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EPA Region 10 Climate Change and TMDL Pilot – South Fork Nooksack River, Washington

Final Project Report

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Foreword

Region 10 of the U.S. Environmental Protection Agency (EPA) and EPA's Office of Water and Office of Research and Development 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 and how they might influence restoration actions in an Endangered Species Act (ESA) salmonid recovery plan. The pilot research project used a temperature TMDL developed by the Washington State Department of Ecology for the South Fork Nooksack River (South Fork) as the pilot TMDL for climate change vulnerability analysis. An overarching objective of the pilot research project was 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 emissions scenarios was 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 is a comprehensive analysis of freshwater habitat for ESA salmon restoration in the South Fork under climate change (EPA 2016). The objective of the qualitative assessment was 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 provides a comparison of QUAL2Kw-modeled stream temperatures, including riparian shading, with and without climate change for the 2020s, 2040s, and 2080s (Butcher et al. 2016). A range of projected climate change impacts from a high-, medium-, and low-impact scenario was 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.

This final report provides an overarching summary of the pilot research project, including the methods used in and the findings of the quantitative and qualitative assessments.

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

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

Abstract – Final Project Report

This final report provides an overarching summary of the EPA Region 10 Climate Change and TMDL Pilot for the South Fork Nooksack River, Washington (pilot research project), including the methods and findings of the quantitative and qualitative assessments. The quantitative and qualitative assessments serve as the technical research reports developed for the pilot research project, while this final report summarizes the overarching approach and conclusions of the project. It is written to appeal to a wide audience of policy makers, managers, agency staff and the general public.

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. The Total Maximum Daily Load (TMDL) program, established by the Clean Water Act, is used to establish limits on loading of pollutants from point and nonpoint sources necessary to achieve water quality standards. One important use of a temperature TMDL is to allocate thermal loads to achieve water temperature criteria established for the protection of cold water fisheries. The pollutant in this case is thermal load and allocations to reduce the load often involve restoration of stream shading, which reduces the solar input. While many temperature TMDLs have been established, the supporting analyses have generally assumed a stationary climate under which historical data on flow and air temperature can serve as an adequate guide to future conditions. Projected changes in climate over the 21st century contradict this assumption. Air temperature is expected to increase in most parts of the US, accompanied in many areas by seasonal shifts in the timing and amount of precipitation, which in turn will alter stream flow. We reran the QUAL2Kw model for future climate conditions (multiple climate models for the 2020s, 2040s, and 2080s) using gridded downscaled climate data and hydrologic model runoff predictions developed by the Climate Impacts Group at the University of Washington to modify the critical conditions inputs using a change factor approach (presented in detail in the quantitative assessment). Establishing a mature riparian forest canopy can take 100 years, so it is important to begin planting riparian buffers now to reduce the anticipated climate change impacts on water temperature. Protection and restoration of local cold water refuges is another important adaptation strategy to mitigate the effects of climate change on aquatic life during high temperature events.

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. As part of the pilot research project, a comprehensive analysis of climate change impacts on freshwater habitat and Pacific salmon in the South Fork was conducted (presented in detail in the qualitative assessment). 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. 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.

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Contents

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Abbreviations and Acronyms

7-DADMax	highest 7-day average of the daily maximum temperatures
7Q10 flow	7-day average flow with a 10-year recurrence frequency
7Q2 flow	7-day average flow with a 2-year recurrence frequency
CIDT	Core Interdisciplinary Team
CIG	Climate Impacts Group
CREP	Conservation Reserve Enhancement Program
CWA	Clean Water Act
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESU	evolutionarily significant unit
GCM	global climate model
in	inches
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
ORD	EPA Office of Research and Development
OW	EPA Office of Water
PNW	Pacific Northwest
QUAL2Kw	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
SPV	system potential vegetation
TMDL	total maximum daily load
USFS	U.S. Forest Service
VIDT	Virtual Interdisciplinary Team
WDNR	Washington State Department of Natural Resources
WQS	water quality standards
WRIA	water resource inventory area

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Acknowledgements

We acknowledge and thank the Core Interdisciplinary Team (CIDT) that was formed to support the pilot research project effort. CIDT team members include members of the Nooksack Indian Tribe: 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; 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 Fisheries, who served as technical advisor.

We also want to acknowledge and thank the Peer Reviewers (Bruce Duncan, EPA Region 10; Karen Metchis, EPA Office of Water; Paul Pickett, Washington Deptartment of Ecology, and; Jim Markwiese, EPA Quality Assurance Officer) of this report for their insightful comments and suggestions that resulted in an 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, the Washington Department of Ecology, EPA ORD, the Lummi Nation, and Water Resource Inventory Area 1 salmon recovery and watershed management staff teams, as well as attendees from the project stakeholder workshops: the *Restoring Salmon Habitat for a Changing Climate In the South Fork Nooksack River, WA* workshop (Seattle, Washington, June 2012) and the *EPA Region 10 Climate Change and TMDL Pilot* workshop (Bellingham, Washington, January 22 and 23, 2013), which was cosponsored by EPA and the Nooksack Indian Tribe.

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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 the Nooksack early Chinook, an iconic species for the Nooksack Indian Tribe. Water temperature is critical to the health of salmon populations: They depend on cool, clean, well-oxygenated water for survival. The South Fork watershed currently is considered to be impaired by high water temperatures. As in most watersheds in the Pacific Northwest (PNW), the original conditions in the South Fork have been modified by human activity. Logging and conversion of native habitat for agriculture have greatly reduced riparian shading from its natural condition. As a result of the rising water temperatures, abundances of Nooksack salmon have dramatically declined from historic levels.

"The Nooksack Indian Tribe relies on salmon for subsistence, commercial, cultural, and ceremonial purposes"

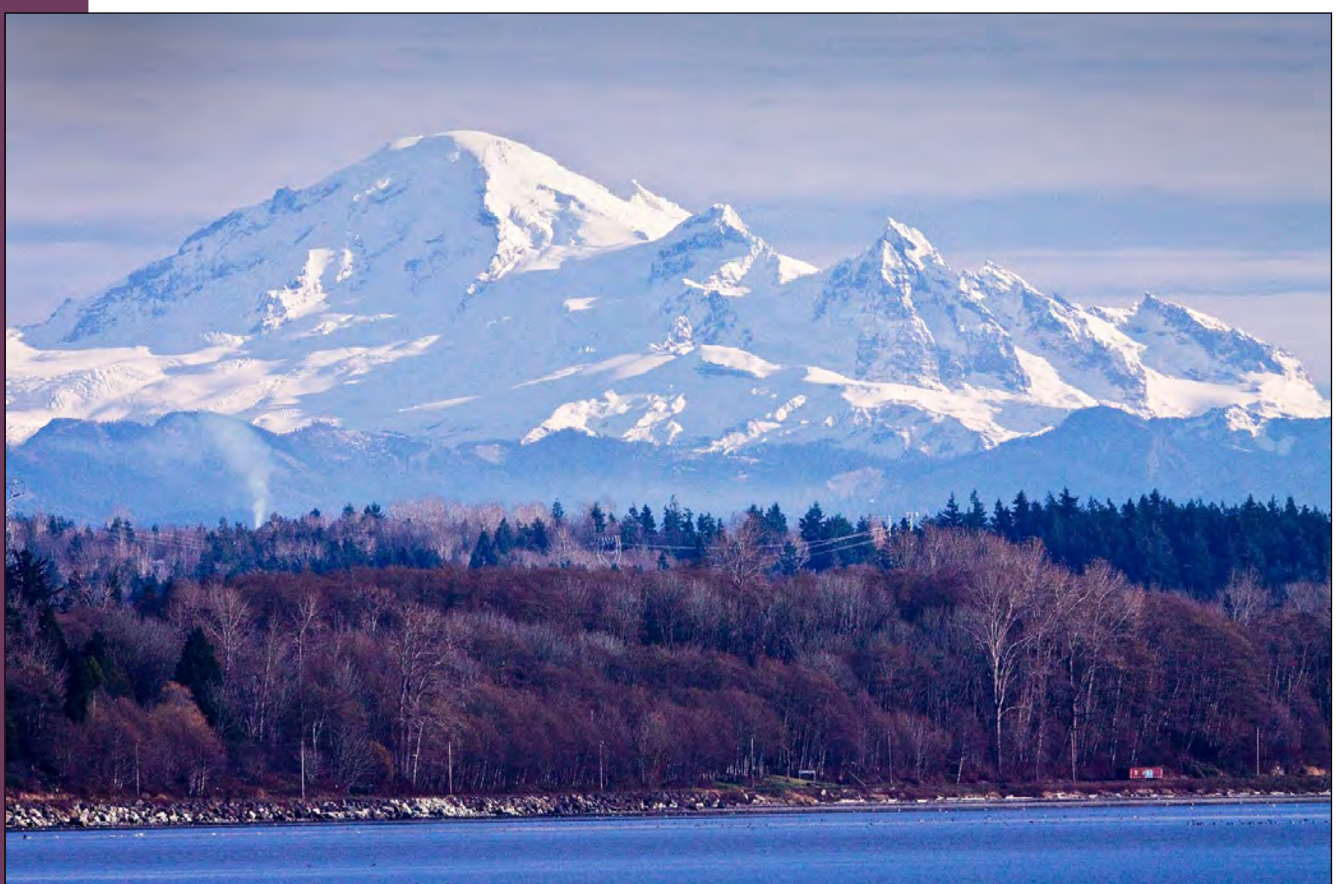
—Oliver Grah, Water Resources Program Manager, Nooksack Indian Tribe

Global climate change will exacerbate the current stresses facing salmon in the PNW. Its effects have the potential to significantly impact freshwater ecosystems through changes in both the thermal and hydrological regimes. The anticipated impacts of climate change combined with the historic legacy impacts in the South Fork represent significant cumulative stressors for salmon species in the river.

To better understand the potential effect of climate change on achieving water quality and salmon recovery goals, the U.S. Environmental Protection Agency's (EPA's) Region 10, Office of Research and Development, and Office of Water; the Washington Department of Ecology; the Nooksack Indian Tribe; and the Lummi Nation launched the collaborative EPA Region 10 Climate Change and TMDL Pilot for the South Fork Nooksack River, Washington (pilot research project).

The overarching goal of the pilot research project was to further EPA's understanding of how to incorporate projected climate change impacts into a total maximum daily load (TMDL) implementation plan, using the temperature TMDL developed for the South Fork as a pilot study. The TMDL program is one of the primary frameworks for maintaining and achieving healthy waterbodies nationwide, implemented pursuant to section 303(d) of the Clean Water Act. Additionally, the collaborative framework and coordinated research components conducted as part of the pilot research project provided the opportunity to move beyond the regulatory goal of the South Fork temperature TMDL and synergistically explore how climate change might influence salmon recovery actions and restoration plans prepared in the context of the Endangered Species Act.

The pilot research project was structured into two research components—a quantitative assessment and a qualitative assessment—and relied on stakeholder engagement as a fundamental, cross-cutting element. The stakeholder-centric element benefited from the participation of both



Mount Baker, northeast of South Fork Nooksack River in Bellingham, WA. Credit: Rick Leche, Flckr.com

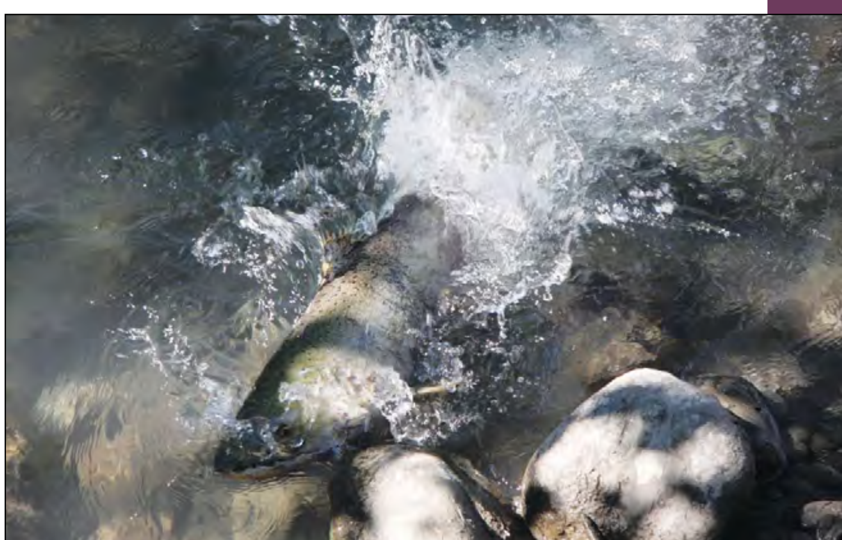
knowledgeable scientists and informed laypeople, and included several stakeholder involvement events (i.e., 10 workshops, meetings, and webinars).

The quantitative assessment evaluates the implications of climate change for the water temperature TMDL developed for the South Fork, using best available climate science (Butcher et al. 2016). This assessment used quantitative methods (e.g., the QUAL2Kw water quality model) to project future temperatures in the South Fork. It compares modeled stream temperatures to the state's cold-water temperature water quality standard to inform the TMDL implementation plan.

Results from the quantitative assessment show that the risk of higher water temperatures will accelerate over time (Butcher et al. 2016). Predicted increases in heat inputs and lower summer flows associated with a reduction in the storage of winter snowpack will combine to exacerbate summer water temperature extremes under low-flow critical conditions. The QUALK2w model simulations suggest that, without restoration of riparian shade, water temperatures during critical summer low-flow conditions could increase by amounts ranging from 3.5 to almost 6 degrees Celsius by the 2080s. Restoration of full system potential riparian shading can help buffer against temperature increases and mitigate from 30 to 60 percent of the critical period increase; however, even with system potential shade, average stream water temperatures are projected to increase.

The qualitative assessment was conducted to consider important habitat features other than riparian shading that also can affect salmon recovery (EPA 2016). This assessment 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. While including the findings of the quantitative assessment, the qualitative assessment used local and tribal knowledge of the Nooksack Indian Tribe to identify and prioritize climate change adaptation strategies.

The qualitative assessment found that 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 (EPA 2016).



Female Chinook salmon. Credit: U.S. Geological Survey, Department of the Interior/USGS, U.S. Geological Survey/photo by Jeff Duda

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 salmon species and life stages vulnerable. The assessment results show that the most important actions to take in ameliorating the impacts of climate change in the South Fork watershed are riparian restoration, floodplain reconnection, wetland restoration, and placement of log jams.

Bull trout. Credit: U.S. Fish and Wildlife Service

1.0 Introduction

Salmon are an integral component of the ecosystem and culture of the Pacific Northwest (PNW). In fact, salmon are considered an *ecological keystone species*[1] because of the benefit they provide to aquatic and terrestrial ecosystems as well as a *cultural keystone species*[2] given their role in the cultural identity of the coastal PNW indigenous tribes (Hilderbrand et al. 2004; Garibaldi and Turner 2004).

The South Fork Nooksack River (South Fork) is located in northwest Washington State (Figure 1-1) and is home to nine species of Pacific salmon, including the Nooksack early Chinook (also referred to as spring Chinook salmon), an iconic species for the Nooksack Indian Tribe. Abundances of Nooksack salmon have dramatically declined from historic levels. Estimates of historical habitat conditions suggest that the South Fork supported approximately 13,000 Chinook salmon (habitat model-based estimate) (WRIA 1 2005). During 2011 through 2013, the average escapement estimate for Nooksack early Chinook was only 70 salmon (Washington Department of Fish and Wildlife 2014).

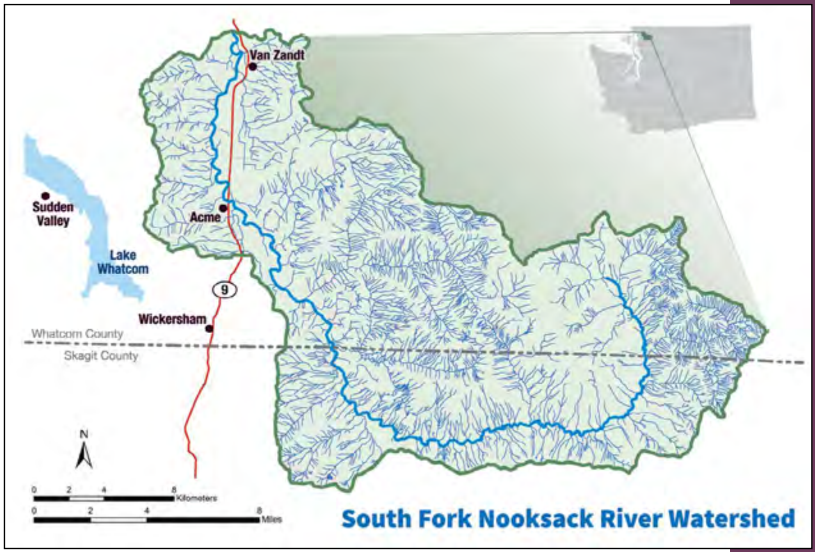


Figure 1-1. Map of the South Fork Nooksack River watershed.

Water temperature is critical to the health of salmon populations: They depend on cool, clean, well-oxygenated water for survival. As with most watersheds in the PNW, the original conditions in the South Fork have been modified by human activity. Logging and conversion of native habitat for agriculture have greatly reduced riparian shading from its natural condition. Diminishing snowpack due to climate change also has contributed to rising water temperatures. The South Fork watershed is currently considered to be impaired by high water temperatures, which can be detrimental to salmon.[3]

Key Message from the *Third National Climate Assessment* for the Pacific Northwest:

"Changes in the timing of streamflow related to changing snowmelt are already observed and will continue, reducing the supply of water for many competing demands and causing far-reaching ecological and socioeconomic consequences."

Mote et al. 2014

1 As further described in Hilderbrand et al. (2004), salmon significantly contribute to nutrient flow across aquatic ecosystems and are of nutritional importance to wildlife.

2 *Cultural keystone species* are the "plants and animals that form the contextual underpinnings of a culture, as reflected in their fundamental roles in diet, as materials, or in medicine" (Garibaldi and Turner 2004).

3 Every two years, states are required to prepare a list of water bodies that do not meet water quality standards. This list is called the Clean Water Act 303(d) list. In Washington State, this list is part of the Water Quality Assessment (WQA) process. Further information is available at the Washington Department of Ecology's Water Quality Assessment website: here.

What is a TMDL?

A *total maximum daily load* (TMDL) is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. That pollutant load is allocated among the various sources. The pollutant for the South Fork Nooksack River is temperature.

Global climate change will exacerbate the current stresses facing salmon in the PNW. It has the potential to significantly impact freshwater ecosystems through changes in both the thermal and hydrological regimes. Stream temperatures are projected to increase in most rivers, influenced by rising air temperatures. Changes in hydrology—particularly a reduction in summer flows resulting from a shift from a snow-dominant to a rain-dominant regime—could diminish river volumes and lead to higher temperatures. The anticipated impacts of climate change combined with the historic legacy impacts in the South Fork represent significant cumulative stressors for salmon species in the river.

Clearly, there is a need for watershed managers and stakeholders to consider climate-induced changes that are currently affecting water quality in the South Fork and to plan for future scenarios. To date, however,

Early South Fork Nooksack River. Credit: Nooksack Tribe

Nooksack River, Whatcom County. Credit: John Lemieux, Flickr.com

climate change has not been addressed in the watershed management tools and strategies used to govern the South Fork watershed.

Indeed, the potential impacts of climate change represent a knowledge gap for water resource managers across the country. The total maximum daily load (TMDL) program is one of the primary frameworks for maintaining and achieving healthy waterbodies nationwide, implemented pursuant to section 303(d) of the Clean Water Act (CWA). A TMDL is developed for an impaired waterbody to determine the maximum pollutant loads allowable that will still permit attainment of water quality standards (WQS) and describes the measures that must be taken to reduce pollution levels in the waterbody. While more than 40,000 TMDLs have been developed in the United States, the vast majority of them have been developed with no consideration being given to climate change (EPA 2017).

Similarly, climate change is of increasing concern in the context of the Endangered Species Act (ESA). While Congress has urged the U.S. Fish and Wildlife Service and NOAA Fisheries to consider the potential effects of climate change on species, no established methodology exists for conducting that analysis (Webb and Weissman 2014).[4]

To help better understand the potential impact of climate change on achieving water quality and salmon recovery goals, the EPA Region 10, Office of Research and Development (ORD), Office of Water (OW), Washington Department of Ecology (Ecology), Nooksack Indian Tribe, and the Lummi Nation launched the

Chinook Salmon (juvenile) Credit: USFWS

4 NOAA recently published eight research case studies on considering climate change in ESA, which are summarized on NOAA's website, A Changing Climate for Endangered Species (2016), available online here. The eight research case studies were published in Conservation Biology and are available online here.

collaborative EPA Region 10 Climate Change and TMDL Pilot for the South Fork Nooksack River, Washington (pilot research project).

This report will summarize the key activities and findings of the pilot research project and is organized into the following sections:

Section 2: Goals and Objectives

Section 3: Problem Formulation

Section 4: Research Approach

Section 5: Stakeholder and Tribal Engagement

Section 6: Results

Section 7: Discussion

Section 8: Conclusions

2.0 Goals and Objectives

The overarching goal of the pilot research project was to further EPA's understanding of how to address projected climate change impacts in a TMDL implementation plan, using the temperature TMDL developed for the South Fork as a pilot study. Additionally, the collaborative framework and coordinated research components conducted as part of the project provided the opportunity to move beyond the regulatory goal of the South Fork temperature TMDL implementation plan to also determine how climate change might influence ESA recovery actions and restoration plans.

The pilot research project was designed as *objective-driven research*[5], in which objectives are established to serve as project goals, rather than *hypothesis-driven research*, in which a hypothesis is created and subjected to empirical testing. In objective-driven research, objectives aimed at scientific and/or technological advances are defined to guide research and used as benchmarks of progress.

Five key objectives were identified to guide project outcomes and include the following:

- Assess the potential impacts of climate change on stream temperature and stream flow for a temperature TMDL implementation plan.
- Prioritize stream restoration actions under climate change for ESA salmon recovery planning.
- Guide implementation of EPA's National Water Program 2012 Strategy: Response to Climate Change.
- Support EPA's National Tribal Science Priorities for Climate Change and Integration of Traditional Ecological Knowledge.
- Internal to EPA: Demonstrate how parts of EPA, the regions, program office, OW, and ORD can jointly engage in the planning, execution, and evaluation of a pilot research project.

The pilot research project was initiated to better understand the impacts that climate change might have on the South Fork and to explore how to integrate that understanding into watershed management tools and strategies.

Specific focus was given to the total maximum daily load (TMDL) program, specifically the TMDL implementation planning process, and salmon recovery planning under the ESA.

NOAA Biologist with Chinook Salmon. Credit: NOAA

5 There is no formal research theory around "objective-driven research" although it is a generally accepted method of developing a research project. An interesting description of objective-driven research being used to drive integrated thinking is found in Provisions for Implementing Integrated Projects (European Research 2002), available online here.

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3.0 Problem Formulation

Climate change has the potential to significantly impact the nation's freshwater ecosystems. No agreed-upon methodologies or approaches exist, however, to incorporate climate change considerations into watershed management planning tools such as the TMDL implementation planning process and ESA salmon recovery planning program. This project was first conceived as a pilot project in 2011 by EPA ORD and EPA Region 10 to assess how adaptation to climate change could be incorporated into the TMDL program, specifically into the TMDL implementation planning process.

ESA Salmon Recovery Planning

The ESA requires NOAA Fisheries and states to develop and implement recovery plans for salmon species listed under the Act. Recovery plans identify actions needed to restore threatened and endangered species to the point at which they are again self-sustaining elements of their ecosystems and no longer need protection.

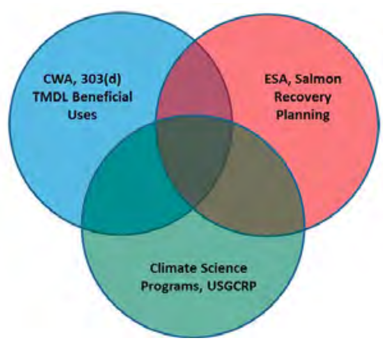
At that time, EPA Region 10, Ecology, the Nooksack Indian Tribe, and the Lummi Nation also began collaborating on the development of a temperature TMDL for the South Fork. The South Fork has 14 mainstem segments and nine tributary segments identified as being impaired for temperature on Washington's 2008 303(d) list. These areas exceed the temperature criteria established by Ecology to protect aquatic life use categories (salmon versus warm-water species) and life-stage conditions (spawning and rearing). The collaborating partners on the South Fork temperature TMDL expressed independent interest in better understanding how climate change might impact water temperature in the future and influence the TMDL implementation plan.

EPA developed the concept of using a *parallel study strategy* to concurrently accomplish the research objective of exploring how climate change considerations could be incorporated into the TMDL implementation plan, with the regulatory objective of developing the South Fork temperature TMDL. This parallel study strategy allows EPA to *learn by doing*. The project team for the pilot research project expanded from EPA ORD, EPA Region 10, EPA OW, and EPA's consultant (Tetra Tech) to include Ecology, the Nooksack Indian Tribe, and the Lummi Nation as cooperating partners.

The project team recognized that appropriate problem formulation was key to achieving both the research and regulatory objectives; and that stakeholder input would be critical to developing meaningful goals and activities. 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's scope, approach, and methods.

At the workshop, stakeholders clearly demonstrated that important linkages exist between the TMDL implementation plan and ESA salmon recovery planning processes. There was a general recommendation to structure the pilot research project in such a way that it would mutually enforce both of these watershed management planning tools for the South Fork. Thus, the pilot project design was expanded to consider not only how awareness of projected climate change impacts could be incorporated into the South Fork temperature TMDL implementation plan, but also how those impacts might influence restoration actions and plans for the South Fork.

Stakeholders also recognized that simply assessing changes in temperature relevant to WQS would not provide a robust assessment of habitat factors that influence salmon. Local and tribal knowledge was identified as a critical element to assess, identify, and ultimately implement site-appropriate adaptation strategies.



The pilot research project represents the integration of three key environmental management programs.

Based on this feedback, the pilot research project was formulated to integrate three key management programs: CWA section 303(d), which provided the science and policy context; the ESA salmon recovery goals, which are integral to achieving both salmon recovery and attaining the beneficial uses under the CWA; and the latest climate science out of the *U.S. Global Change Research Program* (USGCRP). To support this programmatic framework and achieve the project goals and objectives, the pilot research project was designed to include two primary assessments:

- Quantitative Assessment—to evaluate the implications of climate change for the water temperature TMDL implementation plan developed for the South Fork, using best available climate science (Butcher et al. 2016). This assessment used quantitative methods (e.g., the QUAL2Kw water quality model) to estimate future temperatures of the South Fork.
- Qualitative Assessment—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 (EPA 2016). While including the findings of the quantitative assessment, the qualitative assessment used local and tribal knowledge of the Nooksack Indian Tribe to identify and prioritize climate change adaptation strategies.

USGCRP Climate Science Programs

The U.S. Global Change Research Program (USGCRP) is a federal program that coordinates and integrates global change research across 13 government agencies to ensure that it most effectively and efficiently serves the nation and the world. Refer to www.globalchange.gov/

3.1 Pilot Area

The South Fork was identified as the pilot area for this research effort primarily because of the interest expressed by the Nooksack Indian Tribe and Lummi Nation to consider climate change in the temperature TMDL implementation plan for the South Fork.

The pilot area includes all portions of the South Fork Nooksack River watershed, which is located in Whatcom and Skagit counties in northwest Washington State (Figure 3-1). The river flows to the mainstem Nooksack River, which empties into Bellingham Bay. The South Fork is in an area considered typical of the mountainous, remote, forested landscape in that region, with minor urban and agricultural land uses. Forest practices, including road building and timber harvest, are the dominant land-use practices in the watershed.

The South Fork and its tributaries provide migration routes, and spawning and rearing habitat for nine salmon species throughout the year. Salmon in the Nooksack River watershed are of great subsistence, ceremonial, and cultural importance to the Lummi Nation and Nooksack Indian Tribe, yet abundances of many salmonid populations have diminished substantially from historic levels. Local spring Chinook, bull trout, and steelhead populations comprise components of the Puget Sound Chinook Evolutionarily Significant Unit (ESU), Puget Sound Steelhead ESU, and Coastal-Puget Sound Distinct Population Segment (DPS), all of which are listed as threatened under the federal ESA.

At the June 2012 kick-off meeting, the following benefits of using the South Fork as the pilot area for the pilot research project were identified:

- The synchronized pairing of the research project with a real-world temperature TMDL implementation plan ensures better understanding of the needs of water managers.
- The pilot area represents a typical landscape in the PNW, which promotes broader direct application of the project results.
- The pilot research project will be able to leverage downscaled climate data sets and integrate ongoing research by other agencies that is directly relevant to the project (see text box on the following page).
- Stakeholder desire (Lummi Nation and Nooksack Indian Tribe) was strong to collaborate on a climate change study that also informs ESA salmon recovery planning.

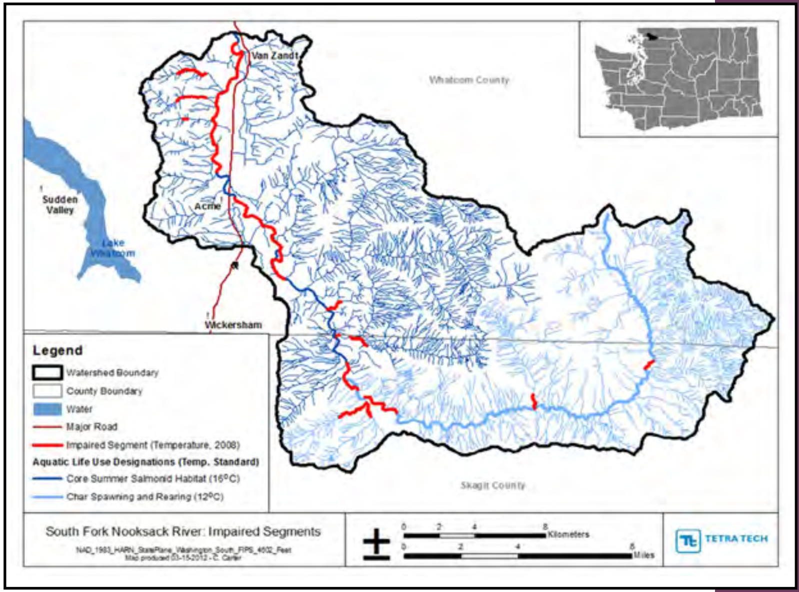


Figure 3-1. Map of the pilot area with temperature-impaired stream segments in red.

3.2 Risk Assessment Framework

Because of the inherent uncertainty of climate change and the iterative nature of watershed management, the project team recognized that a logic model was needed as a framework to guide the assessment process.

The project is structured as a *risk assessment* in which a range of outcomes from the Intergovernmental Panel on Climate Change (IPCC) emission scenarios is assessed, rather than a single prediction of climate change effects on stream temperature and the related WQS.

The team leveraged the traditional risk assessment paradigm used by EPA and other federal agencies that was originally developed for the human health context and then applied to the ecological context. This traditional risk assessment paradigm was extended to the climate change context and is presented as Figure 3-2.

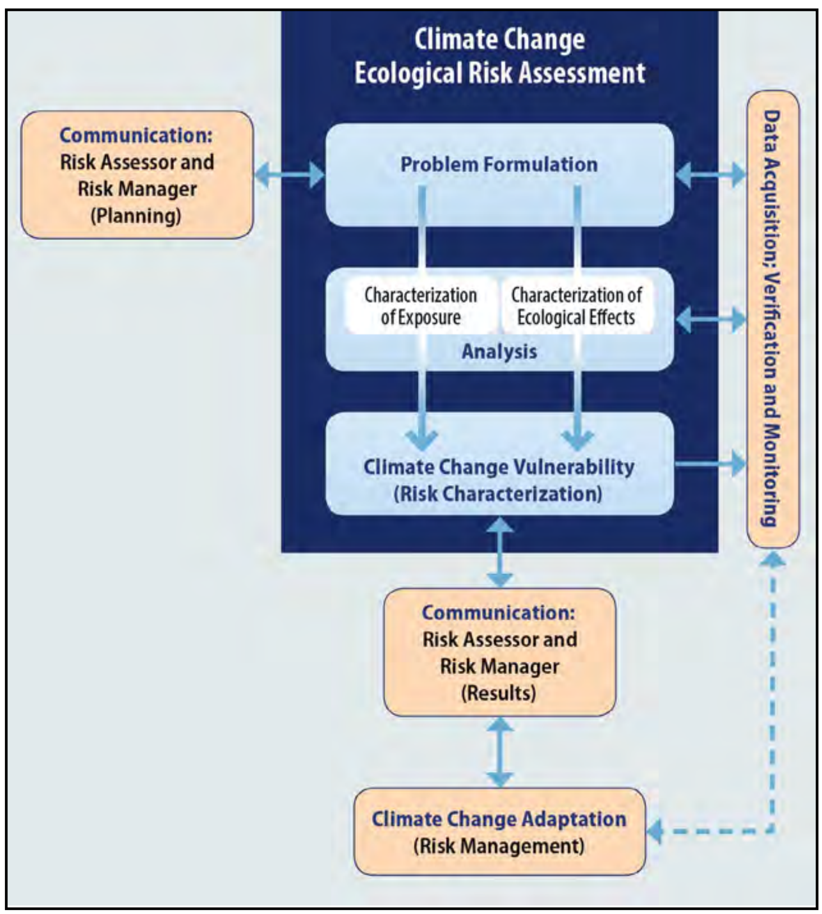


Figure 3-2. Ecological risk assessment framework with climate change included in the process. Modified from Framework For Ecological Risk Assessment, EPA/630/R-92/0001, February 1992.

Ability to Leverage Notable Research for the South Fork

Notable research involving the South Fork and available to be leveraged for the pilot research project was identified at the workshop and includes the following:

- ✓ The Climate Impacts Group (CIG) of the University of Washington has developed hydroclimatic scenarios for the PNW, including for the pilot area (Mauger and Mantua 2011).
- ✓ Dan Isaak, USFS, with support from the Great Northern Landscape Conservation Cooperative, is developing a regional stream temperature model.
- ✓ Tim Beechie, National Oceanic and Atmospheric Administration (NOAA), is exploring steelhead salmon vulnerability, including from climate stress (Beechie et al. 2013).
- ✓ Cristea and Burges, University of Washington, conducted an assessment of stream temperature and riparian shading for several streams in the Wenatchee River Basin to evaluate the potential impact of climate change on stream temperature (Cristea and Burges 2010).

As illustrated in the figure, climate change is viewed as an additional stressor to the environment. Climate change risk is analyzed through a characterization of exposure and ecological effects. Risk is continually reevaluated through new data acquisition. Thus, the iterative risk management framework is essentially an adaptive management framework that can be used as an approach to verify, monitor, and evaluate climate change adaptation strategies.

Climate change presents additional complexities beyond the traditional risk assessment. The magnitude of consequence, as well as the likelihood of future risk, must be understood. The National Climate Assessment presents a risk matrix paradigm to explore iterative risk management (Melillo et al. 2014). The project team expanded that model by adding two dimensions to make it robust enough to address both climate change effects and salmon habitat as end points (Figure 3-3). The dimensions of time—2020, 2040, and 2080—were added, while the uncertainty of climate change is expressed by a range of outcomes. In the diagram, the green line represents the low-impact scenario, the blue line represents the medium-impact scenario, and the purple line represents the high-impact scenario. The color of the box—yellow, orange, or red—determines whether the approach should be watching, evaluating, or developing, and implementing strategies to invoke climate change adaptation and reduce risk. While this matrix was originally developed to consider impacts on infrastructure, the project team considers this matrix (with the additions of time and climate scenarios) a useful framework to evaluate species and habitat risk.

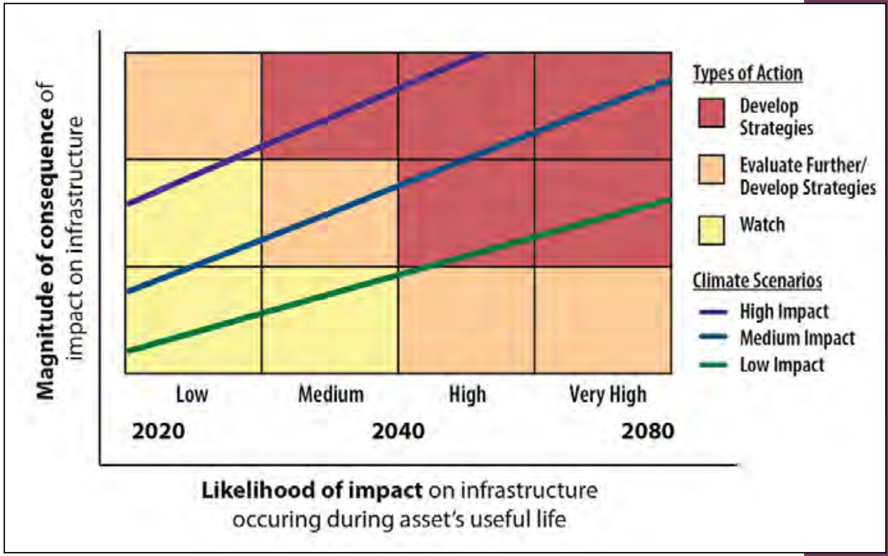


Figure 3-3. Risk matrix showing appropriate types of action based on likelihood of impact, magnitude of consequences, and climate scenarios (purple, blue, and green lines) (Source: Yohe 2001).

Critically for this project, restoration actions that are undertaken today may not be fully realized until far into the future. Restoration actions such as the establishment of mature riparian forests and flood plain reconnections could take decades to manifest themselves in the natural environment. For climate change, it is important to factor in the element of time, both in the timing of future impacts and in the planning and realization of future adaptation strategies.

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4.0 Research Approach

4.1 Parallel Study Strategy

A parallel study strategy was developed to provide a structured research approach in the context of regulatory implementation. The study strategy was designed to maximize the timing of research activities so that findings could be integrated into the development of the South Fork temperature TMDL. Figure 4-1 illustrates the parallel study strategy, where the research

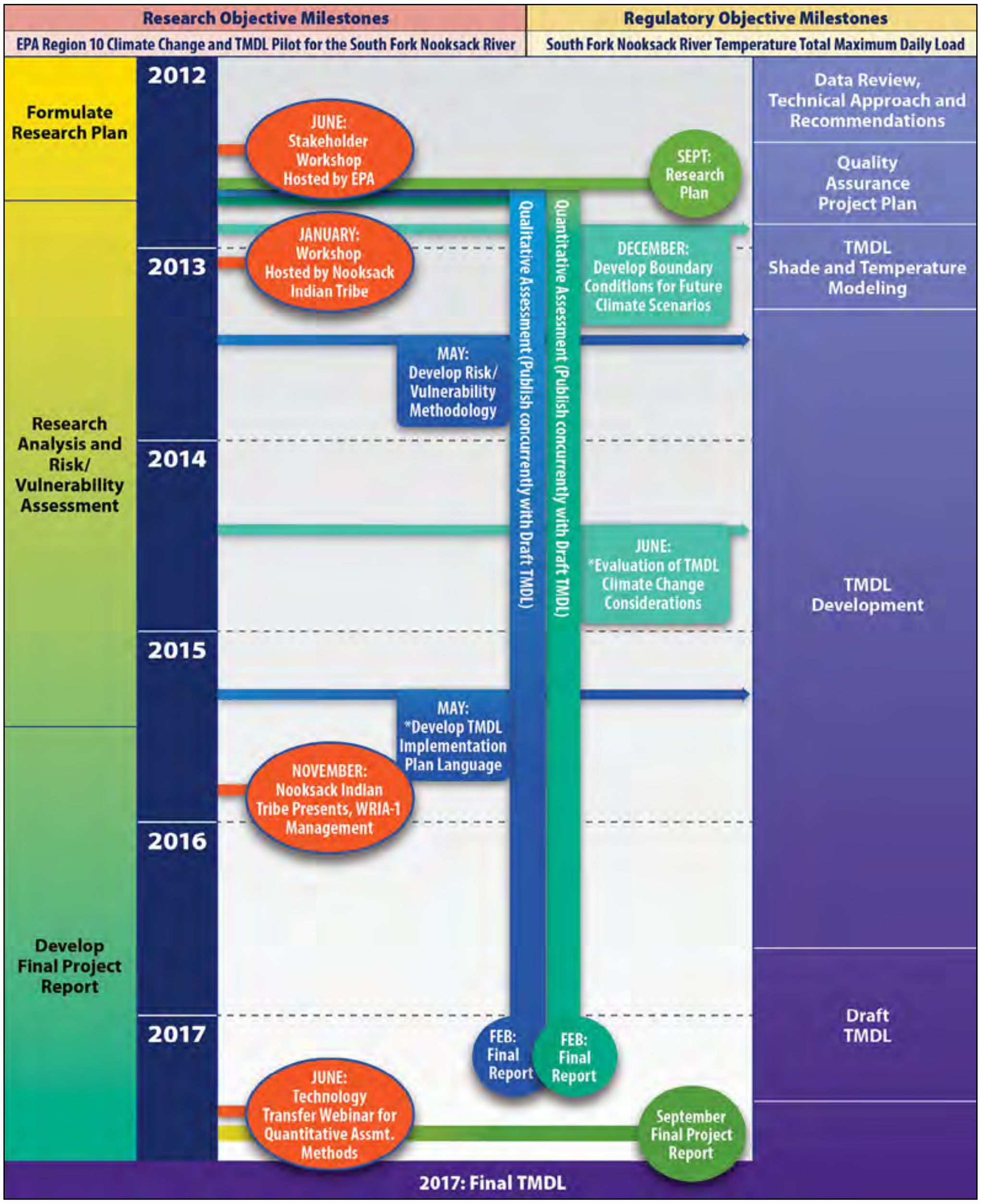


Figure 4-1. Pilot research project and temperature TMDL parallel study strategy and major milestones.

and regulatory objective milestones are identified across the project time horizon (beginning with 2012 at the top of the graphic and ending with 2017 at the bottom). This strategy was used to concurrently accomplish the research objective of exploring how adaptation to climate change could be incorporated into the TMDL implementation planning process, with the regulatory objective of developing the South Fork temperature TMDL.

The research thread (on the left in the figure) runs from the development of the project research plan at project outset through publishing of the final project report (this document), which summarizes project activities and findings. The quantitative and qualitative assessment milestones flow from top to bottom as components of the research thread.

The regulatory thread (on the right in the figure) identifies milestones associated with the South Fork temperature TMDL, including the filing of the TMDL by Ecology.

The two threads are playing out across time (2012–2017), with the research outputs directly incorporated into the regulatory thread. Research outputs include the development of boundary conditions for future climate scenarios and comparison of modeled stream temperatures to the state's cold-water temperature WQS from the quantitative assessment; and development of risk/vulnerability methodologies and TMDL implementation plan language from the qualitative assessment.

Stakeholder involvement, which is critical to the success of the pilot research project, occurred throughout the project and is described in section 5. Key stakeholder engagement milestones are shown in orange circles.

The final reports from the quantitative (Butcher et al. 2016) and qualitative (EPA 2016) assessments are companion methods documents to the regulatory TMDL developed by Ecology and the updated ESA salmon recovery plan for the South Fork developed by the Nooksack Indian Tribe. The methodology of the two assessments is described in section 4.2, while the findings are summarized in section 6.

4.2 Methods

The pilot research project was structured using quantitative and qualitative assessments, and relied on stakeholder engagement as a fundamental, cross-cutting element.

The quantitative assessment compares output of stream temperatures from the QUAL2K water quality model (including riparian shading), for scenarios with and without climate change for the 2020s, 2040s, and 2080s (Butcher et al. 2016). It directly relates to the CWA numeric cold-water standard.

To consider all of the other important habitat features that come into play for salmon recovery, the qualitative assessment was conducted. It is a comprehensive analysis of freshwater habitat for ESA recovery actions in the South Fork under climate change. The results, which were included in the TMDL implementation plan, are a prioritized list of climate change adaptation strategies—real-world implementation—that support the restoration. Taken together, the quantitative and qualitative assessments will help protect the beneficial uses and ESA recovery goals under climate change.

Figure 4-2 highlights the overarching stepwise methodology of the pilot research project, which included problem formulation (step 1), development of the research approach (step 2), and climate change analysis and vulnerability assessment (step 3), with stakeholder engagement cross-cutting the process. Climate change analysis and vulnerability assessment (step 3) was conducted via the quantitative and qualitative assessments. The quantitative assessment involved four substeps: watershed modeling, climate change modeling, developing future boundary conditions, and

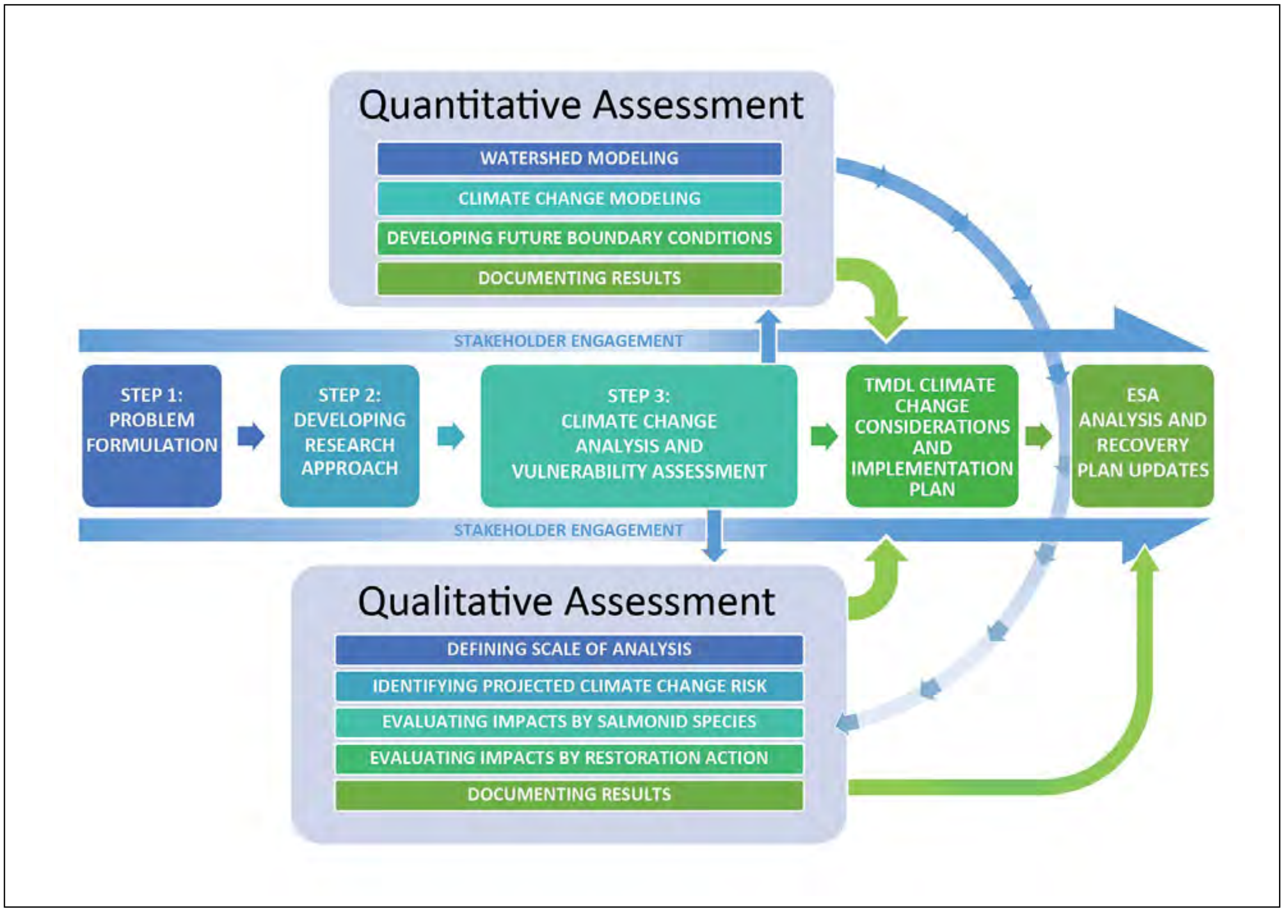


Figure 4-2. Relationships between the outputs of the quantitative and qualitative assessments in the pilot research project process

documenting results (Butcher et al. 2016). The qualitative assessment involved five substeps: defining the scale of analysis, identifying projected climate change risk, evaluating the impacts by salmonid species, evaluating the impacts by restoration action, and documenting the results (EPA 2016).

Figure 4-2 also illustrates the relationships between the outputs of the assessments. The quantitative assessment results were used to inform the qualitative assessment. Results of both assessments were used to inform the South Fork temperature TMDL implementation plan. The qualitative assessment also will be used to inform future ESA salmon recovery plans for the South Fork.

4.2.1 Quality Assurance

The pilot research project 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 the pilot research project 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 the quantitative and qualitative assessments. Other published and unpublished reports are used as secondary data and cited throughout this report. 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 judgment 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.

The Quantitative Assessment is considered a methods manual for the climate change modeling conducted for the pilot research project.

The Quantitative Assessment objectives include:

- Compare modeled stream temperature, including riparian shading, with and without climate change for the 2020s, 2040s, and 2080s.
- Compare modeled stream temperatures to the cold-water temperature WQS for protecting salmonids to inform the TMDL implementation plan.
- Use a risk assessment approach to provide risk managers with an understanding of potential climate change impacts on stream temperatures and stream flow.

The Quantitative Assessment is available online here.

4.2.2 Quantitative Assessment Methods

The quantitative assessment serves both as a place-based analysis of risks associated with climate change in the South Fork and as a *how-to* example of technical methods that can be applied in temperature TMDL implementation plans at other sites and, more generally, the evaluation of any temperature-sensitive watershed responses important to regulatory and planning applications.

The quantitative assessment evaluated the implications of climate change for the water temperature TMDL implementation plan developed for the South Fork (Butcher et al. 2016). The associated modeling used stream hydrology simulations in conjunction with an analysis of shading to predict the temperature in the South Fork during the critical period, which is the period with summer low flows and elevated air temperatures, when river temperatures are most at risk of exceeding the water quality criteria, jeopardizing aquatic life uses of the river.

In Washington State WQS, aquatic life use categories are described using key species (e.g., salmon versus warm-water species) and life-stage conditions (e.g., spawning versus rearing). The temperature criteria established to protect these species and conditions include numeric criteria of 12 degrees Celsius (°C) for char spawning and rearing; and 16 °C for core summer salmonid habitat. The criteria are based on the highest 7-day average of daily maximum temperatures (7-DADMax). Temperatures are not to exceed the criteria at a probability frequency of more than once every 10 years on average. When the background condition is cooler than the criteria, the temperature increases resulting from the combined effect of all nonpoint source activities in the waterbody must not, at any time, exceed 2.8 °C.[6]

The temperature criteria applicable to the South Fork are listed in Table 4-1. Where the 'natural' conditions are greater than the numeric criteria, the state standards allow an increase of no more than 0.3° due to human actions.

The South Fork has 14 mainstem segments and nine tributary segments identified as impaired by elevated water temperature on Washington's 2010 303(d) list. These segments are documented to exceed the temperature criteria established by Ecology to protect aquatic life use categories (salmonid habitat) and life-stage conditions (spawning and rearing).

Table 4-1. Washington State temperature criteria for the South Fork Nooksack River watershed

Use Classification	Numeric Temperature Criteria[1,2]
Core summer salmonid habitat, spawning, rearing, and migration	< 16 °C 7-DADMax
Char spawning and rearing	< 12 °C 7-DADMax
Supplemental salmonid spawning and incubation	< 13 °C 7-DADMax (Sept 1–Jul 1)

Source: WAC 173-201A-200, 2003 edition.
Notes:
[1] The highest annual running 7-day average of daily maximum temperatures.
[2] When a water body's temperature is warmer than the criteria in Table 200 (1)(c) (or within 0.3°C (0.54°F) of the criteria) and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C (0.54°F)" (WAC173-201A-200(1)(c)(i)).

6 As identified in the Washington Administrative Code [WAC] 173-201A-200; 2003 edition.

The temperature TMDL implementation plan is intended to address these conditions and identify the solutions needed to improve river temperatures and support designated uses. The quantitative assessment methodology was developed to complement the South Fork temperature TMDL modeling efforts and explore how future climate scenarios might impact achievement of temperature criteria important for development of the implementation plan.

The South Fork TMDL modeling analysis used to estimate the temperature TMDL consists of a shade model (Ecology 2003b) linked to the QUAL2Kw water quality model (Ecology 2003a). The shade model quantified the potential daily solar load and generated the percent effective shade, while QUAL2Kw was used to simulate instream water temperature. The quantitative assessment used these same models but accounted for air and water temperature and stream flow changes as a result of various climate scenarios and applied shading at different levels to evaluate the effects on stream temperature (Butcher et al. 2016). The quantitative assessment methodology steps included watershed modeling, climate change modeling, and developing future climate-related stream flow conditions. The approach for each of these steps is described in more detail below.

Watershed Modeling

The shade model was used to evaluate the impacts of restoring system potential vegetation (SPV) and associated shade in the TMDL. SPV is the mature (100-year+) tree community expected to be obtained on a given soil type if the riparian corridor was left undisturbed, also considered to be most like the natural watershed conditions prior to European settlement. Increased shading typically reduces daily maximum water temperatures but has a lesser impact on minimum and daily average water temperatures (Johnson 2004). Washington State Department of Natural Resources (WDNR) and county soil surveys identify Douglas fir and western hemlock as the dominant species over most of the project area. At SPV, these trees, in this location, should have a 90th percentile height of 50.66 meters. Figure 4-3 illustrates the model results for

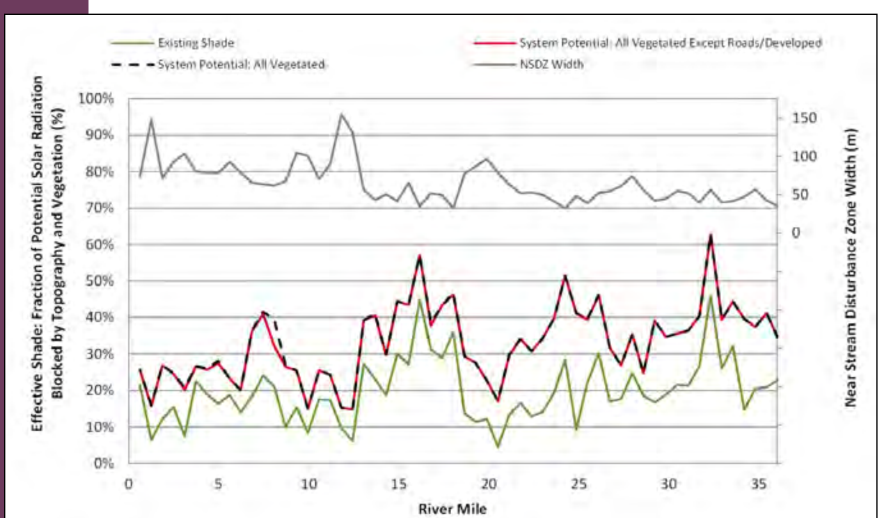


Figure 4-3. Effective shade values under existing conditions and at system potential vegetation.

effective shade cover over the river under existing vegetation conditions and at the SPV shade levels.

For the TMDL, the QUAL2Kw model was applied to conduct focused analyses of critical conditions (e.g., late summer low flow, clear sky, and high air temperature conditions) that exacerbate temperature impairments, from which TMDL targets were determined directly. The models were developed for well-monitored 2007 and 2010 summer conditions.

The modeling team developed a series of modeling scenarios to evaluate stream temperatures on the mainstem of the South Fork under various typical and critical summer conditions. During both typical low-flow and critical low-flow conditions, and corresponding meteorological conditions in the summer, the calibrated model estimated that the South Fork exceeds the numeric water quality criteria of 12 °C (from the headwaters to reach 28) and 16 °C (from reach 28 to the outlet) in nearly all mainstem river segments, consistent with recent observations. To estimate the stream temperature profile under conditions of maximum potential shade, the models were run with 100-year SPV, associated microclimate effects, and tributaries and headwaters at or below the numeric water quality criteria. Under both typical and critical 100-year SPV scenarios, the model predicted that the stream will continue to exceed the numeric water quality criteria for temperature.

Due to the legacy impacts on the South Fork (such as landuse changes from forestry practices, clearing and settlement, and agriculture), several supplemental modeling scenarios were undertaken as a sensitivity analysis for the TMDL analysis to compare possible stream temperature responses during critical conditions with inferred historical conditions for the watershed land cover and stream channel geometry. These analyses suggest that, under historical conditions, stream temperatures during low-flow critical conditions could be as much as 16 percent lower than predicted under the 100-year SPV scenarios, with the predicted average maximum stream temperature across all reaches dropping from 18.7 to 15.8 °C.

Conditions Prior to European Settlement

- Cooler headwater tributaries
- Reduced natural channel width
- Increased riparian climax tree height, greater buffer width
- Enhanced hyporheic exchange
- Reduced critical condition water temperature
- Reduced levels of sediment delivery, loading, and transport

Climate Change Modeling

The primary objective of this modeling effort was to supply new climate information to the QUAL2Kw model based on projected future changes to the climate and to assess the results.

This project was able to leverage downscaled climate data sets and integrate ongoing research by the Climate Impacts Group (CIG) of the University of Washington. The basis of the CIG's climate change assessment is a common set of simulations from the Special Report on Emissions Scenarios (SRES) using 21 global climate models (GCMs)

What's the 7Q10 Flow?

The lowest 7-day average flow that occurs once every 10-years, on average.

What's the 7Q2 Flow?

The lowest 7-day average flow that occurs once every 2 years, on average.

coordinated through the IPCC (Randall et al. 2007). These GCMs have established a range of projections of future climate based on various emission scenarios. The GCMs model project climate conditions at a large spatial scale (approximately 15,000 square miles), however, and do not account for local topography.

The CIG used a downscaling approach to determine the relationship between GCM output and local climate variations for a more local analysis. The group took projected time series from GCMs and downscaled the meteorological output to a 1/16-degree resolution (approximately 6,600 acres) for the PNW (Hamlet et al. 2013; Polebitski et al. 2007).

A general schematic of the relationships between CIG climate products and the TMDL model is shown in Figure 4-4. For this project, a limited subset of model results for the IPCC A1B emissions scenario was selected for evaluation.

The A1B scenario was considered a moderate emissions scenario as compared to several other IPCC scenarios with more rapid increases in greenhouse gasses. The models in the A1B scenario have a mean temperature increase that is 1 °C lower at the end of the 21st century than the A2 (high emissions) scenario, but the range among models in the A2B scenarios covers most of the A2 range as well. Three time horizons (representative of projected climate in the 2020s, 2040s, and 2080s) were evaluated using results from GCMs under the A1B scenario downscaled for the South Fork Nooksack watershed.

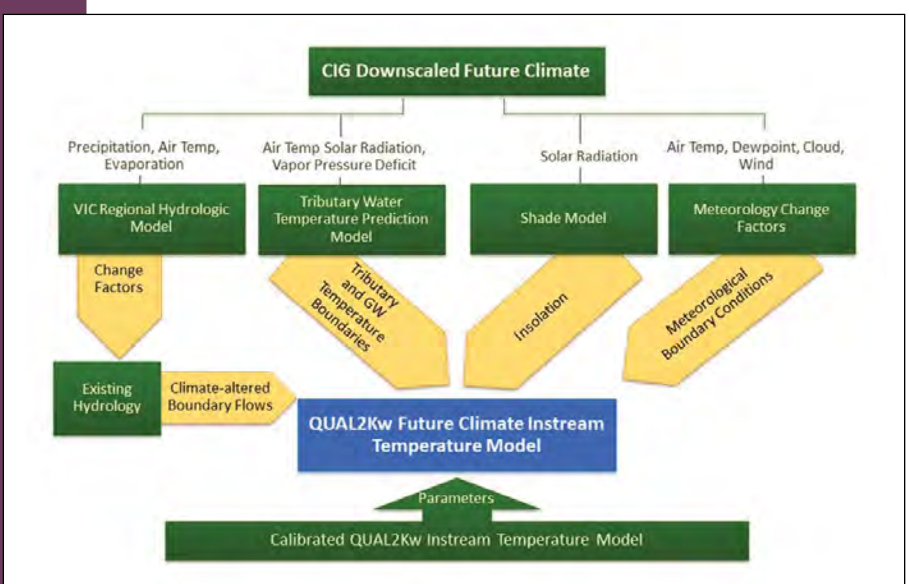


Figure 4-4. Schematic of model and climate data integration for the quantitative assessment (Butcher et al. 2016).

Critical summer water temperatures are affected by both air temperature and flow regime. Within the A1B emissions scenario, the project team identified three GCMs for the analysis that are anticipated to cover the reasonable range of potential futures, including a scenario that predicts low warming of air temperature and increased summer precipitation (model low-impact scenario), a medium amount of warming (medium-impact scenario), and a high amount of summer warming coupled with decreased summer

Table 4-2. Summary of the scenarios, associated models, and general climatic trends

Scenario	GCM	General Trends
Low Impact	CGCM3.1-t47 (Third Generation Coupled Global Climate Model)	Low warming, increased precipitation
Medium Impact	CCSM3 (Community Climate System Model)	Average warming, decreased summer precipitation
High Impact	HADGEM1 (Hadley Centre Global Environmental Model)	High warming, decreased precipitation

precipitation (high-impact scenario), resulting in three climate models by three time horizons, or nine model runs (Table 4-2). This collection of models addressed the project objective of evaluating the ensemble *range of outcomes* from one IPCC emissions scenario for the climate change risk assessment.

The draft TMDL analysis was developed using a steady-state QUAL2Kw water quality model applied to critical conditions (summer low flows and high air temperatures) within the South Fork (Ecology 2003a). In the quantitative assessment, the modeling team reevaluated each of the critical condition parameters under estimated future climate conditions (Butcher et al. 2016).

The critical conditions model run for the draft TMDL was based on the 7-day average flow with a 10-year recurrence frequency (7Q10 flow), representing a critical low-flow condition combined with air temperatures of a similar recurrence (the 90th percentile 7-day annual maximum). Some model simulations also were conducted using the 7-day average flow with a 2-year recurrence frequency (7Q2 flow) combined with the median summer maximum temperature to represent the temperature stress on salmonid populations during an average, or *typical*, year. Flow conditions under future climates were based on an estimate of the effect of climate on flow during low-flow periods. To make this estimate, predicted changes in summer base flow were incorporated into the model.

In addition to flow conditions, the modeling team adjusted other parameters under the climate change scenarios, including water temperature, air temperature, dew point temperature, and groundwater discharge temperature. Cloud cover and wind were not adjusted from the TMDL model conditions.

4.2.3 Qualitative Assessment Methods

The qualitative assessment complements the modeling investigations of the TMDL provided in the quantitative assessment and evaluates additional restoration actions and strategies, beyond riparian shading, to enhance salmon recovery under climate change in the South Fork (EPA 2016).

The Qualitative Assessment is considered a methods manual for the evaluation of restoration actions to enhance salmon recovery under climate change for the pilot research project.

The Qualitative Assessment objectives include:

- Comprehensively analyze freshwater salmon habitat for ESA salmon restoration in the South Fork under climate change.
- Create a prioritized list of strategies that support salmon restoration in the South Fork under climate change.
- Apply the method described in *Restoring Salmon Habitat For a Changing Climate* (Beechie et al. 2013).

The Qualitative Assessment is available online here.

The Nooksack Indian Tribe led the qualitative assessment because they shared authorship of the current Water Resource Inventory Area (WRIA) 1 ESA salmon recovery plan and they have substantial local knowledge of the South Fork watershed and fish habitat (WRIA 1 2005).

While the *WRIA 1 Salmonid Recovery Plan* articulated the watershed vision for the Nooksack River Basin—to recover self-sustaining salmonid runs to harvestable levels—the very low populations of the early Chinook salmon necessitated a focus on the immediate benefits of implementation actions on the abundance and productivity of the populations. Therefore, the potential impacts of climate change on the South Fork were not considered in the past to address this gap (WRIA 1 2005, p. 21). The goal of the qualitative assessment was to evaluate salmonid species life-cycle biology and ESA species recovery actions in the South Fork TMDL, and to incorporate climate change risk into salmonid recovery planning in the South Fork (EPA 2016).

The objectives of the assessment were 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 are intended to inform development of the South Fork temperature TMDL implementation plan, updates to the *ESA WRIA 1 Salmonid Recovery Plan*, and other land-use and restoration planning efforts.

In the qualitative assessment, historic conditions (or natural conditions in the South Fork temperature TMDL) and the changes resulting from those conditions are evaluated (EPA 2016). 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, resulting in degraded habitat conditions that threaten the survival of salmonids. Climate change has exacerbated and will continue to exacerbate those cumulative effects.

It is important to consider past (historical), current (existing), and future (climate change) habitat conditions to evaluate ESA recovery actions in the South Fork. This approach recognizes process-based principles for restoration, which include (1) targeting root causes of habitat and ecosystem change; (2) tailoring restoration actions to local potential; (3) matching the scale of restoration to the scale of physical and biological processes; and (4) clearly defining expected outcomes, including recovery time, to guide sustainable recovery of salmonid populations (Beechie et al. 2010).

The qualitative assessment methodology was 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 unlikely to ameliorate a climate change effect on high stream flows, low stream flows, and stream temperatures.

Impacts of climate change will vary across rivers and will include several different climate 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. Evaluating the effectiveness of regulatory protections in the face of climate change also is a key component of developing an effective recovery strategy. The methodology used in this evaluation was based on applying the Beechie method to the geographic and regulatory context of the South Fork—determining the geographical extent of the climate change assessment and evaluating impacts by climate risk, salmonid species, and restoration actions (Beechie et al. 2013).

Defining the Geographic Scale of Analysis

The mainstem South Fork was divided into five reaches based on river miles (RMs): RMs 0–14.3 (floodplain; impaired TMDL reach); RMs 14.3–18.5 (canyon); RMs 18.5–25.4 (core Chinook spawning); RMs 25.4-31 (confined areas); and upstream of RM 31 (mostly U.S. Department of Agriculture- 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 4-5 illustrates these reaches and subbasins.

Identifying Impacts by Climate Risk

In the qualitative assessment, 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 are evaluated (EPA 2016). Modeling conducted as part of the quantitative assessment (Butcher et al. 2016) was relied upon in the qualitative assessment to determine the magnitude of effects on temperature, flow, and sediment dynamics.

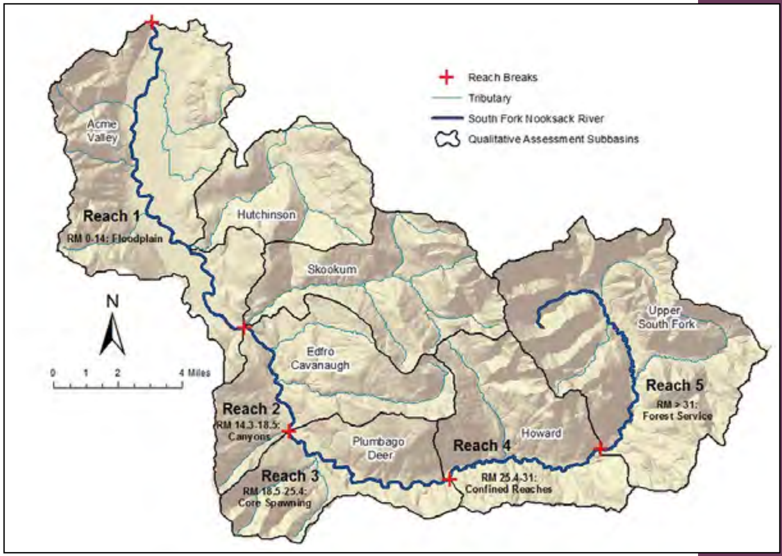


Figure 4-5. South Fork Nooksack reaches and subbasins.

Evaluating Impacts per Salmonid Species

Nine species of Pacific salmonids inhabit the South Fork, including spring Chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), pink salmon (*O. gorbuscha*), sockeye salmon (*O. nerka*), cutthroat trout (*O. clarkii*), steelhead trout (*O. mykiss*), and bull trout (*Salvelinus confluentus*). The first step in determining the impacts of climate change by species involved overlaying the species life stage periodicity in the South Fork with vulnerability to climate change. Then, the species distribution was overlaid with the model output. Temperature requirements and the modeled annual temperature regime were plotted against each other graphically. This was done in detail for the ESA listed species: spring Chinook salmon, steelhead trout, and bull trout. The remaining five species were analyzed using the life stage periodicity overlay with vulnerability to climate change impacts.

Evaluating Impacts per Salmon Restoration Action

Generally, actions for mitigating future climate change impacts on salmon involve reducing the existing threats to their freshwater habitats caused by legacy land and water use activities that impair natural physical and biological processes. Because of the small size of salmonid populations and their importance to regional recovery, the goal of the assessment was to ensure that restoration actions address the current limiting factors while considering the longer term future threats such as increased development and climate change.

Salmon recovery actions and the ability of each action to ameliorate climate change effects were evaluated on that basis. Restoration actions were prioritized by reach and subbasin based on the ability to ameliorate various climate change impacts and/or increase salmon resilience, and on the potential effectiveness of each restoration action.

5.0 Stakeholder and Tribal Engagement

"In the end, almost all adaptation is local. To be effective, it needs strong local knowledge and strong local adaptive capacity."

—Sattertheaite et al. 2007, p. 74

The pilot research project was developed as a stakeholder-centric process. Stakeholder outreach and engagement was considered a critical, cross-cutting element of the methodology. Local stakeholders are the most familiar with watershed processes and habitat conditions in the South Fork watershed and engaging these stakeholders in project activities makes it more likely that the findings and recommendations will be embraced and ultimately implemented.

Two federally recognized American Indian tribes are involved in watershed management of the South Fork: the Lummi Nation and the Nooksack Indian Tribe. Throughout the project, EPA has recognized and maintained the federal Indian trust responsibility to protect their tribal treaty rights, lands, assets, and resources. Engagement with the tribes has occurred on a *government-to-government* basis, recognizing the sovereignty between the United States and both federally recognized tribes. For thousands of years, the Lummi Nation and the Nooksack Indian Tribe have cared for the land and waterways in the project area. Stakeholder engagement efforts centered on incorporating the leadership and knowledge of the tribes into the activities of the pilot research project.

Local stakeholders, including federally recognized tribes, have always been on the front line when it comes to protecting rivers and streams from pollution and the encroachment of development and land use change, and their role will become increasingly important as climate change exacerbates the existing stressors.

5.1 Stakeholder Identification

Success of the pilot research project depended to a significant degree on identifying and engaging local stakeholders and all other interested parties in the interactive project. Even within EPA, there was increased stakeholder engagement and interaction. During project scoping and the initiation of the research planning process, EPA's Region 10 and OW coordinated with EPA ORD to create the *One EPA Team*, which recognized the importance of incorporating climate change considerations into the South Fork temperature TMDL (with EPA Region 10 having regulatory authority for the TMDL).

A community-based approach to problem solving requires working solutions at the local level. To initiate the project, EPA reached out to the tribes, state and local governments, and technical experts already involved in the South Fork watershed, including representatives of the following:

"The Nooksack Indian Tribe relies on salmon for subsistence, commercial, cultural, and ceremonial purposes," Oliver Grah, water resources program manager of the Nooksack Indian Tribe, said. "The Tribe is an active part of the efforts to sustain salmon population in the face of climate change."

EPA 2014, p. 1-2

- County agencies: Whatcom Conservation District, Whatcom County Marine Resources Committee, Whatcom County Planning Department, Whatcom County Public Works.
- Federal agencies: USFS, NOAA Fisheries (regulatory authority for ESA), U.S. Geological Survey.
- Local organizations: Whatcom Land Trust, Whatcom Watersheds Information Network.
- Tribes: Lummi Nation, Nooksack Indian Tribe.
- Universities: University of Washington CIG (developed climate scenarios for the South Fork), Western Washington University.
- Washington state agencies: Department of Ecology (lead for the South Fork temperature TMDL), Department of Fish and Wildlife, WDNR.
- Watershed management authority: WRIAs are planning and administrative boundaries developed by Washington State. WRIA 1 is the Nooksack River watershed organizational structure integrating tribes, county and city governments, and the public utility.

From the beginning of the pilot research project, EPA recognized the special status of the tribal governments that were involved in the project. The tribes play a key role in on-the-ground implementation. In particular, the pilot research project has capitalized on the significant participation and involvement of the Nooksack Indian Tribe to ensure that the problem formulation, research activities, and findings and recommendations of the project are relevant and implementable in the real-world context of the South Fork watershed.

Their significant involvement supports, and is emblematic of, EPA's policy of integrating traditional ecological knowledge into environmental science, policy, and decision-making (2011), which recognizes the significance of tribes' traditional values and cultures and the importance of their accumulated knowledge and understanding of the local environment in shaping scientific research, environmental decision-making, and implementation.

5.2 Stakeholder Organization

A stakeholder organizational structure was developed to optimize stakeholder involvement and maintain regular interaction over the life of the project. This section describes the organizational structure and is followed by a description of stakeholder engagement platforms and activities in section 5.3.

Project Sponsorship and Contract Support

Sponsors of the pilot research project included EPA ORD, EPA OW, and EPA Region 10 (One EPA Team). Ecology, the Nooksack Indian Tribe, and the Lummi Nation are cooperating sponsors. Ecology led the South Fork temperature TMDL effort, while the Nooksack Indian Tribe and Lummi Nation led local ESA recovery efforts.

The EPA consultant (Tetra Tech) provided technical and logistical contract support to the project sponsors. Tetra Tech conducted the quantitative assessment and supported other activities under the pilot research project, including supporting Region 10 and Ecology in the development of the South Fork temperature TMDL.

Core Interdisciplinary Team

The project sponsors recognized that significant stakeholder engagement would be necessary to develop the qualitative assessment in a robust manner and to facilitate locally appropriate project activities. The formation of a core interdisciplinary team (CIDT) was recommended during the January 2013 stakeholder engagement and project scoping facilitation meeting to guide the qualitative assessment and broader outreach efforts. Six key stakeholders agreed to serve on the CIDT: four staff members of the Nooksack Indian Tribe Natural Resources Department—Treva Coe, Ned Currence, Oliver Grah, and Mike Maudlin; Tim Beechie from NOAA; and Steve Klein from EPA ORD.

The Nooksack Indian Tribe is a key implementer of recovery actions and the CIDT's tribal members agreed to lead the team's technical activities. These staff members are among the primary authors of the *WRIA 1 Salmonid Recovery Plan* and associated implementation documents (3-Year Work Plans, Restoration Strategy Matrices). Jezra Beaulieu of the Nooksack Indian Tribe provided technical support. Tim Beechie served on the CIDT as the primary author of the Beechie methodology, used in the qualitative assessment to incorporate climate change considerations into recovery actions. Steve Klein served on the CIDT as the project manager of the pilot research project. Tetra Tech provided facilitation and technical support for the CIDT.

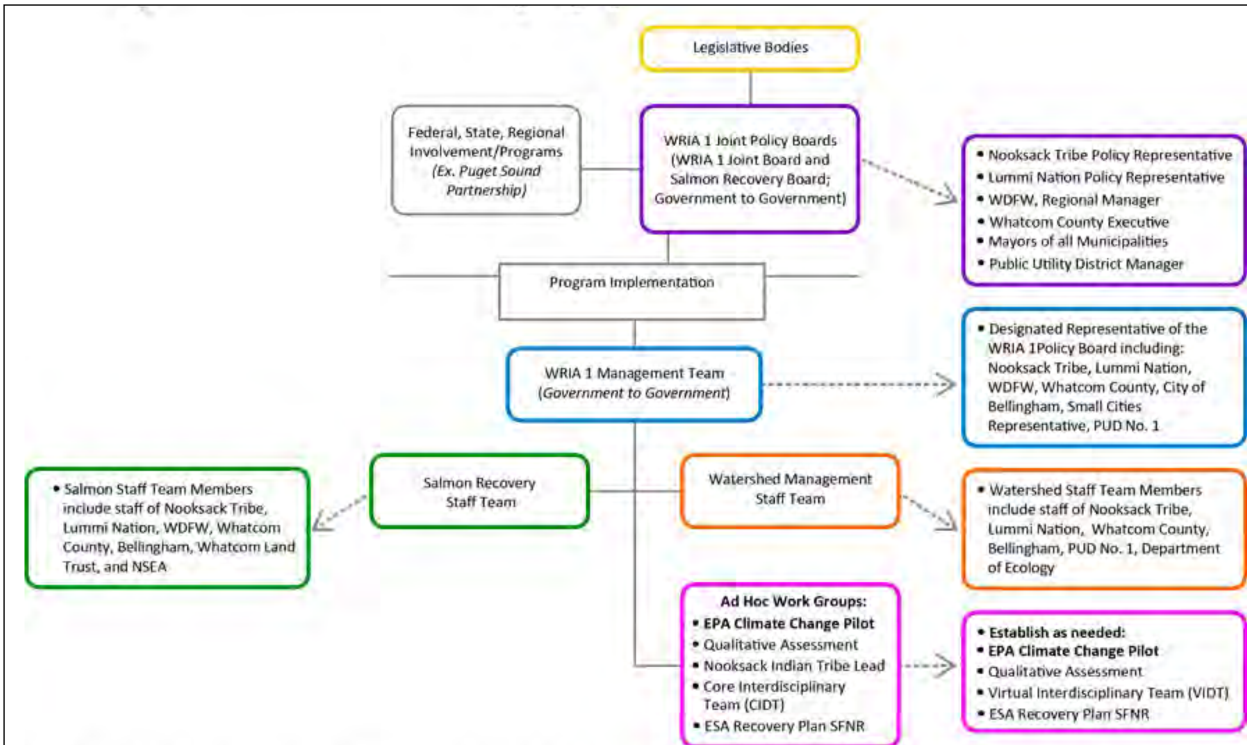
The CIDT used regular conference calls, email communication, and in-person meetings to provide input to and oversight of development of the qualitative assessment. The team also identified and led stakeholder engagement activities related to the assessment and supported broader stakeholder engagement efforts. The formation of the CIDT allowed for a sustained high level of interaction from key stakeholders, while narrowing down the number of participants to a manageable level for continued day-to-day progress on the project.

Virtual Interdisciplinary Team

To complement the CIDT, the formation of a larger virtual interdisciplinary team (VIDT) also was recommended during the January 2013 meeting. The VIDT was developed to provide review of and comment on the qualitative assessment. The CIDT served as the coordinating arm for engagement of the larger VIDT.

The VIDT has approximately 50 members, including representatives from all the stakeholder groups listed in section 5.1. Membership was considered flexible and able to expand to include other stakeholders depending on need and/or interest.

The VIDT provided a platform for broader stakeholder involvement but minimized demands on the time and schedules of the members. While the CIDT met on a regular basis (virtually and in person), the VIDT convened as necessary to provide review of and comment on the qualitative assessment. The VIDT served as a useful mechanism to provide structured communication and receive input from the larger group.



Source: WRIA 1 Policy Board; approved June30, 2009 *Governance Structure for Implementing WRIA 1 Programs*, modified for EPA Region 10 Climate Change and TMDL Pilot

Figure 5-1. Organizational Structure of WRIA 1.

Relationship with WRIA-1

As the local watershed authority, WRIA 1 was recognized as an important organizational element for stakeholder engagement. WRIA planning units were established by the Washington State Legislature in 1997 (pursuant to Revised Code of Washington 90.82) as part of an integrated approach to managing water resources in the state. There are 62 WRIAs that delineate the state's major watersheds, with WRIA 1 encompassing the Nooksack watershed. WRIAs are authorized to apply for funding assistance for planning and implementing watershed plans.[7]

WRIA 1 has a distinct watershed organizational structure that includes policy boards, a management team, staff teams, and working groups. The structure integrates tribes, county and city governments, and the public utility (see Figure 5-1).

The stakeholder organizational approach used for the pilot research project is closely aligned with the WRIA 1 structure.

The Nooksack Indian Tribe is the nexus of the multilayered and integrated approach to stakeholder engagement that was critical to the success of this project. The tribe acted as a consistent and unifying voice through multiple layers of stakeholders. The CIDT and VIDT were aligned within the existing WRIA 1 governance structure shown in Figure 5-2.

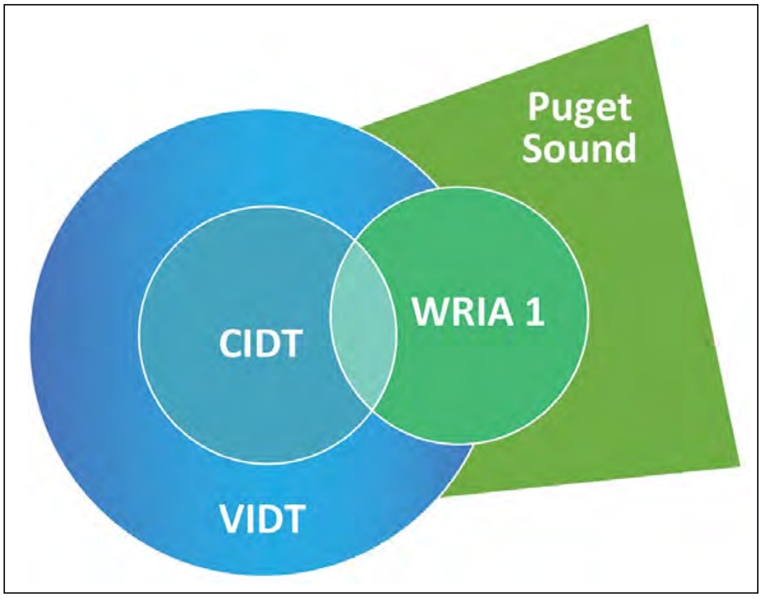


Figure 5-2. Integration and interaction between stakeholder groups and local governance structures.

The Nooksack Indian Tribe is at the center of the CIDT, the VIDT, and the WRIA 1. The tribe is a member of each group. Involvement with WRIA 1 leads to higher level buy-in and implementation support and promotes the methodology used in the South Fork watershed to be expanded to other watersheds in the Puget Sound basin.

7 More information on WRIAs is available on Ecology's website at here.

5.3 Stakeholder Engagement Platforms and Activities

The pilot research project benefited from stakeholder engagement through a myriad of platforms designed to provide strategic input at critical milestones. Stakeholder and tribal engagement was considered a two-way street whereby information exchange came from both the technical project participants and local stakeholders; leading to actual changes in the approach based on information received from the stakeholders. Thus, one important element of the process was determining the type of stakeholder engagement platform that would best service project-specific needs. The pilot research project used in-person meetings and webinars to interact with stakeholders and promote two-way communication. Key project-focused stakeholder engagement opportunities and outcomes are summarized in Figure 5-3 and described following the figure.

Additionally, the project team sought to reach a broader audience and participate in national, regional, and tribal climate change conversations. These broader activities are described as promoting internal EPA coordination (One EPA Team activities) and external awareness-building through conferences and presentations.

In-Person Meetings

In-person meetings were held at critical moments in the project to maximize generation of stakeholder feedback.

Stakeholder Workshop hosted by EPA Region 10 in Seattle, WA, June 2012. The pilot research project was launched by EPA Region 10 at a workshop held on June 25, 2012, in Seattle, Washington. The goal of the workshop was to solicit from key stakeholders input on the project objectives and activities. Specific workshop objectives were developed to meet both the regulatory and research goals. Sixty-six attendees participated in the workshop, including 38 in-person attendees and 28 virtual attendees via GoToMeeting. These stakeholders provided valuable insight into problem formulation, including development of both a quantitative and qualitative assessment, and instrumental in the project accomplishments.

This workshop was structured as a question-and-answer session and open forum. After introductory presentations were given, the meeting was run town-hall style to encourage participation. The presentations were intentionally complex and technical to encourage the stakeholders to provide technical comments and questions based on their local knowledge and understanding of the South Fork. Top experts attended and presented at the meeting to provide a solid base of information and identify what factors were known and what questions needed to be addressed by the

Figure 5-3. Stakeholder engagement opportunities and outcomes.

project. The result was a highly interactive workshop that allowed for real-time adjustments in how the pilot research project was going to proceed. Feedback from the stakeholders significantly impacted the project by identifying factors other than temperature that influence salmon recovery.

Stakeholder Engagement and Project Scoping Facilitation Meeting hosted by Washington's WRIA 1 Watershed Management and Salmon Recovery staff teams in 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 their input on issues, concerns, and opportunities to improve the scope and effectiveness of the project. There were 12 meeting attendees.

Addressing ecological degradation and climate change adaptation is the *science of place*—the application of ecological principals to the right scale and context. This meeting was directed at working the problem by reaching out to the WRIA 1 watershed management and salmon recovery teams in their place and relying on their expertise to define the problem and project, essentially creating a local problem-solving effort and embedding the project in a local integrating organization. Involving these teams helped the project to gain legitimacy in the community.

The key outcome of the October 2012 meeting was agreement by the WRIA 1 salmon recovery team that consideration of potential climate change impacts in the South Fork watershed 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.

Stakeholder Engagement and Project Scoping Facilitation Meeting hosted by the Nooksack Indian Tribe in 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 method for evaluation of salmon recovery strategies in the face of climate change in the South Fork (Beechie et al. 2013). Thirty-two participants attended the 2-day meeting.

The meeting was used to move the project from a concept to a formal methodology specific to the South Fork. Initially a formal agenda was planned, but the participants got so actively involved that the agenda was dropped, and the group began designing a mockup of the qualitative assessment. Workshop participants were working the problem by applying the Beechie methodology to each of the South Fork stream reaches and identifying points of agreement and knowledge gaps (Beechie et al. 2013). Allowing the meeting to follow the momentum of the participants created an impromptu way to make significantly more progress than was initially expected. One of the key outcomes from the workshop was that participants agreed to form the CIDT and VIDT to develop and provide input on the qualitative assessment (further details in section 5. 2).

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

Treva Coe of the Nooksack Indian Tribe led a briefing of the WRIA 1 salmon recovery staff team to seek peer input on the draft final qualitative assessment. This briefing fulfilled a commitment to maintain substantive interaction between the Nooksack Indian Tribe and the WRIA 1 team. In keeping with the deep engagement strategy, this briefing ensured that the lines of communication were kept open and provided the salmon recovery team with the opportunity to voice any concerns, ask questions, and ultimately endorse the draft qualitative assessment before the report moved to the WRIA 1 management team.

WRIA 1 Management Team Information Briefing on the Final Qualitative Assessment, November 9, 2015.

Oliver Grah and Treva Coe of the Nooksack Indian Tribe led a briefing of the WRIA 1 management team to present the draft qualitative assessment. The objective of the briefing was to ensure that the management team actively supported the findings of the qualitative assessment. The management team was given the opportunity to ask questions and provide comments that could be addressed in the final version of the qualitative assessment. Not only is buy-in from the management team important for implementing the pilot research project findings, but also because the pilot research project offers a bottom-up approach to assessment that can be scaled to a broader Puget Sound basin research project for WRIA consideration. Scaling up would be a clear shift from research demonstration project to operational implementation.

Webinars

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

The goal of the webinar was to solicit input from the VIDT on the proposed methodology for conducting the qualitative assessment. The VIDT webinar was an opportunity to transfer technical details from the CIDT to the VIDT. It offered an effective way to engage stakeholders in the process of moving from project concept to actual project methods and provided participants with the opportunity to react to the proposed methodology and provide input before it was finalized. Forty members of the VIDT participated in the webinar. After hearing the webinar presentations, the majority of attendees agreed that the proposed methodology was appropriate for the qualitative assessment.

VIDT Webinar on the Qualitative Assessment Findings cosponsored by EPA ORD and the Nooksack Indian Tribe, May 19, 2015.
The second VIDT webinar was held to present the methodology, findings, and recommendations of the qualitative assessment. Listening to and addressing comments from the VIDT members was a key objective of the meeting. As a rapid-prototype pilot, it is hoped that the methods used in the qualitative assessment can be applied to other watersheds. The webinar sought to obtain valuable stakeholder input on the process and recommendations of the qualitative assessment and to ensure consensus on the findings as the team 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 them to other watersheds such as the Middle and North Forks.

Technical Transfer Webinar on the Quantitative Assessment, July 13, 2017.
A technical transfer webinar was held on July 13, 2017 to present the findings and methodology of the quantitative assessment. Tetra Tech delivered the webinar to the VIDT as well as to an audience of EPA regional and OW personnel, state departments of environmental quality, tribal environmental organizations, and TMDL practitioners to promote national level knowledge transfer.

Internal EPA Coordination and One EPA Team Activities

The One EPA Team consists of representatives of EPA ORD, EPA OW, and EPA Region 10. The interactions of this coordinated team led to the jointly hosted June 2012 kickoff for the pilot research project. Interaction was sustained through internal EPA briefings, which also served to build awareness across EPA of the pilot research project process and findings.

Internal EPA awareness-building activities included:

- EPA OW brownbag seminar (July 2012);
- EPA climate change speaker series (September 2013);

- EPA Region 10 and OW briefing (August 2014);
- EPA OW and regions briefing (August 2015), and;
- EPA OW National Water Program Resilience Workgroup (March 2017).

External Awareness-Building: Websites, Conferences, and Presentations

Because the pilot research project has the potential for regional and national scale application, the project sponsors wanted to ensure that project activities and findings reached a larger audience beyond local stakeholders. Thus, the Science Inventory on EPA's public website was used to post project deliverables. *The Quantitative Assessment of Temperature Sensitivity of the South Fork Nooksack River Nooksack River under Future Climates using QUAL2Kw* (Butcher et al. 2016) is available on EPA's website at https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=288533. *The Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA* (EPA 2016) is found on EPA's website at https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryID=320470.

Both EPA ORD and the Nooksack Indian Tribe presented on pilot research project activities and findings through posters and presentations at several public workshops and conferences. The illustrative public events include the following:

- EPA Poster, PNW Climate Science Conference (September 2013);
- Nooksack Indian Tribe Presentation, EPA Tribal NPS Workshop (March 2014);
- EPA and Nooksack Indian Tribe Co-Presentation, National Adaptation Conference (May 2015);
- EPA Presentation, Coastal and Estuarine Research Federation Conference (November 2015);
- EPA Presentation, Northwest Climate Conference (November 2015);
- EPA Presentation, Future of Our Salmon Technical Workshop (August 2016);
- EPA and Nooksack Indian Tribe Co-Presentation and EPA Poster, River Restoration Northwest (January 2017); and
- EPA Poster, National Adaptation Forum (May 2017).

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6.0 Results

6.1 Quantitative Assessment Modeling Results

Once the modeling team applied all the future climate boundary conditions to the QUAL2kw model of TMDL critical conditions, the model was run to determine the maximum water temperature predictions for the 2020s, 2040s, and 2080s under the low-, medium-, and high-impact scenarios (Butcher et al. 2016). The daily maximum water temperature predicted by the steady-state model under critical conditions was assumed to be equivalent to the 7-DADMax as defined in the WQS.

The model processed 18 future climate simulation scenarios, including one representing the current climate and current shade conditions at 7Q10 flows and one representing current climate and SPV shade at 7Q10 flows to represent baseline (presettlement) conditions. The remaining scenarios represented various combinations of high-, medium-, and low-impact scenarios in 2020, 2040, and 2080, with either current shade or the SPV shade. 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 was chosen by Ecology as the TMDL natural condition scenario. To consider additional mitigation of water temperature increases through effective buffering on all tributaries to the South Fork; an additional natural conditions scenario was investigated, including for future climate scenarios.[8]

In this section, we discuss the customary TMDL results first, then the findings from the future climate scenario runs. The TMDL simulations, even with maximum shade conditions, exceeds the numeric temperature criteria throughout the river and approaches the temperature levels identified as potentially lethal for 1-day and 7-day exposures (22 °C and 23 °C, respectively) in the downstream reaches.

The simulations estimating the impact of climate change on scenarios using 7Q10 flow with current shade levels are noticeably warmer than under the SPV scenarios, and they are projected to exceed the 1-day maximum lethality threshold of 23 °C over much of the river, even by the 2020s. This is of practical concern for implementation activities because it will take considerably longer than a decade to achieve SPV. It should be recalled that TMDLs are based on extreme critical conditions, however, and more typical conditions will not be as adverse.

Documenting Results

The research team developed two products associated with the quantitative assessment:

- *Quantitative Assessment of Temperature Sensitivity of the South Fork Nooksack River under Future Climates using QUAL2Kw* fully documents the modeling approach and results and is considered a technical supplement to the South Fork temperature TMDL.
- *Climate Change Considerations for TMDL Development in the South Fork* discusses the implications of the quantitative assessment for the South Fork TMDL implementation plan.

8 Refer to the qualitative assessment section 5.1.1.1.1 Sensitivity Analysis for Natural Conditions Estimate using Current Climate for more, including modeled natural condition scenarios

As shown in Figure 6-1, water quality criteria are not met under any of the scenarios using critical low-flow (7Q10) conditions. Under 2080 climate conditions, the maximum lethality temperature is exceeded for all scenarios with current shade conditions. If shade conditions are restored to the system potential value natural conditions (defined as pre-European development conditions), however, the river can remain below the maximum salmonid lethality thresholds, even though WQS are not necessarily maintained at all times.

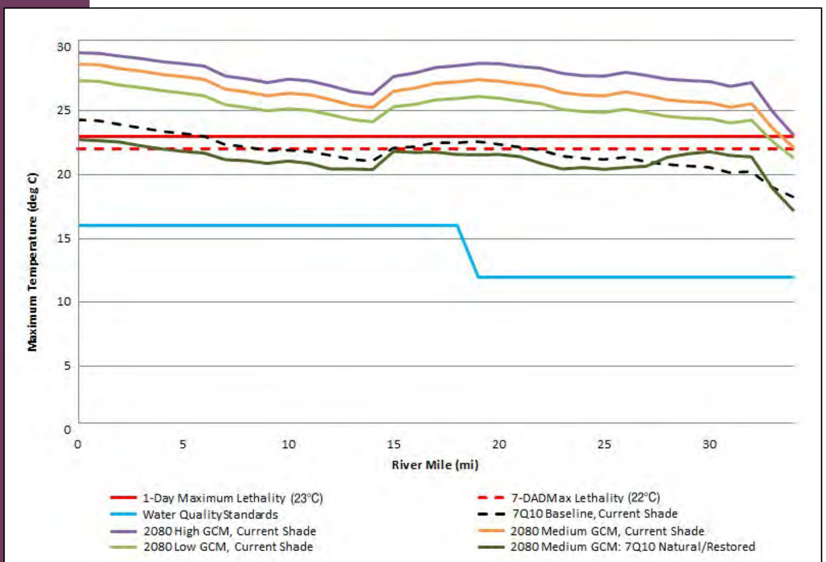

Figure 6-1. Maximum stream temperature by RM under 7Q10 flows.

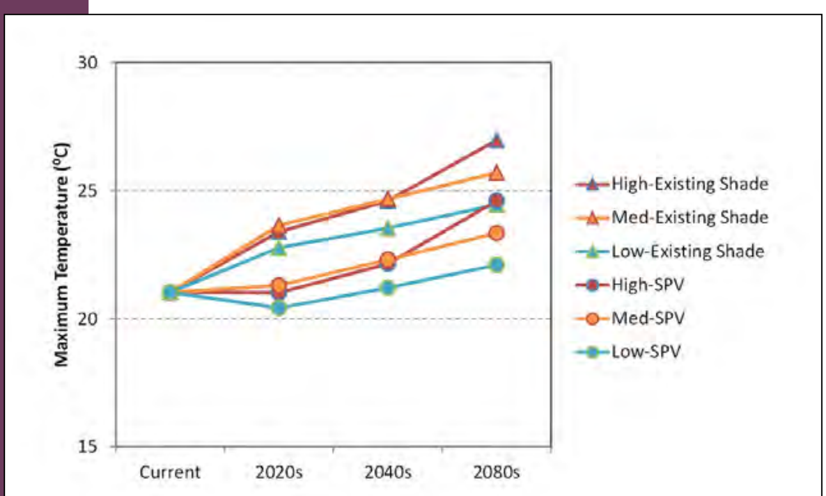

Figure 6-2. Summary of 18 climate scenario-predicted maximum temperatures with existing shade and SPV.

Note: "Low". "Med", and "High" refer to the Low, Medium, and High Impact climate scenarios. SPV refers to restoration of 100-yr system potential vegetative shading of the stream channel.

Examining average 7Q10 flow water temperatures across the modeled reaches of the river on the same plot, SPV reduces average water temperature by about 2 °C when compared to the current shade levels. Figure 6-2 summarizes all 18 climate scenarios and the expected steady increase in water temperature over time. SPV is estimated to mitigate climate-related water temperature increases through the 2020s and to reduce increases (relative to existing shade) through the end of the century.

The TMDL analysis of critical conditions purposefully represents relatively extreme worst-case conditions that will not occur every year. The modeling team also looked at some of the less extreme (more frequently occurring; i.e., based on 2 year increments) conditions. Updating the TMDL modeling for average annual 2080 climate conditions using 7Q2 flows, the modeling team simulated the maximum stream temperatures that salmon are expected to encounter during a typical year.

Model results for 2080s climate coupled with SPV and 7Q2 flows and meteorology are shown in Figure 6-3. The low-, medium-, and high-impact scenarios all remain below the 1-day lethality temperature over

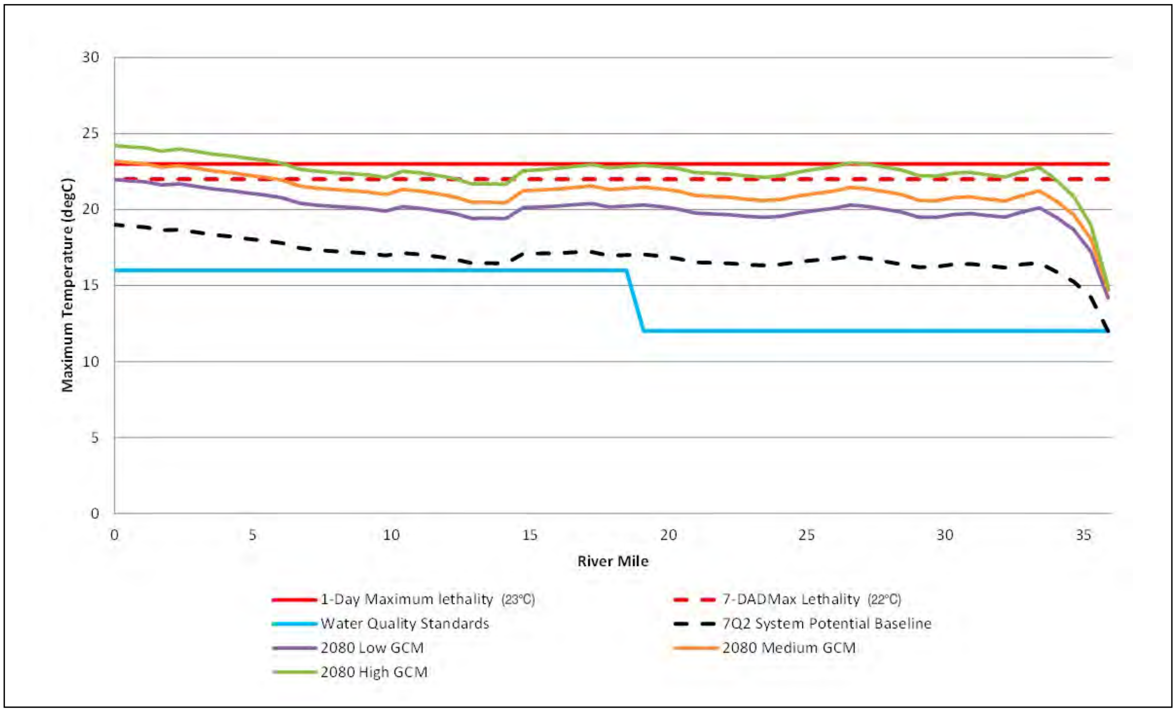

Figure 6-3. 2080s maximum temperature at 7Q2 flows and SPV for the low-, medium-, and high-impact models for the medium impact scenario.

most of the length of the South Fork mainstem. The high-impact scenario, however, does predict temperatures higher than 23 °C for the lower 7 kilometers of the South Fork, even under these less extreme, more typical flow conditions. This could present a barrier to migration because thermal blockages for salmon are reported to consistently occur in the range of 19–23 °C (Mantua et al. 2010; McCullough et al. 2001; Richter and Kolmes 2005).[9]

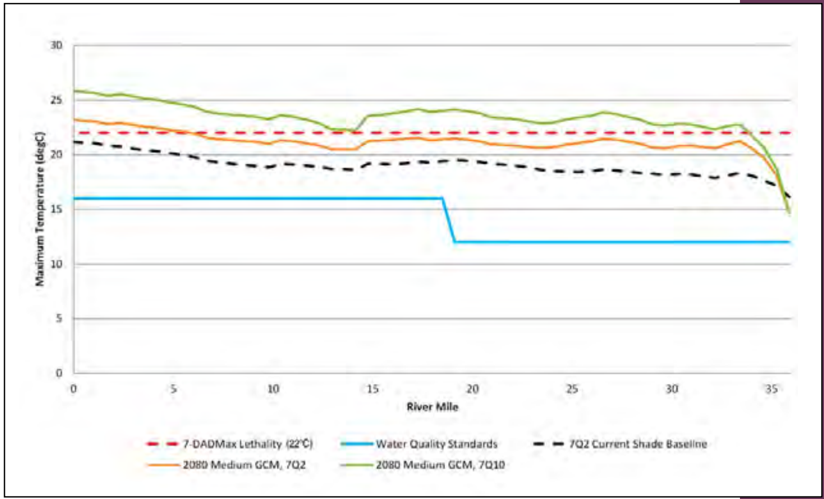

Figure 6-4. Comparison of 2080s maximum temperatures at 7Q2 and 7Q10 flows for the medium impact scenario.

A comparison of the medium-impact scenario at 7Q2 and 7Q10 flows is shown in Figure 6-4. During a typical year, the 7-DADMax lethality temperature of 22 °C is projected to be exceeded in only the farthest

9 Fine scale thermal heterogeneity and the role of thermal refugia is a current active research area that can also help with thermal barriers. These concepts will be further discussed as part of the qualitative assessment (section 6.2).

downstream reaches of the river, while under more extreme low-flow conditions (7Q10 flows), the lethality temperature is exceeded along nearly the entire mainstem.

Additional Effects from Climate Change

Modeling efforts for this project and others in the region show that, in addition to increasing temperatures and decreasing flows, other effects of climate change are likely to alter habitat conditions in the South Fork. Most notably, higher-elevation runoff is expected to shift from a mix of rain and snow to a rain-dominant regime, with more runoff occurring earlier in the year. A possible result of this regime shift is an increase in extreme high flows, which can cause the scouring and loss of salmonid eggs.[10]

Mass wasting refers to the movement of a rock particle down a slope due to gravity. Examples of mass wasting include rock falls, slumps, and debris flows. Mass wasting can occur slowly over time or occur very rapidly, such as in a landslide.

Studies have shown that flood magnitude can be a significant predictor of Chinook salmon survival rates. The magnitude and frequency of flooding are likely to increase dramatically in the winter months in watersheds that shift from rain and snow to a rain-dominated system. Modeling suggests that the magnitude of floods could increase by 4–39 percent.

Another effect of more variable flows with increased peaks is the changes in sediment. Increased bed and bank erosion are likely to occur. The severity of erosion is dependent on channel shape and plan-form. Changes in mass wasting also are likely, as is an increase in the number of unstable road-fill failures. Riparian buffer effectiveness also will be threatened by

Table 6-1. Summary of predicted changes in future conditions

Future Conditions for the South Fork Nooksack River	
Parameter	**Change Direction**
Air Temperature	Increase
Annual Precipitation	Steady
Summer Precipitation	Decrease
Snow Water Equivalent	Decrease
High Flows	Increase
Low Flows	Decrease
7-DADMax Water Temperature	Increase
Sediment/Turbidity	Increase

10 Climate-induced changes in temperature and precipitation can impact the hydrologic processes of a watershed system in a variety of ways, in addition to the conditions modeled in this study (such as the potential for nutrient loading). In addition to direct effects on the hydrologic cycle, climate change will directly and indirectly alter ecological disturbances that are influenced by hydrologic processes (such as potential for increased wildfires, forest mortality, vector borne diseases, and ecosystem shifts). It was not practical to model each of these processes for this study, although it could be important to do so in the future as more information on these changes becomes available.

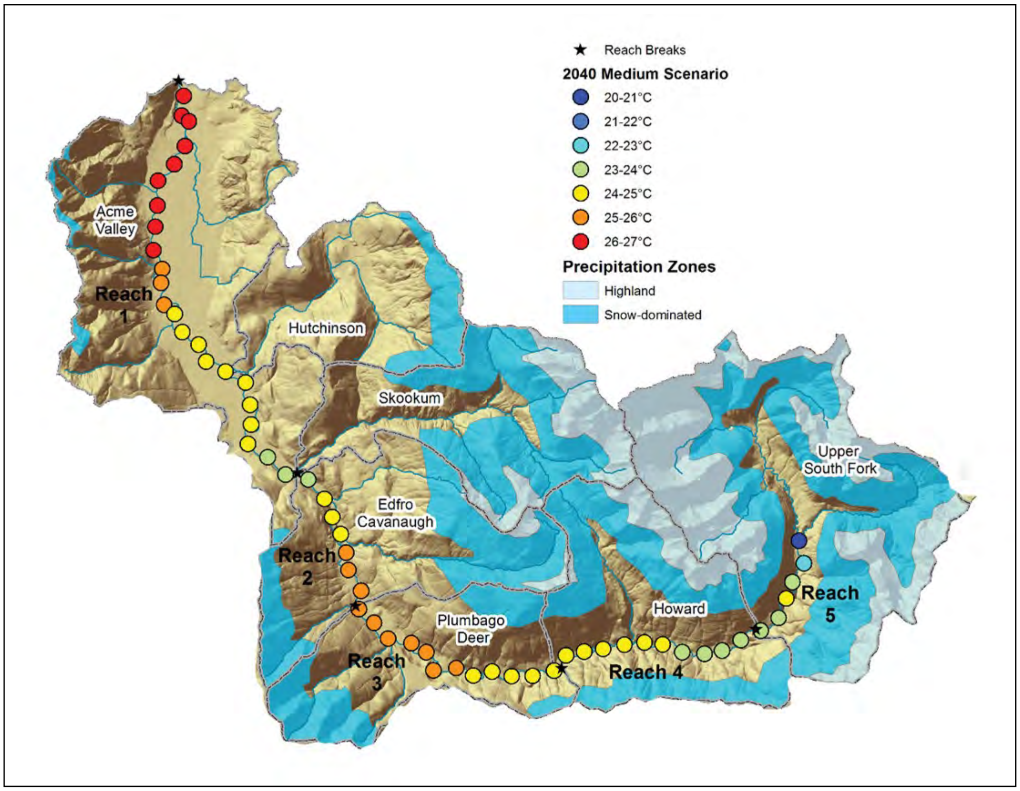

Figure 6-5. Summer low-flow temperatures under the 2040 medium-impact scenario.

increased peak flows. Table 6-1 summarizes the general trend for a number of conditions.

6.2 Qualitative Assessment Results

As described above, climate change will have a significant effect on temperature in the South Fork watershed—it is projected to rise by 2.81–6.31 °C by the 2080s—and could substantially reduce the amount and quality of preferred salmon habitat. Other important climate change impacts could include altered hydrology (higher peak flows, floods, and lower late-summer flows) and sediment dynamics (increased sedimentation). Climate change will cause the altitude at which the lower limit of snow accumulation occurs to be higher and reduce the area and depth of snow accumulation, which in turn will increase flows in the fall-winter-spring period, but reduce flows during the critical low-flow period. There will likely be an increase in the frequency and magnitude of mass earth failures resulting from oversaturation of oversteepened glacially carved mountain slopes. More frequent landslides, both natural and human-induced (e.g., caused by forest practices, roads, and clearcuts), could increase the sediment loading of the South Fork. All of these impacts will have adverse effects on Pacific salmon in the South Fork and must be taken into consideration when restoration plans are being modified, updated, and prepared to be climate-ready for the future.

Summer low-flow temperature modeling shows that the greatest impact to water temperature will occur in the lower three reaches of the South Fork. These areas either currently exceed the 7-DADMax lethal limit of 22 °C or are expected to exceed this limit under the medium-impact climate change scenario, as illustrated in Figure 6-5.

Increased winter peak flow is expected to be more pronounced in reaches of the South Fork that have been impacted by artificial confinement to prevent erosion. 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. Table 6-2 summarizes the distribution and severity of climate change impacts through the reaches and subbasins of the South Fork Nooksack River watershed.

Table 6-2. Summary of distribution and severity of potential climate change impacts across South Fork reaches and subbasins

Reach or Subbasin	Climate Impact				
	Reduced Spring Snowmelt	Elevated Summer Temperature	Reduced Summer Low Flow	Increased Winter Peak Flow	Sediment
Reach					
1 (RM 0–14.3)	Moderate	High	High	High	Moderate
2 (RM14.3–18.5)	High	High	Moderate	Low	Moderate
3 (RM 18.5–25.4)	High	High	Moderate	Moderate	Low
4 (RM 25.4–31)	High	High	Moderate	Low	Moderate
5 (Upstream of RM 31)	High	Moderate	Moderate	Moderate	Moderate
Subbasin					
Hutchinson	Moderate	High	High	Moderate	Moderate
Skookum	High	Moderate	Moderate	Moderate	Moderate
Acme Valley	Low	High	High	Moderate	Moderate
Plumbago and Deer	Moderate	Moderate	Moderate	Moderate	Moderate
Edfro and Cavanaugh	Moderate	Moderate	Moderate	Moderate	Moderate
Howard	High	Low	Low	Moderate	Moderate
Upper South Fork	High	Low	Low	Moderate	Moderate

Impact Potential		
Low Impact	Moderate Impact (Mod)	High Impact

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). According to Rieman and Isaak (2010, p. 1), “a rapidly expanding literature” has indicated that 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.

The potential magnitude of the impact that climate change could have on Pacific salmon species and life stages in the South Fork was evaluated for the nine species of Pacific salmonids that inhabit the South Fork. 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 evaluated during spawning and intragravel development stages, with high potential also recorded for several species during upstream migration/holding and rearing.

The three ESA listed species have several commonalities: They experience summer and snowmelt adult migration and holding; year-round rearing leading to exposure to climate change effects all year long; and spawning areas above partial barriers. Also Chinook salmon and winter steelhead trout have summer spawning and/or incubation. Figures 6-6, 6-8, and 6-9 show the species life stages overlaid with climate change vulnerabilities. Figure 6-7 shows an example of the life-cycle temperature requirements for Chinook compared to the future year-round temperature regime predicted as a function of air temperature for the medium impact scenario using a Mohseni empirical model (see EPA 2016 for details). The remaining

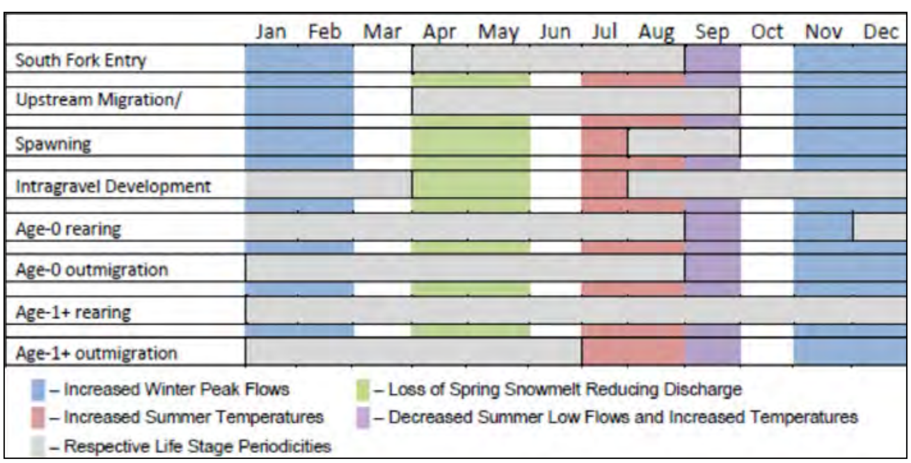

Figure 6-6. Chinook vulnerability to climate change impacts by life-cycle stage.

graphical displays of temperature requirements are provided in the full qualitative report (EPA 2016). As shown, all life-cycle stages for the ESA listed species are impacted in some way by the effects of climate change.

Restoration actions, the ability of each action to ameliorate climate change effects, and the priority level for each technique are presented by South Fork reach (Table 6-3) and subbasin (Table 6-4). Specific recommendations for adaptation to address both legacy and climate change impacts are presented by action type in Table 6-5.

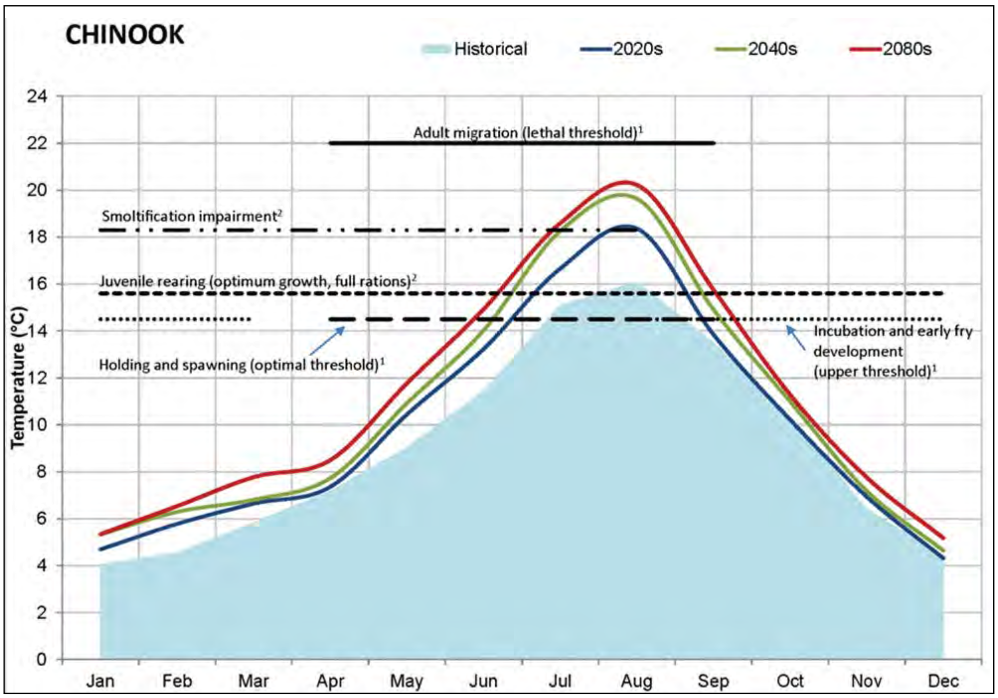

Figure 6-7. Chinook life-cycle temperature requirements plotted against predicted water temperature at Potter Rd. for the medium impact scenario using a Mohseni Model (see EPA, 2016).

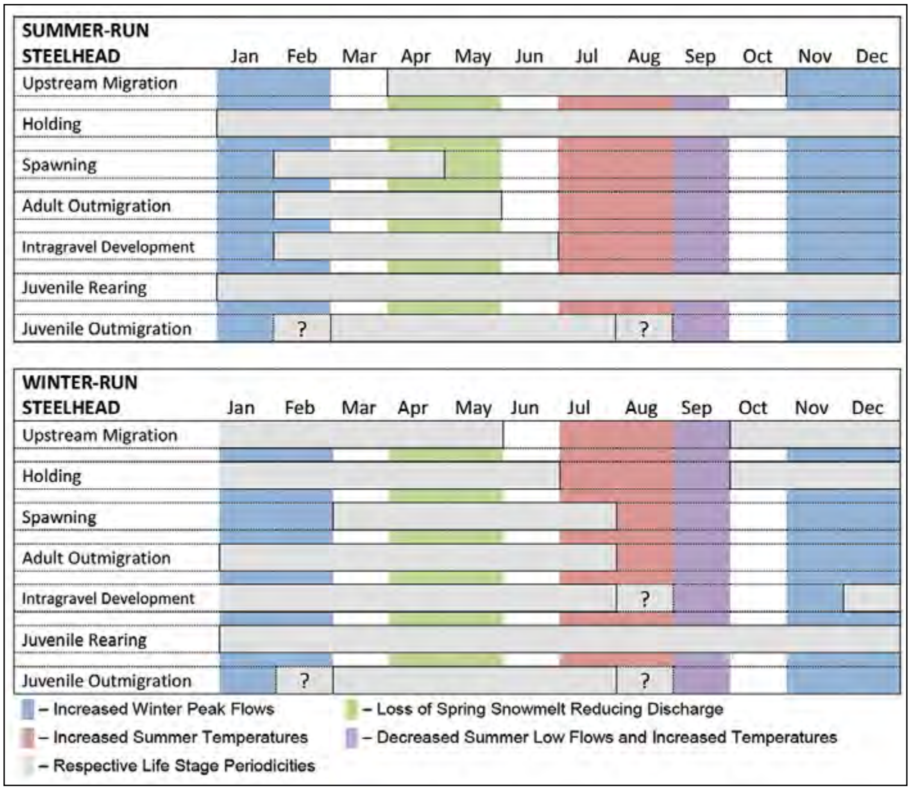

Figure 6-8. Summer-run steelhead trout (*upper half*) and winter-run steelhead trout (*lower half*) vulnerability to climate change impacts by life-cycle stage.

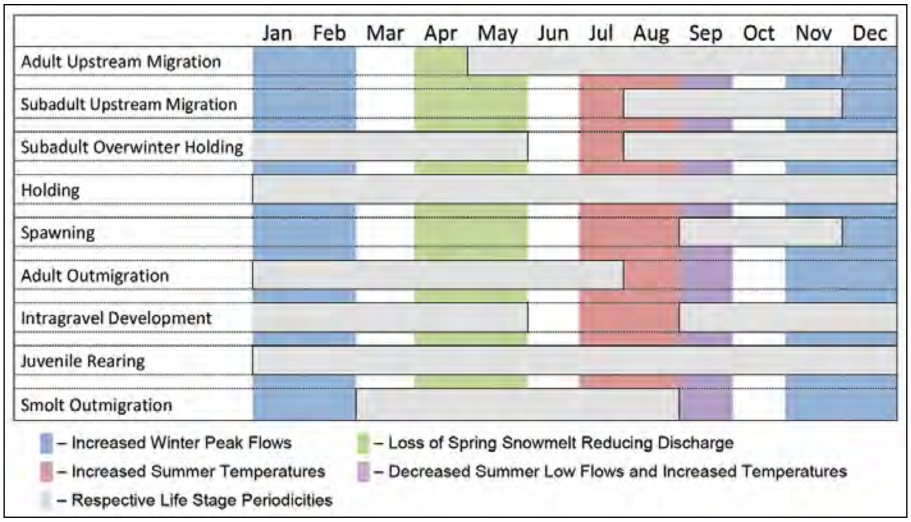

Figure 6-9. Bull trout vulnerability to climate change impacts by life-cycle stage.

Table 6-3. Recommended Restoration Actions for South Fork Reaches (Source: Beechie et al. 2013)

Category	Analogous South Fork Technique	Ameliorates Climate Change Effects?[3]					Priority of Restoration Action (by Reach)[4]				
		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 Sediment 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 nonnative plants	◐	◐	○	○	○	High	High	High	High	High
Instream Rehabilitation	Placement of log jams, other wood	◐[2]	○	○	○	○	High	Low	High	Low	Low

Notes:
[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 rehabilitation can ameliorate temperature increase by creating temperature refuges, increasing hyporheic exchange by encouraging bedform diversity, and narrowing active channel and increasing effective shade.

[3] Ability to Ameliorate Climate Change Effects	
●	Yes
○	No
◐	Context-dependent

[4] Impact Potential	
(yellow)	Low Impact
(orange)	Moderate Impact (Mod)
(red)	High Impact

Table 6-4. Recommended Restoration Actions for South Fork Subbasins (Source: Beechie et al. 2013)

Category	Common Techniques	Analogous South Fork Technique	Ameliorates Climate Change Effects?[3]					Priority of Restoration Action (by Reach)[4]						
			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	○	○	○	○	●[1]	Mod	Mod	Low	Low	Low	Low	Low
		Improve passage at natural barriers	○	○	○	○	●[1]	Low	Low	Mod	Low	Low	Low	Low
Stream Flow Regimes	Reduce water withdrawals, restore summer base flow	Reduce withdrawals	●	●	○	○	○	High	Low	Low	Low	Low	Low	Low
		Restore floodplain wetlands	●[2]	●	○	○	○	High	Low[5]	Low[5]	Low[5]	Low[5]	Low[5]	Low[5]
	Disconnect road drainage from streams	Disconnect road drainage from streams	○	○	●	●[3]		Low	Low	Low	Low	Low	Low	Low[6]
Erosion and Sediment Delivery	Landslide hazard reduction (sidecast/ fill removal)	Landslide hazard reduction (sidecast/ fill removal)	○	○	○	●[3]	○	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 nonnative 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]

Sources:
[1] Beechie et al. 2006; Waples et al. 2006.
[2] Poole et al. 2008; Arrigoni et al. 2008.
[3] Beechie et al. 2005.
Notes:
[4] Techniques and amelioration effects not cited individually are from Beechie et al. 2013.
[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 more than 2 °C cooler than the South Fork).

[9] Ability to Ameliorate Climate Change Effects	
●	Yes
○	No
◐	Context-dependent

[10] Impact Potential	
(yellow)	Low Impact
(orange)	Moderate Impact (Mod)
(red)	High Impact
(blue)	Moderate/Low

Table 6-5. Summary of recommended actions for the South Fork

Restoration and Protection Action	Recommendations
Floodplain Reconnection	• Increase the pace of broader scale floodplain reconnection projects by increasing opportunity 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 landowners 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 maximum extent possible (e.g., water banking). • Develop a ground water-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 Program (CREP) 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 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 considerations into updates of *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 watershed.
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.

7.0 Discussion

Climate change is an emerging field of study and practice for scientists, policy-makers, and local stakeholders. There are no agreed-upon methodologies or approaches to incorporating climate change considerations into watershed management planning tools. This project provided an opportunity to use climate change risk and adaptation concepts developed by the IPCC and USGCRP and apply them using the South Fork watershed as a pilot. This section reflects on how some of these key concepts were interpreted and applied in this project with the intent of identifying practical considerations and initial lessons learned.

The project team first sought to develop a stepwise research approach that could be easily replicated and scaled (see Figure 4-2). The project, including formulation of the quantitative and qualitative assessments, was generally structured to follow the USGCRP resilience framework to explore climate threats, assess vulnerability and risks, investigate options, prioritize actions, and take action.[11] Importantly, the project team recognized the necessity of moving from climate change vulnerability assessment to adaptation actions. The quantitative assessment modeled projected climate change impacts and future stream conditions of the South Fork (Butcher et al. 2016). The qualitative assessment used that information to explore the vulnerability and risk thresholds of South Fork salmonids (EPA 2016). The quantitative assessment focused on riparian restoration to maximize stream shading, which is the approach used in most temperature TMDLs in forested watersheds. In contrast, the qualitative assessment identified and then prioritized a suite of adaptation strategies. Both assessments were designed to provide direct input into the South Fork temperature TMDL implementation plan and ESA salmon recovery plan, so that watershed managers can act on the findings. Thus, the quantitative and qualitative assessments were structured to synergistically amplify each other and to provide actionable information that could provide direct input into existing watershed regulatory tools. The pilot research project approach seeks to bridge the gaps between science, policy, and practice; thus, moving to *actionable science*.

Climate change presents temporal challenges beyond the traditional risk management paradigm—the uncertainty surrounding the magnitude and consequences of future impacts complicates climate change adaptation planning. EPA has a rich history of risk assessment, and the project team leveraged the Agency's traditional risk assessment paradigm to develop an *iterative adaptive risk management framework*. As presented in Figure 3-2, climate change is considered an additional stressor to the environment.

11 As illustrated and described in the USGCRP Toolkit, which is located online here

Climate change risk is analyzed through a characterization of exposure and ecological effects, with risk continually reevaluated as new data is acquired. An iterative adaptive risk management framework is a flexible process that uses a research, evaluation, monitoring, and learning process (cycle) to improve future management strategies. Important to this project, an iterative adaptive risk management framework provides a process of *learning by doing*, whereby there is continued adaptation to improve outcomes (USGCRP 2014). The pilot project approach and parallel study strategy allowed the project team to concurrently accomplish the research objective of exploring how climate change considerations could be incorporated into the TMDL implementation plan and the regulatory objective of developing the South Fork temperature TMDL. It is hoped that this structure provides a process so that as new information becomes available, the TMDL implementation plan and future ESA salmon recovery updates monitor effectiveness of the proposed strategies and adjust as necessary (e.g., based on new information and lessons learned).

Perhaps most critically, the project team recognized the significance of the role of local stakeholders in the ultimate success of this pilot research project. Local stakeholders are responsible for implementing proposed adaptation options and using the adaptive management framework. The project was structured as a stakeholder-centric process, whereby:

- Stakeholder input provided the basis for problem formulation and approach (specifically through initial project kick-off activities including the June 2012 stakeholder workshop and October 2012 stakeholder engagement and project scoping facilitation meeting).
- Key stakeholders were also leaders —four staff of the Nooksack Indian Tribe served as lead authors of the qualitative assessment. The Nooksack Indian Tribe are key implementers of recovery actions and authors of the current ESA salmon recovery plan.
- An inclusive stakeholder engagement process was developed (via the VIDT) to interact with all relevant stakeholders at key project milestones.
- The stakeholder organizational approach was embedded within the local watershed management structure, WRIA 1. Project activities were closely coordinated with the WRIA 1 salmon recovery and management teams, with the Nooksack Indian Tribe serving as the nexus of this integrated approach.

Stakeholder engagement was considered a critical component of the pilot research project and strategic opportunities for engagement and awareness building were provided throughout the life of the project. The dynamic stakeholder engagement process used in this project (and described in section 5) fostered the shared production of knowledge on climate change risks and adaptation options for the South Fork watershed. The shared or coproduction of knowledge is described as a means "to produce usable climate science knowledge through a process of collaboration between scientists and decision makers" (Meadow et al. 2010, p.1). The objective is to yield better adaptation strategies and outcomes. The pilot research project team generated robust interaction between scientists, policy makers, and local stakeholders to coproduce climate change information that is actionable within the context of the South Fork. The project team also embedded the process in existing governance structures so the project networks and findings are sustainable and can be carried on past the life of this project.

Adult Chinook. Credit: U.S. Fish and Wildlife Service

The project team used a deliberate approach to identifying and applying the latest climate change science and approaches to this pilot research project. In addition to the technical findings and recommendations described in this report, the following overarching lessons identified by the project team are considered important to the pilot project:

- Although considerable uncertainty (e.g., from future greenhouse gas emissions and ability of models to simulate responses of future climate) surrounds future climate change conditions and impacts, risk assessment and management is not an entirely new construct. The temporal challenges of climate change can be easily integrated into traditional risk approaches by using adaptive management frameworks. Pilot projects provide opportunities to learn by doing and to update adaptive management frameworks and policy approaches in the near term.
- Stakeholder engagement should be structured to build relationships and communication channels between scientists, policy makers, and stakeholders that foster the coproduction of knowledge and yield more effective adaptation strategies and outcomes.
- Embedding climate change risk assessment and adaptation planning in existing watershed management governance and planning frameworks helps to ensure the uptake and implementation of recommendations and strengthens the possibility that an adaptive management framework will be used in the future.

- The potential to see results and scale pilot activities greatly benefits from robust stakeholder engagement, as such a process can increase the potential that stakeholders will embrace, and ultimately implement, the resulting recommendations.

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. The involvement of members of the WRIA 1 watershed management and salmon recovery staff teams in this pilot is considered critical to extending the application to other WRIA 1 watersheds. The pilot research project can also be applied in other watersheds across the country, although the procedures and methods may differ depending on site specific considerations, existing information, and watershed tools (e.g., TMDL modeling tools). The key steps of the quantitative and qualitative assessment are summarized in the call out boxes below, along with a few key take away messages for the application of these steps in other watersheds. It is recommended that an initial step for any practitioner that is interested in applying these methods in a local watershed context is to read the quantitative and qualitative assessments as the methods and findings are fully described and provide important context and detail.

Chinook Salmon. Credit: U.S. Geological Survey

Quantitative Assessment

Key Steps and Take-Away Messages on Application to other Watersheds

The quantitative assessment provides a demonstration of how climate change can be incorporated into the modeling that supports a temperature TMDL. The quantitative assessment contains six general steps:

1. **Water Quality Response Model:** Developing a TMDL and associated point source wasteload allocations and nonpoint source load allocations requires a linkage analysis that relates stressor inputs to criteria outcomes using either a process-based or empirical model. For the South Fork Nooksack temperature TMDL, the QUAL2Kw model provides a process-based linkage between thermal inputs and water temperature response.

2. **Evaluate Critical Conditions:** The TMDL must protect uses across a range of conditions, including critical conditions of high risk. For a temperature TMDL, this involves assuring that criteria are achieved under warm, late summer conditions with high thermal inputs and low instream flows. These critical conditions determine the type of information that is needed for assessing risk associated with future climate projections.

3. **Select Climate Scenarios:** Climate models contain uncertainty regarding the course of future climate and no model is a perfect predictor of what will happen. It is important to look at an ensemble of climate models to approximate the envelope of future conditions to which adaptation may be needed.

4. **Derive Future Boundary Conditions:** Output of selected climate scenarios is processed to provide alternative boundary conditions (e.g., weather, streamflow) for the TMDL critical conditions. It is important to use data that have been processed via downscaling designed to correct for bias and provide results that are appropriate to the spatial scale of the problem of interest.

5. **Apply Response Model:** Once future boundary conditions are assembled, the TMDL water quality response model can be run for multiple future climate conditions along with different implementation options.

6. **Interpret the Results:** The quantitative assessment can be thought of as an embedded ecological risk assessment that is intended to help inform TMDL development and associated implementation plans that take into account potential needs for climate adaptation.

Note that most of these steps are part of the standard TMDL development process, the difference here being that alternate future climate conditions are incorporated into the analysis in Steps 3 and 4. The general process would be applicable to assessment of water quality concerns other than temperature.

The quantitative assessment for the South Fork Nooksack River shows one way that a specific set of tools and analyses can be successfully used to complete the six steps shown above. The details are intended to be informative, but not proscriptive. Indeed, there are a variety of ways in which the six steps could be completed, at varying levels of effort. For the South Fork Nooksack River plentiful continuous monitoring of water temperature was available at multiple locations, enabling the calibration of a detailed temperature response model (QUAL2Kw in this case, but other models could have been used instead). An analysis could also have been performed with less data and/or less resources, for instance by pursuing an empirical statistical analysis that relates water temperature to weather conditions. While a simpler approach may introduce additional uncertainty, it can still be informative. The important point is to evaluate the risks that may be associated with future climate to plan for and maximize implementation success over the longer term.

Qualitative Assessment

Key Steps and Take-Away Messages on Application to other Watersheds

The qualitative assessment provides a demonstration of incorporating climate change risk into salmonid recovery planning in the South Fork to support a TMDL implementation plan and ESA salmon recovery plan. The qualitative assessment contains five general steps, which is adapted from *Restoring Salmon Habitat for a Changing Climate* (Beechie et al. 2012):

1. **Define the Geographic Scale of Analysis:** The impacts of climate change will vary among rivers and will include several different climate risks (e.g., increase in temperature, decrease in base flow, increase in peak flow). In turn, the risks to salmonid populations can vary according to salmonid species (e.g., impairing optimal temperature thresholds according to life cycle). The first step in applying the Beechie method is for practitioners to determine the geographical scale of the climate change assessment. Considerations when determining the scale of the assessment include the resources available to conduct the assessment, data availability and coverage, and units used for planning efforts to date.

2. **Identify Projected Climate Change Risk:** This step involves assessing the projected impacts of climate change to the respective geographic region, relative to changes that have already occurred. For the South Fork, the QUAL2kw modeling runs conducted for the quantitative assessment provided future climate change scenarios that were assessed per river mile.

3. **Evaluate the Impacts by Salmonid Species:** Salmonids have species-specific tolerances and life history requirements which are important criteria in determining how changes in temperature and stream flow will impact the salmon population. The development of visualization tools can assist in understanding life cycle impacts and priority vulnerabilities to the respective species (refer to Figures 6-6 and 6-7).

4. **Evaluate the Impacts by Restoration Action:** Restoration actions can then be prioritized based on the ability to ameliorate various climate change impacts and/or increase salmon resilience, and on the potential effectiveness of each restoration action. For the South Fork, restoration actions were prioritized by reach and subbasin.

5. **Document the Results:** The results of the analysis can be used to inform relevant watershed, land-use, and restoration planning efforts and tools. In this case, the results were used to develop the South Fork temperature TMDL implementation plan. The qualitative assessment will also be used to inform future ESA salmon recovery plans for the South Fork.

As illustrated in this case study, the Beechie method can be tailored fairly easily for salmon recovery efforts in other watersheds. There was considerable effort on the part of the Nooksack Indian Tribe to conduct research and develop visualization tools and graphics to assist with the evaluation of climate change impacts by salmonid species. These graphics are considered particularly helpful in mapping out the complicated relationships between species life stage periodicity, species distribution with temperature requirements, and future climate change projections. But, if the information is not available or time/resources insufficient, then assumptions can be made and plotted.

A particularly important aspect of the qualitative assessment is the reliance on local knowledge and use of robust stakeholder methods. Local stakeholders have an understanding of historic and current conditions, lessons learned on the application of salmon recovery efforts, and engaging these stakeholders in project activities makes it more likely that the findings and recommendations will be embraced and ultimately implemented. The special status of the Nooksack Indian Tribe as leaders of the qualitative assessment is considered critical, as the tribe plays a key role in on-the-ground implementation.

8.0 Conclusions

The climate change analysis conducted for the quantitative assessment was designed to provide an understanding of potential climate change impacts (magnitude and timing) on stream temperature and streamflow (Butcher et al. 2016). TMDLs—and, by extension, their implementation plans—have typically been developed using historic data, based on the assumption that climate is stable. That type of TMDL might not accurately represent conditions under potential future climate regimes. In the past, data for estimating future impacts of climate change have not been readily available to state agencies, who are responsible for developing TMDLs.

The evaluation of climate change vulnerability can help inform the South Fork TMDL implementation plan. Climate change is time-dependent. The pace (timing/rate) and priorities of restoration actions for TMDL implementation to protect against potential impacts of climate change are key components of an iterative risk management strategy. A key finding of the quantitative analysis for the South Fork is that the shade associated with system potential vegetation (SPV shade) can likely provide substantial resiliency into the future that will help protect beneficial uses, especially if

South Fork Nooksack River. Credit: Nooksack Tribe

combined with other actions that provide cold-water refuges during high-temperature periods (Butcher et al. 2016). **To approach achieving SPV (60–70-year-old trees) by the 2080s, planting should occur now and riparian areas along the mainstem South Fork should be protected**.

The modeling analysis of water temperature associated with future climate change in the South Fork watershed suggests a significant effect on maximum temperature in the river that could substantially reduce preferred salmon habitat. It is important to remember, however, that TMDL modeling analysis is purposefully based on an analysis of reasonable worst-case conditions (7Q10 flow combined with 90th percentile annual air temperature maximum) that could occur at a sufficiently low frequency so as to allow recovery or adaptation of the population. The analyses of more typical 7Q2 conditions still suggest significant stress on the salmon population, but are not nearly as dire as the 7Q10 flow projections. Many rivers within the current salmon range, including the Snake and Willamette river basins, have monitored temperatures above published lethal or protective thresholds, yet salmon currently occupy the majority of those rivers (Beechie et al. 2012).

While the modeling scenarios show that restoring SPV shade will have a strong beneficial impact on the summer temperature regime in the South Fork, future climate scenarios predict water temperature regimes that increasingly deviate from preferred habitat for salmon. The impact of occasional high-temperature events is in large part determined by whether the fish can find sufficient cold-water refuges that are cooler than the reach average and within their physiological tolerance ranges. The qualitative assessment was conducted to analyze a range of restoration strategies, and particularly smaller scale habitat management activities considered important to protect the resource (EPA 2016).

The qualitative assessment evaluated restoration actions that address legacy, ongoing, and future climate change impacts within each South Fork reach and subbasin (EPA 2016). 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. As discussed earlier, the quantitative assessment findings indicate that restoring the riparian zone of the mainstem of the South Fork alone is not enough to ameliorate excessive temperatures in the river. That outcome strongly suggests that additional study of salmon recovery efforts is required to identify other watershed-scale actions that will address both legacy impacts and future continued climate change.

The qualitative assessment 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 (EPA 2016). Most of these actions 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. The qualitative assessment thus urges that the recommended actions it presents are considered and implemented in a timely fashion to support a climate-resilient ecosystem and ESA recovery (EPA 2016).

There is considerable overlap between existing salmon recovery priorities and those considered to be climate ready priorities. Adapting salmon recovery plans to incorporate climate change considerations 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, the qualitative assessment has encouraged a broadening of the restoration planning horizon. **The greatest discrepancy between current and climate ready salmon recovery priorities is the elevated priority of actions with longer time scale-to-benefit ratios (e.g., riparian and wetland restoration).**

Adapting salmon recovery plans to incorporate climate change considerations is unlikely to require wholesale change, but rather a dramatic increase in the scale and pace of implementation.

While climate projections often seem dire, the importance of taking action now to offset future impacts could help motivate restoration practitioners and resource managers to redouble their efforts to address barriers to implementation. Highlighting the benefits of restoration on ecosystem services (i.e., reducing flood risk to downstream communities by reconnecting floodplains) might 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.

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9.0 References

Arrigoni, A.S., G.C. Poole, L.A.K. Mertes, S.J. O'Daniel, W.W. Woessner, and S.A. Thomas. 2008. Buffered, lagged, or cooled? Disentangling hyporheic influences on temperature cycles in stream channels. *Water Resources Research*. 44:W09418 pp13.

Beechie, T., C.N. Veldhuisen, E.M. Beamer, D.E. Schuett-Hames, R.H. Conrad, and P. DeVries. 2005. Monitoring Treatments to Reduce Sediment and Hydrologic Effects from Roads. Chapter 3 in *Monitoring Stream and Watershed Restoration*, ed. P. Roni, pp. 35–68. American Fisheries Society, Bethesda, MD.

Beechie, T., E. Buhle, M. Ruckelshaus, A. Fullerton, and L. Holsinger. 2006. Hydrologic regime and the conservation of salmon life history diversity. *Biological Conservation* 130: 560–572.

Beechie, T.J., D. Sear, J. Olden, G.R. Pess, J. Buffington, H. Moir, P. Roni, and M.M. Pollock. 2010. Process-based principals for restoring river ecosystems. *BioScience* 60:209–222.

Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2013. Restoring salmon habitat for a changing climate. *River Research and Applications* 29(8):939–960. doi: 10.1002/rra.2590.

Butcher, J.B., M. Faizullabhoy, H. Nicholas, P. Cada, and J.T. Kennedy. 2016. *Quantitative Assessment of Temperature Sensitivity of the South Fork Nooksack River Nooksack River under Future Climates using QUAL2Kw*. EPA/600/R-14/233. Western Ecology Division, National Health and Environmental Effects Research Laboratory, Corvallis, OR.

Cristea, N.C., and S.J. Burges. 2010. An assessment of the current and future thermal regimes of three streams located in the Wenatchee River basin, Washington State: Some implications for regional river basin systems. *Climatic Change* 102:493–520.

Ecology (Washington Department of Ecology). 2003a. QUAL2Kw.xls – A Diurnal Model of Water Quality for Steady Flow Conditions. Washington Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/models.html.

Ecology. 2003b. Shade.xls – A Tool for Estimating Shade from Riparian Vegetation. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/models.html.

EPA (Environmental Protection Agency). 2016. *Qualitative Assessment: Evaluating the Impacts of Climate Change on Endangered Species Act Recovery Actions for the South Fork Nooksack River, WA*. EPA/600/R-16/153. Western Ecology Division, National Health and Environmental Effects Research Laboratory, Corvallis, OR.

EPA. 2014. Helping to Protect Wild Salmon. *EPA Science Matters Newsletter*, April 2014. Accessed August 2015. https://19january2017snapshot.epa.gov/sciencematters/epa-science-matters-newsletter-helping-protect-wild-salmon-published-april-2014_.html.

EPA. 2017. Clean Water Act Section 303(d): Impaired Waters and Total Maximum Daily Loads (TMDLs). 2017. Accessed August 2015. https://www.epa.gov/tmdl.

Garibaldi, A. and N. Turner. 2004. Cultural keystone species: implications for ecological conservation and restoration. *Ecology and Society* 9(3): 1. Accessed August 2015. http://www.ecologyandsociety.org/vol9/iss3/art1/.

Hamlet, A.F., M.M. Elsner, G.S. Mauger, S.-Y. Lee, I. Tohver, and R.A. Norheim. 2013. An overview of the Columbia basin climate change scenarios project: Approach, methods, and summary of key results. *Atmosphere-Ocean* 51(4):392–415.

Hilderbrand, G.V., S.D. Farley, C.C. Schwartz, and C.T. Robbins. 2004. Importance of salmon to wildlife: Implications for integrated management. *Ursus* 15(1):1-9.

Isaak, D.J., C.H. Luce, B.E. Rieman, D.E. Nagel, E.E. Peterson, D.L. Horan, S. Parkes, and G.L. Chandler. 2010. Effects of climate change and wildlife on stream temperatures and salmonid thermal habitat in a mountain river network. *Ecological Applications* 20(5):1350–1371.

Johnson, S.L. 2004. Factors influencing stream temperatures in small streams: Substrate effects and a shading experiment. *Canadian Journal of Fisheries and Aquatic Sciences* 61(6):913–923.

Mantua, N., I. Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change* 102:187–223.

Mauger, G.S., and N. Mantua. 2011. Climate Change Projections for USFS Lands in Oregon and Washington (draft). University of Washington, Climate Impacts Group, Seattle, WA. Accessed September 9, 2013. http://cses.washington.edu/picea/USFS_ORWA/pub/USFS_ImpactsReport_DRAFT_GMauger.pdf.

McCullough, D.A., S. Spalding, D. Sturtevant, and M. Hicks. 2001. Issue Paper 5: *Summary of Technical Literature Examining the Physiological Effects of Temperature on Salmonids*. EPA-910-D-01-005. U.S. Environmental Protection Agency, Region 10, Seattle, WA.

Meadow, A.M., D.B. Ferguson, Z. Guido, A. Horangic, and G. Owen. 2015. Moving toward the Deliberate Coproduction of Climate Science Knowledge. *Water, Climate, and Society* 7:179-191.

Melillo J.M., T.C. Richmond, G.W. Yohe (eds). 2014. *The Third National Climate Assessment*. Global Change Research Program, U.S. doi:10.7930/J07H1GGT

Mote, P., A. K. Snover, S. Capalbo, S. D. Eigenbrode, P. Glick, J. Littell, R. Raymondi, and S. Reeder. 2014. Chapter 21: Northwest. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 487-513. doi:10.7930/J04Q7RWX

Polebitski, A., L. Traynham, and R.N. Palmer. 2007. Technical Memorandum #4: *Approach for Developing Climate Impacted Meteorological Data and its Quality Assurance/Quality Control*. Climate Change Technical Subcommittee of the Regional Water Supply Planning Process, Seattle, WA.

Poole. G.C., S.J. O'Daniel, K.L. Jones, W.W. Woessner, E.S. Bernhardt, A.M. Helton, J.A. Stanford, B.R. Boer, and T.J. Beechie. 2008. Hydrologic spiralling: the role of multiple interactive flow paths in stream ecosystems. *River Research and Applications*. 24: 1018-1031.

Randall, D.A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi, and K.E. Taylor. 2007. Climate Models and Their Evaluation. Chapter 8 in *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, pp. 589–662. Cambridge University Press, Cambridge, UK.

Richter, A., and S.A. Kolmes. 2005. Maximum temperature limits for Chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. *Reviews in Fisheries Science* 13:23–49.

Rieman, B.E., and D.J. Isaak. 2010. *Climate Change, Aquatic Ecosystems, and Fishes in the Rocky Mountain West: Implications and Alternatives for Management*. General Technical Report RMRS-GTR-250. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Sattertheaite, D., S. Huq, M. Pelling, A. Reid, and P. L. Romero. 2010. Adapting to climate change in urban areas: The possibilities and constraints in low-and middle-income nations. *Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges*, Earthscan Publications Ltd., New York, 3-47.

Washington Department of Fish and Wildlife. 2014. Puget Sound Chinook Comprehensive Harvest Management Plan, Annual Report, 2013-2014 Fishing Season. WDFW, Bellingham, WA.

Water Resource Inventory Area (WRIA) 1 Salmon Recovery Board. 2005. *WRIA 1 Salmonid Habitat Restoration Strategy*, Version 2.5a, June 10, 2005. Lummi Nation, Bellingham, WA.

Webb, R. and S. Weissman. 2014. Addressing Climate Change without Legislation. Center for Law, Energy, and the Environment University of California, Berkeley, School of Law.

Yohe, G. 2011. Incorporating (Iterative) Risk Management into the National Climate Assessment. Presentation. National Climate Assessment and Development Advisory Committee, July 12, 2011, Regional Working Group Background Document, and Climate Assessment.

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