower 25 miles of the river. Low flow also inhibits their ability to migrate into the larger tributaries for spawning and may limit their ability to pass the partial barriers at RM 25 and 31.

Winter-run steelhead enter the South Fork after the end of the low flow/ high temperature period and begin their upstream migration. Perhaps due to a lower metabolism related to the cooler water during their migration period, winter-run steelhead do not migrate as far upstream as summer-run steelhead. They use the mainstem below the RM 25 barrier and moderate and larger accessible tributaries for spawning. Currently, slightly more than half the winter-run spawning in the South Fork is in tributaries, and reduced spring discharges from climate change may impair access to the smaller tributaries. It may also possibly limit the ability to pass the partial barrier at RM 0.7 on Hutchinson Creek. Due to their migration timing, winter-run steelhead are likely less severely impacted than summer-run steelhead by high temperature and low flow during their migration and holding period. Their broad distribution and extensive tributary use likely increases population resiliency compared to summer steelhead and Chinook.

###### 5.2.4.2.3 Spawning and Adult Outmigration

Nooksack winter-run steelhead spawning begins in lowland tributaries as early as February and is later in higher elevation areas. In the South Fork subbasin, recent fisheries co-manager spawn surveys have recorded redds from March through June, with most built in April and May. This timing is seen for both river spawners and tributary spawners. Spawning by winter-run steelhead occurs throughout the South Fork downstream of RM 25, and while data are limited (in part due to visibility issues), spawning densities appear to be fairly uniform in these reaches, including in the most downstream reach.

South Fork summer-run steelhead spawn timing is poorly understood, but redds were reported in the Upper South Fork and Wanlick Creek in February and March. There is temporal overlap in spawn timing for the two populations, but summer-runs are thought to spawn only in areas inaccessible to winter-run steelhead (WDG 1984). The RM 25 barrier separates the populations. Because both populations spawn during the early part of the year (February-April for summer-runs and primarily March-June for winter-runs), they are less susceptible to low flow and elevated water temperatures. Early spawning summer-runs could be impacted by increased frequency of high flows.

Since steelhead adults can spawn multiple times during their lifetime, adults (primarily females) may out-migrate to saltwater as kelts after spawning. The adult outmigration is generally timed during the spring run-off period, but can extend into July. A reduction in the amount of snowmelt run-off could slow or change the timing of their outmigration period, and increased temperatures in July could also adversely affect them.

###### 5.2.4.2.4 Intragravel Development

Steelhead incubate during the late winter and spring run-off period. Increased frequency of high-flow events during this period will likely increase redd scour and reduce incubation success. Increased temperatures could result in earlier emergence, exposing emerging fry to higher flow and/or desynchronizing emergence from pulses in food availability.

###### 5.2.4.2.5 Juvenile Rearing and Outmigration

Puget Sound steelhead exhibit a diversity of life history strategies, with extended freshwater rearing for one to four years before smolting, though often the majority are age two. Young-of-the-year (0+) trout were captured year-round in minnow traps and beach seining, with the highest catches from June to October (Naef 2002). Young-of the-year (0+) steelhead or cutthroat trout were found in Hutchinson Creek, Nesset's Creek, and Pond Creek, with very few (<3) in each of the sampled South Fork floodplain areas: Rothenbuhler Slough, Roos Slough, and Landingstrip Creek (Naef 2002). Steelhead have been caught at the lower South Fork smolt trap the entire period of operation (mid-January through July), with the majority in April and May (Nooksack Natural Resources, unpublished data). It is unknown what percentage of the outmigrants derives from each of the two steelhead stocks. By late June, young-of-the-year downstream migrant steelhead or cutthroat were also recorded.

Since steelhead will be widely distributed across habitat types throughout the anadromous portion of the watershed for multiple years, rearing juveniles will be subjected to all of the effects of climate change. Increased winter peak flows will likely affect the early rearing age 0+ juveniles and the overwintering period for multiple age classes that continue to rear in the South Fork. The increase in winter peak flow will likely lead to an increase in outmigration during the winter period as fish are flushed from the South Fork.

The reduction in spring snowmelt could reduce available rearing habitat for yearling and older juveniles and increase the migration time for all spring and early summer outmigrants. These effects could affect freshwater rearing of juveniles and lead to smaller fish entering the saltwater, where they would be at a competitive disadvantage and subject to greater predation compared to larger migrants. Warmer spring temperatures could offset this effect, by increasing the growth rate during the freshwater rearing period if enough food is present.

The reduction in summer low-flow discharge will affect rearing space for all age classes of steelhead and could increase stranding of fish in isolated habitats. In smaller tributaries, increased portions may dewater during summer months. The loss of habitat area will also likely lead to an increase in competition with other species for limited high-quality rearing space. Juvenile surveys in the South Fork have identified steelhead in flow-dependent habitats, such as braids and floodplain channels. Fish that prefer to rear in side channels and floodplain tributaries, which often are more diverse habitat than the mainstem channel, will be more susceptible to stranding as the flow drops and these channels become dewatered. The loss of rearing space and direct mortality would likely disproportionally impact those fish with a longer freshwater rearing period, and possibly encourage a shift toward earlier outmigration. This shift again will lead to smaller fish entering the saltwater and may lead to increased predation and poor competition with large fish in the marine environment.

Increased water temperature will likely directly impact rearing juveniles that over summer for one or more years in the warmer water. The upper threshold of optimal temperatures for juvenile rearing (i.e., when optimum growth occurs at full rations) is 19 °C (Beechie et al. 2013). QUAL2Kw modeling (see Section 5.1) indicates that that threshold is exceeded currently during both normal conditions in reaches 1 and 2 (average 19.7 °C, 19.1, 19.0, 18.3, and 17.8 °C in reaches 1 through 5) and in reaches 1 through 4 during critical (average 22.0, 21.4, 21.2, 20.2, 18.9 °C in reaches 1 through 5) low-flow conditions. By 2080, temperatures during critical conditions may exceed that threshold throughout the South Fork by 6 °C or more, causing direct mortality or forcing juveniles to seek refuge in cooler tributaries or other temperature refuges. Furthermore, juveniles may be exposed to temperatures beyond optimal conditions for a longer period, which may lead to suppressed growth, impaired smoltification, and other sub lethal effects. Average monthly temperatures in the lower South Fork are projected to exceed optimal conditions for about five weeks by the 2040s and 2080s (Figure 5-25). Steelhead that leave the watershed as two, three or four-year-olds will need to over summer multiple times, each year being subjected to the impacts of the elevated water temperature. An increase in mortality from heat stress would be expected as well as behavioral changes as the fish seek refuge from the warmer South Fork water. The warmer water could lead to suppressed growth and/or a redistribution of fish into lower quality cover and poorer habitat to escape the warm water, or encourage rearing in tributaries or downstream in the mainstem Nooksack. A loss of thermal refuge areas from cooler water tributaries, such as Black Slough and Hutchinson Creek, would affect rearing in Hutchinson Creek and also likely reduce the summer rearing quality in the Acme Valley, where these cool water refuge areas are limited. Changes in temperature and flow regime will also influence community structure, affecting the abundance, distribution and behavior of predators, competitors, and prey, although the nature of those impacts is not well-understood.

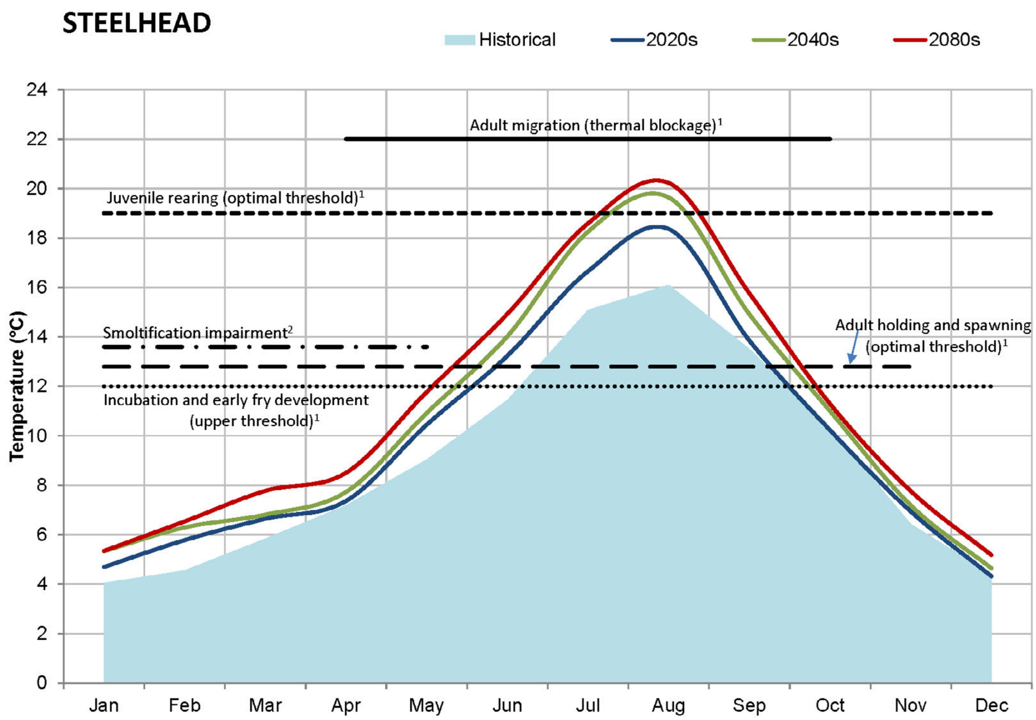


**Figure 5-25. Steelhead Temperature Requirements and Periodicity by Life Stage, Compared with South Fork Monthly Average Water Temperature at Potter Road (ccsm3_A1B medium impact scenario). Temperature Requirements as Reported in [1]Beechie et al. 2013 and [2]McCullough 2001.**

## 5.2.5 Bull Trout

### 5.2.5.1 Population Description

The Nooksack watershed supports one of eight core spawning aggregations of bull trout in Puget Sound (USFWS 2004). There are ten local populations identified, and the South Fork supports three of these. All Nooksack bull trout are native and have wild production with no history of hatchery releases. Puget Sound bull trout were federally listed as a threatened species Nov. 1, 1999 (64 FR 58910). Bull trout in Puget Sound and the Olympic Peninsula have diverse life histories, and contain the only anadromous bull trout in the coterminous United States (USFWS 2004). The USFWS is drafting a final recovery plan which is expected to be completed in 2015.

The three local populations in the South Fork are the Upper South Fork, Lower South Fork and Wanlick Creek populations (Figure 5-26). The Upper South Fork local population includes the mainstem between RM 34 (confluence with Wanlick Creek) and RM 39 and the accessible tributaries upstream of Wanlick Creek. The Lower South Fork local population includes the mainstem and all tributaries downstream of Wanlick Creek, with Hutchinson Creek considered the downstream limit of spawning because of elevated temperatures lower in the watershed. The Wanlick Creek local population consists of Wanlick Creek and its accessible tributaries including Loomis Creek. Nooksack bull trout include anadromous, probably fluvial, and possibly resident life history strategies. Analysis of a small number of tissues collected from native char in the upper South Fork were bull trout, while those from small resident fish in inaccessible portions of Bell Creek (upstream of the falls) and in “Pine Creek” were determined to be Dolly Varden trout (various authors described in USFWS 2004). No abundance estimates are currently available for Nooksack bull trout.

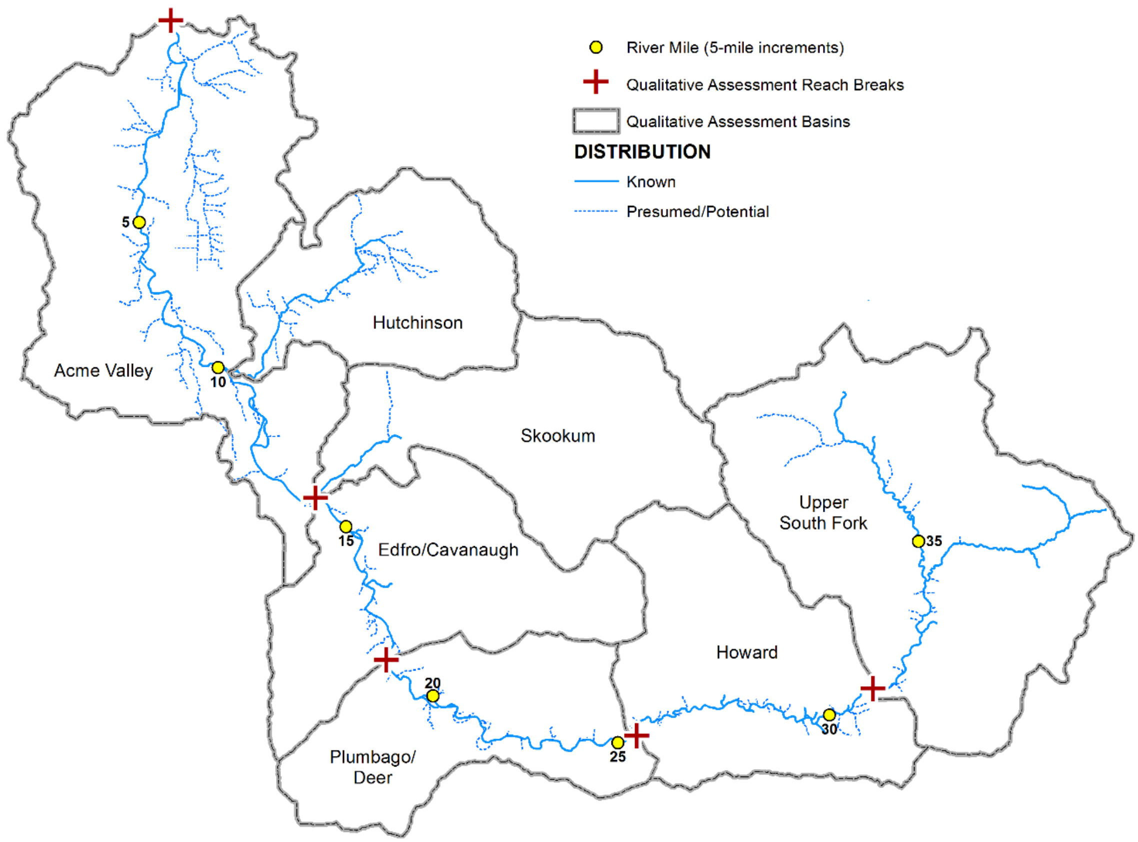


**Figure 5-26. Bull Trout Distribution in the South Fork Watershed (SSHIAP 2004).**

The native char that utilize the mainstem South Fork are considered bull trout, and primarily anadromous in nature, although fluvial bull trout likely also occur in the Upper South Fork. Bull trout in the lower South Fork are considered anadromous and highly migratory. Bull trout are repeat spawners, and are long-lived fish. They normally reach sexual maturity in 4-7 years and can live more than 12 years (USFWS 2004). Tributary spawners rear for one to four years before migrating to lakes (adfluvial life history), to rivers (fluvial life history) or saltwater (anadromous life history). After smolting in spring (often as two year olds), bull trout forage in nearshore areas over the summer, then return to freshwater as sexually immature subadults to forage and overwinter. In general, Puget Sound anadromous bull trout outmigrate to sea again the following late winter to forage, then begin adult migrations to their natal spawning areas, which are usually the coldest streams. They spawn in the fall on falling stream temperatures, and generally when temperatures fall below 9 °C (various authors cited in USFWS 2004). They can spawn annually or every other year, and the annual migrations to marine waters and back means river migration corridors are very important. Egg incubation is normally 100-145 days and emergence can surpass 200 days after egg deposition due to cool temperatures, and fry emergence is usually April or May (USFWS 2004). Bull trout are primarily found in streams below 15 °C and exhibit a patchy distribution, even in pristine habitats (USFWS 2004).

Eventually they can become large fish, and a native char (bull trout) of 28-30 inches was recorded in lower Wanlick Creek in 2002 (Ecotrust, unpublished data). Native char were also recorded in 2002 in Hutchinson Creek, upstream from the cascades at RM 0.8 (Ecotrust, unpublished data). Older juvenile native char were captured by minnow traps in lower Hutchinson Creek in November 2001, including two at the mouth (81mm, 89 mm fork length; Nooksack Natural Resources, unpublished data) and another slightly upstream (52mm; Naef 2002). Known bull trout spawning in the South Fork is located upstream of RM 25, and it is undetermined how far downstream bull trout spawn (USFWS 2004). Since temperatures elevate moving down-river, spawning is likely limited to cooler tributaries.

Early rearing is thought to primarily occur near spawning areas, with yearling and older juveniles also dispersing to rear in more downstream habitats. Rearing also occurs throughout the South Fork, at a minimum by juveniles prior to outmigration, and by foraging subadults. Older juvenile rearing also probably occurs to some extent throughout the South Fork, and certainly by subadults. On August 15, 2002 and August 16, 2002, snorkel surveys in the reach between Acme and Saxon recorded bull trout (Ecotrust and Nooksack Natural Resources, unpublished data), including one approximately 6-8 inches in length.

Subadult and adult bull trout also hold and forage through the mainstem South Fork. Adults would be expected to hold through the summer as they migrate to natal spawning grounds, where they spawn in the fall when water temperatures drop to below 9 °C (McCullough et al. 2001). After spawning, they migrate back downstream to overwinter and regain condition in mainstem areas. Subadult bull trout would be expected to forage in the lower mainstem reach from summer until the outmigration period the following spring. Subadult bull trout would be expected to forage in floodplain tributaries in the Acme Valley as well as within the mainstem South Fork. In the lower South Fork, a bull trout of likely subadult size was caught in lower Black Slough in November 2001 (Nooksack Natural Resources, unpublished data). Foraging subadult bull trout have wider distributions than other life stages, and these opportunistic feeders could be found in any streams accessible to anadromous fish of their size.

In summary, bull trout are highly migratory, and one or more life history phases use the mainstem South Fork at all times of the year (Figure 5-26). The mainstem is used for summer upstream migration and holding by anadromous adults, overwintering by adults post-spawning, upstream migration and rearing (foraging) by anadromous subadults after returning from estuary and nearshore areas in summer, subadult rearing (including overwintering) until the following spring, and rearing during downstream migrations by juveniles (at a minimum) prior to smolting. Lower Hutchinson Creek also has rearing by older juveniles, and other cooler tributaries almost certainly also do. Lower tributaries with cooler waters are likely temperature refuges for multiple life stages.

#### 5.2.5.2 Climate Change Vulnerability

Bull trout would be impacted by increased winter peak flows, loss of spring snowmelt that reduces discharge, increased summer temperatures, and decreased summer low flows (Figure 5-27). Adult and subadult upstream migration, subadult and adult holding, spawning, adult outmigration, incubation, and juvenile rearing life stages are vulnerable to increased winter peak flows. Lower spring discharges may impact upstream migration, holding, rearing, and outmigration. Increased summer temperatures and/or decreased summer low flows would impact all life stages; and is likely to impact anadromous bull trout and the Lower South Fork bull trout local population the most as their suitable habitat may decline.

The upper incipient lethal threshold for juvenile bull trout is 22-23 °C for a 7-day exposure; adult salmonids generally appear to have lethal tolerances 2-3 °C lower than juveniles (McCullough et al. 2001). Reach-averaged modeled temperatures for the critical conditions scenario (7Q10 flows, 90$^{th}$ percentile 7-day air temperature) under current conditions are 22.0, 21.4, 21.2, 20.2, and 18.9 °C for South Fork reaches 1-5, respectively. Assuming the 2080 medium emissions scenario, modeled critical conditions maximum temperatures are 26.4, 25.9, 26.2, 25.3, and 23.7 °C for reaches 1-5, which is above the lethal threshold in all reaches. Restoring the South Fork to natural conditions will be important for bull trout persistence in the South Fork, and for preserving the anadromous life history strategy. Restoring natural conditions is estimated to reduce critical condition maximum temperatures (2080 medium emissions scenario) to 20.8, 20.8, 20.4, 20.4, and 19.4 °C, below the lethal threshold for juveniles and near the threshold of adults, and less than current conditions. More normal conditions (7Q2 flows, 50th percentile 7-day air temperature) appear somewhat less dire. Modeled current maximum temperatures under normal conditions are 19.7, 19.1, 19.0, 18.3, and 17.8 °C for reaches 1 through 5, and 18.8, 18.8, 18.3, 18.6, 18.2 °C with restoration to the natural conditions scenario. Impacts of increased water temperatures will also extend beyond the low-flow period; average monthly temperatures in the lower South Fork are expected to increase year-round (Figure 5-28).

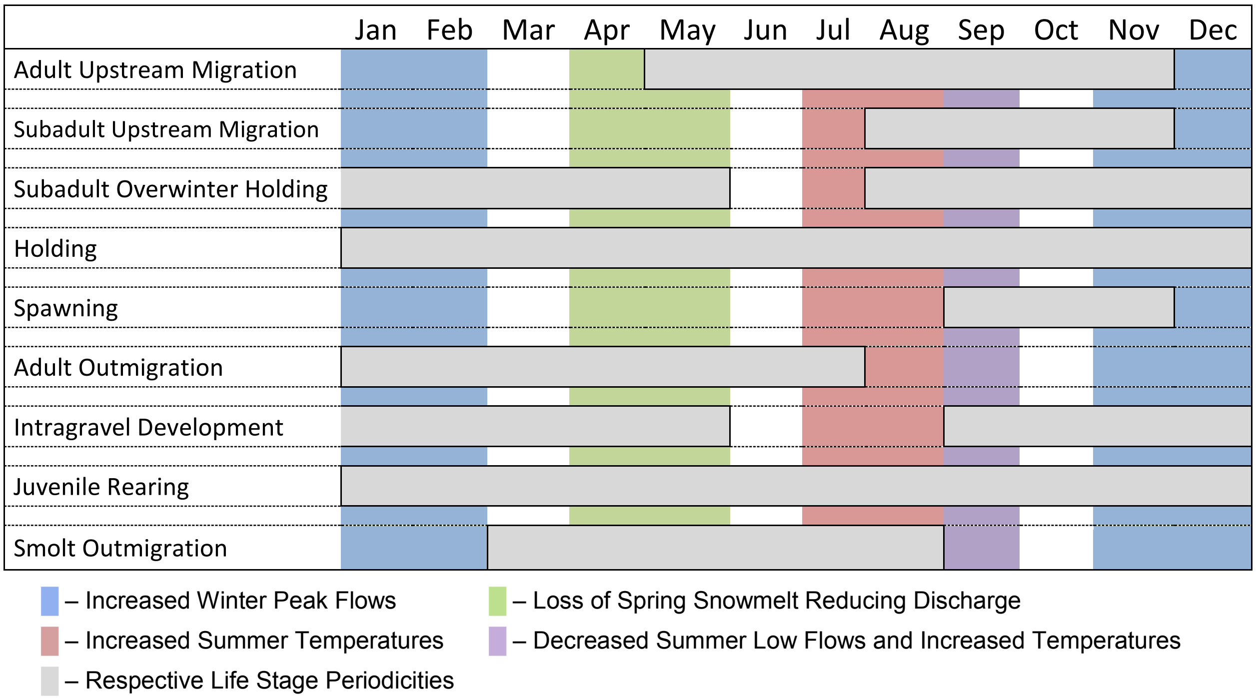


**Figure 5-27. Bull Trout Life Stage Periodicity in the South Fork and Vulnerability to Climate Change Impacts.**

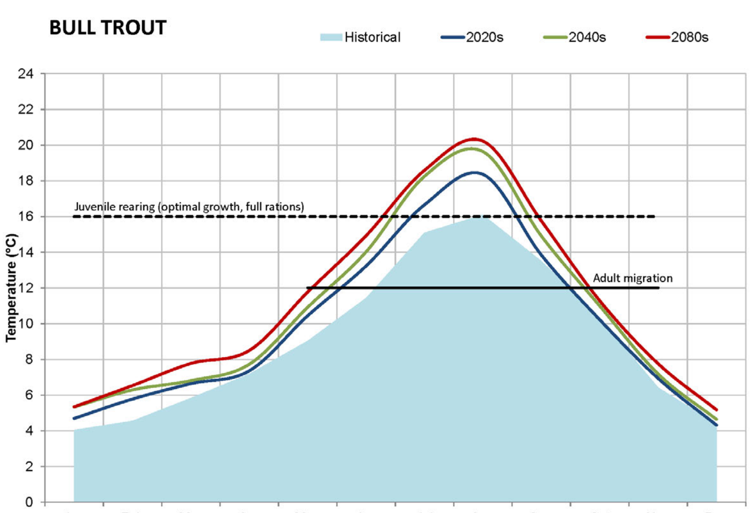


**Figure 5-28. Bull Trout Temperature Requirements and Periodicity by Life Stage, compared with South Fork Monthly Average Water Temperature at Potter Road (ccsm3_A1B medium impact scenario). Temperature Requirements as Reported in McCullough 2001; Note: Spawning and Incubation Stage Requirements not Shown as Spawning Occurs Higher in Watershed.**

#### 5.2.5.2.1 Migration

Adult anadromous bull trout migrate upstream toward their natal spawning areas in summer. Radio tagging from the Skokomish drainage found that when migration to the upper watershed occurred, they typically moved 2-3 km per day, and in the lower river fish may travel even faster (Kraemer 1994). That migration rate is similar to the average migration rates for Nooksack spring Chinook (Barclay 1980, Barclay 1981). Bull trout are seen incidental to South Fork spawn surveys and snorkel surveys for spring Chinook. As such, climate change effects on adult anadromous bull trout are anticipated to be similar to spring Chinook and summer-run steelhead, except that bull trout have more specific habitat requirements than most other salmonids (Rieman and McIntyre, as described in USFWS 2004). Peak upstream movement of bull trout has been found to coincide with water temperatures of 10-12 °C (McPhail and Murray 1979, reported in McCullough et al. 2001). Increased temperatures during migration could impact bull trout by direct lethality to adults and smolts, delays in migration, depletion of energy stores through heightened respiration, deformation of eggs and viability of gametes, and increased incidence of disease (McCullough et al. 2001). Availability of temperature refuges, especially for anadromous individuals, will be critical to successful migration to spawning grounds in the upper South Fork watershed. Factors that can influence bull trout ability to survive in warmer rivers include availability and proximity of cold-water patches (refugia), and food productivity (Myrick et al. 2002). Upstream migration may be delayed by low flows that affect passability at the partial RM 25 and RM 31 barriers. The specific discharge conditions that enable passage at these partial barriers is unknown, and a worst case scenario would be that passage is no longer possible. Fluvial bull trout migrations in the upper South Fork would likely be much less affected. Bull trout smolts have been recorded at the lower South Fork trap in April and May (Nooksack Natural Resources, unpublished data). Anadromous outmigrants have been caught in the lower Nooksack River smolt trap at Hovander Park from early April through late August (Lummi Nation, unpublished data 1994-2002). Outmigration may be delayed by lower spring flows and further increase exposure of juvenile, subadult, and adult life stages to higher temperatures in the South Fork.

#### 5.2.5.2.2 Holding

During the upstream migration phase, fish (including bull trout) hold during periods when they are not moving. If stream temperatures are elevated, they may occupy local thermal refugia if it exists, such as cooler tributaries or thermally stratified pools. As spawning grounds are approached, bull trout then stage in holding areas. Prior to spawning, adult bull trout stage in holding areas near spawning grounds, and these holding areas are often deep pools, long runs with cover, undercut banks, or log jams (Kraemer 1994). They can stay in the same general area, even the same pool, for several months. Sometimes adults are concentrated in a few holding areas, and many holding areas have groundwater upwelling. With dropping water temperatures adults migrate from these holding areas to the spawning areas. Bull trout are thus vulnerable to increased winter peak flows, decreased spring and summer/fall flows, and increased temperatures with climate change. Increased temperatures during summer, as well as year-round, would impact this life stage similarly to Chinook, resulting in increased mortality, increased stress that may reduce reproductive success and/or increase incidence of disease, or affect behavior, distribution, and timing. Increased fine sediment inputs leading to high turbidities may also stress this life stage. Anadromous bull trout migrate up and down the lower South Fork as often as twice annually, and these effects could affect them more than fluvial bull trout. Reduced summer discharge and increased temperatures could reduce available holding and staging habitat for adults, leading to increased competition for these areas. Subadult anadromous bull trout reenter freshwater later in summer than adults. They forage opportunistically, and being immature, do not migrate to natal headwater spawning areas. Thermal impacts to them are expected to be less than for holding adults.

#### 5.2.5.2.3 Spawning and Incubation

Bull trout spawning initiates as temperatures drop below 9 °C (McCullough et al. 2001). Increases in temperatures may delay spawning and reduce the time available to complete subsequent life stages (McCullough et al. 2001). This may reduce the available habitat that is suitable for successful spawning. Decreased fall flows may also reduce spawning habitat availability and result in spawning in lower flow portions of the channel, followed by increased exposure to redd loss due to increased winter peak flows.

Optimal incubation for bull trout eggs occurs at constant temperatures in the range of 2-6 °C; and increases in temperatures of even 2 °C can reduce egg survival and size at emergence (McCullough 2001). With increased temperatures, some suitable spawning areas are likely to no longer be suitable. Since bull trout often spawn in the coldest streams that are located high in watersheds, barriers such as waterfalls are likely to prevent colonization of new habitats. The result is likely to be a net loss of suitable spawning areas as lower portions warm beyond usability. Increased temperatures during incubation could also result in earlier emergence that may increase exposure to winter peak flows. Pratt (1992) indicates increases in fine sediment reduce bull trout survival to emergence, so increased fine sediment inputs resulting from climate change could also reduce survival to emergence.

#### 5.2.5.2.4 Juvenile Rearing

Maximum growth rate of juvenile bull trout at full rations occurs at 16 °C, although growth rate was maximized at 8-12 °C at 33 percent rations (McCullough et al. 2001). The probability of finding juvenile bull trout often declines dramatically in streams that exceed summer mean temperatures of 10-12 °C (as reported in Riemann and Isaak 2010). Juvenile bull trout are thought to generally smolt at age two, so they are exposed to summer and winter climate change effects multiple years before smolting. Projected average monthly temperatures in the lower South Fork with climate change would exceed the 16 °C threshold throughout summer and exceed the 12 °C threshold from late spring into fall. Increasing temperatures with climate change could cause direct lethality, suppressed growth, increased incidence of disease, or avoidance of certain habitats. Fish exclusion for Nooksack Indian Tribe instream LWD restoration projects in the South Fork near Hutchinson Creek in 2012 and 2014 did not encounter bull trout, while several yearling bull trout were encountered in relocation efforts for the 2014 North Fork Farmhouse project, where glacially influenced river temperatures were much lower. This suggests the summer temperatures in the South Fork are already affecting rearing bull trout distributions. Additional temperature increases are likely to further reduce availability of suitable rearing habitats.

Juvenile and adult bull trout frequently use side channels, stream margins, and pools with suitable cover (Sexauer and James 1997). Decreased spring and summer flows may limit access and/or availability of floodplain habitats that could provide important refuges from high temperatures. High temperatures may also impair smoltification. Changes in abundance of food sources with changes in temperature, sediment, and hydrologic regime may also affect rearing success and survival to adulthood. Bull trout are apex predators, and salmon eggs and juveniles are important freshwater food. Further decline in Nooksack salmonid abundances due to climate change is expected to reduce the available prey base for bull trout. This could affect juvenile growth rates, the ability of post spawning adults to recover of body condition, and growth for foraging subadults. Increases in fine sediments leading to high turbidities may reduce sight distance and feeding opportunities. High turbidity could also lead to avoidance of habitats and increase outmigration. Over the long term, climate change impacts in the South Fork may reduce rearing in the South Fork, increasing migration of juveniles to somewhat cooler rearing habitats in the lower Nooksack River, where competition for limited rearing habitats may be increased.

## 5.3 Evaluation Per Salmon Recovery Actions

Generally, actions for mitigating future climate change impacts on salmon include reducing the existing threats to their freshwater habitats caused by legacy land and water use activities that impair natural physical and biological processes. Reversing the legacy of land use impacts will likely require trade-offs with other land and water uses, such as agriculture and forestry, in the South Fork. With a greater demand for water during the low-flow period expected as a result of climate change and population growth, explicitly evaluating these tradeoffs is critical to recovering salmon. Due to small salmonid population sizes and their importance to regional recovery, the goal of this assessment is to ensure restoration actions address the current limiting factors, while considering the longer-term future threats such as increased land development and climate change. Evaluating the effectiveness of regulatory protections in the face of climate change is also a key component of this recovery strategy.

Table 5-7 summarizes the work conducted by Beechie et al. (2013, Table 3) and adapted for the South Fork. Building off this work, restoration actions, ability of each action to ameliorate climate change effects, and action priority are presented by South Fork reach (Table 5-8) and subbasin (Table 5-9). Action Priority integrates the potential to implement the action in the analysis unit, ability of the action to ameliorate climate impacts, and the time scale of benefit (Table 5-10). Description of applicable areas, current status, and recommendations for adaptation to address climate change impacts are presented by action type below. Descriptions of the five major reaches and their respective RMs are defined in Section 4 of this document.

**Table 5-7. Summary of Beechie et al. (2013) Adapted for this Report.[1]**

| Category | Common Techniques | Analogous South Fork Technique | Applicable Units | | Ameliorates Climate Change Effects? | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | **South Fork** | **South Fork Subbasins** | **Ameliorates Temperature Increase** | **Ameliorates Base Flow Decrease** | **Ameliorates Peak Flow Increase** | **Ameliorates Sediment Increase[2]** | **Increases Salmon Resilience** |
| Longitudinal connectivity (barrier removal) | Removal or breaching of dam | | | | ● | ● | ○ | | ● |
| | Barrier or culvert replacement/removal | Barrier or culvert replacement/removal | | Yes | ○ | ○ | ○ | ○ | ●[3] |
| | | Improve passage at natural barriers | Yes | Yes | ○ | ○ | ○ | ○ | ●[3] |
| Lateral connectivity (floodplain reconnection) | Levee removal | Hydromod removal/setback | Yes | | ● | ○ | ● | ● | ● |
| | Reconnection of floodplain features (e.g. channels, ponds) | | | | ● | ○ | ● | | ● |
| | Creation of new floodplain habitats | | | | ● | ○ | ● | | ● |
| Vertical connectivity (incised channel restoration) | Reintroduce beaver (dams increase sediment storage) | | | | ● | ● | ● | | ● |
| | Remove cattle (restored vegetation stores sediment) | | | | ● | ● | ● | | ○ |
| | Install grade controls | Log jams to reconnect floodplains | Yes | | ● | ● | ● | ● | ○ |
| Stream flow regimes | Restoration of natural flood regime | | | | ● | ● | ○ | | ◒ |
| | Reduce water withdrawals, restore summer baseflow | Reduce withdrawals | Yes | Yes | ● | ● | ○ | ○ | ○ |
| | | Restore floodplain wetlands | Yes | Yes | ●[4] | ● | ○ | ○ | ○ |
| | Reduce upland grazing | | | | ○ | ◒ | ◒ | | ○ |
| | Disconnect road drainage from streams | Disconnect road drainage from streams | | Yes | ○ | ○ | ● | ●[5] | ○ |
| | Natural drainage systems, retention ponds, other urban stormwater techniques | | | | ○ | ◒ | ● | | ○ |

| Category | Common Techniques | Analogous South Fork Technique | Applicable Units | | Ameliorates Climate Change Effects? | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | South Fork | South Fork Subbasins | Ameliorates Temperature Increase | Ameliorates Base Flow Decrease | Ameliorates Peak Flow Increase | Ameliorates Sediment Increase[2] | Increases Salmon Resilience |
| Erosion and sediment delivery | Road resurfacing | | | | ○ | ○ | ○ | | ○ |
| | Landslide hazard reduction (sidecast removal, fill removal) | Landslide hazard reduction (sidecast removal, fill removal) | | Yes | ○ | ○ | ○ | ●[5] | ○ |
| | Reduced cropland erosion (e.g. no-till seeding) | | | | ○ | ○ | ○ | | ○ |
| | Reduced grazing (e.g. fencing livestock away from streams) | | | | ◒ | ○ | ○ | | ○ |
| | | Reduce stream-adjacent sediment inputs (wood placement to reduce toe erosion) | Yes | | ○ | ○ | ○ | ○ | ○ |
| Riparian functions | Grazing removal, fencing, controlled grazing | | | | ● | ○ | ○ | | ○ |
| | Planting (trees, other vegetation) | Riparian treatments | Yes | Yes | ● | ○ | ○ | ○ | ○ |
| | Thinning or removal of understory | | Yes | Yes | ○ | ○ | ○ | ○ | ○ |
| | Remove non-native plants | | Yes | Yes | ◒ | ◒ | ○ | ○ | ○ |
| Instream rehabilitation | Re-meandering of straightened stream, channel realignment | | | | ◒ | ○ | ○ | | ◒ |
| | Addition of log structures, log jams | Placement of log jams, other wood | Yes | Yes | ◒ | ○ | ○ | ○ | ○ |
| | Boulder weirs and boulders | | | | ◒ | | | | |
| | Brush bundles, cover structures | | | | ○ | ○ | ○ | | ○ |
| | Gravel addition | | | | ○ | ○ | ○ | | ○ |

| Category | Common Techniques | Analogous South Fork Technique | Applicable Units | | Ameliorates Climate Change Effects? | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | **South Fork** | **South Fork Subbasins** | **Ameliorates Temperature Increase** | **Ameliorates Base Flow Decrease** | **Ameliorates Peak Flow Increase** | **Ameliorates Sediment Increase[2]** | **Increases Salmon Resilience** |
| Nutrient enrichment | Addition of organic and inorganic nutrients | | | | ○ | ○ | ○ | | ○ |

[1] Techniques and amelioration effects not cited individually are from Beechie et al. 2013.
[2] Beechie et al. did not evaluate potential for actions to ameliorate increases in sediment. Call is based on best professional judgment.
[3] Beechie et al. 2006, Waples et al. 2006
[4] Poole et al. 2008, Arrigoni et al. 2008
[5] Beechie et al. 2005

| Ability to Ameliorate Climate Change Effects | |
|---|---|
| ● | Yes |
| ○ | No |
| ◓ | Context-dependent |

**Table 5-8. Recommended Restoration Actions for South Fork Reaches (adapted from Beechie et al. 2013).**

| Category | Analogous South Fork Technique | Ameliorates Climate Change Effects? | | | | | Priority of Action (by Reach) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ameliorates Temperature Increase | Ameliorates Base Flow Decrease | Ameliorates Peak Flow Increase | Ameliorates Sediment Increase[1] | Increases Salmon Resilience | 1 | 2 | 3 | 4 | 5 |
| Longitudinal connectivity (barrier removal) | Improve passage at natural barriers | ○ | ○ | ○ | ○ | ● | N/A | N/A | Mod | Mod | N/A |
| Floodplain reconnection | Hydromodification removal/setback | ● | ○ | ● | ● | ● | High | Low | Low | Low | Low |
| | Log jams to reconnect floodplains | ● | ● | ● | ● | ○ | High | Low | Mod | Low | Low |
| Stream flow regimes | Reduce water withdrawals | ● | ● | ○ | ○ | ○ | High | Low | N/A | N/A | N/A |
| | Restore floodplain wetlands | ● | ● | | | ○ | High | Low | Mod | Low | Low |
| Erosion and dediment delivery | Reduce stream-adjacent sediment inputs (wood placement to reduce toe erosion) | ○ | ○ | ○ | ○ | ○ | Low | Low | Low | Low | Low |
| Riparian functions | Planting (trees, other vegetation) | ● | ○ | ○ | ○ | ○ | High | High | High | High | High |
| | Thinning or removal of understory | ○ | ○ | ○ | ○ | ○ | High | High | High | High | High |
| | Remove non-native plants | ◒ | ◒ | ○ | ○ | ○ | High | High | High | High | High |
| Instream rehabilitation | Placement of log jams, other wood | ◒ [2] | ○ | ○ | ○ | ○ | High | Low | High | Low | Low |

[1] Beechie et al. (2013) did not evaluate potential for actions to ameliorate increases in sediment. Call is based on best professional judgment.
[2] Instream restoration can ameliorate temperature increase by creating temperature refuges, increasing hyporheic exchange by encouraging bedform diversity, and narrowing active channel and increasing effective shade.

| Ability to Ameliorate Climate Change Effects | | Action Priority | |
|---|---|---|---|
| ● | Positive effect | (blue) | Low |
| ○ | No effect | (yellow) | Moderate (Mod) |
| ◒ | Context-dependent | (orange) | High |

**Table 5-9. Recommended Restoration Actions for South Fork Subbasins (adapted from Beechie et al. 2013)[1].**

| Category | Common Techniques | Analogous South Fork Techniques | Ameliorates Climate Change Effects? | | | | | Priority of Action in Subbasins | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ameliorates Temperature Increase | Ameliorates Base Flow Decrease | Ameliorates Peak Flow Increase | Ameliorates Sediment Increase | Increases Salmon Resilience | Acme | Hutchinson | Skookum | Edfro/ Cavanaugh | Plumbago/ Deer | Howard | Upper South Fork |
| Longitudinal connectivity | Barrier or culvert replacement/ | Barrier or culvert replacement/ | ○ | ○ | ○ | ○ | ●[2] | Mod | Mod | Low | Low | Low | Low | Low |
| | | Improve passage at natural barriers | ○ | ○ | ○ | ○ | ●[2] | Low | Low | Mod | Low | Low | Low | Low |
| Stream flow regimes | Reduce water withdrawals, restore summer baseflow | Reduce withdrawals | ● | ● | ○ | ○ | ○ | High | Low | Low | Low | Low | Low | Low |
| | | Restore floodplain wetlands | ●[3] | ● | ○ | ○ | ○ | High | Low[5] | Low[5] | Low[5] | Low[5] | Low[5] | Low[5] |
| | Disconnect road drainage from streams | Disconnect road drainage from streams | ○ | ○ | ● | ●[4] | | Low | Low | Low | Low | Low | Low | Low[6] |
| Erosion and sediment Delivery | Landslide hazard reduction (sidecast/ fill removal) | Landslide hazard reduction (sidecast/ fill removal) | ○ | ○ | ○ | ●[4] | ○ | Low[7] | Low[7] | Low[7] | Low[7] | Low[7] | Low[7] | Low[7] |
| Riparian functions | Planting (trees, other vegetation | Riparian treatments | ● | ○ | ○ | ○ | ○ | High | High | Mod | Mod | Mod | Mod | Mod |
| | Thinning or removal of understory | | ○ | ○ | ○ | ○ | ○ | | | | | | | |
| | Remove non-native plants | | ◒ | ◒ | ○ | ○ | ○ | | | | | | | |
| Instream rehabilitation | Addition of log structures, log jams | Placement of log jams, other wood | ◒ | ○ | ○ | ○ | ○ | Mod/ low[8] | Mod/ low[8] | Mod/ low[8] | Mod/ low[8] | Mod/ low[8] | Mod/ low[8] | Mod/ low[8] |

[1] Techniques and amelioration effects not cited individually are from Beechie et al. 2013.
[2] Beechie et al. 2006, Waples et al. 2006
[3] Poole et al. 2008, Arrigoni et al. 2008
[4] Beechie et al. 2005
[5] Prioritization deferred pending analysis of beaver restoration potential.
[6] Upper South Fork subbasin is federal ownership. USFS is underfunded for road maintenance, so more information is needed to evaluate priority.
[7] Prioritization deferred pending development of sediment budget to quantify relative contributions of sediment sources.
[8] Moderate priority applies to cold-water tributaries (temperatures >2°C cooler than South Fork.

| Ability to Ameliorate Climate Change Effects | | Action Priority | |
|---|---|---|---|
| ● | Yes | (blue) | Low |
| ○ | No | (yellow) | Moderate (Mod) |
| ◒ | Context-dependent | (orange) | High |

**Table 5-10. Typical Response Time, Duration, Variability of Success and Probability of Success for Common Restoration Techniques (Beechie et al. 2003, modified from Roni et al. 2002).**

| Restoration type[a] | Specific action | Years to achieve response | Longevity of action (years) | Variability of success among projects | Probability of success |
|---|---|---|---|---|---|
| *Reconnect habitats* | Culverts | 1-5 | 10-50+ | Low | High |
| | Off channel | 1-5 | 10-50+ | Low | High |
| | Estuarine | 5-20 | 10-50+ | Moderate | Moderate to high |
| | Instream flows | 1-5 | 10-50+ | Low | High |
| *Roads and land use* | Road removal | 5-20 | Decades to centuries | Low | High |
| | Road alteration | 5-20 | Decades to centuries | Moderate | Moderate to high |
| | Change in land use | 10+ | Decades to centuries | Unknown | Unknown |
| *Riparian restoration* | Fencing | 5-20 | 10-50+ | Low | Moderate to high |
| | Riparian replanting | 5-20 | 10-50+ | Low | Moderate to high |
| | Rest-rotation or grazing strategy | 5-20 | 10-50+ | Moderate | Moderate |
| | Conifer conversion | 10-100 | Centuries | High | Low to moderate |
| *Instream habitat restoration* | Artificial log structures | 1-5 | 5-20 | High | Low to high[b] |
| | Natural LWD placement | 1-5 | 5-20 | High | Low to high[b] |
| | Artificial log jams | 1-5 | 10-50+ | Moderate | Low to high[b] |
| | Boulder placement | 1-5 | 5-20 | Moderate | Low to high[b] |
| | Gabions | 1-5 | 10 | Moderate | Low to high[b] |
| *Nutrient enrichment* | Carcass placement | 1-5 | Unknown | Low | Moderate to high |
| | Stream fertilization | 1-5 | Unknown | Moderate | Moderate to high |
| *Habitat creation* | Off channel | 1-5 | 10-50+ | High | Moderate |
| | Estuarine | 5-10 | 10-50+ | High | Low |
| | Instream | See various instream restoration techniques above | | | |

[a] The first three categories of restoration (reconnect isolated habitats, roads and land use, and riparian restoration) are considered process-based or passive restoration, the last three (instream, nutrient enrichment, and habitat creation) are considered enhancement or active restoration.
[b] Depends on species and project design.

## 5.3.1 Restoration and Protection Actions

There is considerable overlap between the restoration and protection actions identified and prioritized above and those that are being implemented to address legacy impacts in the South Fork watershed (WRIA 1 SRB 2016). The following section describes the relevant restoration and protection actions by category, including discussion of applicable reaches/subbasins, current status, action priority,[19] and specific recommendations for adaptation to address climate change impacts. Many of these actions, especially floodplain reconnection and instream rehabilitation, are already high priority actions for salmon recovery in WRIA 1, in which case recommendations focus on increasing the pace and expanding the scale of implementation by explicitly addressing barriers to implementation. In other cases, this assessment has led to identifying new actions (e.g. improve passage at natural barriers) or elevating the priority of existing actions relative to current salmon recovery priorities (e.g. riparian restoration). Where such discrepancies with current salmon recovery actions and priorities exist, consideration of updates to salmon recovery action priorities is recommended. Adapting to climate change will require substantial planning and assessment, agency consultation, landowner cooperation, stakeholder involvement, funding, and political support.

### 5.3.1.1 Longitudinal Connectivity

Restoring longitudinal connectivity is intended to reestablish salmon migration to diverse habitats that have been lost through construction of artificial barriers. Reconnection often also restores downstream transport of sediment, wood or other organic matter, and flow. Through this assessment, we have expanded the action to improving passage at natural fish passage barriers that prevent migration into the upper portions of the South Fork watershed, where summer stream temperatures are considerably cooler than the lower elevation portion of the watershed. Actions also address barriers in tributaries and floodplain channels that limit access to crucial rearing habitat and overall lower stream temperatures. Reconnecting habitat is considered to have immediate and long-lasting benefits and a high probability of success (Table 5-10).

#### 5.3.1.1.1 Status

Two partial natural barriers exists in the South Fork at RM 25 and RM 31 that may preclude access to upstream cooler water habitat in Reaches 4 and 5, respectively. Reach 4 contains approximately 6 miles of historically used mainstem habitat, while Reach 5 contains approximately 7 miles of mainstem habitat. Together this represents approximately 35 percent of the mainstem habitat. Modeling of the stream temperature for the 7Q10 baseline and current riparian conditions show that these are the coolest reaches of the mainstem South Fork (Figure 5-13). Reach 5 (upstream of RM 31) is the only reach with a modeled temperature less than 20°C under current 7Q10 flow conditions. Both of these barriers are related to boulder cascades associated with rock falls in bedrock canyons, and both are considered to be flow-dependent and species-dependent for passage. Historically, Reach 4 (between the barriers at RM 25 and 31) was heavily used for early Chinook spawning, but recent surveys have shown no spawning in this six-mile reach. It is unclear if this change in use is related to changes in the physical characteristics of the RM 25 barrier, chinook population abundance, or habitat conditions in reach 4. Natural barriers also are present in Skookum Creek at RM 0.4 (partial) and RM 2.4 (complete), and in Hutchinson Creek at RM 0.7 (partial). While tributary temperatures were not modeled as part of the TMDL, Skookum and Hutchinson creeks are important cooler water tributaries to the South Fork and thought to be large enough to support chinook salmon upstream of the natural barriers.

[19] As noted above, action priority, or priority of an action in the context of climate change, integrates: (1) the potential to implement the action in the analysis unit; (2) ability of the action to ameliorate climate impacts; and (3) the time scale of benefit.

Seventy-three full or partial fish passage barriers have been identified on road crossings within the Acme Valley and Hutchinson subbasins (WDFW 2014). Of these 73 barriers, 40 percent are owned by Whatcom County, 40 percent are on private roads, 18 percent are state-owned forest roads or highways, and 2 percent have an unknown ownership. Several of these barriers have been made fish-passable as a result of regulatory and voluntary programs, such as road maintenance (RMAP) requirements for forest landowners or the Family Forest Fish Passage Program, focused on improving fish passage. All barriers associated with industrial and state forest land are expected to be addressed by 2016. Washington State Department of Transportation (WSDOT) barriers associated with State Route 9 are expected to be addressed by 2030. Private and County-owned barriers have an unknown schedule and rely on uncertain funding sources. Restoring fish passage has been required by WDFW when barrier culverts have been replaced. Of these 73 barriers, there are four that lie in close proximity to the mainstem South Fork channel and likely inhibit floodplain use by rearing juvenile chinook. It is likely that with increasing winter peak flow, floodplain refuge areas will gain importance for overwintering juvenile salmon as they seek lower velocity and less turbid water.

##### 5.3.1.1.2 Priority

While restoring passage at chinook obstructions is a high priority in the greater Nooksack watershed, longitudinal reconnection is not currently a high salmon recovery priority in the South Fork. The man-made barriers that exist in the watershed do not block chinook from their spawning areas and few likely impact juvenile chinook rearing areas. Providing passage at natural barriers was not considered as a strategy in the South Fork when the WRIA 1 Salmon Recovery Plan was developed. Because restoring fish passage can be an important strategy in increasing resilience of salmon populations to climate change impacts (Beechie et al. 2013; Table 5-7 and Table 5-8), priority of this action in the context of climate change is at the natural barriers at RM 25 and 31 (upstream extent of reaches 3 and 4), for the natural barriers in the Skookum watershed, and for the man-made barriers in the Acme Valley and Hutchinson subbasins. Eighty percent of the man-made barriers in these sub-basins are private or Whatcom County ownership and not scheduled to be repaired under the RMAP program or by WSDOT, so the timeframe for repair is uncertain. There are few man-made fish passage barriers in the other sub-basins, so restoring longitudinal connectivity in the Edfro/Cavanaugh, Plumbago/Deer, Howard, and Upper South Fork subbasins is still considered a lower priority.

##### 5.3.1.1.3 Recommendations

- Evaluate feasibility of improving passage at natural barriers (South Fork at RM 25 and RM 31, Skookum Creek at RM 0.5 and 2.4) – and implement feasible projects. Improving passage at natural barriers will require assessment of current passability and other factors that may limit chinook use, as well as the feasibility of improving and maintaining access over the long term. Feasibility assessment should also evaluate possible negative impacts to viability and persistence of salmonid populations that currently use the upper watershed, which may require stream surveys to improve understanding of the distribution of various salmonid populations relative to natural barriers. For example, the RM 25 barrier on the South Fork effectively segregates winter-run and summer-run steelhead populations, and improving passage there may increase introgression between the two populations. This action will need to be developed by the fisheries co-managers, – Nooksack Indian Tribe, WDFW and Lummi Nation – in coordination with landowners. Funding will need to be sought to complete the analysis of the passage barriers, assess the population response and design the project.
- Increase use of cooler upstream habitats through release of hatchery-origin South Fork chinook smolts to such habitats. Release of hatchery chinook smolts should be conducted in coordination with assessment of chinook passability and may be especially warranted where passage at natural barriers is improved to accelerate colonization. Any such release strategy would need to be developed and agreed to by the fisheries co-managers. Additional funding would be required to

identify release sites and implement the strategy. Access to the South Fork and upper Skookum Creek is limited and likely would require coordination with land managers in the upper South Fork watershed.

- Prioritize barrier replacement in cool-water tributaries to the South Fork that could function as cold-water refuge habitat. Whatcom County is the responsible agency for approximately 40 percent of barriers in the South Fork that are associated with county roads. Since this is not currently a high priority for our existing salmon recovery funding sources, developing partnerships to bring in additional funding will be necessary to address these barriers. Private barriers can be addressed through several incentive programs, and public-private partnerships between the program sponsors and landowners will need to be developed to address these barriers.

#### 5.3.1.2 Floodplain Reconnection

Floodplain reconnection addresses both vertical and lateral floodplain connectivity. Vertical connectivity is focused on reversing the historic trend of floodplain incision, and lateral reconnection addresses bank hardening, levees and other infrastructure that limit channel migration and reduce floodplain inundation. Floodplain reconnection can restore river-floodplain dynamics that create diverse habitats and/or restore fish access to floodplain habitats. Reconnecting floodplains (including restoring vertical connectivity) can help ameliorate increased peak flows by increasing flood storage and reducing flood peaks and ameliorate the effects of increased temperature and decreased base flow by increasing the length of hyporheic flow paths and restoring floodplain aquifer storage (Beechie et al. 2013). QUAL2Kw modeling indicates that enhanced hyporheic exchange in the South Fork mainstem lowers critical condition stream temperatures (Table 5-2), although effects of restoring meander-scale hyporheic exchange were not modeled. The action can also potentially ameliorate increased sediment by allowing fines to settle in floodplain areas, thereby reducing sediment load in the main channel. These benefits may increase resilience of salmon populations to climate change impacts (Beechie et al. 2013, Table 5-9). Actions include reconnection or creation of side channels, removal or setback of levees, beaver reintroduction, and remeandering straightened channels to store flood water and reduce flood peaks or create refuges from high velocity and warm summer water temperatures. Floodplain and off-channel habitat reconnection is considered to have immediate and long-lasting benefits and a high probability of success (Table 5-10).

##### 5.3.1.2.1 Status

The upper South Fork (upstream of Reach 1) has a long history of channel downcutting and floodplain formation in the post-glacial period, as the channel has eroded through glacial fill over the last several thousand years. Abandoned fluvial terraces stair step the valley walls in the upper reaches of the South Fork, indicating periods of floodplain formation and abandonment. Much of this eroded material was transported downstream to the Acme Valley (reach 1) and deposited in the lower gradient, unconfined portion of the valley, creating deep alluvial deposits in the valley. Descriptions of the valley from the early historic period indicate that the floodplain was well-connected and accessed every several years by floodwater. An extensive system of wetlands, small channels and ponds occupied the valley floor in Reach 1, including a large open water wetland in the Black Slough area. Collins and Sheikh (2004) estimated 622 hectares (approximately 1,533 acres) of palustrine wetland in Reach 1 in the 1880s, which was reduced to 359 ha (890 acres) by 1998. The authors also noted the impact of floodplain drainage on tributary channels, finding that 22 percent of floodplain channel length in Reach 1 was ditched by 1998.

The floodplain changes identified by Collins and Sheikh (2004) were also noted within the active channel area. Between the 1880s and 1998, the authors found a decrease in forested islands in Reach 1 of the South Fork from approximately an island every 1.7 miles to an island every 12.4 miles of channel length. The loss of side channel associated with these islands constituted a major change in floodplain habitat. The authors found that this loss of secondary channel length was compounded by a shortening of the main channel length and a loss of sinuousity. Several of the historic changes in the channel were not reflected in the QUAL2Kw modeling. These include the loss of channel sinuousity that likely increased the length of hyporheic flow paths and improved shading, loss of stable side channels that likely would have been narrower and better shaded, and loss of flow impedance and channel roughness from extensive accumulations of wood in the channel. It is likely that these effects would have further reduced stream temperature in the South Fork, but it is difficult to estimate the magnitude of the impact.

The past land use practices, such as vegetation clearing, channel straightening, bank armoring, and wood removal have also led to channel incision and floodplain abandonment in the reaches that once were well-connected to the floodplain. For example, modeling of the 100-year flood in the upper portions of reach 1 shows that floodwater no longer accesses the majority of the mapped 100-year floodplain, essentially reducing the 100-year floodplain width from over 6000 feet to less than 2000 feet. This has allowed for continued encroachment into the historic floodplain and created challenges for river management to maintain the channel in its current degraded state.

There are approximately 47,750 feet (9 miles) of bank armoring along the mainstem channel in reach 1. Much of this lies at the outer extent of the historic (1859-2009) migration zone (HMZ), approximately 310 acres (19 percent) of the HMZ has been isolated from the current channel. The 100-year erosion hazard area, which lies beyond the historic area and represents the area that the channel could occupy given its past migration over the last 100 years, has been reduced by approximately 2,750 acres (52 percent) due to bank protection and infrastructure in the floodplain. Flood control levees are not common in the South Fork; however several structures, such as the railroad embankment, the City of Bellingham pipeline crossing, several county roads and Highway 9, all act as levees at certain flow levels.

While opportunity to set back hardening is strongly constrained by lack of willing landowners, there has been limited bank hardening removal, setback, or replacement with wood in Reach 1 implemented as a component of habitat restoration projects conducted by the Lummi Nation, Nooksack Indian Tribe and Whatcom County, including the Lower Hutchinson Creek (2006), Acme (2010), Downstream of Hutchinson Phase 2 projects (2012-2015), Todd/Sygitowicz (2008-2010), Van Zandt (2010) and Hardscrabble (2012) projects. Project designs in the portions of the watershed upstream of Reach 1 are increasingly incorporating the objective of restoring floodplain connectivity by promoting aggradation, including Lummi's Larson Reach Restoration project.

To address the lack of landowner willingness, floodplain acquisition has been a high priority for salmon recovery in WRIA 1. To date, approximately 950 acres of floodplain in Reach 1 have been acquired, most located in the upstream portion of the reach between Acme and the Saxon Bridge. The acquisition has been led by the Whatcom Land Trust and Whatcom County with funding from both salmon recovery and flood hazard reduction sources. Acquisition to date has prioritized properties that are adjacent to the mainstem of the South Fork that can facilitate instream and riparian restoration, in addition to allowing improved floodplain connectivity. This action will continue to be a high salmon recovery priority for the watershed.

##### 5.3.1.2.2 Priority

Floodplain reconnection by addressing hydromodifications and infrastructure is currently a high WRIA 1 salmon recovery priority and vertical reconnection through placement of log jams is a moderate priority, although lack of landowner willingness has constrained both the scale and pace of implementation. The analysis conducted as a part of the climate change pilot project has emphasized the importance of this action to address the expected changes in flow, temperature and sediment. The analysis indicates that a transition from opportunistically addressing bank armoring at the project site scale to a more focused effort on broader floodplain reconnection is needed. The pace of implementation of habitat restoration projects that treat impaired floodplain processes will also need to be accelerated to address the expected impacts of climate change.

Reconnecting the South Fork to its floodplain ranges from moderate to high priority in the context of climate change, depending on the type of action and reach. Floodplain reconnection activities would be focused in naturally unconfined reaches of the South Fork that have a floodplain that is inaccessible to the river. These areas generally lie in Reach 1 (lower 14.3 miles) and the unconfined sections of Reach 3 (Core Chinook Spawning). To ameliorate effects of climate change, priority of this action is high in reach 1, moderate in reach 3, and low elsewhere in the South Fork. Vertical connectivity has been identified as a high and moderate priority in reaches 1 and 3, respectively, and lateral connectivity has been identified as a high priority in reach 1. The focus in reach 1 is on continued land acquisition to facilitate restoration and setting back or removing infrastructure that disconnects the floodplain, whereas reconnecting floodplains in reach 3 is focused on placing wood to promote aggradation.

These priorities are generally consistent with current salmon recovery priorities. Setting back or removing bank hardening is currently a high salmon recovery priority in reach 1 from the mouth to RM 10.9 and a moderate priority in reach 1 from the Saxon Road Bridge to Skookum Creek (RM 12.8-14.3). Lowering artificial levees to native bank/floodplain elevations is a high (RM 7.2-8.6) or moderate (RM 0-1.8, 5.1-7.2, 8.6-10.9) salmon recovery priority in reach 1. Relocating river-adjacent infrastructure outside the 100-year erosion hazard area is a high (RM 7.2-8.6) or moderate (RM 0-7.2, 8.6-14.3) salmon recovery priority in reach 1. General floodplain reconnection is a moderate salmon recovery priority in parts of reaches 1 (RM 0-1.8, 9.6-12.8) and 3 (22-25.4), and a high salmon recovery priority in other parts of reach 3 (RM 20.6-22). Acquisition of properties necessary to facilitate restoration, including floodplain reconnection, is a high priority through most of Reach 1 (to 12.8) and moderate upstream to RM 31, where opportunities are more limited.

##### 5.3.1.2.3 Recommendations

- Continue to develop and implement restoration project designs that reconnect floodplains (setback/remove infrastructure, reconnect floodplain channels and promote aggradation) to the extent feasible given landowner willingness. This is already a high salmon recovery priority. Restoration project implementation in the South Fork has been conducted by a variety of agencies including the Nooksack Indian Tribe, Lummi Nation, Whatcom County and Whatcom Conservation District. These projects often provide an immediate and long-lasting benefit to salmon recovery.
- Increase the pace of broader-scale floodplain reconnection projects by:
  - Increasing opportunity to restore floodplain connectivity for channel migration and flood routing and storage by acquiring conservation easements or fee simple title to property in the floodplain or otherwise working with existing landowners to increase stewardship. In addition, work with land owners and develop plans that facilitate floodplain reconnection on specific parcels. Given considerable interest in maintaining the existing land base in agricultural production, exchanging river-adjacent land for property further from the river may prove the most feasible approach in the long term. This action is currently a high salmon recovery priority, and WRIA 1 has committed a substantial portion of its salmon recovery funding to acquisition projects. The Whatcom Land Trust has taken the lead in acquiring floodplain properties along the South Fork.
  - Integrate floodplain restoration with flood risk reduction via programs like Floodplains by Design and regulatory updates, such as the comprehensive flood hazard management plan. This action would be led by Whatcom County Public Works.
  - Increase public support for floodplain reconnection by developing a watershed outreach program and conservation plan for the South Fork floodplain. This is a planning process that is being led by the Nooksack Indian Tribe in coordination with other local agencies and

landowner representatives. See also recommendation to "develop a watershed management/conservation plan" under section 5.3.2.1 below.

  - Procure necessary funding to implement large floodplain reconnection projects where landowner willingness allows, such as through Floodplains by Design or Salmon Recovery Funding Board. Developing broad-scale floodplain restoration projects will require a long timeframe and will likely be implemented incrementally as properties become available.

- Work with infrastructure owners to develop plans to set back infrastructure (railroads, roads, pipelines, bridges/bridge footings) in the floodplain to the extent possible, especially infrastructure that currently function as levees and/or requires bank hardening but also that which may be threatened under climate change scenarios. Realistically, such relocation will be implemented incrementally over the long-term, as structures are maintained and/or replaced.
- Incorporate climate change scenarios (i.e., expected increases in magnitude of 100-year flood), changing land use regulations and restoration plans into comprehensive flood hazard management planning, channel migration zone delineation, and shoreline management program and National Flood Insurance Program implementation. Whatcom County River and Flood will continue to integrate fish habitat and floodplain function into the flood hazard reduction management planning process. Given expected increases in sediment load, wood recruitment and peak flows, active channels and floodplains may widen.

### 5.3.1.3 Restoring Stream Flow Regimes

Restoring stream flow regimes entails restoring the river to its natural flow conditions by reducing water withdrawals, road or stormwater drainage input, or upland grazing (Beechie et al. 2013). The presence of impermeable surfaces causes greater peak flood flows while decreasing infiltration potential and water storage in soils. This in turn causes lower summer baseflows without the input of cooler groundwater that can potentially ameliorate high summer stream temperatures.

The Instream Resource Protection Program (IRPP) established closures or flow regulation for the South Fork in 1986. Since then, optimal instream flow levels for fish were estimated using best available science through the WRIA 1 Watershed Management Project. Efforts to establish new instream flow levels, however, have been unsuccessful to date. Currently, the South Fork does not meet the existing IRPP minimum instream flow requirement (300 cfs) during the summer low-flow period. Establishing new instream flows for WRIA 1 is currently a high priority in WRIA 1 and is one of the key near-term (10-year) actions in the *WRIA 1 Salmonid Recovery Plan* (WRIA 1 Salmon Recovery Board 2005).

#### 5.3.1.3.1 Status

There are currently 2,638 acre feet per year (860 million gallons per year) represented by water right certificates and claims in the South Fork. Estimates of water use indicate that agricultural uses dominate in the South Fork watershed. As of 2001, there were approximately 800 irrigated acres and 686 total million gallons used annually—480 million gallons of groundwater and 206 million gallons of surface water (WRIA 1 2005). Agricultural water use is highest between June and September, typically peaking in July and August, when flow is the lowest in the river. Changes in agricultural crops in the valley can change the amount of water use. Recent changes from silage crops and hybrid poplars to evergreen trees and blueberries have likely changed the amount of water withdrawn for irrigation. Domestic and commercial water uses are relatively low in the South Fork watershed, using an estimated 42 million gallons per year (WRIA 1 2005).

The U.S. Geological Survey (USGS) recently completed a preliminary study of groundwater-surface water interactions affecting streamflow and temperature in the South Fork (Gendaszek 2014). A hydrogeological framework was developed from geologic mapping and well data, and groundwater-surface interactions were investigated by conducting seepage runs, monitoring South Fork water surface elevations relative to groundwater-levels in river-adjacent wetlands, and deploying a fiber-optic distributed temperature sensor cable in several reaches of the South Fork. The study reported the occurrence and location of discrete cold-water anomalies with low diurnal temperature variability in the South Fork active channel that may function as temperature refuges, and also found that some (but not all) river-adjacent wetlands are dynamically linked to the South Fork. Future work identified include development of a groundwater-flow model coupled with a watershed model that can evaluate the effects of current and future land use and restoration scenarios.

Another source of stream flow alteration is the impact of land use on the timing of run-off. Floodplain diking and drainage, roads, and changes in land cover can all effect the timing and amount of run-off. On private and state forest lands, the Forest Practice Rules for Washington State require forest landowners to develop a road maintenance and abandonment plan (RMAP) and have all forest roads and railroad grades used for forest practices since 1974, be brought up to current road standards by 2016 (or 2021 if landowners were granted an extension) or be officially abandoned. Across the Nooksack watershed, private and state timber owners have brought 90 percent of their forest roads up to current standard. The remaining road length is to be completed by 2021, with the highest priority[20] watersheds either already completed or scheduled for completing early in the extension period. The RMAP process leaves a substantial length of “orphaned” road that has not been used since 1974 on the landscape that forest landowners are not legally required to maintain or abandon. While some orphaned roads or road segments do get addressed when re-activated and a small percentage have been voluntarily abandoned, orphaned roads have the potential to affect the hydrologic regime of the South Fork by pirating streams, or extending the channel network through interception of shallow groundwater by road ditches.

Forest road maintenance on federal lands is severely underfunded, and the Mt. Baker-Snoqualmie National Forest (Forest) is conducting a Minimum Roads Analysis to identify road segments that can be decommissioned so that the limited maintenance funding can be used to keep roads up to standard. The analysis was completed in 2015, and the Forest is currently evaluating alternatives.

Agricultural drainage and wetland conversion, as described in Section 5.3.1.2, have also likely had an impact on the timing and amount of stream flow. The distribution and severity of the impacts are currently unknown, so the cumulative impact of land use on streamflow is currently unknown.

##### 5.3.1.3.2 Priority

Water withdrawals and degraded floodplain wetlands are largely associated with agricultural and rural residential development in Reach 1 of the South Fork. The forest road network is distributed throughout all of the South Fork subbasins. Actions that address low summer baseflow in the South Fork are not currently prioritized for salmon recovery voluntary restoration funding. The *WRIA 1 Salmonid Recovery Plan* explicitly defers establishment and management of instream flows to the WRIA 1 Watershed Management Project coordinated by an integrated decision-making structure composed of representatives from Nooksack Indian Tribe, Lummi Nation, WDFW, Public Utility District No. 1 of Whatcom County, City of Bellingham, Whatcom County, and the smaller cities of WRIA 1. Restoring floodplain wetlands in the South Fork to support temperature and baseflow maintenance functions was identified as a strategy during South Fork restoration planning (Soicher et al. 2006). Flow restoration is not currently a priority for Salmon Recovery Funding Board (SFRB) and Puget Sound Acquisition and Restoration (PSAR) funding in WRIA 1. This action can ameliorate the effects of temperature increases and baseflow decreases (Beechie et al. 2013). Sensitivity analysis conducted as part of the quantitative assessment indicates a decrease of 0.025 °C per percent increase in headwater and tributary flow (Butcher et al.

[20] Forest landowners are required to prioritize RMAP work using a “worst first” approach.

2016). The climate change priority of this action is high in reach 1, low in reaches 2 through 5, moderate in Acme Valley subbasin, and low in the remaining subbasins.

#### 5.3.1.3.3 Recommendations

- Quantify tribal instream flow treaty rights for the South Fork (in conformance with the WRIA 1 Instream Flow Selection and Adoption Plan or alternative settlement approach) and implement measures to meet those flows. Evaluate impacts of climate change on hydrology of the South Fork, including change in the frequencies of recommended instream flows. This will need to be implemented through negotiations among water users, Department of Ecology, Tribes, and other stakeholders coordinated through the integrated decision-making structure for salmon recovery, watershed management and ecosystem recovery in WRIA 1.
- Enforce water rights and incentivize water conservation in the lower South Fork valley to the extent possible (e.g., water banking). This action is the on-going responsibility of the Department of Ecology.
- Develop a groundwater-flow model coupled with a watershed model for the South Fork basin to evaluate future development/restoration scenarios to inform land use decisions and identify and prioritize floodplain wetland restoration projects. This high priority action would likely be led by the Nooksack Indian Tribe and would be an important step in identifying projects that could help address impacts to stream flow. Funding for this action is not currently available and will need to be secured.
- Develop a watershed conservation plan that will work with floodplain land owners and managers to modify land use practices, such as land conversion and drainage, to reduce impacts on flow regimes. The planning effort would also include working with the USFS to assess, prioritize, and address forest road drainage deficiencies and improve road maintenance on federal lands, and assessing the potential for state and private orphaned roads to affect hydrologic regime and prioritize and implement orphaned road abandonment projects. This action was identified as an important planning step based on the findings of the qualitative assessment. The plan will help lay the groundwork for addressing land use impacts that exacerbate the impacts of climate change. The Nooksack Indian Tribe is taking the lead on the planning process, with collaboration from a variety of local agencies, landowners and non-profit groups. See also recommendation to "develop a watershed management/conservation plan" under section 5.3.2.1 below.
- Assess feasibility of and implement floodplain wetlands restoration projects to improve stream temperature and support base flows in the South Fork; potential actions include: removing drainage tiles, filling drainage ditches, re-establishing direct connect of tributaries to the river, reforesting historically forested wetlands, revegetating scrub and herbaceous wetlands, and/or introducing beaver. While this action was not identified as a high priority in the habitat restoration plan, it is considered a high priority for addressing the impacts of climate change on flow. A variety of groups are working to preserve and restore wetlands in the South Fork watershed.

### 5.3.1.4 Reducing Erosion and Sediment Delivery

With increased extreme precipitation events and subsequent increased peak flows projected for the region with climate change, erosion and sediment flux will also likely increase. Large amounts of sediment in a river system can have multiple adverse effects on aquatic habitat that can include widening and/or incision of the channel and aggradation of large pools, thereby increasing stream temperatures. Actions that could reduce sediment delivery to the South Fork include road resurfacing and landslide hazard reduction. Such actions have long term benefits, but take 5-20 years to achieve those benefits. The projects are considered highly likely to achieve their goals.

#### 5.3.1.4.1 Status

The South Fork valley contains extensive glacial deposits mantled along the valley walls. Following deglaciation, the South Fork eroded into these deposits and triggered large stream-adjacent landslides along much of the length of reaches 3 and 4, with less frequent occurrences in reach 5. These landslides can contribute a substantial amount of sediment to the channel. These features were mapped in 1986 (Lummi Natural Resources data), and then remapped in 1995 (Osbaldiston 1995) and 2005 (Brown and Maudlin 2007). Thirty-seven slides were mapped in 1986 with a cumulative active area of 1.5 million square feet. In 1995, 25 slides were mapped with a cumulative active area of 1.1 million square feet and in 2005, 50 landslides were mapped with a cumulative area of 1.3 million square feet. Only one restoration project has been designed to reduce sediment inputs from such features: in 2001, Lummi Natural Resources constructed a 130m-long woody revetment in front of the toe of a left bank deep-seated landslide as part of the Larson's Bridge project. The landslide has completely filled the basin behind the structure and it is now revegetating with deciduous trees (Maudlin and Coe 2012).

One hundred and ninety-nine shallow rapid landslides were mapped in the South Fork Valley between 1940 and 1995, with the majority of these occurring in relation to drainage systems and either clearcuts or roads (Watts 1996). More recent landslide inventories in the Acme subbasin area indicate that failures from roads are decreasing as a result of improved road maintenance (Powell et al. 2010). Improved Forest Practice Rules that require geotechnical review before operating on unstable slopes have decreased the impacts of harvest on these landforms. Road maintenance and abandonment plans are also generally on track to bring roads in the South Fork up to current forest practices standards by 2016, with the exception of some areas in the Skookum and Hutchinson subbasins, which have been extended to 2021.

The RMAP process does leave a substantial length of "orphaned" road that has not been used since 1974 on the landscape that forest landowners are not legally required to maintain or abandon. While some orphaned roads or road segments do get addressed when re-activated, and a small percentage have been voluntarily abandoned, orphaned roads have the potential to affect the sediment regime of the South Fork. This represents an important gap in Washington's Water Quality Management Plan to Control Nonpoint Sources of Pollution (Hashim and Bresler 2005), which relies on the Forest Practice Rules to address forestry-related nonpoint sources. On road segments where RMAP work is not required, the plan calls for sediment reduction work on high risk areas.

While sediment sources are abundant in the watershed, the impact on salmon habitat is considered low to moderate (WRIA 1 SRB 2005), as evidenced from bulk sediment samples collected in spawning gravel. Thirty-nine samples collected in the late 1980s and in the mid-2000s had an average fine (<0.85mm) sediment level of 14 percent, which is likely impacting permeability of the substrate, but not likely limiting incubation success.

#### 5.3.1.4.2 Priority

Addressing chronic sediment sources (i.e. stream-adjacent large inputs) is currently a moderate salmon recovery priority in parts of reaches 1 (RM 5.1-7.2), 3 (to RM 20.6) and 4 (RM 22-31), while assessing and treating orphaned roads to reduce sediment inputs is a moderate salmon recovery priority throughout all of the subbasins. Habitat restoration has focused on addressing sediment sources where they exist within priority project reaches for instream habitat restoration, rather than directing projects to landslide sites. Reducing landslide hazards can ameliorate sediment increases. However, given that the relative contributions of various sediment sources are not well understood, actions to address erosion and sediment delivery in the South Fork and its watershed are a low priority throughout the South Fork watershed in the context of climate change. Prioritization is deferred pending development of a sediment budget to quantify the relative contributions of sediment sources and identification of effective actions to ameliorate them.

#### 5.3.1.4.3 Recommendations

- Develop a relative sediment budget to evaluate the magnitude of various sediment sources and their failure mechanisms and factor climate change impacts into the sediment budget. This project will be led by the Nooksack Indian Tribe and is currently under development. This project is important to help develop a better understanding of impacts of climate change on sediment sources and routing and fill an important data gap.
- Characterize and monitor sediment dynamics over the long term to document climate change impacts on sediment dynamics. As characterization of sediment dynamics is refined, update predicted impacts on fish habitat. This is an on-going project with collaboration by Whatcom County, USGS, Western Washington University, Nooksack Indian Tribe, and the University of Washington. While not identified as a salmon recovery priority, it is seen as a priority for meeting water quality standards and flood management.
- When designing restoration in a project reach of the South Fork, continue to evaluate feasibility of reducing sediment inputs from any stream adjacent landslides in the reach. This is a moderate salmon recovery priority for the reaches identified above. This action is being implemented by restoration practitioners in the South Fork.
- Develop a conservation plan that works with USFS to evaluate, prioritize, and address road network deficiencies. The USFS lacks funding to adequately maintain road network to FFR standards, so this may require additional grant funding to advance. The plan will also identify road segments that are chronic sources of sediment, and work with landowners on sediment reduction actions, road relocation and road abandonment. Assess potential for orphaned roads to deliver sediment and prioritize and implement orphaned road abandonment projects. This action is currently a moderate salmon recovery priority, but completing the sediment budgeting may increase its importance for salmon recovery. The conservation planning effort was initiated by the Nooksack Indian Tribe and other local partners in 2016, and will likely be expanded in the near future to address these tasks. See also recommendation to "develop a watershed management/conservation plan" under section 5.3.2.1 below.

### 5.3.1.5 Riparian Functions

Restoring the riparian zone of the South Fork and subbasins would substantially ameliorate high stream temperatures due to climate change and has been a major focus of restoration activities in the watershed. Examples of this action include removing invasive plant species that inhibit the growth of native species, planting native plant species, and controlling livestock grazing or interruption of the riparian zone. Not only does riparian vegetation provide direct shade, but forested riparian areas also deliver large wood to the channel that creates deep pools for thermal refugia. Riparian restoration is currently considered a moderate salmon recovery priority (WRIA 1 SRB 2016), because WRIA 1 SRFB/PSAR funding decisions prioritize projects that provide immediate benefit to chinook abundance and productivity, and there are alternative funding sources for riparian restoration (e.g. Department of Ecology Centennial Clean Water Fund, EPA section 319 funding, NRCS Conservation Reserve Enhancement Program). Riparian restoration is considered to have long–term benefits, but it can take decades to realize the benefits (Table 5-10). Actions such as conifer interplanting have a high variability of success and low to moderate certainty of success.

#### 5.3.1.5.1 Status

There has been substantial riparian restoration along reach 1 of the South Fork. A 200-foot' wide buffer area (extending out from the edge of the near-stream disturbance zone, or NSDZ) was assessed by the Nooksack Indian Tribe in 2008 using aerial photos (taken that same year), and 78 percent of the 682 acres (535 acres) were either forested or had been replanted. Of remaining unplanted areas in the buffer analyzed, 5 percent was infrastructure or buildings (35 acres), and 16 percent was agricultural lands (112 acres). Comparatively, the TMDL analysis included a survey of existing vegetation from the NSDZ boundary to a 150-foot wide buffer area using aerial imagery from 2006. Along reach 1, the TMDL analysis found a similar distribution, with a total of 513 acres of land made up of 82 percent vegetation (421 acres), 3 percent infrastructure and buildings (16 acres), and 15 percent pasture, cropland, or lawn (76 acres).

Reaches 2 and 3 of the South Fork flow through industrial forest lands, and site potential stream buffers[21] are required for the channel and the channel migration zone. While much of this area is immature forest, it is expected that continuing protection and recovery of natural successional processes will improve the riparian stand conditions. Efforts have been made to under-plant conifers in deciduous-dominated stands to accelerate natural succession. Reach 4 of the South Fork flows through conservation lands owned by Seattle City Light. The property has been managed to improve habitat conditions, and a substantial amount of riparian restoration has been completed in this reach. Reach 5 is in federal ownership and is managed by the USDA Forest Service under the *Northwest Forest Plan*. The riparian zone is protected and recovering from past forest practice activities. It is assumed that passive restoration will lead to recovery of the riparian area and little riparian management has been conducted in this reach.

Stream shading hazard was determined for the South Fork subbasins based on 2001 aerial imagery (Coe 2001). Shading hazard is defined by the degree to which the percentage canopy cover was below elevation-based targets. Moderate and high hazards are those that are more than 10 percent below target values. In the Acme Valley subbasin, 64 percent of the riparian zone was determined to be a moderate or high hazard for shading. Fifty-six percent of the Hutchinson subbasin was classified as a moderate or high shade hazard. The Skookum Creek subbasin was found to have 41 percent high or moderate hazard. The Edfro/ Cavanaugh subbasin had the lowest amount of high or moderate hazard riparian area at 30 percent. Plumbago and Deer (61 percent high or moderate hazard) was found to be similar to the Acme Valley subbasin, in spite of the lack of agricultural land in this area. The Howard subbasin was 39 percent and the Upper South Fork subbasin was 30 percent high or moderate hazard for shade (Coe 2001).

Stream shade was modeled and incorporated into temperature modeling as a part of the temperature TMDL (Ecology 2016). For the shade model, a cross-section of the channel and riparian zone was characterized at 100–meter stations along the channel. The current riparian tree height and the width of the near-channel disturbance zone were measured and used to project shade onto the wetted channel. Shade was also modeled for "system potential vegetation", which assumes riparian tree height is the 100-year site potential (i.e. site class-dependent) tree height. The difference between the current and system potential vegetation scenarios can be used to highlight reaches with more impaired shading (Figure 5-29). Reaches 1 and 4 were the most deficient in shade, with 66 percent and 52 percent of the modeled cross-sections not meeting potential shade. Reach 2 had 28 percent of cross-sections not meeting potential for shading, Reach 3 had 40 percent, and Reach 5 had 37 percent. Much of this difference was related to channel widening between the current conditions and the restored conditions and channel orientation. Restoring shade levels will require improved riparian stand conditions coupled with in-stream restoration that restores the narrower pre-disturbance active channel width.

[21] Per Washington State Forest Practices Rules (Title 222 WAC), riparian management zone (RMZ) width varies from 90 ft (Site Class V) to 200 ft (Site Class I) and consists of a 50 ft no-touch core zone and, for streams greater than 10 ft width, 18 ft (Site Class V) to 100 ft (Site Class I) inner zone where forest practices must be conducted so as to meet or exceed stand requirements, and an outer zone where 20 riparian leave trees per acre must be left after harvest. Forest Practices rules effectively yield buffers on streams greater than 10 ft width ranging from 68 to 150 ft.

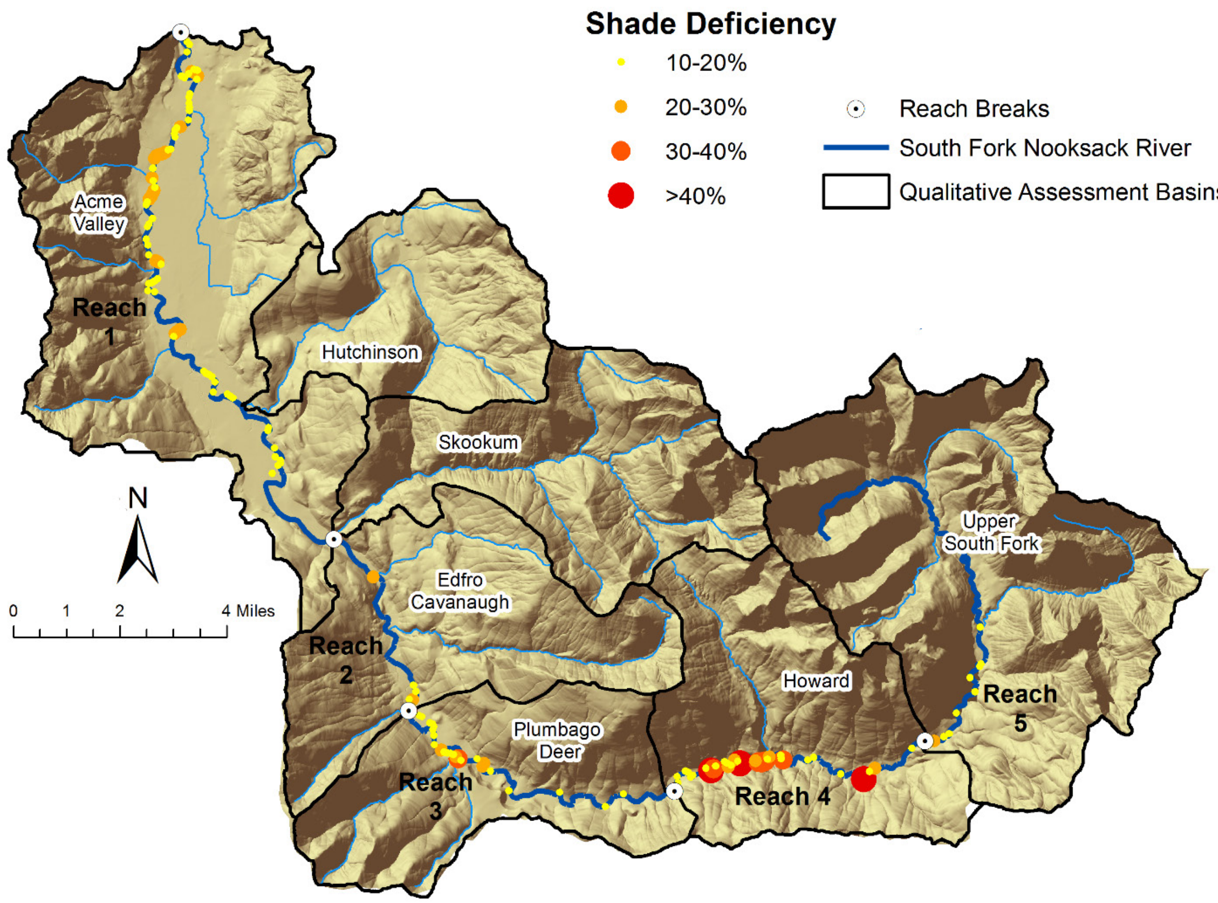


**Figure 5-29. Shade Deficiency along the South Fork Nooksack River.**
Note that shade deficiency is defined as the difference in effective shading within 100-m reaches between system potential vegetation and current vegetation scenarios. Further note that only reaches with at least 10 percent shade deficiency are shown in this figure. (Source: shade model data provided by J. Butcher, Tetra Tech; see Ecology 2016 for description of how shade model was developed.)

#### 5.3.1.5.1 Priority

Riparian restoration to ameliorate climate change impacts is a high priority in all five reaches of the South Fork, as well as for the Acme Valley and Hutchinson subbasins, and a moderate priority for Skookum, Plumbago/Deer, Edfro/Canamaugh, Plumbago/Deer, Howard, and Upper South Fork subbasins (Table 5-7 and Table 5-8). Current salmon recovery priorities focus on strategies with likelihood of immediate benefit to Nooksack Chinook abundance and productivity. Nonetheless, reforesting the HMZ plus a 300-foot’ buffer is a moderate salmon recovery priority throughout reaches 1 and 3, removing invasive species is a moderate salmon recovery priority from RM 9.6 in reach 1 through reach 4, and improving riparian conditions along floodplain channels outside of the HMZ plus 300-foot’ buffer is a moderate salmon recovery priority in parts of reach 1 (RM 0-1.8; 9.6-12.8). Restoration of tributary riparian areas is a moderate salmon recovery priority along Hutchinson, Skookum, Cavanaugh, Fobes, Deer, Roaring, and Plumbago Creeks. Riparian restoration can ameliorate temperature increases. As shown in Table 5-2, temperature modeling indicates riparian restoration along the South Fork to climax conditions could lead to maximum temperature reductions of 1.1 °C to 1.4 °C, under current climate conditions, while reducing tributary temperature by 20 percent (i.e. through riparian restoration) could lead to maximum temperature reductions in the South Fork of 0.6 °C to 0.9 °C. Given the time scale to benefit and the importance of this action to ameliorating temperature and other climate change impacts, it will be important to considerably expand the pace and scope of this action in the near term.

#### 5.3.1.5.2 Recommendations

- Continue to implement and expand CREP program through the lower South Fork. Seek funding to extend 15-year lease terms and/or otherwise work to protect existing CREP buffers over the long-term to ensure that vegetation reaches a functional size. This would be led by the Whatcom Conservation District with support from salmon recovery partners.
- Increase opportunity and funding for riparian/wetlands protection and restoration along the lower South Fork through purchase of conservation easements, development rights, and/or fee simple title and/or working with landowners to foster stewardship (see above, under *Floodplain Reconnection*). The Whatcom Land Trust has been the lead on conservation easements and fee-simple acquisition in the South Fork and will continue to work on floodplain protection. Whatcom County is the lead on purchase of development rights in the watershed; currently, funding for the County purchase of development rights program is insufficient to meet the demand. Several salmon recovery partners have been active in seeking funding for and implementing riparian restoration in the South Fork.
- Develop a watershed conservation plan to work with landowners and State Lands managers on alternative buffering strategies that provide greater protection for riparian forest and increase the amount of forest land cover in the South Fork watershed. Work with landowners to protect and restore riparian vegetation in tributary riparian areas, especially floodplain tributaries; but extending throughout the stream network, including through non-fish-bearing tributaries up to and including the upper extent of perennial flow. Work with forest landowners to voluntarily reduce rotation frequency and clearcut size to increase forest land cover in the South Fork watershed. The Nooksack Indian Tribe is currently working on a conservation plan with watershed partners to work with forest landowners on identifying shading needs. Implementation of the plan will require partnership between private and public entities. See also recommendation to "develop a watershed management/conservation plan" under section 5.3.2.1 below.
- Control non-native invasive vegetation that outcompete native vegetation to accelerate trajectory to recovery in riparian areas along the South Fork and tributaries (especially Hutchinson Creek). The goal of this action is to reduce competition with native riparian vegetation and speed the riparian community toward the Site Potential conditions. Whatcom County has been the lead on invasive species control and has implemented an aggressive control program for the upper South Fork.
- Develop a riparian restoration plan for the South Fork watershed that identifies and prioritizes appropriate treatments by location. Treatment options include: establishing a riparian buffer, controlling competition from non-native invasive plants, thinning, and interplanting conifers in hardwood-dominated stands to speed stand succession and achievement of riparian function. The Nooksack Indian Tribe has taken the lead on assessing riparian conditions and developing a restoration plan in the South Fork. The plan will include monitoring of the effectiveness of past projects and identify additional maintenance needs, as well as assessment of the potential for expanding planting sites.

### 5.3.1.6 Instream Rehabilitation

Important instream rehabilitation activities include remeandering of the channel or strategically placing log jams or boulder weirs in areas to encourage the formation of deep pools. Instream restoration projects may ameliorate temperature increases by creating cold-water refuges through thermal stratification (Gendaszek 2014) or pool formation in areas of cool water input (Nooksack Indian Tribe, unpublished data), increasing hyporheic exchange (Parzych 2015), and narrowing active channel width, thereby increasing effective shade. Instream restoration can also ameliorate sediment inputs from large deep-seated landslides, as observed for the South Fork Larson's Bridge project that was implemented by Lummi Natural Resources in 2001.

#### 5.3.1.6.1 Status

The South Fork has been a priority for instream habitat restoration since the late 1990s. The first engineered logjams were built in the river in Reach 3 (Larson's Bridge) in 2001. Given the critically low abundance and productivity of South Fork Nooksack early Chinook, the current voluntary restoration strategy prioritizes actions that will have an immediate benefit to its abundance and productivity. Priority limiting factors that have been identified in the South Fork are elevated summer water temperature, low habitat diversity, and a lack of key habitat (deep pools with woody cover). Voluntary restoration has focused on engineered log jam (ELJ) placement and riparian planting. ELJs are designed to form deep pools with complex cover, especially in areas of cool-water influence (seeps, cool tributaries). Through the end of 2014, 15 projects had been completed, with 142 total structures constructed in the river. Design is being completed in several more reaches, with multiple projects likely to be implemented in these areas in the next five years. The bulk of the effort has been in reach 1, where 100 structures have been constructed through the 14.3 mile reach. Fifteen structures have been constructed in reach 2, near the confluence with Cavanaugh Creek. Twenty structures have been constructed in reach 3—the core spawning area for spring Chinook. Design work is being completed on two additional project reaches in this area. Reach 4 lies upstream of a partial passage barrier, so the amount of habitat restoration work has been minimal in this area. One project was completed in this reach, consisting of four structures placed instream in association with the removal of a bridge.

Habitat restoration in the anadromous portions of the tributaries has been limited. There has been some wood placement in floodplain tributaries in the Acme Valley subbasin, but to date no projects have been completed in other subbasins.

#### 5.3.1.6.2 Priority

Instream restoration, primarily through the placement of ELJs to create temperature refuges, is an important strategy to buffer against increased temperatures in the near term while processes that support natural temperature regimes recover (i.e. through riparian, streamflow, and floodplain restoration). Instream restoration is a high priority in naturally unconfined reaches of the South Fork (reaches 1 and 3), where they are expected to have the greatest benefit to Chinook salmon, and moderate in tributaries to the South Fork that provide cold-water refuge (i.e. with temperatures over 2 °C cooler than the South Fork). These occur in all of the subbasins downstream of the RM 31 anadromous barrier. Placing log jams to form deep complex pools, especially in cool-water inflow areas (seeps, cool tributaries), is also a high salmon recovery priority for the South Fork throughout reaches 1 and 3. Replacing riprap with wood bank structures (reach 1, RM 0-10.9, 12.8-14.3), improving in-channel woody debris loading in floodplain channels (reach 1, RM 0-1.8, 9.6-12.8), and restoring habitat in Hutchinson Creek are all moderate salmon recovery priorities.

#### 5.3.1.6.3 Recommendations

- Continue and increase the pace of instream restoration in high priority reaches of the South Fork. Instream project designs should be developed at the reach-scale and incorporate the following objectives:
    - Create cold-water refuges by placing log jams to form deep pools in areas of cool-water influence. Sources of cold-water during summer include lateral and pool bottom seep inflow, cool tributaries, and hyporheic flow (Bilby 1984, cited in McCullough 1999).
    - Increase effective shade by narrowing active channel and/or encouraging the low-flow South Fork channel to engage with existing forested riparian areas. Promote the formation and maturation of forested islands and/or floodplain forest encroachment.
    - Increase channel roughness (i.e., through log jams) to promote bedform diversity and increase hyporheic exchange.

  - Reconnect floodplain channels (for flood refuge, overwinter rearing habitat) and other floodplain surfaces by promoting aggradation and/or locally increasing water surface elevations. See also *Floodplain Reconnection*.
  - Decrease shear stresses in the active channel to reduce potential for redd scour.
  - Create hydraulic refuge for juveniles.
- Assess natural occurrence of temperature refuges and monitor effectiveness of log jam placement at creating new temperature refuges and otherwise ameliorating temperature impacts on salmonids. Research mechanisms to maximize temperature refuge formation and maintenance (i.e. hyporheic, groundwater and surface flow dynamics that contribute cool water; pool morphology or structural elements like wood that prevent immediate mixing of cool and warm water). Incorporate findings into restoration project designs.
- Improve habitat quality in cool-water tributaries, especially floodplain tributaries that provide important flood refuge and overwinter rearing habitat, by placing logs and log jams.

### 5.3.2 Additional Actions Needed

#### 5.3.2.1 Planning Actions

- Incorporate climate change into updates to *WRIA 1 Salmonid Recovery Plan* and development and prioritization of projects for SRFB/PSAR funding. The WRIA 1 Salmon Recovery Board is the Salmon Recovery Lead Entity for WRIA 1 and responsible party for this action.
- Develop a watershed management/conservation plan that facilitates the South Fork temperature TMDL implementation plan and comprehensively addresses the impacts of land management and climate change on the ecological health of the South Fork and rectification of direct, indirect, and cumulative impacts of land management. Components of the plan needed to support specific action types are identified in sections 5.3.1.2.3, 5.3.1.3.3, 5.3.1.4.3, and 5.3.1.5.3. This action will require engagement of a broad array of stakeholders and landowners in the South Fork watershed.
- The planning process should be recommendations provided by action type above and the following:
  - Public outreach to inform land owners, including agricultural landowners and commercial forestry operators, on measures that should be implemented watershed-wide to directly address temperature problems in the South Fork.
  - Development of measures beyond regulatory BMPs that would further rectify cumulative impacts and address future stream temperature, streamflow, and sediment impacts on tributaries and the South Fork.
  - Development of a funding strategy for implementation.

#### 5.3.2.2 Monitoring, Research, and Adaptive Management

Hypothesized impacts to salmonid populations in the South Fork watershed are based on research and expert opinion. Monitoring into the future will be critical to reducing uncertainty and supporting adaptive management. Several monitoring, research, and adaptive management recommendations have been identified by action type above. Additional recommendations include:

- Develop life cycle models for South Fork salmonid populations to identify limiting life stages and support quantitative assessment of climate change impacts on salmon recovery. This would most likely be undertaken by the salmon co-managers (Nooksack Indian Tribe, Lummi Nation, and WDFW) with potential support from academic institutions and/or consultants.

- Monitor distribution and periodicity and assess productivity by life stage of priority salmonid species. As resources allow, undertake studies of species/life-stage-specific survival in the South Fork. The salmon co-managers coordinate salmonid population monitoring and research.
- Monitor effectiveness of recovery actions and land use regulations at restoring and protecting habitat conditions and salmonid populations and addressing climate impacts. The WRIA 1 Salmon Recovery monitoring and adaptive management program is under development, and responsible parties for specific monitoring activities will be determined at a later date.
- Incorporate monitoring and/or refined future climate scenarios into adaptive management of South Fork restoration and protection actions. Responsible parties for this action include the WRIA 1 Salmon Recovery Staff Team and project sponsors.
- Incorporate climate change, especially the findings and recommendations of this report, into WRIA 1 Salmonid Recovery Plan updates, salmon recovery voluntary restoration project prioritization and planning, and *Salmon Recovery Monitoring and Adaptive Management Plan* development. This is the responsibility of the WRIA 1 Salmon Recovery Board and WRIA 1 Salmon Recovery Staff Team.
- Incorporate new findings and work into adaptive management of South Fork temperature TMDL and/or associated implementation plans. The Washington Department of Ecology is the lead for TMDL implementation.

## 5.4 Conclusions

This qualitative assessment characterizes legacy and future climate impacts to watershed conditions, presents hypothesized climate change impacts to salmonids, and prioritizes actions to address those impacts. The overall objective of this project was to identify the most appropriate and effective climate change restoration and adaptation strategies for the South Fork that support the designated use of the river and the temperature TMDL. The Beechie method (Beechie et al. 2013), with some adaptation to the South Fork watershed, was used to provide a systematic, stepwise approach to analyzing climate change impacts in the context of the South Fork watershed, including evaluation by climate risk (focusing on temperature, hydrologic, and sediment regimes), per salmonid species (emphasizing ESA-listed species), and per restoration action. The South Fork watershed was divided into twelve analysis units, including five reaches of the South Fork and seven subbasins. Restoration actions evaluated are those that address legacy, ongoing, and future climate change impacts within each reach and subbasin.

*Climate Impacts*

The cumulative effect of legacy and ongoing impacts from timber harvest, flood control, transportation facilities, and conversion of forested land to agricultural uses in the South Fork has substantially degraded ecosystem processes, habitat and water quality; threatening the viability of salmonids in the watershed. Climate change will strongly impact temperature, hydrologic, and sediment regimes; thereby further exacerbating legacy and ongoing impacts.

Loss of riparian shading along the South Fork and throughout tributary watersheds, coupled with channel widening and a likely reduction in hyporheic exchange, have contributed to increases in summer temperatures in the South Fork. In addition, annual average air temperatures in the vicinity of the South Fork have increased an average of 1.3 °C from 1905 through 2010, which may indicate a climate-related increase in summer water temperatures of about 0.9 °C during that period (Isaak et al. 2011). South Fork water temperatures, without restoration of riparian shade, are projected to rise further by amounts ranging from 3.5 to almost 6 °C during critical low-flow conditions by the 2080s. Although not as profound as during summer, temperature increases will also occur through other seasons.

Impacts to the South Fork hydrologic regime include draining and ditching of floodplain wetlands, forest roads that extend the drainage network, and hydromodifications that narrow the channel and disconnect the floodplain. Gaged and simulated flows in the South Fork indicate at most a limited response to changes in climate conditions between 1915 and 2016, with a small increase in total flows and high flows. Climate change is projected to decrease critical (7Q10) low flows by 15-26 percent and increase the magnitude of floods in the South Fork by 15-39 percent (2-year flood), 12-35 percent (10-year flood), and 11-34 percent (25-year flood).

While the South Fork has a naturally high sediment load, removal of channel-spanning log jams, bank armoring, clearing of riparian areas, and elevated mass wasting associated with clearcuts and forest road construction have likely increased sediment supply. Channel form has also changed over time: General Land Office surveys indicate the unconfined lower 13 miles was historically more narrow, more sinuous, and complex, with multiple low-flow channels and stable forested islands across the floodplain. Sediment loads are likely to increase under climate change due to loss of soil-protecting snowpack, increased saturation of soils on steep slopes, increased frequency and magnitude of over-steepened slopes associated with valley glacier recession, increased entrainment and transport of sediment within the channels, and increasing intensity of precipitation events yielding more extreme peak flows.

*Salmonid Impacts*

Climate change impacts on temperature, hydrologic, and sediment regimes could profoundly affect the distribution, life history periodicity, survival and productivity of salmonids in the South Fork. Climate impacts will extend through the year, from reduced discharge in spring to increased temperatures and reduced base flows in summer to increased peak flows in winter, rendering all species and life stages vulnerable. Species that migrate during summer and/or rear for extended periods in freshwater are especially vulnerable. High temperatures may kill fish, lead to dissolved oxygen limitations, increase incidence of pathogens, affect growth of juveniles, create thermal barriers to migration, affect food supply and feeding, and render some habitats uninhabitable during certain times of the year. Loss of spring snowmelt may reduce overall availability of habitat, increase time of outmigration, and reduce access to floodplain habitats. Decreased low flows in summer and fall will further increase water temperatures, create temporary blockages to upstream migration, and reduce availability of holding, spawning, and oversummer rearing habitat. Increased winter peak flows may decrease survival-to-emergence, reduce habitat diversity, or displace juveniles. Increased sediment load may affect habitat diversity and stability and increase turbidities, which may in turn cause gill trauma, reduce feeding efficiency, and delay migration. Specific population responses to climate change may be mitigated by the distribution and extent of habitats from the microhabitat to drainage scale that can provide refuge from high temperatures, flows, and sediment load. Continued monitoring and research on South Fork salmonid populations will be important to test the hypotheses presented in this report.

*Adaptation to Climate Change*

Actions that can ameliorate the impacts of climate change on salmonid habitats include longitudinal connectivity, lateral and vertical floodplain reconnection, restoration of streamflow regimes, restoring riparian shading, and instream rehabilitation (Beechie et al. 2013). These actions were adapted to and prioritized for South Fork reaches and watershed subbasins based on the potential to implement an action within the analysis unit, ability of the action to ameliorate climate impacts and/or increase salmon resilience to climate change, and the time scale of benefit. Priority actions for the South Fork include:

- Reach 1 (RM 0–14, floodplain; impaired TMDL reach): This segment of the South Fork is the most impaired of the five segments due to cumulative legacy impacts resulting from agriculture, forest practices, flood control, bank protection, railroad embankments, and road embankments, which have continued to result in loss of riparian vegetation and loss of floodplain connection. The high priority actions in this reach are removal and/or setback of hydromodifications, placement of log jams to reconnect floodplains, reduction in water withdrawals, floodplain wetland restoration, riparian restoration, and placement of log jams to buffer against increased temperatures in the near-term while processes that support natural temperature regimes recover.

- Reach 2 (RM 14.3–18.5, canyon): This segment of the South Fork has a more confined morphology dictated by bedrock valley walls and erosion-resistant terraces. Riparian restoration is a high priority action in this reach.
- Reach 3 (RM 18.5–25.4, core Chinook spawning): The unconfined sections of the river in this segment represent the core spawning areas for South Fork spring Chinook and have been the focus of instream habitat restoration since the 1990s. The high priority actions in this reach are riparian restoration and placement of log jams, while improving passage at the RM 25 barrier, placement of log jams to promote aggradation, and restoring wetlands are moderate priorities.
- Reach 4 (RM 25.4–31, confined areas): A partial passage barrier marks the break between this reach and the downstream core spawning area. The channel is sinuous and intermittently anastomosing in some reaches with occasional large gravel bars. Deep-seated landslides and abundant shallow-rapid landslides have occurred in this reach. Riparian restoration is a high priority, while improvement of passage at the RM 31 barrier is a moderate priority.
- Reach 5 (RM >31, lands administered by USDA and USFS): This segment of the river lies above the anadromous barrier at RM 31. Much of the watershed above RM 31 lies within land administered by the USFS and is currently protected by the Northwest Forest Plan. Riparian restoration is a high priority action in this reach.
- Highest priority actions implemented at the watershed scale include reducing water withdrawals and restoring floodplain wetlands in the Acme subbbasin and riparian restoration along tributaries in the Acme and Hutchinson subbains. Barrier or culvert replacement and/or improving passage at natural barriers in the Acme, Hutchinson, and Skookum subbasins are moderate priorities, along with riparian restoration in the Skookum, Edfro/Cavanaugh, Plumbago/Deer, Howard, and Upper South Fork subbasins. Addition of log jams or structures to improve cold-water refuge is a moderate priority in cold-water tributaries throughout the South Fork watershed.

The most important actions to implement to ameliorate the impacts of climate change in the South Fork watershed are riparian restoration, floodplain reconnection, wetland restoration, and placement of log jams. Although specific targets were not established through this assessment, these actions are intended to result in the following:

- Increased floodplain connectivity
- Increased effective shading (South Fork and tributaries)
- Reduced floodplain drainage (ditches, tiles)
- Increased abundance and distribution of cold-water refuges (South Fork and tributaries)
- Increased fish passage
- Increased hydraulic refuge

Effectiveness monitoring should be designed accordingly.

Most of these actions are already being implemented to varying degrees, but the pace and scale of implementation will need to be increased by explicitly addressing barriers to implementation. This will require substantial planning, project feasibility assessments, agency consultation, landowner cooperation, stakeholder involvement and funding. The key planning actions that will facilitate addressing barriers to implementation are developing a watershed conservation plan and explicitly incorporating climate change into the *WRIA 1 Salmonid Recovery Plan* and associated implementation and prioritization documents. It is important to act upon the recommendations presented herein now to ensure that benefits of restoration can offset climate impacts in the future. QUAL2Kw modeling of summer maximum temperatures under the "natural conditions scenario" (Figure 5-16 and Figure 5-17) indicate that restoration implemented at a sufficient scale to restore natural conditions can substantially offset future climate impacts.

*Lessons Learned*

There is considerable overlap between existing salmon recovery priorities and those incorporating climate change. Adapting salmon recovery plans to incorporate climate change is unlikely to require wholesale change, but rather a dramatic increase in the scale and pace of implementation. For the South Fork watershed, where chinook spawner abundances are critically low, current salmon recovery priorities have emphasized actions likely to produce immediate benefit. Although it is still extremely important to boost chinook abundance and productivity in the near-term, this assessment has encouraged a broadening of the restoration planning horizon. The greatest discrepancy between current salmon recovery priorities and those that incorporate climate change is the elevated priority of actions with longer time scale to benefit (riparian and wetland restoration).

While climate projections often seem dire, the importance of taking action now to offset future impacts may help motivate restoration practitioners and resource managers to redouble their efforts to address barriers to implementation. Highlighting the ecosystem services benefits of restoration (i.e. reduction in flood risk to downstream communities by reconnecting floodplains) may increase opportunity for restoration. Finally, climate change will force freshwater ecosystems beyond the historic range of variability, necessitating the development and implementation of novel restoration tools and strategies.

# 6 Next Steps

## 6.1 South Fork Climate Change Pilot Research Project: Context and Previous Outreach and Engagement

This qualitative assessment is an integral component of EPA-ORD's Pilot Research Project applied to the South Fork and designed to be a research demonstration on how to address ESA salmon recovery, CWA 303(d) Temperature TMDL implementation, and climate change in one integrated project. The qualitative assessment was based on pertinent scientific literature and most specifically *Restoring Salmon Habitat for a Changing Climate* (Beechie et al. 2013). The project involved engaging stakeholders, including tribes (Nooksack Indian Tribe and Lummi Nation), WRIA 1 watershed management and salmon recovery lead entities and staff, scientists, and informed public. The project developed methods, conducted analyses, and completed a proof-of-concept research pilot demonstration.

The qualitative assessment has greatly benefited from the participation and involvement of the key stakeholders in the South Fork watershed, particularly the Nooksack Indian Tribe, to ensure that the problem formulation, research activities, and ultimately, that the findings and recommendations will be relevant and implementable to the real world context of the South Fork watershed in general and specifically salmon habitat restoration and climate change vulnerability assessment and adaptation planning. As detailed in Section 3 (Stakeholder Engagement), there have been significant stakeholder outreach and engagement opportunities to date, including a workshop hosted by EPA to solicit input from stakeholders on project goals and activities (June 2012), a workshop hosted by Washington's WRIA 1 Watershed Management and Salmon Recovery staff teams where members recommended implementing the qualitative assessment as a rapid-prototype pilot (October 2012), a workshop hosted by the Nooksack Indian Tribe where VIDT members conducted a cursory application of the Beechie methodology to each of the South Fork stream reaches (January 2013), a webinar with the VIDT (webinar #1) to agree upon the proposed methodology for the qualitative assessment (November 2013), VIDT webinar #2 where the results of the analysis was presented (May 19, 2015), and a presentation to the WRIA 1 joint management team on assessment results (November 9, 2015). Further application of this pilot to other Puget Sound watersheds is intended as is the implementation of the recommendations in this report.

## 6.2 Prioritize Recommended Protection and Restoration Actions

Section 5.4 lists a comprehensive set of recommended protection and restoration actions that address water quality improvement, CWA compliance, and salmon recovery for the South Fork watershed. These actions have been assigned broad priorities, but implementation of these actions may require further prioritization that involves the public, many agencies, and stakeholders; potential considerations for further prioritization include timing, importance, feasibility, effectiveness, risk, urgency, benefit/cost, affordability, flexibility, collateral benefits, and consistency with community sentiments and goals. As this qualitative assessment is acted on as a pilot, the various groups involved with implementing the recommended actions will likely prioritize the actions by applying a system of prioritization yet to be developed. A survey could be developed that would facilitate agencies, public, and stakeholders in developing/refining a prioritization scheme.

## 6.3 Develop a South Fork Watershed Conservation Plan

Many of the recommended planning actions listed in Section 5.4 relate to the development of a watershed conservation plan. Although this qualitative assessment and the TMDL focusses on water quality exceedances, legacy impacts, climate change impacts, and salmon recovery in the mainstem South Fork, recommended restoration and protection actions target both the mainstem and the broader watershed.

Protection and restoration actions will require a substantial public outreach and stakeholder engagement program that would identify issues, concerns, opportunities, and willingness to voluntarily participate in such a watershed conservation planning process.

A public outreach and stakeholder engagement process has been developed and initially implemented that will facilitate development of a watershed conservation plan. An initial planning team was convened early in 2015 to begin the process of conceptualizing what such a plan would entail, who would be involved, and how public outreach and stakeholder engagement would be implemented. Recent federal grant funding has allowed the planning process to move forward. The public involvement and stakeholder engagement program involves 1) inviting the local WRIA 1 watershed management and salmon recovery programs to participate; 2) identifying and engaging stakeholder interest groups individually, including government [(federal, tribal, state and local) and NGOs], fisheries, agriculture, forestry, transportation, recreation, flood control, and water availability; 3) developing a comprehensive list of issues, concerns, and opportunities based on stakeholder meetings; 4) expanding the planning team to include representatives of the stakeholder groups; 5) holding a public meeting to inform the public on the scope and context of the watershed planning project and to solicit additional issues, concerns, and opportunities; 6) expanding the planning team to include agencies and stakeholder groups; 7) acting on the issues, concerns, and opportunities compiled from previous meetings and that would drive the content of the watershed conservation plan; 8) developing an organizational structure that would direct the development of the plan; 9) developing the draft plan; 10) conducting a public information meeting; and 11) developing the final plan.

The South Fork watershed conservation plan will: 1) document the planning and public outreach and stakeholder engagement process; 2) identify parcel, cover type, condition, quality, function, opportunity for effective restoration and protection, land use, and owner/operator; 3) identify conceptual restoration opportunities on the parcels; 4) describe results of coordinating with parcel owners on voluntary protection and restoration actions; 5) identify potential funding sources for action implementation; 6) evaluate potential results of action implementation; and 7) present a conceptual monitoring program for plan implementation and effectiveness. This work would be developed through an organizational structure formed from the public outreach and stakeholder engagement process.

## 6.4 Scale and Refine the Qualitative Assessment Methodology to other Nooksack Watersheds

As a pilot demonstration project, the South Fork Pilot Research Project can be applied to other watersheds in the Nooksack River basin with similar species, limiting factors, and restoration planning, such as the Middle Fork and North Fork Nooksack rivers, and the lower mainstem of the Nooksack River. Similar procedures and methods would be applied to those rivers as described in this document, although the quantitative analyses that support the qualitative assessment may differ. The involvement of the WRIA 1 Watershed Staff Team and WRIA 1 Salmon Recovery Staff Team-members of this Pilot is considered critical to extending the application to other WRIA 1 watersheds.

The hydrology of the upper Nooksack River watershed, specifically for the Middle Fork and North Fork Nooksack rivers, has recently been updated using contemporary downscaled climate data, more recent flow data, and calibration and verification procedures using the Distributed Hydrology, Soils, Vegetation Model (DHSVM). The calibrated DHSVM was then used to project changes in hydrology under various climate general circulation models and assumed greenhouse gas scenarios to evaluate the projected impacts of climate change on river flows. Similar temperature modeling for the Middle and North Fork Nooksack rivers as for the South Fork is underway to project the impacts of climate change on stream temperatures. This information will be used to evaluate the effectiveness of existing salmon recovery actions in the face of climate change and make recommendations on updating the WRIA 1 salmon recovery plan based on the information developed by applying the qualitative assessment. Similarly, the qualitative assessment pilot could be applied to the lower mainstem of the Nooksack River.

## 6.5 Inform the Update of the ESA WRIA 1 Salmonid Recovery Plan

One of the primary goals of this qualitative assessment is to incorporate climate change into updates to the *WRIA 1 Salmonid Recovery Plan* and associated planning and implementation documents. Doing so will require scaling up the assessment to evaluate the potential impacts of climate change across the broader landscape that Nooksack chinook and other salmonids inhabit, including the watersheds of the North Fork, Middle Fork, and lower Mainstem Nooksack River (as described in section 6.4 above), as well as independent tributaries to Bellingham Bay and the Strait of Georgia, and estuarine, nearshore, and offshore marine habitats. Development of quantitative salmonid life cycle models, as recommended in section 5.3.2.2, will inform the integration of vulnerability assessments and prioritization of adaptation actions across this scale. Updating the WRIA 1 Salmonid Recovery Plan and associated planning and implementation documents is a specific function of the WRIA 1 Salmon Recovery Board, the Lead Entity for salmon recovery in WRIA 1, and any updates will be vetted through the established decision-making and stakeholder engagement structure.

## 6.6 Scale and Replicate the Qualitative Assessment Methodology for ESU-Wide Implementation

As a pilot demonstration project, the South Fork Pilot Research Project can be applied to other watersheds in the Puget Sound basin using procedures and methods described in this document and inform "Climate-Ready" updates to existing ESA Salmonid Recovery Plans throughout the basin. This would involve connecting and coordinating with other Puget Sound watershed management and salmon recovery lead entities, WRIAs, Puget Sound Partnership (PSP), PSP Salmon Recovery Council, EPA National Estuaries Program (NEP), NOAA Fisheries, Washington Departments of Fish and Wildlife and Ecology, and others, to inform these groups on the relevance and application of this pilot to other watersheds in the Puget Sound basin.

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