

EPA Region 10 Climate Change and TMDL Pilot

Project Research Plan

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ABBREVIATIONS AND ACRONYMS

CCA	Climate Change Adaptation
CIG	Climate Impacts Group
CWA	Clean Water Act
DPS	Distinct Population Segment
Ecology	Washington Department of Ecology
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
GCM	Global Climate Model
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
LA	Load Allocation
LIDAR	Light Detection and Ranging
MOS	Margin of Safety
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NWP	National Water Program
ORD	EPA's Office of Research and Development
OSP	Office of Science Policy
OW	EPA's Office of Water
PNW	Pacific Northwest
QAPPs	Quality Assurance Project Plans
SFNR	South Fork Nooksack River
TMDL	Total Maximum Daily Load
USFS	U.S. Forest Service
USGCRP	United States Global Change Research Program
USGS	U.S. Geological Survey
VIC	Variable Infiltration Capacity model
WLA	Wasteload Allocation
WQS	Water Quality Standard
WRIA 1	Water Resources Inventory Area Number 1

EXECUTIVE SUMMARY

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

The total maximum daily load (TMDL) program is one of the primary frameworks for the nation to maintain and achieve healthy waterbodies, implemented pursuant to section 303(d) of the Clean Water Act (CWA). More than 40,000 TMDLs have been developed in the United States to determine the maximum pollutant loads allowable that would still permit attainment of water quality standards. However, the majority of these analyses have been conducted using assumptions of a stationary climate under which historical data on flow and temperature can be assumed to be an adequate guide to future conditions (Johnson et al. 2011). Research is needed to illuminate the ways in which climate change considerations could be incorporated into a TMDL, and how climate change might influence restoration plans.

The U.S. Environmental Protection Agency (EPA) Region 10 and EPA's Office of Research and Development (ORD) and Office of Water (OW) have launched a pilot research project to consider how projected climate change impacts could be incorporated into a TMDL and influence restoration plans. The pilot research project will use a temperature TMDL being developed for the South Fork Nooksack River (SFNR), in Washington, as the pilot TMDL for climate change analysis. An overarching goal of the pilot research project is to ensure that relevant findings and methodologies related to climate change are incorporated into the SFNR Temperature TMDL in such a way that the regulatory objectives and timelines of the TMDL are also met.

Because of the collaborative nature of this project, the project objectives have been specified for EPA Region 10 and OW, and for EPA ORD. The pilot research project objectives are summarized below.

EPA Region 10 and OW Objectives

1. Support the implementation of EPA's National Water Program 2012 Strategy: Response to Climate Change.
2. Assess a range of outcomes from the Intergovernmental Panel on Climate Change (IPCC) Scenarios and Regionally Downscaled Global Climate Models (GCMs).
3. Explore the potential linkages between available climate change research and the TMDL process.

EPA ORD Objectives

1. Develop an EPA pilot research project and project report that documents the process and analysis to incorporate climate change considerations into a regional TMDL for the SFNR.
2. Assess the potential impacts of climate change on stream temperature and stream flow. Model the effects of riparian shading under climate change on Ecology's temperature criteria for salmonid designated uses.
3. Evaluate the effects of using inherently uncertain data from Regionally Downscaled GCMs to bracket a range of outcomes and create the boundary conditions for QUAL2Kw.
4. Integrate the objectives of the CWA 303(d) TMDL provisions to protect and restore designated uses, which support the recovery goals of the Endangered Species Act (ESA) Salmonid Recovery Plan.
5. Evaluate the prioritization of stream restoration actions in the SFNR.
6. Investigate the application of methods to identify coldwater refuges and evaluate the potential for protection/restoration actions under climate change.
7. Collaborate and incorporate the findings from the U.S. Geological Survey (USGS) Groundwater/Surface Water Study of the SFNR.

The pilot research project consists of three primary project phases: *Phase 1 Research Plan*, March–September 2012; *Phase 2 Research Analysis and Risk/Vulnerability Assessment*, October 2012–September 2013; and *Phase 3 EPA Report*, October 2013–September 2014.

This document constitutes the final deliverable of *Phase 1 Research Plan*. The research plan identifies the goals and objectives of the pilot research project and outlines the technical approach, major activities, subtasks, and schedule for completing the study. Tasks 1-4 as outlined in this research plan are associated with Phase 2; whereas Task 5 is associated with Phase 3. The first task (*Process Roadmap*) will develop an organizing graphical framework that will serve to both illustrate the TMDL and climate change assessment processes and to highlight potential linkages and integration points for further study. The second task (*Quantitative Assessment*) will provide climate-altered boundary conditions for the QUAL2Kw model. The QUAL2Kw model will assist in the analysis of potential climate change impacts on SFNR temperatures and TMDL allocations. Under the third task (*Qualitative Assessment*), a comprehensive analysis of freshwater habitat for ESA salmon restoration in the SFNR under climate change will be conducted, which will result in a prioritized list of climate change adaptation strategies to support salmon restoration. The fourth task (*Climate Change Considerations for TMDL Development in the SFNR*) will examine EPA TMDL regulatory requirements to identify potential areas where climate change could be considered for inclusion in the SFNR temperature TMDL. Each of project tasks one through four results in an interim deliverable. The fifth task, production of the Phase 3, EPA final report, will integrate and synthesize the results from the task reports into a coherent EPA final report, which will serve as the final project outcome.

INTRODUCTION

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

The total maximum daily load (TMDL) program is one of the primary frameworks for the nation to maintain and achieve healthy waterbodies, implemented pursuant to section 303(d) of the Clean Water Act (CWA). More than 40,000 TMDLs have been developed in the United States to determine the maximum pollutant loads allowable that would still permit attainment of water quality standards (WQS). However, the majority of these analyses have been conducted using assumptions of a stationary climate under which historical data on flow and temperature can be assumed to be an adequate guide to future conditions (Johnson et al. 2011). Research is needed to illuminate the ways in which climate change considerations could be incorporated into a TMDL, and how climate change might influence restoration plans.

The U.S. Environmental Protection Agency (EPA) Region 10, Washington Department of Ecology (Ecology), Nooksack Indian Tribe, and the Lummi Nation are collaborating on a temperature TMDL for the South Fork Nooksack River (SFNR), in Washington.¹ In addition to this regulatory objective, Region 10 has partnered with EPA's Office of Research and Development (ORD) and Office of Water (OW), to initiate a pilot research project to consider how projected climate change impacts for the SFNR could be incorporated into the TMDL and influence restoration plans.² EPA is using a *parallel study strategy* to concurrently accomplish the research objective (Longitudinal Analysis (Start-To-Finish) Climate Change and Temperature TMDL) and regulatory objective (SFNR Temperature TMDL). This allows EPA to *learn by doing*.

Using the SFNR as the pilot area for this research effort has several benefits, specifically: (1) the synchronized pairing of the research project with a *real-world* temperature TMDL to ensure better understanding of the needs of water managers; (2) the pilot area represents a typical landscape in the Pacific Northwest (PNW), which promotes broader direct application of the project results; and (3) the pilot research project will be able to leverage downscaled climate datasets and integrate ongoing research by other federal agencies that is directly relevant to the project.

The SFNR is in northwest Washington and in an area considered typical of the mountainous, remote, forested landscape in that region, with minor urban and agricultural

¹ The project team for the regulatory project consists of EPA Region 10, Ecology, and the EPA consultant. The Nooksack Indian Tribe and the Lummi Nation are cooperating partners.

² The project team for the pilot research project consists of EPA ORD, EPA Region 10, and the EPA consultant. Ecology, the Nooksack Indian Tribe and the Lummi Nation are cooperating partners.

land uses. However, forest practices, including road building and timber harvest, are the dominant land use practices in the SFNR watershed. The SFNR and its tributaries provide migration routes, and spawning and rearing habitat for several salmon species throughout the year. The SFNR has 14 segments, and 9 tributary segments are 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). These segments have data that indicate exceedances. Other segments without data might also be experiencing exceedances. The temperature TMDL will identify the issues and outline the solutions needed to improve river temperatures.

Several relevant research efforts are ongoing to provide increased understanding of how the SFNR temperature could change under climate scenarios, which will be leveraged for the pilot research project:

1. The Climate Impacts Group (CIG) has developed hydroclimatic scenarios for the PNW, including for the pilot area (Mauger and Mantua 2011). The hydroclimatic scenarios have been developed for the A1B (moderate emissions scenario)³ climate scenario using three downscaling approaches (hybrid delta, transient Bias Corrected Statistical Downscaling, and the delta method) and include three time steps (2020s, 2040s, and 2080s).
2. Dan Isaak, U.S. Forest Service (USFS), with support from the Great Northern Landscape Conservation Cooperative, is developing a regional stream temperature model, which includes the SFNR. A potential application of this project will be to map river network temperatures to identify when and where WQS are being met and how that might change under climate change scenarios.
3. Tim Beechie, National Oceanic and Atmospheric Administration (NOAA), is exploring salmon vulnerability in Washington, including in the SFNR, by assessing salmon vulnerability from habitat and stock status stress, and from climate stress as determined through future temperature and future precipitation stress (Beechie et al. 2012).
4. 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). We will use this study as a regional example of QUAL2Kw modeling and riparian shading under climate change.

The present day condition of freshwater salmonid habitat in the SFNR is the result of natural disturbances, land use (mostly forest and agricultural) and land use practices (current and historical). Current Best Management Practices (BMPs) and restoration

³ The A1 scenario family assumes very high economic growth, global population peaking mid-century and then declining, and energy needs being met by a balance of fossil fuels and alternative technologies. A1B (a subset of the A1 family) lies near the high end of the spectrum for future greenhouse gas emissions, particularly through mid-century. A1B projects a future where technology is shared between developed and developing nations in order to reduce regional economic disparities. See CIG's website for more information: <http://cses.washington.edu/cig/fpt/climatemodels08.shtml>.

actions will take decades to restore watershed processes and historical habitat conditions in the SFNR. The Habitat Conservation Plan (HCP) under the ESA are additional measures for forest land use that go beyond the requirements of the Washington Forest Practices Act (WFPA) to address current and historical impacts on freshwater salmonid habitat in the SFNR .

Climate change adds an additional stressor to salmonid habitat in the SFNR. The methodology outlined in this research plan uses downscaled GCMs, the Variable Infiltration Capacity (VIC) and QUAL2Kw hydrologic models to assess the impacts of climate change on salmonid habitat in the SFNR. The quantitative and qualitative assessments in this Research Plan facilitate the integration of multiple stressors, current and past land use practices, and restoration actions (ESA recovery and TMDL implementation) to present an integrative analysis of future freshwater salmonid habitat in the SFNR under Climate Change.

This research plan identifies the goals and objectives of the pilot research project and outlines the technical approach, major activities, subtasks, and schedule for completing the study.

PROJECT OBJECTIVES

The following EPA objectives have been developed for this project:

1. EPA Regional (Region 10) and Program Office (OW) Objectives

- Support the implementation of EPA's National Water Program 2012 Strategy: Response to Climate Change – March 2012⁴ to help achieve EPA's Vision Statement on Water Quality by promoting the management of sustainable surface water resources under changing climate conditions (USEPA 2012a).
- Assess a range of outcomes from the Intergovernmental Panel on Climate Change (IPCC) Scenarios and Regionally Downscaled Global Climate Models (GCMs), rather than a single prediction of climate change effects on stream temperature and the related WQS.
- Explore the potential linkages between available climate change research and the TMDL process.

2. EPA Management Objectives

- Involve environmental practitioners and policy makers (federal, tribal, state, local and nongovernmental organization) in developing a climate change risk assessment/management (vulnerability/adaptation) research pilot.
- Operate as one EPA (Region 10, OW, ORD) in the planning, execution and evaluation of this project.

⁴ Note that this document is currently available as a public review draft. The final draft has not yet been released and may differ from the public review draft.

- Encourage the consideration of EPA's National Tribal Science Priorities for Climate Change and Integration of Traditional Ecological Knowledge.
- Use a parallel study strategy to concurrently accomplish the research objective (Start-To-Finish Climate Change Temperature TMDL) and regulatory objective (SFNR Temperature TMDL).

3. EPA Research (ORD) Objectives

- Develop an EPA project and project report that documents the process and analysis used to incorporate climate change considerations into a regional temperature TMDL for the SFNR.
- Assess the potential impacts of climate change on stream temperature and stream flow from IPCC Emission Scenario A1B (moderate emissions scenario), based on regionally downscaled GCMs for the 2020s, 2040s and 2080s (Mauger and Mantua 2011). Model the effects of riparian shading under climate change on Ecology's temperature criteria for salmonid designated uses.
- Evaluate the effects of using inherently uncertain data from Regionally Downscaled GCMs by using the hybrid delta results under the A1B scenario for the GCM that is anticipated to produce model low (least warming) model medium (medium warming) and model high (highest warming) to bracket a range of outcomes and create the boundary conditions for QUAL2Kw.
- Integrate the objectives of the CWA 303(d) TMDL provisions to protect and restore designated uses, which support the recovery goals of the Endangered Species Act (ESA) Salmonid Recovery Plan. Use the best available science from the Climate Science Programs under the United States Global Change Research Program (USGCRP).
- Evaluate the prioritization of stream restoration actions in the SFNR on the basis of the watershed processes or functions they attempt to restore and their ability to ameliorate climate change effects on high stream flows, low stream flows, and high stream temperatures (Beechie et al. 2012).
- Investigate the application of methods to identify coldwater refuges and evaluate the potential for protection/restoration actions to increase the effective use of thermal refugia by coldwater fish under climate change (USEPA 2012b).
- Collaborate and incorporate the findings from the United States Geological Survey (USGS) Groundwater/Surface Water Study of the SFNR, WA (in progress and commissioned by the Nooksack Indian Tribe).

STAKEHOLDER ENGAGEMENT

This project is structured as a stakeholder-centric process. This project began with extensive discussions involving EPA's Region 10, OW, and ORD about the scope and purpose of the project. This conversation was expanded to include key stakeholders in the

SFNR including Washington's Department of Ecology (Ecology), Nooksack Indian Tribe, and Lummi Nation, along with the University of Washington's CIG, USFS, NOAA Fisheries and the USGS as research partners. Two stakeholder engagement meetings have been held to date, and are further described below.

A workshop was held on June 25, 2012, at EPA Region 10 in Seattle to solicit input from key stakeholders, scientists, environmental practitioners and policy makers (federal, tribal, state, local and nongovernmental organization) and help develop the scope, methods and study design for the EPA Region 10 Climate Change TMDL Pilot and Temperature TMDL.

On October 4, 2012, a project scoping meeting was held with Washington's Water Resources Inventory Area Number 1 (WRIA 1) Salmon Recovery Team. The purpose of the meeting was to brief the team on the EPA Region 10 Climate Change and TMDL Pilot and to solicit input on issues, concerns and opportunities to improve the scope and effectiveness of the project. The WRIA 1 Salmon Recovery Team recommended implementing Task 3 (*Qualitative Assessment*) as a *rapid-prototype pilot*.⁵ Specifically, these recommendations included: (1) developing an assessment methodology based on *Restoring Salmon Habitat For A Changing Climate*, Beechie et al. 2012 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.

The Nooksack Indian Tribe has identified two issues that are of substantial interest to the tribe, and we will accommodate those issues in the analyses to the extent we can within the scope, resources, and capabilities available to this project: (1) upland watershed processes are fundamental biophysical mechanisms or systems that govern the movement, delivery, or gain/loss of water, sediment, nitrogen and large woody debris to aquatic ecosystems on the landscape, and (2) riparian buffer effectiveness on regulating stream temperature from forest practices. To the extent these issues are not readily addressed in the analyses, we will identify possible future studies that can directly assess the issue in more detail.

We will continue the stakeholder engagement during the research planning, implementation and documentation phases of this project. The EPA Region 10 climate change TMDL pilot is all about demonstrating how cutting-edge science can be applied in a real-world problem-solving context with the participation of scientists, environmental practitioners and stakeholders.

⁵ Rapid prototyping is an engineering design method that is commonly used in the manufacturing and software development sectors. The emphasis is on minimal planning and rapid development to allow the accomplishment of a *working model* in a relatively short time frame. The chief advantage is the *working model* is available for testing, evaluation and refinement in a much shorter time frame than would normally be required. In addition, the *working model* creates an opportunity for adaptive management and learning that is unavailable in a more traditional development cycle. In this case the Beechie et al. 2012 method is the concept, the Task 3 Qualitative Assessment is the rapid prototype development of a *working model* in the SFNR and the engineering design refinement and scaling is the follow-on project for the entire Nooksack River Basin.

RESEARCH APPROACH

Task 1 – Process Roadmap

Background and Problem

While the evaluation of potential climate change impacts has become increasingly prevalent in water resources assessments, little research has been done on how to incorporate climate change findings and data into the TMDL process. A comprehensive review of the specific elements of a TMDL is needed to evaluate how to best integrate the evolving understanding of climate change impacts into TMDL determinations and implementation plans and to account for the inherent uncertainty underlying climate change. Given the complexities of such an assessment, developing an organizing graphical framework would serve to both illustrate the TMDL and climate change assessment processes and to highlight potential linkages and integration points for further study. This Project provides an opportunity to explore the climate change implications of stream temperature on the SFNR.

Approach and Methods

The process flowchart, referred to in this document as the *process roadmap*, will serve as an organizing methodology for the pilot research project and will specifically guide Task 4 of this research plan. The process roadmap will be continually updated through the life of this project to illustrate the primary steps and decision points of the quantitative and qualitative assessments and document climate change considerations as they relate to, and inform the TMDL process. The three primary components of the process roadmap are illustrated and described below.

TMDL Process (Figure 1)

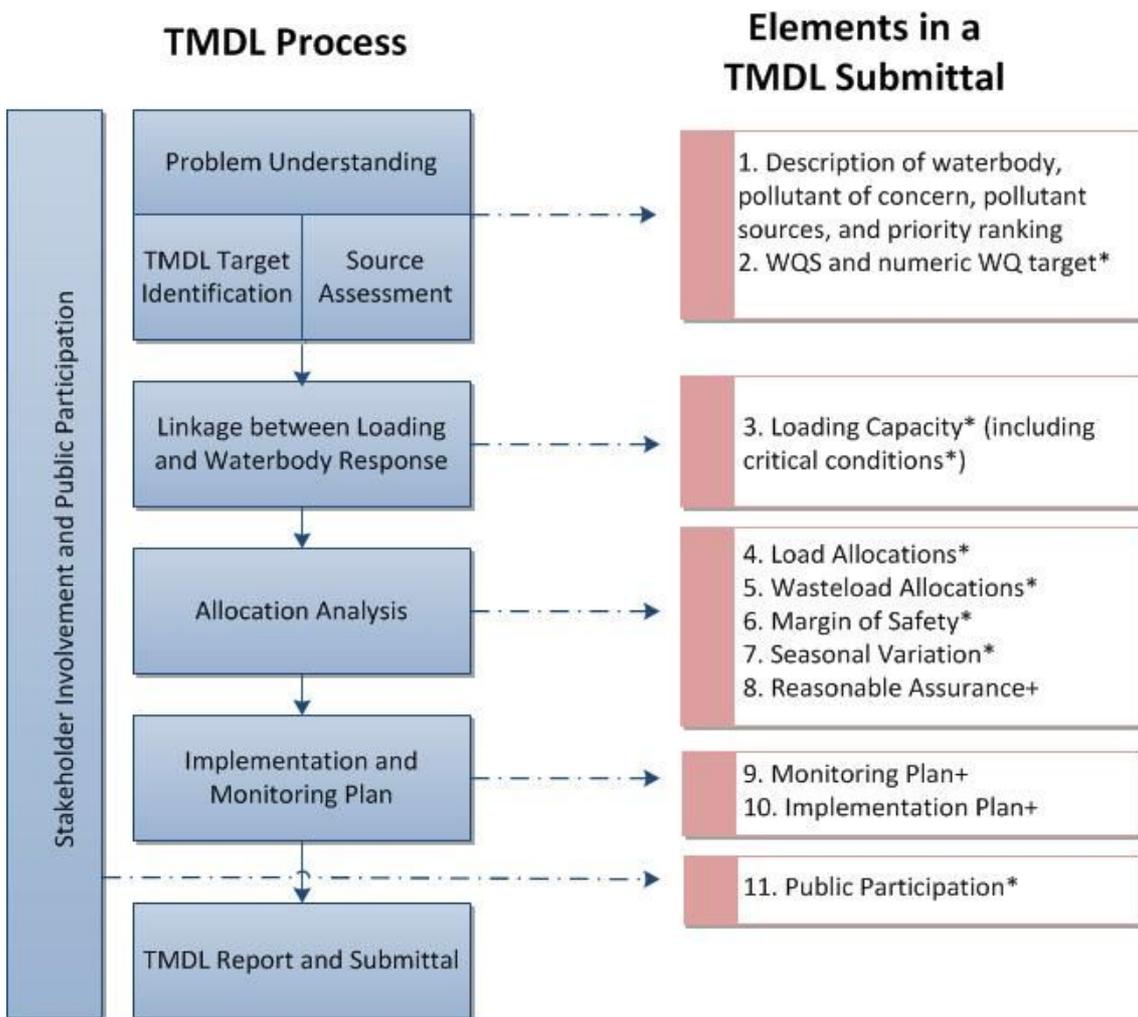
The TMDL process and elements are presented as Figure 1, an adaption from *Guidelines for Reviewing TMDLs under Existing Regulations issued in 1992* (USEPA 2002). EPA identified 13 elements as part of the TMDL process; however two of those elements (including a submittal letter and keeping an administrative record) are not considered germane to TMDL development. Figure 1 thus includes only the 11 elements necessary for developing the TMDL. Of the 11 elements, 7 are required by regulation (40 CFR 130.7), and 3 elements are recommended for inclusion by EPA guidance. The elements have been conceptually grouped (and labeled TMDL Process in Figure 1) on the basis of how TMDL practitioners typically address EPA requirements and recommendations in the TMDL process.

Climate Change Assessment Process (Figure 2)

The primary elements generally associated with a climate change assessment are illustrated in Figure 2, an adaptation from *Scanning the Conservation Horizon, A Guide to Climate Change Vulnerability Assessment* (Glick et al. 2011). While there is no set formula for conducting a climate change assessment, as climate assessments vary by sector focus, geographic and temporal scales, and by the resources available to conduct the assessment, the elements in Figure 2 constitute primary considerations when developing a climate change assessment.

TMDL and Climate Change Assessment Process Linkages (Figure 3)

The conceptual linkages between the TMDL and climate change assessment processes are presented as Figure 3. It is anticipated that the tasks conducted as part of the pilot research plan will further refine the understanding of how these two processes can better inform and reinforce each other. The process steps illustrated in Figure 3 will be further categorized into sub-process steps, decision points, and causal relationships according to research findings from the quantitative and qualitative assessments. Relevant findings and lessons learned from other EPA climate change research will also be incorporated as appropriate.



Notes:

* *Required by regulation (40 CFR 130.7)*

+ *Recommended through guidance*

Figure 1. Process roadmap: TMDL process and elements

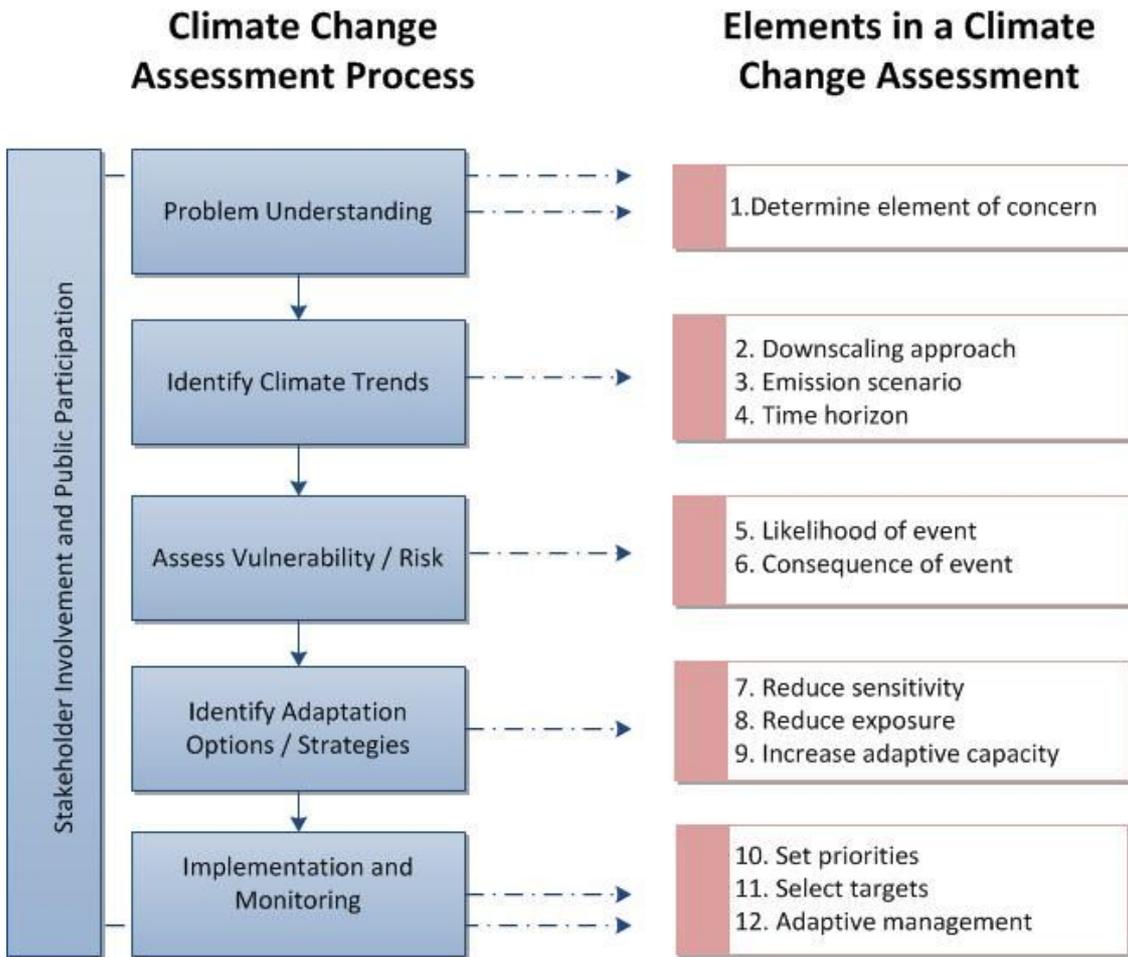


Figure 2. Climate change assessment process and elements

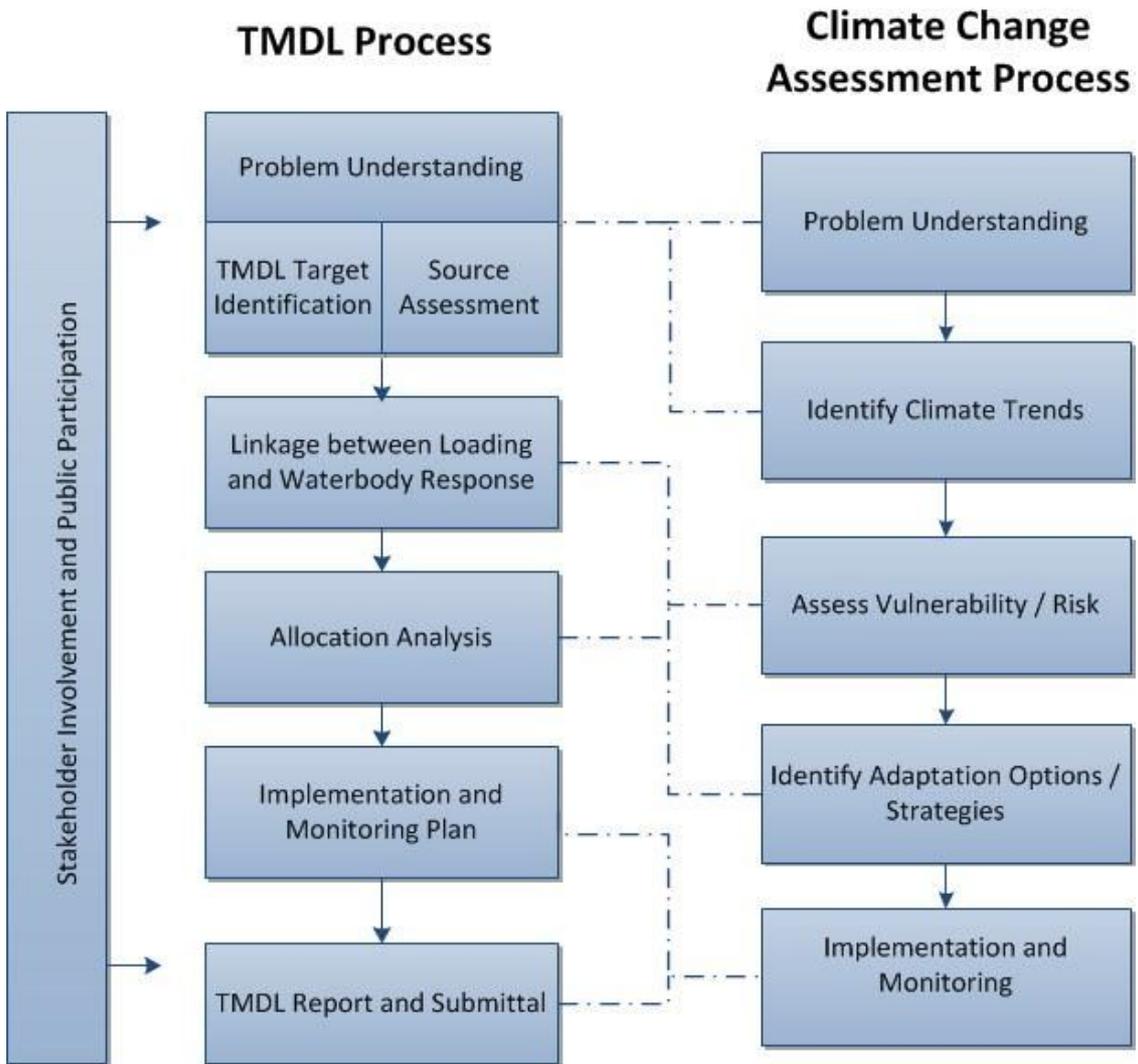


Figure 3. Process roadmap: Illustrative linkages, TMDL and climate change assessment processes

Task 2 – Quantitative Assessment

Background and Problem

Segments of SFNR and some of its tributaries were included on Washington's 2008 303(d) list of impaired waterbodies for temperature violations of WQS. Ecology is required under CWA section 303(d) to develop TMDLs for impaired waters of the state. High water temperatures in the SFNR are detrimental to fish and other native species that depend on cool, clean, well-oxygenated water. EPA, Ecology, the Nooksack Indian Tribe, and the Lummi Nation are cooperating on developing a temperature TMDL for the SFNR.

The study area includes all portions of the SFNR watershed, which is in Whatcom and Skagit counties of Washington (see Figure 4). The river flows to the mainstem Nooksack River, which empties into Bellingham Bay. The Nooksack River watershed, including the SFNR, Middle Fork Nooksack River, North Fork Nooksack River, and associated tributaries, provides migration spawning, incubation, rearing, and foraging habitats for all native PNW salmon and trout species. These fish species are highly valued by the many state residents that depend on them for cultural, recreational, or economic reasons. Salmon in the Nooksack River watershed are a significant source of sustenance and are of great 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 compose 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 ESA.

Improving water quality in the SFNR watersheds is necessary to support the recovery of threatened coldwater fish species that spawn, rear, or live there. To protect these species, Washington has established maximum temperature criteria for different portions of the SFNR that range from 12 to 16 degrees Celsius (°C), expressed as the highest annual running 7-day average of daily maximum temperatures. The criteria, along with the impaired segments, are shown in Figure 4. Washington's water quality standards recognize that portions of many waterbodies cannot meet the assigned criteria due to natural conditions. The estimated natural conditions of the SFNR will be calculated as part of the Regulatory TMDL. Washington water quality standards also recognize that background conditions are sometimes cooler than the criteria; and in such cases, the allowable rate of warming from human actions is restricted.

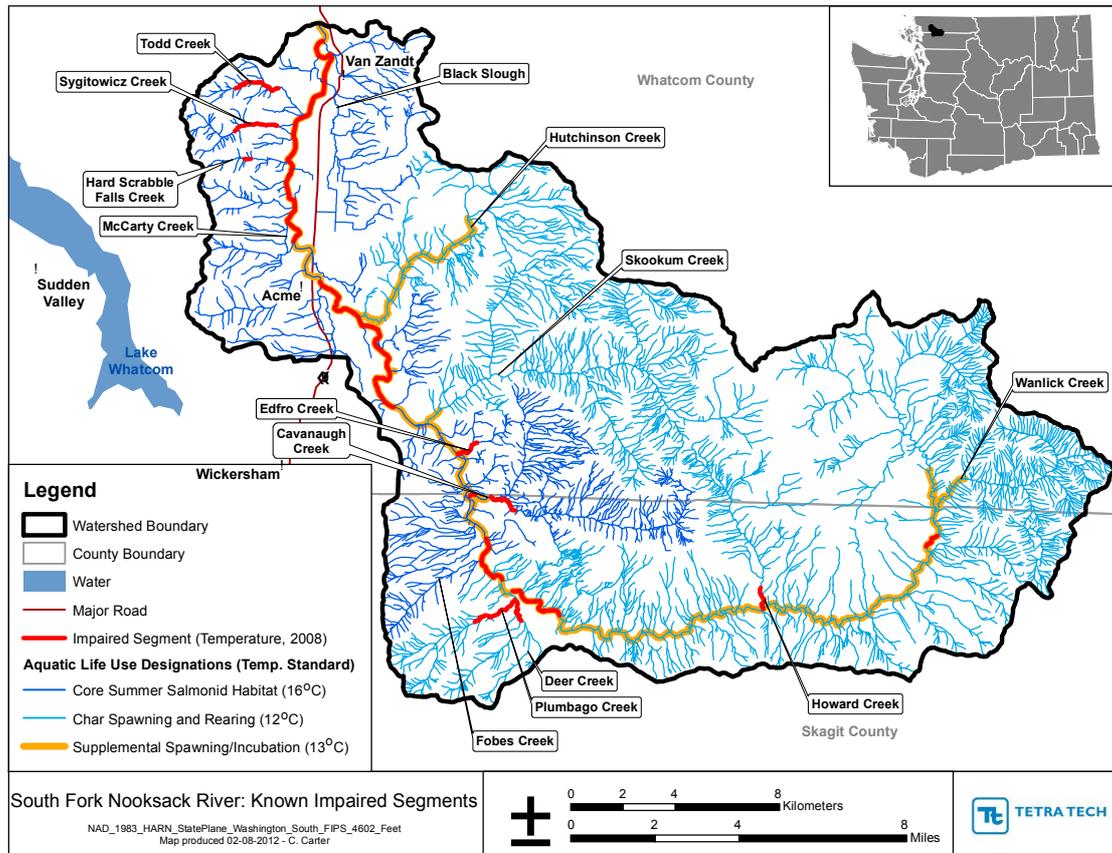


Figure 4. The SFNR and known temperature impairments (Kennedy and Butcher 2012)

The Regulatory Project Team’s TMDL study includes developing a predictive temperature model that will be used to determine the river’s capacity to assimilate thermal loads and estimate the “system potential” temperature. The system potential is the estimated water temperature if mature riparian vegetation and microclimate conditions were present, along with any local groundwater and channel or streamflow improvements planned for the future; and is an estimation of the natural condition of that waterbody. The model will be used to determine the loading capacity that meets temperature water quality criteria to protect designated uses and to evaluate potential alternative pollutant allocation scenarios for point and nonpoint sources that meet the loading capacity.

The modeling approach consists of a Shade model (Ecology 2003a) linked to the QUAL2Kw water quality model. QUAL2Kw (Chapra and Pelletier 2003; Ecology 2003b) serves as the model to perform in-stream temperature simulations. The steady-state QUAL2Kw model is appropriate for evaluating impairments and determining specific conditions during the summer low-flow period. The Shade model will simulate shading factors on the basis of topography and riparian vegetation coverage, which will feed into the QUAL2Kw in-stream model.

QUAL2Kw is a quasi-steady state model and is Ecology's preferred tool for temperature TMDLs (Kennedy and Butcher 2012). The model simulates daily temperature and heat budget with hourly variations in input parameters and boundary conditions.

Meteorological conditions have strong influences on water temperature. Parameters included in QUAL2Kw input that affect stream temperature are effective shade, solar radiation, air temperature, cloud cover, relative humidity, headwater and tributary temperature, and hyporheic flow. These parameters are calculated (e.g., effective shade from Shade model), obtained from weather station information, or interpreted from other sources.

QUAL2Kw will be applied to conduct focused analyses of critical conditions (e.g., late summer low flow, clear sky, high air temperature conditions) that affect temperature impairments from which TMDL targets can be determined directly. Model input for the TMDL simulations will include flow, meteorological, and water temperature boundary conditions developed from available data.

TMDL allocations and implementation plans developed in this way are contingent on current climate, and might not be sufficient to support designated uses under potential future climate regimes. The Pilot Research Project Team, therefore, intends to analyze potential climate change impacts on SFNR temperatures and TMDL allocations. This will be accomplished by reapplying the QUAL2Kw model using climate-altered boundary conditions. The purpose of the work described in this task is to provide altered boundary conditions for the QUAL2Kw modeling under the A1B climate scenario and for three time horizons (2020s, 2040s, and 2080s). The actual QUAL2Kw modeling will be accomplished as part of the Regulatory Project Team's SFNR Temperature TMDL.

Approach and Methods

After the QUAL2Kw TMDL model setup is completed and the model provides acceptable predictions of current temperature conditions, it will be applied to examine the system potential temperature and the potential climate change impacts on SFNR temperatures. This project will supply climate-altered boundary conditions to the QUAL2Kw model. These boundary conditions will be derived from the work conducted and served by CIG at the University of Washington (e.g., Mauger and Mantua 2011; Hamlet et al. 2010).

CIG has taken output from GCMs and downscaled the meteorological output to a 1/16 degree scale for the PNW using quantile mapping on historical meteorological time series (see Polebitski et al. 2007a). This has been done for 10 GCMs and multiple emission scenarios for the period through 2099. Downscaling is also done in two different ways: a composite delta method in which there is a single average change (delta) for each month calculated from a time slice of the GCM for the region that is applied to every day in that month, and a hybrid delta approach that uses statistical bias correction to maintain the probability distribution. There is also a composite delta run that represents the central tendency of the 10 hybrid delta GCMs for a given emission scenario.

CIG has also produced gridded estimates of surface runoff and baseflow at the 1/16 degree scale, using the Variable Infiltration Capacity or VIC model (Elsner et al. 2010).

Seventy-nine climate scenario products are available from CIG covering the SFNR watershed. Initial work for this project will focus on a limited subset of runs based on the IPCC A1B emissions scenario because this is a robust available dataset. The A1B scenario is considered a moderate emission scenario as compared to the other IPCC emission scenarios. While there is uncertainty associated with any of the IPCC emission scenarios, the A1B multi-model average is commonly considered to be “an informative future climate scenario (i.e., it is closest to most model estimates and the weighting scheme discounts extreme values)” (Beechie 2012). The A1B (moderate emission) scenario has an ensemble mean that is 1° Celsius (C) lower in 2080 than the A2 (high emission) scenario. The highest GCM model average for A1B projects a temperature increase for 2080 that is 0.6 ° C lower than the A2 highest GCM model average.⁶

Three time horizons (2020s, 2040s, and 2080s) will be evaluated using the hybrid delta results from GCMs under the A1B scenario for the South Fork Nooksack watershed, the GCM that is anticipated to produce model low (least warming) model medium (medium warming) and model high (highest warming), resulting in 3 climate products x 3 time steps = 9 runs. This will achieve a project objective of evaluating the ensemble *range of outcomes* from one IPCC scenario for the climate change risk assessment.

The following subtasks describe specific methods for converting CIG climate products into appropriate boundary conditions for the QUAL2Kw model of the SFNR.

Subtask Descriptions, Schedule, and Milestones

Subtask 2.1. Selection of Climate Scenarios

As noted above, the range of potential impacts will be evaluated at three time horizons (2020s, 2040s, and 2080s) using the Scenario A1B hybrid delta results for GCMs under the A1B scenario for the South Fork Nooksack watershed, the GCM that is anticipated to produce model low (least warming) model medium (medium warming) and model high (highest warming). The first subtask will be to review and select GCMs with the appropriate characteristics from the available CIG products. This will be accomplished through comparison of seasonal statistics on precipitation and temperature among the different GCM outputs for the South Fork Nooksack watershed.

⁶ The Research Team is aware of current regional (Pacific Northwest) experimentation and model comparison by the Climate Impacts Research Consortium (CIRC) of IPCC CMIP5 GCMs and Representative Concentration Pathways (RCPs) that will be used in the upcoming Fifth IPCC Assessment (AR5) in 2014. CIRC has compared current IPCC (CMIP3, IPCC AR4) SRES Scenarios with upcoming (CMIP5, IPCC AR5) RCPs. Although this comparison is useful to put into context current studies (like this one) that use IPCC (CMIP3, IPCC AR4) SRES Scenarios; however, the difference in methodologies between these two IPCC Reports makes direct comparison or crosswalks between the two methods of limited value. The regional implementation of IPCC CMIP5 GCMs and RCPs will need additional testing and implementation of a hydrological model, comparable to VIC, before it is useable in a similar application for water quality/quantity or freshwater salmonid habitat.

The Research Team believes it is more important for this research project to embrace the concept of “Iterative Risk Management” as defined by Yohe (NCADAC 2011). The iterative concept means that the cycle of assessment and adaptive management is an unending process that refreshes itself as the cycle is repeated. The Team believes that the methodology and assessment offered in this Research Plan could be refreshed using the new IPCC CMIP5 GCMs and RCPs (IPCC AR5) when they become available, with the relative efficiency of a report update rather than a wholly new report.

Subtask 2.1 Schedule – Nov. 2012 – Dec. 2012

Milestone 2.1 Title: Excel spreadsheet that compares GCM outputs for the South Fork Nooksack watershed and identifies selected GCMs.

Milestone 2.1 Completion Date: Dec. 2012

Subtask 2.2 Tributary and Mainstem Flow Boundary Conditions

Subtask 2.2 Description: The QUAL2Kw *core model* (existing condition for TMDL) will represent gaged or estimated flows or both in the mainstem and significant tributaries. The TMDL application will scale the flow to a 7Q10 critical low-flow condition (or other low-flow condition if a 7Q10 cannot be calculated). The climate change application can incorporate predicted changes in summer baseflow from assessments conducted by CIG. CIG has paired climate scenarios with the VIC hydrologic model, operating at 1/16 degree resolution. For each grid cell, the VIC produces daily outputs of surface and subsurface flow. During the critical low-flow periods for the TMDL, it is likely that all flow will be baseflow.

The VIC model is a large-scale model that is not explicitly calibrated to the SFNR and cannot be expected to exactly reproduce either current or future conditions for the TMDL. Therefore, mapping/extrapolation of CIG estimates to the QUAL2Kw domain will be necessary. Specifically, the CIG output will be applied using a change method in which the TMDL 7Q10 flow at the model headwaters and for all tributary and diffuse inflows is modified by the ratio of CIG estimates of low flows of a similar return period under current and future climate conditions.⁷ The VIC model output for each grid cell intersecting the South Fork Nooksack watershed will be analyzed to determine the simulated low flow frequency (as depth of flow) for current conditions and for future climate scenarios. The ratios between future climate and current conditions for flows of the critical duration and recurrence will be calculated for each VIC grid cell. For each QUAL2Kw boundary inflow the ratio will be selected from the appropriate VIC grid cell (or from an area-weighted average of multiple VIC grid cells if necessary for larger tributaries) and applied to the boundary inflow to yield the climate-modified inflow estimate for the critical condition. The large-scale VIC model is not expected to provide accurate estimates of flows from individual small streams in the South Fork Nooksack drainage; however, the relative change predicted in unit area flows is believed to provide a reasonable index of potential changes under future climate scenarios.

Subtask 2.2 Schedule – Oct. 2012 – Nov. 2012

Milestone 2.2 Title: Memorandum Documenting Tributary and Mainstem Flow Conditions for Climate Scenarios

Milestone 2.2 Completion Date: Nov. 2012

⁷ Note that output from the VIC model will not be used directly to drive the previously calibrated QUAL2Kw model. Instead, VIC model output will be used to evaluate relative change under different climate forcings. For example, the QUAL2Kw model will likely be applied to a critical low flow condition in the TMDL. For future climate, VIC model output will be used to determine the potential ratio of such low flows under future climate to the low flows used in the TMDL and the QUAL2Kw model input will be adjusted by that ratio.

Subtask 2.3 Tributary and Mainstem Boundary Water Temperatures

Subtask 2.3 Description: The QUAL2Kw model application will encompass the mainstem (only) of SFNR, beginning upstream of the first impaired segment. QUAL2Kw provides a process-based simulation of temperature changes in the simulated reaches; however, it requires specification of water temperatures for all influent boundary conditions.

Boundary temperatures will be documented for critical conditions used in the TMDL model. For the climate scenarios, these boundary temperatures will be altered using a delta change method, in which an incremental change is imposed on the existing temperature daily maximum and minimum.

The water temperature deltas will be assessed using a regression approach on the basis of CIG output. CIG provides daily minimum and maximum air temperature and daily surface and subsurface flow. These will be used as independent variables (along with other variables such as elevation and tributary shading) to develop two multiple regression equations for available monitoring data on current climate tributary daily minimum and maximum stream temperatures. The regression equations will then be applied to future climate conditions, and the difference between future and current condition predictions will be used as the delta on the temperature maximum and minimum. Developing the regression relationships will be documented, including an analysis of model fit uncertainty. Hourly temperatures will be distributed between the minimum and maximum according to the diurnal pattern in the TMDL model. Output of this process will be a 24-hour time series for QUAL2Kw.

Subtask 2.3 Schedule – Oct 2012 – Dec. 2012

Milestone 2.3 Title: Memorandum Documenting Boundary Temperatures for Future Climate Scenarios

Milestone 2.3 Completion Date: Dec 2012

Subtask 2.4 Meteorological Forcing

Subtask 2.4 Description: Temperature simulation in the QUAL2Kw model requires specification of a number of meteorological series, as described below.

Air temperature: Boundary air temperature is defined as a 24-hour time series in QUAL2Kw. The QUAL2Kw core model will use meteorological data from a nearby station for the existing air temperature on the simulation date. The TMDL application will likely scale the air temperature to a critical condition such as the 90th percentile. The climate change application can incorporate predicted changes in summer air temperature from assessments conducted by the CIG. Mapping/extrapolation of CIG estimates to the QUAL2Kw domain will be handled using a delta change method in which the existing time series is modified by the predicted arithmetic change between current and future air temperature conditions. Specifically, CIG output on daily minimum and daily maximum temperatures will be used to establish deltas to predict future climate air temperature minimum and maximum, and the hourly values will be distributed between the future minimum and maximum according to the pattern contained in the TMDL model.

Cloud cover: The QUAL2Kw core model will use meteorological data from a nearby station for the existing cloud cover on the simulation date. The TMDL application will likely adjust the cloud cover to zero (clear sky) as a critical condition. No climate change adjustment will be made for cloud cover because the critical condition will remain clear sky.

Relative humidity: CIG provides monthly summaries of relative humidity that will be used to specify changes under future climates.

Wind: Conduction and convection heat exchange at the water surface depend on wind. Wind stress will be kept constant at TMDL conditions for all climate change scenarios. While wind is likely to change under future conditions, downscaled analysis of this variable is not available from CIG.

Subtask 2.4 Schedule – Nov. 2012 – Dec. 2012

Milestone 2.4 Title: Memorandum Documenting Meteorological Boundary Conditions

Milestone 2.4 Completion Date: Dec 2012

Subtask 2.5 Other Boundary Conditions

Subtask 2.5 Description: *Riparian Shade:* The QUAL2Kw core model will use estimates of existing shade on the mainstem river based on observations (e.g., Light Detection and Ranging (LIDAR), field sampling) and the Shade model. The TMDL application will likely include alternative shade conditions, including the natural condition of full potential shade (“system potential” conditions). Even though there is a likelihood that riparian vegetation composition (e.g., diversity and abundance) might change due to climate change, we do not have the tools to predict these changes and do not plan to evaluate a climate change adjustment in riparian shade outside the range of conditions to be evaluated for the TMDL.

Channel Structure: The channel structure will be set to existing conditions for all model setups, including climate change scenarios. If adequate information on historic channel geometry or changes in channel geometry due to winter high-flow events (as a result of climate change) are available, channel geometry could be adjusted in QUAL2Kw.

Groundwater Inflow Temperatures: The QUAL2Kw TMDL model will use estimates of existing groundwater inflow temperatures on the mainstem river. If existing data are available, current conditions groundwater inflows are generally set at the average groundwater temperature for the area. In the critical condition TMDL model, groundwater may be set to the average of the maximum groundwater temperatures. For the climate change scenarios, groundwater inflow temperatures will be modified on the basis of the change in average annual air temperatures predicted by the CIG climate scenarios.

Hyporheic Exchange: In rivers with coarse (sand, gravel, cobble) bed sediments, a portion of the flow (hyporheic flow) occurs within the bed sediment. Heat flux between the water and sediment during hyporheic flow can help stabilize stream water temperatures and provide cooling during summer months. Changes to flow and

temperature under future climates could alter the effectiveness of hyporheic exchange in maintaining stable water temperatures.

In QUAL2Kw, the heat flux from hyporheic exchange of water between the stream and the hyporheic sediment zone is computed as

$$J_{hyp,i} = \frac{E'_{hyp,i} \rho C_p}{A_{sf,i}} (T_{2,i} - T_{1,i}) \left(\frac{100 \text{ cm}}{\text{m}} \right)$$

where $E'_{hyp,i}$ is the bulk hyporheic exchange flow in reach i (m^3/day ; user input), $A_{sf,i}$ is the surface area of the hyporheic zone in reach i (m^2 , calculated from stream segment length and width), $T_{2,i}$ is the temperature of the bottom sediment ($^{\circ}\text{C}$, calculated), $T_{1,i}$ is the temperature of the water ($^{\circ}\text{C}$, calculated), and ρC_p is the density of the sediment (g/cm^3) times the specific heat of the sediment ($\text{cal}/\text{g}\cdot^{\circ}\text{C}$). The model estimates the product ρC_p as κ_s/α_s , where κ_s is the thermal conductivity ($\text{cal}/\text{s}\cdot\text{cm}\cdot^{\circ}\text{C}$) and α_s is the thermal diffusivity (cm^2/s), both of which are input by the user based on the bed material. The overall heat balance for the bottom sediment is then calculated as

$$\frac{dT_{2,i}}{dt} = - \frac{J_{s,i} + J_{hyp,i}}{\rho_s C_{ps} H_{2,i}}$$

where $H_{2,i}$ is the *effective* thickness of the sediment layer (cm, input by user).

The user inputs to QUAL2Kw that control the effect of hyporheic exchange on water temperature are the thermal conductivity, thermal diffusivity, the effective thickness of the sediment layer, and the bulk hyporheic exchange flow. The QUAL2Kw theory manual recommends: “If hyporheic flow exchange is significant, then the effective thickness of the hyporheic zone of rapid transient storage may typically range from about 20 to 300% of the stream depth (Harvey and Wagner, 2000; Gooseff et al., 2003), with higher relative values in smaller streams.” The exact value of effective thickness will not be known for the South Fork Nooksack, although it can be partially constrained through calibration of the TMDL model, but will be held constant for current condition and future climate runs. The primary uncertainty for addressing climate impacts through hyporheic flow in the QUAL2Kw model is that the bulk hyporheic exchange flow is a user-specified input. The *fraction* of hyporheic flow adopted for the TMDL model will not be altered for the future climate model runs, resulting in specification of a linear change in hyporheic flow as total flow in the reach changes. Therefore, no additional changes to boundary conditions will be needed to evaluate how the effects hyporheic exchange might change under future climates.

Subtask 2.5 Schedule – Dec. 2012 – Dec. 2012

Milestone 2.5 Title: Memorandum Documenting Additional Boundary Condition Assumptions for QUAL2Kw Model Applications to Future Climate Scenarios

Milestone 2.5 Completion Date: Dec. 2012

Subtask 2.6: Quantitative Assessment Report

Subtask 2.6 Description: At the conclusion of Subtask 2.5 a complete set of model boundary conditions for future climate scenarios will be supplied to the Regulatory Project Team. The quantitative assessment is the comparison of QUAL2Kw modeled stream temperatures, including riparian shading, with and without Climate Change for the 2020s, 2040s, and 2080s.

It is assumed that Regulatory Project Team will run and analyze the future climate scenarios using QUAL2Kw and provide the results back to the Pilot Research Project Team. Under this subtask, a summary report on Task 2 will be prepared by the Research Project Team.

Subtask 2.6 Schedule – Apr 2013 – June 2013

Milestone 2.6: Technical Memorandum on Quantitative Assessment of Temperature Sensitivity of SFNR under Future Climate using QUAL2Kw

Milestone 2.6 Completion Date: June 2013

Table 1. Quantitative assessment milestone schedule

Quantitative Assessment Milestone Schedule											
Quantitative Assessment Subtask	2012			2013							
	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Subtask 2.1. Selection of Climate Scenarios											
Subtask 2.2 Tributary and Mainstem Flow Boundary Conditions											
Subtask 2.3 Tributary and Mainstem Boundary Water Temperatures											
Subtask 2.4 Meteorological Forcing											
Subtask 2.5 Other Boundary Conditions											
Subtask 2.6 Quantitative Assessment Report											

Task 3 – Qualitative Assessment**Background and Problem**

The workshop that was held in EPA Region 10 on June 25, 2012, made clear the benefits of separating the climate change risk assessment (see Figure 5) into two assessments processes—one quantitative and one qualitative.

The quantitative assessment is directly responsive to the CWA TMDL Numeric Cold-Water Temperature WQS. The quantitative assessment is the comparison of QUAL2Kw modeled stream temperatures, including riparian shading, with and without climate change for the 2020s, 2040s and 2080s.

The qualitative assessment is a comprehensive analysis of freshwater habitat for ESA salmon restoration in the SFNR under climate change. The output of this assessment is a prioritized list of climate change adaptation strategies (stream restoration actions/TMDL implementation) that supports salmon restoration in the SFNR under climate change. Although quantitative methods are used in this assessment, there is no attempt to directly

attribute the quantitative contribution of these stream restoration actions on meeting the CWA TMDL Numeric Cold-Water Temperature WQS.

Taken together, the quantitative and qualitative assessments represents the most robust and comprehensive actions to protect the CWA designated uses (salmon habitat) and ESA recovery goals under climate change.

Approach and Methods

The foundational approach and method of this assessment is based on *Restoring Salmon Habitat For A Changing Climate* (Beechie et al. 2012). In that paper, Beechie et al. (Table III) grouped restoration actions on the basis of the watershed processes or functions they attempt to restore and then classified them as either likely or not likely to ameliorate a climate change effect on high stream flows, low stream flows, and stream temperatures.

The risks of climate change will be evaluated for all three ESA listed (threatened) species in the SFNR: 1) spring chinook (*Oncorhynchus tshawytscha*), 2) summer steelhead (*Oncorhynchus mykiss*), and 3) bull trout (*Salvelinus confluentus*). The Beechie method (Beechie et al. 2012) requires a specific assessment of climate change risks for each fish species/life history and the effectiveness of stream restoration actions to ameliorate those risks.

In order to accomplish the output of the qualitative assessment, a prioritized list of climate change adaptation strategies (stream restoration actions/TMDL implementation) that supports salmon restoration in the SFNR under climate change, integration of the temporal, spatial and limiting factors requirements of all three ESA listed (threatened) species is needed. The lack of a specific ESA Recovery Plan for summer steelhead in the SFNR will limit the testing of specific planned stream restoration actions to ameliorate the risks of climate change. However, many of the stream restoration actions in the ESA Salmonid Recovery Plan for spring chinook and bull trout will benefit summer steelhead and a more general assessment of the risk and vulnerability of climate change to summer steelhead in the SFNR is still possible.

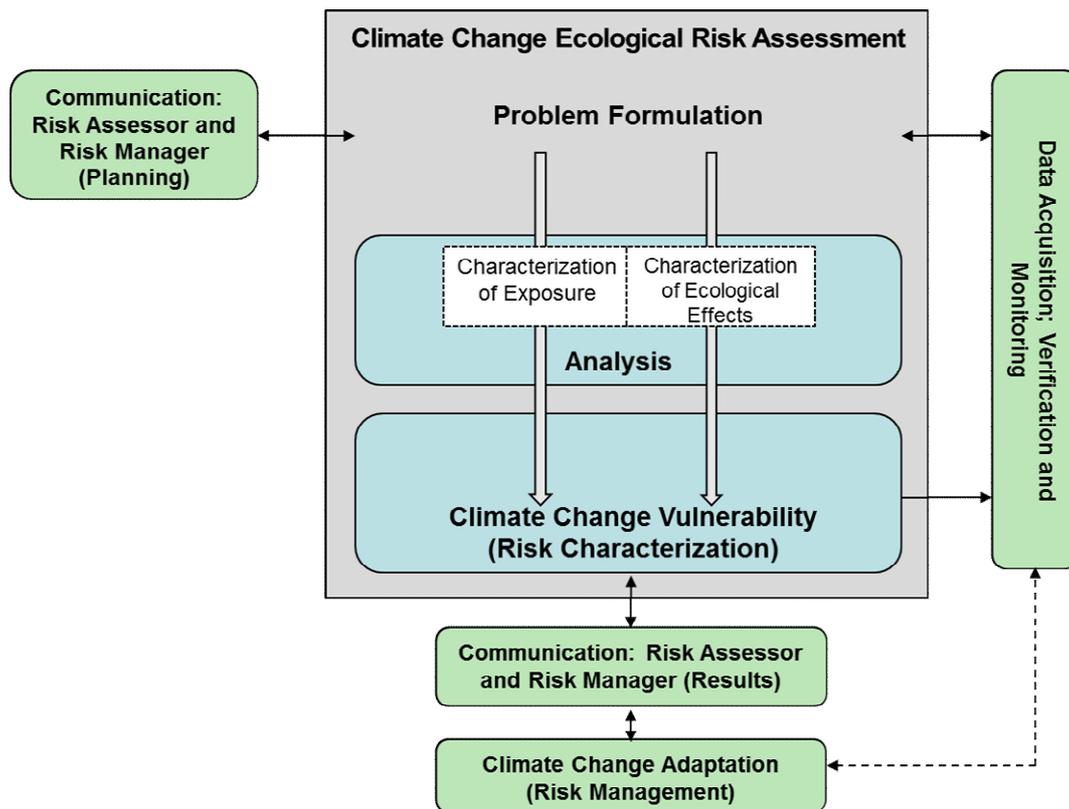
The current restoration actions listed in the ESA Salmonid Recovery Plan for the SFNR will be evaluated and prioritized to optimize those actions that are most effective in their ability to ameliorate a climate change effect on high stream flows, low stream flows, and stream temperatures.

Coldwater refuges will be identified and protection/restoration actions evaluated for their potential to increase the effective use of thermal refugia by coldwater fish under climate change (USEPA 2012b).

The knowledge and experience of environmental practitioners, natural resource managers and tribal members in SFNS Washington will be used to the maximum extent possible. Existing ESA salmonid recovery plans, data sets and assessments by the Nooksack Indian Tribe, Lummi Nation and other federal, state, local and nongovernmental organizations on the SFNR will form the basis of this assessment.

Watershed process-based restoration has a long history of use and application in the Puget Sound Basin. This body of evidence, methods and approaches will be incorporated and used in this assessment (Montgomery et al. 2003; Pollock et al. 2009; Beechie et al. 2010).

We intend to collaborate and incorporate the findings from the USGS Groundwater/Surface Water Study of the SFNR (in progress and commissioned by the Nooksack Indian Tribe).



Note: Modified from USEPA 1992

Figure 5. Climate change ecological risk assessment

Subtask Descriptions, Schedule and Milestones

Subtask 3.1 Title : Stakeholder Engagement and Project Scoping—Two-Day Meeting Hosted by the Nooksack Indian Tribe—Restoring Salmon Habitat for a Changing Climate in the South Fork Nooksack River, Washington

Subtask 3.1 Description: The purpose of this meeting is to (1) solicit input from stakeholders on climate change and ESA salmon recovery, (2) review existing ESA recovery plans, data sets and related studies, (3) discuss draft outline approach/method for evaluating the risk/vulnerability of climate change on ESA salmon recovery actions,

and (4) gain a better understanding of the setting (biophysical) and current/past restoration of freshwater habitat on the SFNR.

The first day is devoted to a series of presentations and panel discussions to understand how landscape watershed processes and climate change will impact ESA Salmonid Recovery Planning.

The second day is focused on a review of the existing ESA Salmonid Recovery Plan, data sets and related studies to support the development of the step-by-step methodology for the qualitative assessment in the SFNR.

Subtask 3.1 Schedule

Start Date: 1/22/13

End Date: 1/23/13

Milestone 3.1 Title: Stakeholder Engagement and Project Scoping Meeting Report

Milestone 3.1 Completion Date: 1/31/13

Subtask 3.2 Title: Develop a Method for Evaluating the Risk/Vulnerability of Climate Change on ESA Salmon Recovery Actions

Subtask 3.2 Description: This is the step-by-step methodology based on *Restoring Salmon Habitat For A Changing Climate*, Beechie et al. 2012.

Subtask 3.2 Schedule

Start Date: 2/01/13

End Date: 4/30/13

Milestone 3.2 Title: Report; Methods for evaluating the Risk/Vulnerability of Climate Change on ESA Salmon Recovery Actions

Milestone 3.2 Completion Date: 4/30/13

Subtask 3.3 Title: Conducting the Qualitative Assessment of Risk/Vulnerability of Climate Change on ESA Salmon Recovery Actions

Subtask 3.3 Description: This subtask accomplishes the qualitative assessment and provides the prioritized list of climate change adaption strategies (stream restoration actions/TMDL implementation) to support ESA salmon restoration in the SFNR under climate change.

Subtask 3.3 Schedule

Start Date: 5/01/13

End Date: 10/31/13

Milestone 3.3 Title: Draft Report; Risk/Vulnerability of Climate Change on ESA Salmon Recovery Actions in the SFNR.

Milestone 3.3 Completion Date: 10/31/13

Subtask 3.4 Title: Stakeholder Engagement; Communication between Risk Assessors & Risk Managers—One-Day Meeting Hosted by the Nooksack Indian Tribe—Restoring Salmon Habitat for a Changing Climate in the South Fork Nooksack River, Washington

Subtask 3.4 Description: The results of the draft report; qualitative assessment of risk/vulnerability of climate change on ESA salmon recovery actions will be presented and discussed. The goal of this meeting is to gain consensus among the Risk Managers on the prioritized list of climate change adaption strategies (stream restoration actions/TMDL implementation) to support ESA salmon recovery in the SFNR under climate change.

Subtask 3.4 Schedule
 Start Date: 11/15/13
 End Date: 11/15/13

Subtask 3.5 Title: Develop Final Report; Risk/Vulnerability of Climate Change on ESA Salmon Recovery Actions in the South Fork Nooksack River, Washington, based on Stakeholder Engagement.

Subtask 3.5 Description: Develop final report; risk/vulnerability of climate change on ESA salmon recovery actions in the SFNR based on stakeholder engagement.

Subtask 3.5 Schedule:
 Start Date: 11/16/13
 End Date: 2/15/14

Milestone 3.5 Title: Final Report; Risk/Vulnerability of Climate Change on ESA Salmon Recovery Actions in the SFNR
 Milestone 3.5 Completion Date: 2/15/14

Table 2. Qualitative assessment milestone schedule

Qualitative Assessment Milestone Schedule														
Qualitative Assessment Subtask	2013											2014		
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Jan.	Feb.	March
Subtask 3.1 Stakeholder Engagement for Project Scoping														
Subtask 3.2 Climate Change Methodology for ESA Salmon Recovery Actions														
Subtask 3.3 Conducting the Qualitative Assessment														
Subtask 3.4 Stakeholder Engagement for Risk Assessment														
Subtask 3.5 Develop Final Report														

Task 4 – Climate Change Considerations for TMDL Development in the SFNR

Background and Problem

While more than 40,000 TMDLs have been developed in the United States, very few of these analyses have considered the potential implications that climate change could have

on the key parameters influencing water quality, such as flow and water temperature. The potential impact of climate change on water resources has been widely acknowledged in the scientific community; however, the various layers of uncertainty that surround climate change has created confusion among water resource managers and made evaluation of climate change impacts and adaptation options difficult. The importance of using an adaptive management framework, where additional data and findings are able to be incorporated in an evolving context, is an important management tool when dealing with climate change (refer to Figure 6).

Recognizing these challenges, EPA identified climate change as a top priority in its *FY 2011-2015 Strategic Plan* (USEPA 2010) and has included Strategic Action 35 in EPA's *Draft National Water Program Guidance*, which, "encourage[s] that development of future TMDLs include evaluation of projected climate impacts and uncertainty and incorporate this information into the TMDL, as appropriate" (USEPA 2012a).

As a supportive action, EPA Region 10 has identified the SFNR Temperature TMDL as a pilot by which to explore the potential linkages between the TMDL process and climate change considerations.



Figure 6. Adaptive Management Framework

Approach and Methods

The EPA Region 10 climate change and TMDL pilot research concept was developed on the basis of a unique parallel study strategy. The strategy uses a real-world regulatory action, the SFNR temperature TMDL, as a pilot by which to evaluate various methodologies and approaches to incorporate climate change considerations. It is intended that the synchronized pairing of the research project with an *on-the-ground* temperature TMDL will assist the project team in better understanding the needs of water managers, including consideration of schedule and budgetary constraints, along with typical approaches used by water managers to meet the TMDL regulatory requirements.

Task 4 is specifically designed to leverage this parallel study strategy. In this task, the EPA TMDL regulatory requirements will be examined to identify potential areas where climate change could be considered for inclusion in the SFNR temperature TMDL. A systematic methodology will be proposed and used to evaluate climate change considerations to identify those that could be incorporated in the SFNR temperature TMDL, as illustrated in Figure 7, within the constraints of the uncertainty of climate change impacts, schedule, budget, and need for additional input.

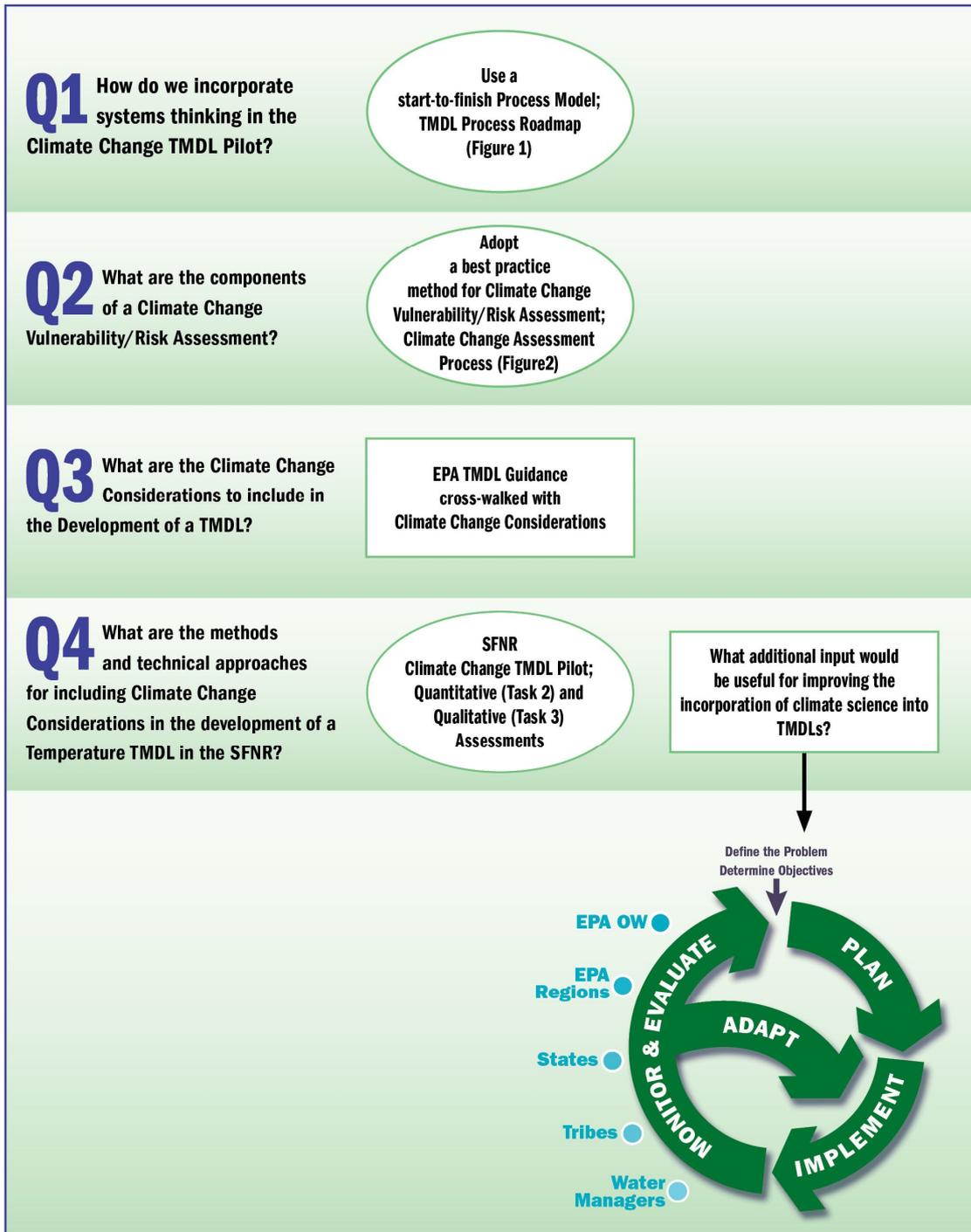


Figure 7. Illustrative decision-tree for evaluating climate change considerations in the SFNR TMDL.

The following elements of a TMDL submittal will be used as an organizing research framework (see USEPA 2002).⁸

1. Identification of Waterbody, Pollutant of Concern, Pollutant Sources, and Priority Ranking
2. Description of the Applicable WQS and Numeric Water Quality Target
3. Loading Capacity—Linking Water Quality and Pollutant Sources
4. Load Allocations (LAs)
5. Wasteload Allocations (WLAs)
6. Margin of Safety (MOS)
7. Seasonal Variation
8. Reasonable Assurances
9. Monitoring Plan to Track TMDL Effectiveness
10. Implementation
11. Public Participation

Subtask 4.1 Title: Broad Review of TMDL and Climate Change Issues

Subtask 4.1 Description: Conduct a broad review of issues involved in incorporating climate change into TMDLs. This includes the following steps: 1) review EPA regulatory guidance and technical direction, using the TMDL elements as an organizing framework; 2) identify and review TMDLs that incorporate climate change issues to identify any lessons learned and best practices; and 3) identify the state of the practice for incorporating climate change science in TMDLs.

Subtask 4.1 Schedule:

Start Date: Oct. 1, 2012

End Date: Dec. 30, 2012

Milestone 4.1 Title: Issues for TMDL and Assessment Report

Milestone 4.1 Completion Date: Dec. 30, 2012

Subtask 4.2 Title: Assessment of SFNR TMDL

Subtask 4.2 Description: Best practices and lessons learned from Task 4.1 will be evaluated with respect to the SFNR TMDL and climate science issues and potential research approaches will be identified. The process roadmap will be used to organize the research, which will be considered in the following order:

- Problem Understanding and TMDL Target/Source Assessment (Dec. 1, 2012–Jan. 31, 2013)
- Loading Capacity and Allocation Analysis (Feb. 1, 2013–April. 30, 2013)

⁸ The Process Roadmap described in Task 1 of this Research Plan includes EPA's eleven critical elements and will also be used to conceptually guide the research process.

- Wasteload Allocation Issues (Feb. 1, 2013–April. 30, 2013)
- Margin of Safety Issues (Feb. 1, 2013–April. 30, 2013)

Subtask 4.2 Schedule:

Start Date: Dec. 1, 2012

End Date: April. 30, 2013

Milestone 4.2 Title: SFNR TMDL Climate Change Assessment: Recommendations and Areas for Additional Study

Milestone 4.2 Completion Date: April. 30, 2013

Subtask 4.3 Title: Implementation and Monitoring Plan Assessment

Subtask 4.3 Description: Document and analyze potential approaches that could inform incorporation of updated downscaled climate change scenario information into implementation and monitoring plans.

Identify issues and research areas considered outside the scope of the SFNR TMDL, and recommend approaches.

Subtask 4.3 Schedule:

Start Date: May. 1, 2013

End Date: June 30, 2013

Milestone 4.3 Title: 4.2 Implementation and Monitoring Plan Assessment Report

Milestone 4.3 Completion: Date: June 30, 2013

Subtask 4.4 Title: Final Report

Subtask 4.4 Description: Draft and complete SFNR Temperature TMDL Climate Change Assessment Report – Final Report.

Subtask 4.5 Schedule:

Start Date: July. 1, 2013

End Date: Aug. 31, 2013

Milestone 4.5 Title: SFNR Temperature TMDL Climate Change Assessment Report – Final Report

Milestone 4.5 Completion: Date: Aug 31, 2013

Table 3. Climate change considerations for TMDL development in the SFNR milestone schedule

Evaluation of SFNR TMDL Climate Change Considerations Milestone Schedule											
Program Assessment Subtask	2012			2013							
	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Subtask 4.1 Broad Review of Programmatic Issues											
Subtask 4.2 Assessment of SFNR TMDL											
Subtask 4.3 Implementation and Monitoring Plan Analysis											
Subtask 4.4 Final Report											

Task 5 – EPA Final Report

Background and Problem

The EPA Region 10 climate change TMDL pilot is a complex project with both research and development and demonstration components. The project has been divided into tasks to facilitate the operational implementation of the research. Ultimately, we will have to integrate and synthesize the results from the task reports into a coherent EPA final report.

The output of this task is the EPA final report, which documents the process and analysis used to develop the climate change temperature TMDL for the SFNR.

Approach and Methods

The task reports are the building blocks for the EPA final report. The EPA final report will be written by the task leads with the assistance of a technical writer and editor. The EPA final report will be peer reviewed and cleared by EPA's ORD in conformance with ORD's *Policies and Procedures Manual* (USEPA 2009).

Subtask Descriptions, Schedule and Milestones

Subtask 5.1 Title: Develop the Draft Outline for the EPA Final Report

Subtask 5.1 Description: A draft outline will be developed for the EPA final report. Figures and tables from the task reports will be assembled as an electronic library to facilitate their use in the EPA final report. EndNote reference libraries from the task reports will be consolidated in a master reference library to facilitate its use in the EPA final report.

Subtask 5.1 Schedule

Start Date: 8/15/13

End Date: 9/30/13

Milestone 5.1 Title: Draft Outline for the EPA Final Report with Figures/Tables and Endnote Library.

Milestone 5.1 Completion Date: 9/30/13

Subtask 5.2 Title: Write the Draft EPA Final Report

Subtask 5.2 Description: A draft of the EPA final report will be written by the task leads with the assistance of a technical writer and editor.

Subtask 5.2 Schedule

Start Date: 10/01/13

End Date: 2/28/14

Milestone 5.2 Title: Draft EPA Final Report

Milestone 5.2 Completion Date: 2/28/14

Subtask 5.3 Title: Peer Review and Reconciliation of Draft EPA Final Report.

Subtask 5.3 Description: A peer review and reconciliation will be conducted for the draft EPA final report.

Subtask 5.3 Schedule

Start Date: 3/01/14

End Date: 5/30/14

Milestone 5.3 Title: Peer Reviewed and Reconciled Draft EPA Final Report.

Milestone 5.3 Completion Date: 5/30/14

Subtask 5.4 Title: EPA Final Report Review and Clearance

Subtask 5.4 Description: The EPA final report will be reviewed and cleared through ORD.

Subtask 5.4 Schedule

Start Date: 6/01/14

End Date: 7/31/14

Milestone 5.4 Title: EPA Final Report.

Milestone 5.4 Completion Date: 7/31/14

Table 4. EPA final report milestone schedule

EPA Final Report Milestone Schedule												
EPA Final Report Subtask	2013					2014						
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July
Subtask 5.1 Draft Outline												
Subtask 5.2 Draft Report												
Subtask 5.3 Peer Review and Reconciliation												
Subtask 5.4 ORD Review and Clearance												

RELEVANCY TO EPA DECISION MAKING

The primary objective of this project is to demonstrate a process to evaluate EPA’s decision-making needs for climate change adaptation under the CWA section 303(d) TMDL program.

This project supports the implementation of EPA’s National Water Program 2012 Strategy: Response to Climate Change – March 2012 to help achieve EPA’s Vision Statement on Water Quality by promoting the management of sustainable surface water resources under changing climate conditions (USEPA 2012a).

This project also provides the opportunity to explore the potential linkages between the TMDL process and climate change considerations.

The risk assessment approach used in this project provides decision makers with a robust context and temporal sensitivity for including climate change adaption in their decision making. A *Climate Change TMDL* can be thought of as an embedded climate change risk assessment within a CWA section 303(d) TMDL.

EPA's final report that documents the process and analysis used in this pilot demonstration (climate change temperature TMDL for the SFNR) will assist other EPA regions and states to include climate change adaptation in their CWA 303(d) temperature TMDL programs.

SCHEDULE AND OUTCOMES

The pilot research project consists of three primary project phases: *Phase 1 Research Plan*, March–September 2012; *Phase 2 Research Analysis and Risk/Vulnerability Assessment*, October 2012–September 2013; and *Phase 3 EPA Report*, October 2013–September 2014.

Tasks 1-4 as outlined in this research plan are associated with Phase 2, and Task 5 is associated with Phase 3. The schedule for each of the phases, tasks, and subtasks of the Research Pilot Project are illustrated in Figure 8.

Each of the project tasks result in interim deliverables. The EPA final report will integrate and synthesize the results from the task reports into a coherent EPA final report, which will serve as the final project outcome.

Figure 9 highlights the inter-relationships between the pilot research project and the regulatory project.

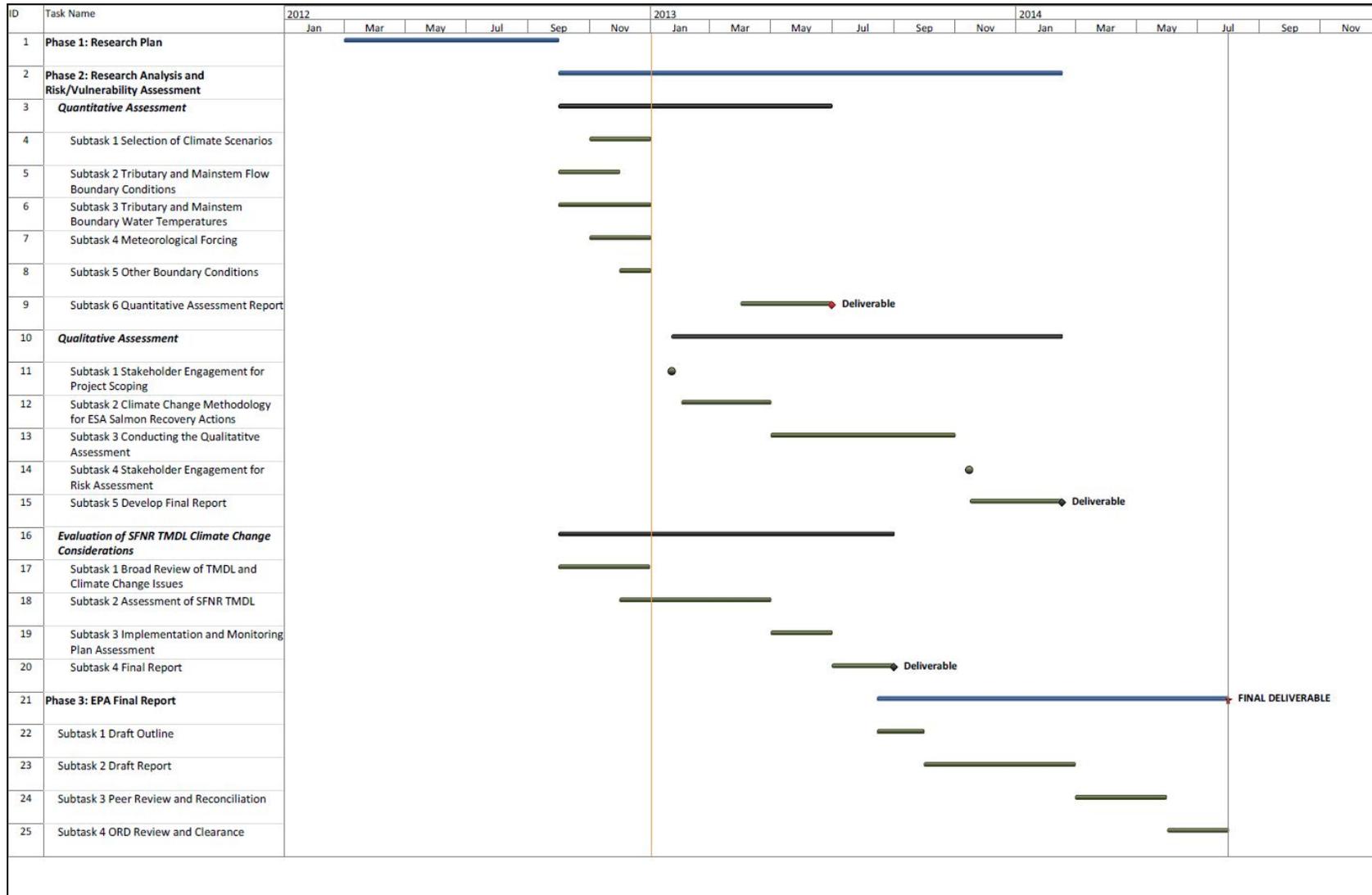


Figure 8. EPA Region 10 climate change TMDL pilot schedule and deliverables

EPA Region 10 Climate Change TMDL Pilot and Temperature TMDL – Parallel Study Strategy

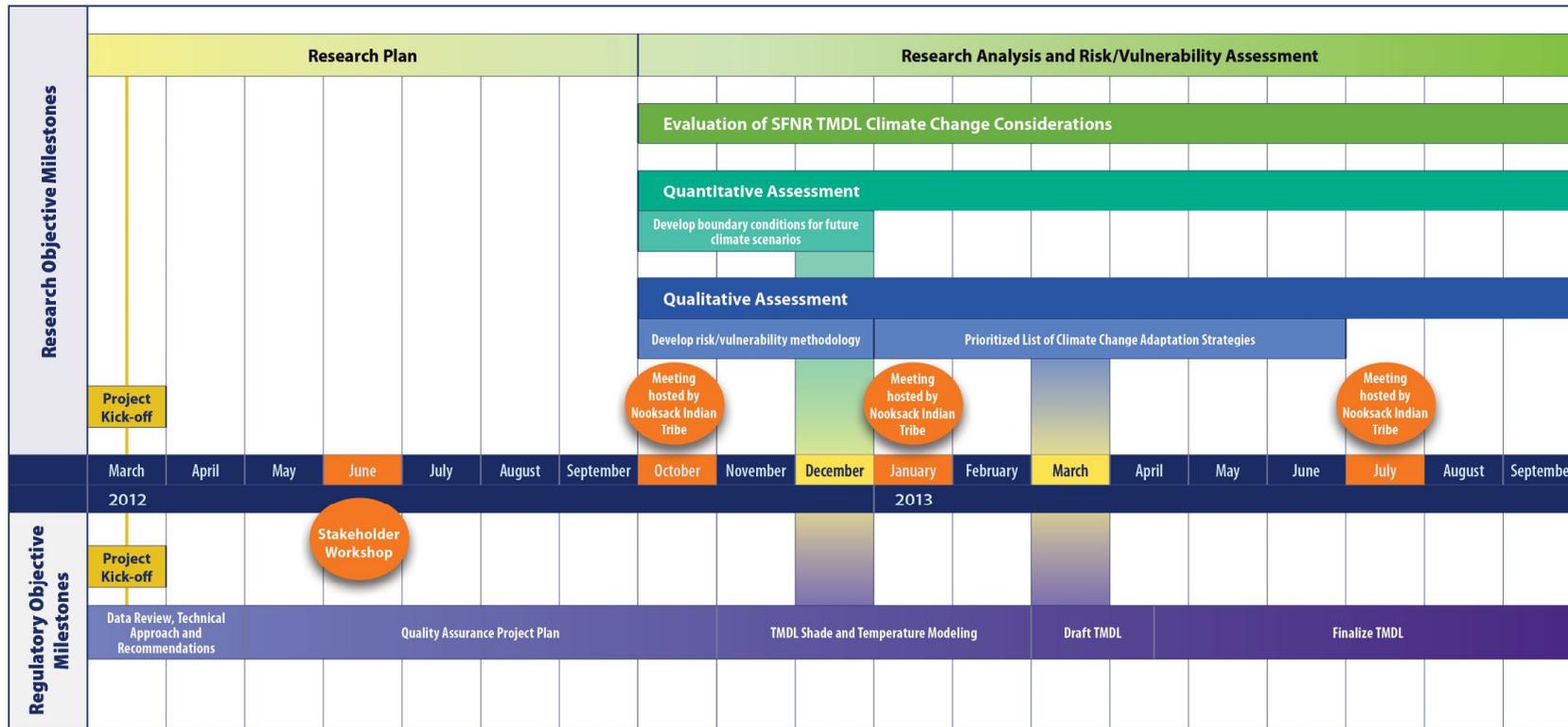


Figure 9. EPA Region 10 climate change TMDL pilot and temperature TMDL—parallel study strategy

MANAGEMENT PLAN AND QUALITY ASSURANCE

Management Plan

The management plan for this project is based on tiered and interactive decision making and responsibility between the project team (project leader, task leaders and collaborators). This project is structured as a stakeholder-centric process and as such the stakeholders have an ongoing role. Within the current ORD research structure of National Programs, the project leader described here would be the Task Leader for ORD Air Climate and Energy (ACE) Task 204. The task leaders described here would be cooperating scientists from EPA ORD or EPA Region 10.

The project leader is responsible for the overall planning, management, and accountability of the project.

The task leaders are responsible for the planning, management and accountability of their respective task.

Collaborators (scientists and environmental practitioners) are responsible for guiding and participating in the technical planning, execution, and documentation of this project.

Stakeholders (decision makers, policy makers, tribal members and concerned citizens) are responsible for making their issues, concerns and needs known to the project team and actively participating in this project.

Quality Assurance

In conformance with ORD's Policies and Procedures Manual, Chapter 13 - Quality Assurance (Draft June 12, 2012), this Project Research Plan is classified as QA Category 2 and the EPA Final Report will be reviewed and published as an Influential Scientific Information (ISI) document.

The overall quality assurance of this project will be guided by a Quality Assurance Project Plan (QAPP). ORD will complete this QAPP by April 30, 2013.

The plan will briefly describe the overall project (referencing this Project Plan for details), and consist primarily of a description of quality assurance activities relating to Tasks 3 – Qualitative Assessment and Task 4 - Climate Change Considerations for TMDL Development in the SFNR. Task 3 is the comprehensive assessment of freshwater habitat for ESA salmon recovery in the SFNR under climate change. Task 4 will examine EPA TMDL regulatory requirements to identify potential areas where climate change could be considered for inclusion in the SFNR temperature TMDL, and will develop a systematic methodology by which to evaluate climate change considerations to identify those that could be incorporated in the SFNR temperature TMDL.

Quality Assurance for Task 2 – Quantitative Assessment, is addressed in a separate QAPP completed by Ecology, EPA Region 10 and Tetra Tech (a contractor to EPA Region 10) ((Kennedy and Butcher 2012)). The quantitative assessment is the

comparison of QUAL2Kw modeled stream temperatures, including riparian shading, with and without climate change for the 2020s, 2040s, and 2080s. An addendum to the SFNR Regulatory QAPP will be developed to address quality considerations for the regression relationships described in subtask 2.3.

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