



Quinault Indian Nation Wetland Climate Change Vulnerability Assessment

**Quinault Indian Nation ~ Taholah, Washington
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Acronyms and Abbreviations

°C	degrees Celsius
CCSM	Community Climate System Model
CCVA	Climate Change Vulnerability Assessment
CMIP	Coupled Model Intercomparison Project
°F	degrees Fahrenheit
FEMA	Federal Emergency Management Agency
GCM	Global Circulation Models
GIS	geographic information system
HGM	hydrogeomorphic
km	kilometer
LiDAR	Light Detection and Ranging
NOAA	National Oceanic and Atmospheric Administration
NWI	National Wetland Inventory
OHWM	ordinary high water mark
QIN	Quinault Indian Nation
RCP	representative concentration pathway
Reservation	Quinault Indian Reservation
RM	river mile
SRES	Special Report on Emissions Scenarios
U&A	usual and accustomed area
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VAP	Vulnerability Assessment Project
VIC	variable infiltration capacity
WRIA	Water Resource Inventory Area
WSI	wetland suitability index

1. INTRODUCTION

The wetlands of the Quinault Indian Reservation (Reservation) are relied upon by its members and inhabitants for a variety of traditional uses such as plant collection, fishing and hunting. These wetlands include unique natural landscapes and ecosystems that distinctly embody the beauty and resources of the Pacific Northwest coast. Limited by the boundaries of the Reservation, the Quinault Indian Nation (QIN) cannot seek outside of the boundaries, or move for adaptation, if and when the natural environment is threatened by changes. Climate change is an increasing threat to the important natural, economic, cultural, and individual resources on Reservation lands. For example, the effect of climate change on the hydrology of the Chehalis Basin, which is immediately south of the Queets/Quinault Basin and within the QIN Usual and Accustomed Areas (U&A), has received special attention as part of the Chehalis Basin Strategy aimed at reducing flood damage and reversing wide-spread degradation of aquatic species habitat (Mauger et al. 2016; Ecology 2017). The study has found that adverse impacts currently affecting water resources and aquatic habitat in the basin are anticipated to worsen as a result of climate change.

Climate change is projected to bring changes to the temperature and precipitation regimes in the Pacific Northwest, primarily including changes in seasonal precipitation, temperature, timing (phenology), and sea level rise. Most climate models project slightly drier summers with slightly wetter conditions fall through spring, and anecdotal evidence also indicates a delay in fall freshet timing (Dalton et al. 2016). Fall freshet occurs when a rush of fresh water flows into the sea from heavy autumn rainfall. While climate changes have occurred in geologic history, the current rate of change is faster than historic trends indicate. Human activities are currently affecting the changing climate through increasing greenhouse gas emissions. These changes are predicted to have far-reaching impacts to natural ecosystems and human populations (Walsh et al. 2014; Dalton et al. 2016). In order to understand and plan for the potential vulnerability of wetlands to climate change, through the Wetland Program Plan, the QIN has identified the strategic importance of conducting a climate change vulnerability assessment (CCVA) of wetlands (QIN 2016).

The Reservation is over 200,000 acres in size, stretching from the Western coast of the Olympic Peninsula east to Lake Quinault. The majority of the Reservation has elevations below 1,000 feet and relatively gentle topographic relief. The landscape has been formed from repeated glacial-age flood deposits emanating from the Olympic Mountains to the east. The highest elevations are located on a series of mountain ridges in the northeastern corner of the Reservation, north of U.S. Highway 101 (Figure 1-1). The ridge top of the Salmon River Lookout is just over 2,600 feet in elevation. In addition, the QIN U&A, per the Treaty of Olympia Tribes, extends most of the length of the Pacific Coast of Washington. The Water Resource Inventory Areas (WRIAs) nearest the Reservation are shown on Figure 1-1. More information on the U&A is located in Section 6.7

The Western Olympic Peninsula receives the most annual precipitation in the continental United States, with 70 to 100 inches along the coastal plains and more than 150 inches on the western

slopes of the Olympic Mountains (Dalton et al. 2016). This very moist climate is home to abundant and unique wetland ecosystems and wetland-dependent species.

The Reservation contains a relatively high percentage of wetlands for the Pacific Northwest, over 8 percent based on a recent conservative estimate (AECOM 2015a; Eide 2017), which include the following hydrogeomorphic (HGM) classes: Estuarine, Riverine, Flats, Depressional, and Slope wetland classes, each with a different HGM setting, water source, and hydrodynamic nature that affect how each class responds to climate change stressors. In this assessment, we consider seven wetland habitat types that are a combination of the HGM classification (Brinson 1993) and the National Wetland Inventory (NWI) classification (Cowardin et al. 1979). For the purposes of this assessment, each wetland habitat is defined as a unique asset class.

The seven wetland asset classes were selected for applicability to the unique features of this landscape. Wetlands have attributes favorable to being understood within the context of climate change, including an inherent resilience, adaptive capacity, and sensitivity to change. The QIN wetland CCVA identifies and describes vulnerable wetlands on the Reservation based on climate change variables, climate-related wetland attributes, and the inherent adaptive nature of each wetland asset class with regard to various climate change variables.

Tribal cultural identity and livelihood are tied to the land and waters on the Reservation; people have inhabited this landscape for at least 12,000 years (Dalton et al. 2016). Therefore, traditional values play a role in natural resources management, and helps maintain the adaptive capacity of the landscape. As the climate changes, tribal adaptation practices may become necessary to build resilience to climate change in order to sustain the traditional way of life (Dalton et al. 2016).

The QIN wetland CCVA builds upon the efforts and methods undertaken in the Treaty of Olympia Tribes Climate Change Vulnerability Assessment (Treaty of Olympia Tribes CCVA) (Dalton et al. 2016), drawing on existing climate change scenarios, available studies and literature, and local expert knowledge. In addition, uncertainties and knowledge gaps are identified. Climate adaptation planning is generally a two-part process: (1) conducting a climate vulnerability assessment and (2) developing a climate adaptation plan to address and reduce the vulnerabilities identified during part one (Treaty of Olympia Tribes CCVA). During the climate vulnerability assessment phase, vulnerability of assets (in this study assets are wetland types) is assessed. During the adaptation plan phase, specific adaptation strategies are developed, with a goal to reduce the higher-vulnerability assets to climate stressors and therefore reduce the overall vulnerability of the study area and increase climate change resiliency.

The study provides details that can be incorporated in planning tools to address impacts of climate change on the Reservation wetland resources. The next step in addressing these predicted impacts will be developing a climate adaptation plan. The climate adaptation plan will include specific adaptation strategies that will be developed to reduce the vulnerabilities of the wetland assets identified in this report as moderate or high vulnerability and therefore increase the climate resiliency of wetlands on the Reservation.

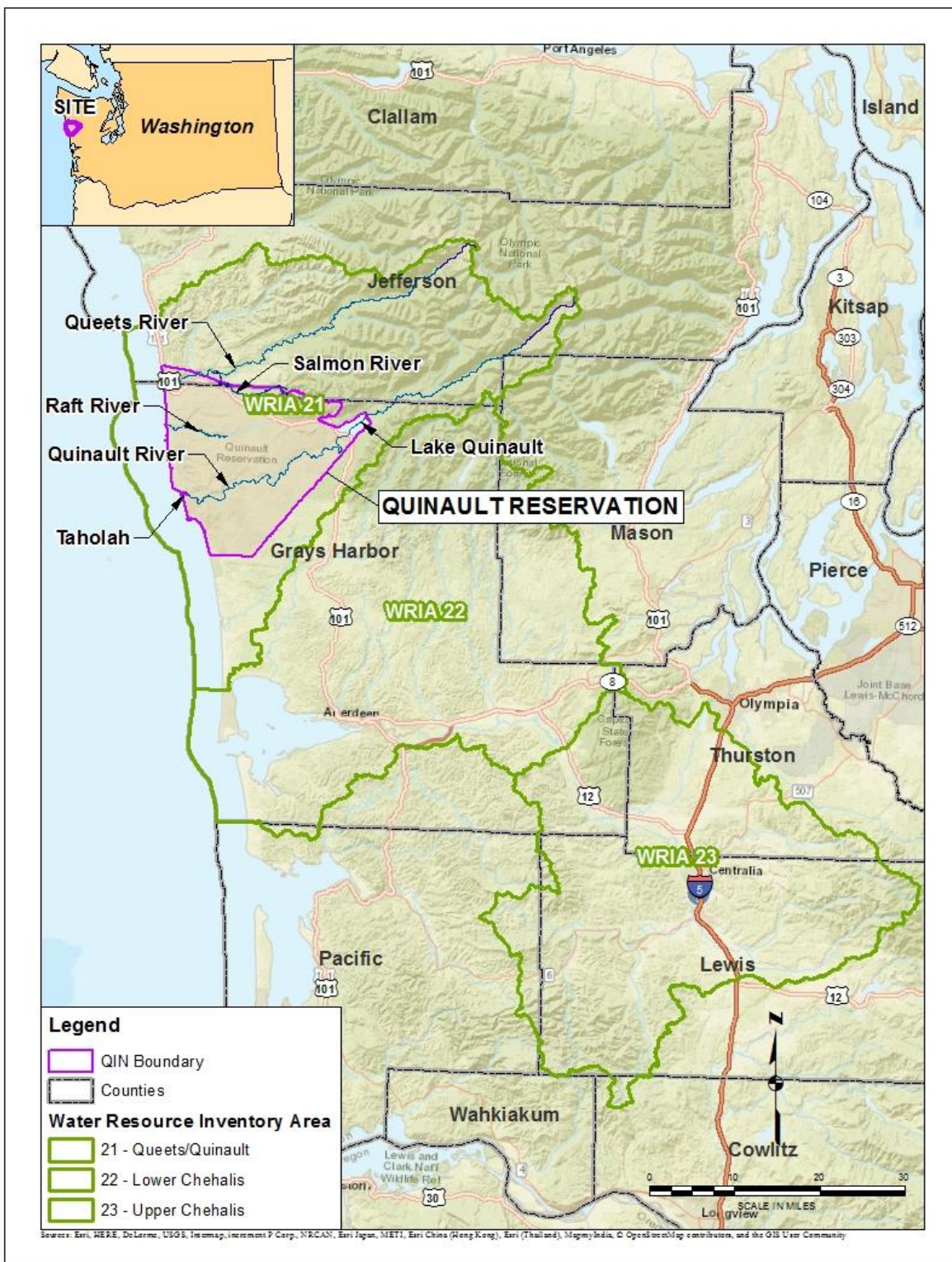


Figure 1-1. Project Area Vicinity

2. ASSESSMENT GOAL AND OBJECTIVES

2.1 Goal

The recently published Treaty of Olympia Tribes CCVA (Dalton et al. 2016) provides an overview of expected trends in regional climate change, along with an assessment of how habitats and species important to the QIN may respond to various climate scenarios.

The goal of the QIN wetland CCVA is to expand the Treaty of Olympia Tribes CCVA work to better understand how wetland habitat types and the species that depend on them in the Reservation may be vulnerable to climate change.

Results of this report may be applied to a future climate adaptation plan that will identify adaptive management solutions that can be implemented by the QIN to reduce the vulnerability of particular wetland habitats identified herein.

2.2 Objectives

Objectives of the QIN wetland CCVA include the following:

1. Describe forecasted climate change on the Olympic Peninsula, and define and describe key climate variables selected to assess wetland vulnerability.
2. Describe wetland habitat types on the Reservation according to the HGM and Cowardin classification systems, based on data from a recent study completed by AECOM for the QIN. The descriptions of the wetland resources provided herein are based on the estimated wetland layer and verified stream layer (AECOM 2015a; AECOM 2015b).
3. Assess the wetland functions and values for each wetland type (asset) in relation to climate change, in order to determine which wetland assets rate as highly vulnerable. Wetlands are assessed and scored by the following characteristics:
 - Vegetative community
 - Fish and wildlife habitat
 - Water quality and hydrology
4. Address stakeholder concerns by evaluating assets of particular cultural importance tied to wetlands on the Reservation. These important assets include the following:
 - Wet prairies
 - Camas habitat
 - Fire regimes
 - Elk habitat
 - Salmon habitat

5. List example management implications for highly vulnerable wetlands within a framework of concerns and opportunities, with actions that can be further developed through a climate adaptation plan.

3. FORECASTED CLIMATE CHANGE ON THE OLYMPIC PENINSULA

As noted in the recent Chehalis Basin climate change study (Mauger et al. 2016) and the Treaty of Olympia Tribes CCVA (Dalton et al. 2016), climate change is projected to bring changes to the temperature and precipitation regimes in the Pacific Northwest. The Chehalis Basin study found that winter riverine flooding on the Chehalis River is projected to increase, and in summer stream flow and low flows will be even lower and that climate models suggest drier summer conditions (Mauger et al. 2016). Broad-scale regime changes in temperature and precipitation, and their interacting effects, are expected to bring subsequent changes to the natural environment.

While the earth has historically experienced several warming and cooling phases, the rate of change is projected to occur faster than historical trends shown in Pacific Northwest ecological systems. Climate changes in the past have been caused by natural factors, yet human activities are currently affecting climate through increasing atmospheric levels of heat-trapping gases and other substances, including particles (Walsh et al. 2014). Fossil fuel burning since the beginning of the Industrial Revolution has been distributing greenhouse gasses to the atmosphere, contributing to an increased rate of change. Continued escalations in greenhouse gas emissions are expected to have far-reaching impacts to natural ecosystems and human populations (Dalton et al. 2016).

Based on forecasted changes and an understanding of current wetland resources, the following climate change variables were selected for the QIN wetland CCVA:

- Temperature
- Precipitation and streamflow
- Snowpack
- Wildfire
- Sea level rise

3.1 Emissions Scenarios

Predicting the exact amount of greenhouse gas emissions resulting from future human activities is not possible, so scientists use greenhouse gas emissions scenarios to represent a range of different future conditions (Mauger et al. 2016). Emissions scenarios are models that estimate future climate conditions based on assumptions about global human population growth, economic development, and technological advancement throughout the twenty-first century (Dalton et al. 2016). It is these “what if” scenarios that are then used to drive global model simulations, which provide estimated changes in temperature, precipitation, and other aspects of the Earth’s climate (Mauger et al. 2016).

This report utilizes twenty-first-century climate projections to describe and understand forecasted change and key climate change variables, based on three different sets of projected future conditions:

1. Representative Concentration Pathways (RCPs) from the most current emissions scenarios based on the latest generation of Global Circulation Models (GCMs), specifically CMIP5 (Coupled Model Intercomparison Project) (van Vuuren et al. 2011).
2. The 2000 Special Report on Emissions Scenarios (SRES) set, based on previous GCMs, specifically CMIP3 (Nakićenović et al. 2000). These scenarios include a range of specific levels of emissions trajectories, including A1B (medium), A2 (higher), and B1 (lower) emissions scenarios.
3. Scenario based on the CCSM4 (Community Climate System Model).

Figure 3-1 shows the range in the carbon emissions and atmospheric carbon dioxide concentrations for the RCP and SRES sets of scenarios, along with temperature projects, demonstrating that there are similarities and variations among and between these two scenarios.

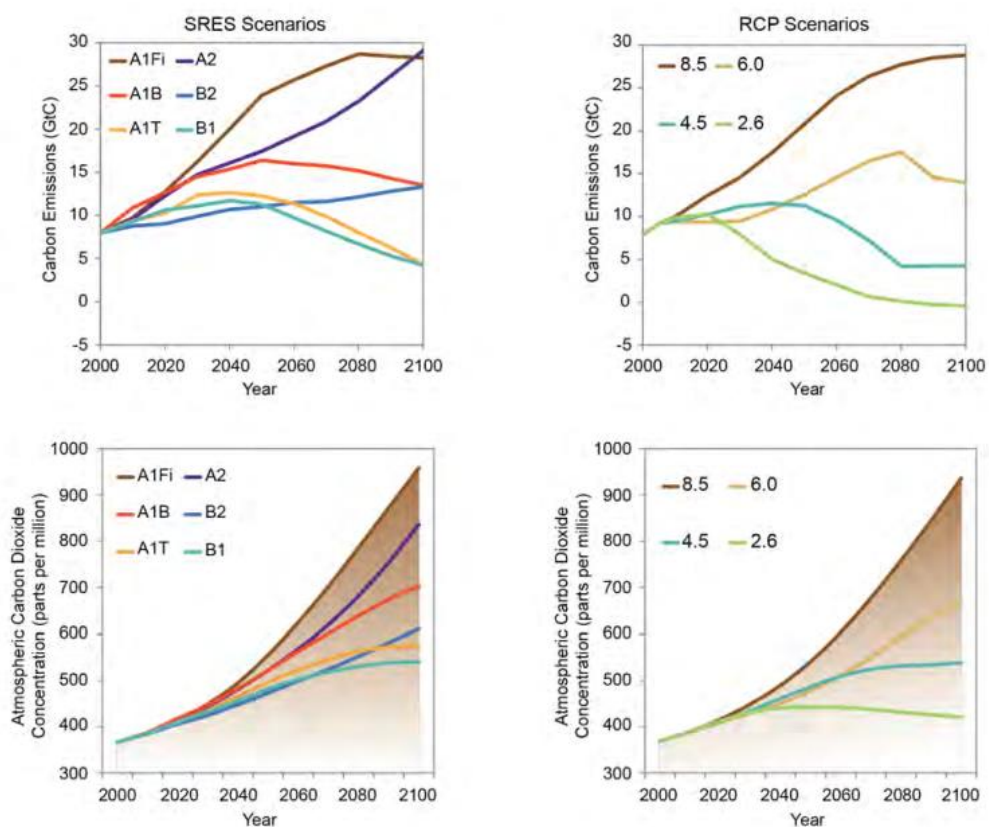
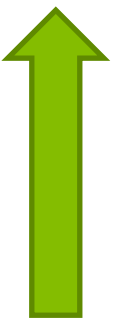


Figure 3-1. SRES and RCP Scenarios (Carbon Emissions, Atmospheric Carbon Dioxide Concentrations, and Temperature Projections)

Source: Walsh et al. 2014

Table 3-1 provides an overview of the primary emissions scenarios applied to describing forecasted climate change and climate change variables in the QIN wetland CCVA and shows at a broader level how the scenarios relate based on respective emissions projections.

Table 3-1. Emissions Scenarios in the QIN Wetland CCVA

Emissions Scenario	Global Climate Model	Description	Emissions
RCP8.5	CMIP5	“Business-as-usual” continuation of emissions, “High emissions future”	
SRES A2	CMIP3	A delayed development or “transitional” scenario	
SRES A1B	CMIP3	Medium emissions scenario	
SRES B1¹	CMIP3	Low emissions scenario	
RCP4.5¹	CMIP5	Moderate efforts to curb emissions, “Low emissions future”	
RCP2.6	CMIP5	Reaching net negative carbon dioxide emissions before end of century	

¹RCP4.5 and SRES B1 emissions scenarios are similar and could be shown as side by side in this table.

To date, none of the scenarios are considered more likely to occur; however, the current emissions use places the expected trajectory of the United States nearest to RCP8.5 (Walsh et al. 2014; Dalton et al. 2016). These emissions scenarios are not meant to be compared directly to one another, as they are from different climate models and are based on differing factors. The emissions scenario with the least amount of emissions is the RCP2.6 (from the more recent CMIP5 GCM), which assumes net negative carbon dioxide emissions before end of century. The emissions scenario with the highest amount of emissions is the RCP8.5 (CMIP5 GCM), which assumes a “Business-as-usual” continuation of emissions, or a “high emissions future.”

This QIN wetland CCVA primarily applies two likely emissions scenarios: the CMIP5 global climate model forced by RCP8.5, which is considered a “Business-as-usual” continuation of emissions, or a “high emissions future”; and a second scenario that assumes moderate efforts to curb emissions, or a “low emissions future” (RCP4.5). This is similar to the Chehalis Basin climate change study, which uses three scenarios: RCP 4.5, SRES A1B, and RCP 8.5 (Mauger et al. 2016).

Note that certain climate variables described in this report, such as snowpack and stream flow, utilize climate scenarios from the previous CMIP3 global climate models, and the soil moisture variable applies a CCSM4 climate model scenario to make use of available data for those climate variables.

3.2 Temperature

As stated in the recent Treaty of Olympia Tribes CCVA (Dalton et al. 2016), average annual temperatures for the Pacific Northwest may increase by close to 6 degrees Fahrenheit (°F) by the mid-twenty-first century under a high emissions scenario, although increases may not be as high for coastal regions. While there is an expected increase in annual precipitation for the Olympic Peninsula, summer precipitation is expected to decrease.

Mean temperature in the Pacific Northwest has warmed by approximately 1.3°F over the past century and is expected to rise throughout the twenty-first century (IPCC 2013, Dalton et al. 2016); see Table 3-2 below for projections based on emissions scenarios. Warming is projected to increase year round, with the greatest increases during the summer months. Due to the coastal location, temperature fluctuations in the Reservation may be less pronounced than inland areas, due to the moderating effect of the Pacific Ocean on temperatures (Dalton et al. 2016).

Table 3-2. Twenty-first Century Projected Temperature Increase in the Pacific Northwest by Scenario

Emissions Scenario	Projected Temperature Increase
Low emissions future (RCP4.5)	+3-8°F
High emissions future (RCP8.5)	+7-14°F

Source: Mote et al. 2013

Table 3-3 shows the projected temperature changes in the Pacific Northwest averaged by seasonal mean for midcentury (2041-2071), compared to the baseline (1950-1999) for low emissions (RCP4.5) and high emissions (RCP8.5) future scenarios (Mote et al. 2013).

Table 3-3. Mid-Twenty-First Century Projected Temperature Changes in the Pacific Northwest

Mid-21st Century Temperature Projections	RCP4.5 (Range)	RCP8.5 (Range)
Annual	4.3°F (2.0, 6.7)	5.8°F (3.1, 8.5)
Winter (DJF)	4.5°F (1.6, 7.2)	5.8°F (2.3, 9.2)
Spring (MAM)	4.3°F (2.3, 7.4)	5.4°F (1.8, 8.3)
Summer (JJA)	4.7°F (2.3, 7.4)	6.5°F (3.4, 9.4)
Fall (SON)	4.0°F (1.4, 5.8)	5.6°F (2.9, 8.3)

Notes: DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November

Source: Dalton et al. 2016, adapted from Mote et al. 2013

Projected monthly average temperatures for the Queets and Quinault watersheds are shown below in Figure 3-2. Monthly averages of maximum (top) and minimum (bottom) temperature are shown for four time periods for RCP4.5 (left) and RCP8.5 (right) for the Queets-Quinault region. The 30 CMIP5 model average is shown by the solid lines and the shading represents the standard deviations.

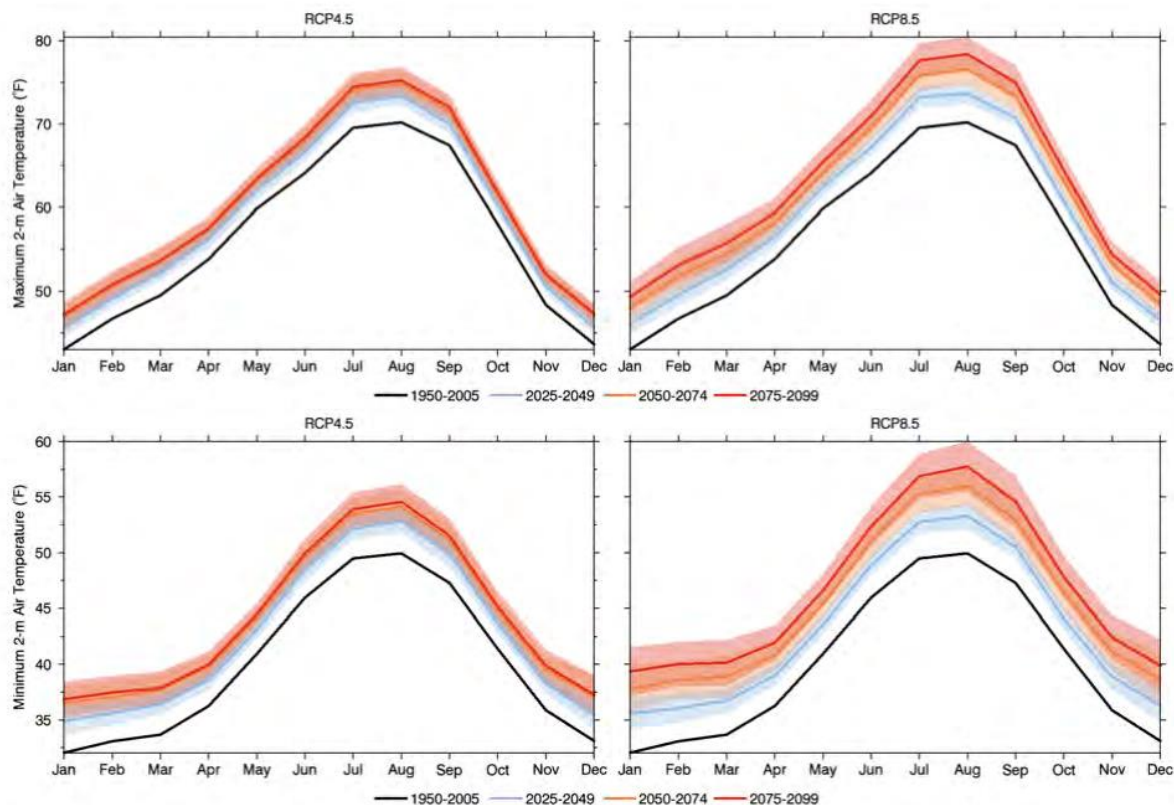


Figure 3-2. Monthly Average Temperatures for the Queets and Quinault Watersheds

Source: USGS National Climate Change Viewer Summary of Queets-Quinault, as shown in Dalton et al. 2016

AECOM utilized the U.S. Geological Survey (USGS) Regional Climate Downloader website to obtain precipitation and temperature data more geographically specific to the Reservation. The most recent model data available on the website was reviewed and mapped for purposes of estimating predicted changes in mid and late twenty-first-century summer rainfall and temperature. These climate data were derived from a model titled CGCM3.1 (T47) that uses the CMIP3 emissions scenarios (Scinocca et al. 2008). Because the predicted changes in summer rainfall and temperature are anticipated to have a substantial effect on wetland conditions, the mean summer precipitation and temperature data were gathered for two possible emissions scenarios at mid and late century time periods. One scenario (A1) describes a future world of very rapid economic growth and a global population that peaks in midcentury and declines thereafter, coupled with rapid introduction of new and more efficient technologies. As a result, increased summer temperatures and declining summer precipitation are greatest at the midcentury time period.

A second scenario (A2) describes a very heterogeneous world with continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented relative to other scenarios. Under this scenario, summer temperatures and drought continue to increase gradually over the course of the current century. Both scenarios (A1 and A2) are shown in Figures 3-3 and 3-5.

Mean summer temperatures (shown in degrees Celsius [$^{\circ}\text{C}$]) downscaled to the 1/16 degree or approximately 6 kilometer (km) in grid size are shown in Figure 3-3. The image on the left shows the baseline image. The top middle and top right images show the 2050 and 2099 predicted mean summer temperatures based on the Medium (A1B) emissions scenario. The bottom middle and bottom right images show the 2050 and 2099 predicted mean summer temperatures based on the Medium-High (A2) emissions scenario.

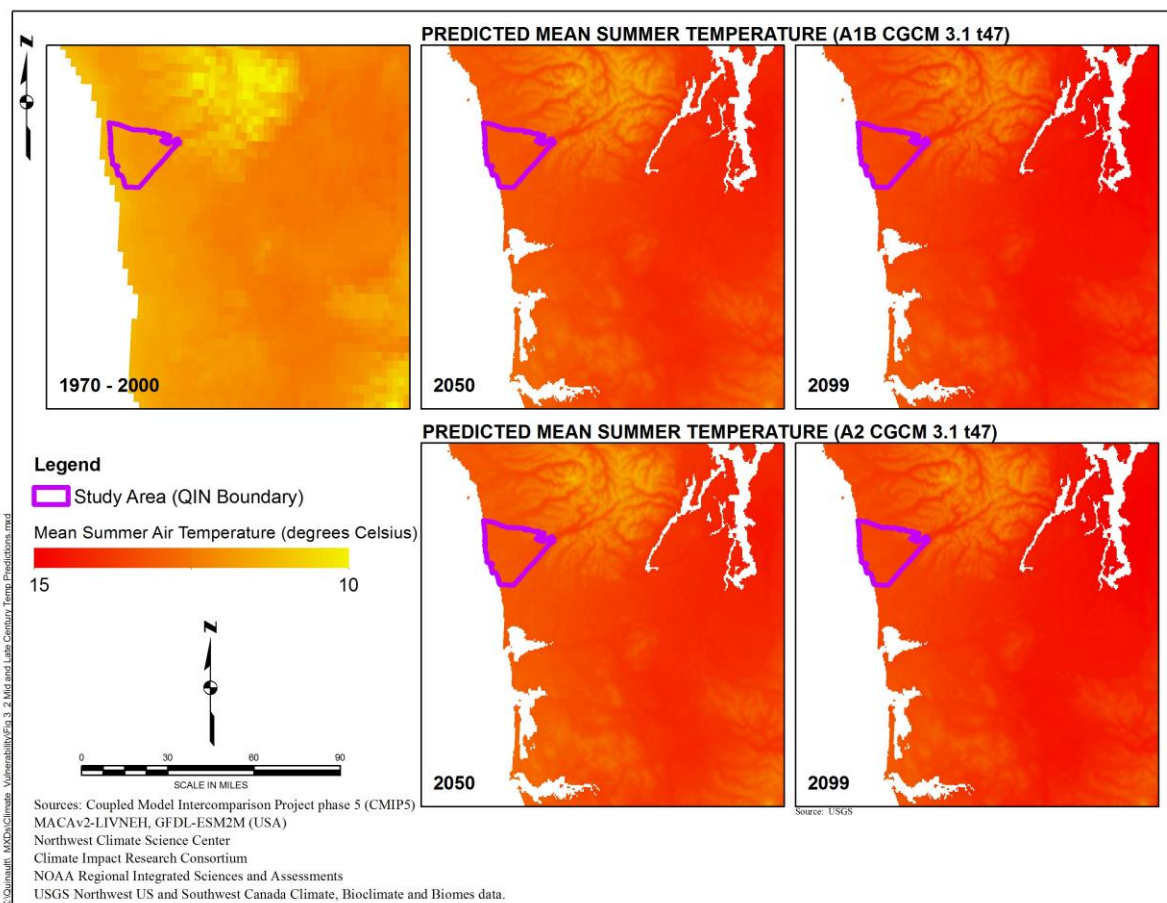


Figure 3-3. Predicted Mean Summer Temperature on the Reservation under the Medium (A1B) and Medium-High (A2) Emissions Scenarios

Source: USGS Regional Climate Downloader, <http://regclim.coas.oregonstate.edu/visualization/rcd/tutorial/index.html>

The predictions shown in Figure 3-3 are based on CMIP3 global climate models for the baseline (1970 to 2000), midcentury, and late-century time periods, under the Medium (A1B) Medium-High (A2) scenarios. The baseline mean summer temperature was approximately 11 to 12 $^{\circ}\text{C}$ (51.8 to 53.6 $^{\circ}\text{F}$) during the time frame of 1970 to 2000. The mean summer temperature is predicted to increase towards 13 $^{\circ}\text{C}$ (55.4 $^{\circ}\text{F}$) by midcentury under the Medium (A1B) scenario, and towards 14 $^{\circ}\text{C}$ (57.2 $^{\circ}\text{F}$) under the Medium-High (A2) scenario. By late-century, mean summer temperature is predicted to increase beyond 13 $^{\circ}\text{C}$ (55.4 $^{\circ}\text{F}$) under the Medium (A1B) scenario and towards 15 $^{\circ}\text{C}$ (59 $^{\circ}\text{F}$) under the Medium-High (A2) scenario.

An increase in summer temperature is predicted to have direct effects on wetlands, particularly when combined with a decrease in summer precipitation. While the mean temperature change may increase by 10°F, increases in extreme heat events could exacerbate the effects. The warmer, drier weather could decrease available soil moisture and accelerate the drying out of wetlands, potentially decreasing the number and size of wetlands on the Reservation.

3.3 Precipitation and Streamflow

Precipitation

Precipitation on the Olympic Peninsula is dynamic, and no significant trend in annual water year has been observed in the region (Dalton et al. 2016); however, spring precipitation in the Northwest has significantly increased by 2 to 5 percent per decade over the past century (Abatzoglou et al. 2014, Dalton et al. 2016). Regionally, there are typically a few freshets (high river flows from large rain events) in September and accelerating into October, but tribal members interviewed during the Treaty of Olympia Tribes CCVA (2016) reported that in recent years, September has been drier with no freshets (Dalton et al. 2016). This anecdotal evidence would indicate a delay in fall freshet timing.

Future projections indicate slightly wetter conditions annually overall; however, the models disagree. Most models project a slightly drier summer with slightly wetter conditions fall through spring (Dalton et al. 2016). As described in the Treaty of Olympia Tribes CCVA (Dalton et al. 2016), extreme precipitation and storm events are expected to increase, which will affect fishing and traditional gathering that occurs seasonally. Table 3-4 below displays the projected changes in Pacific Northwest average annual and season precipitation for midcentury, when compared against the baseline (1950 to 1999), showing the low (RCP4.5) and high (RCP8.5) emissions future scenarios.

Table 3-4. Projected Changes in Pacific Northwest Mid-Century Precipitation

Mid-21st Century Precipitation Projections	RCP4.5 (Low Emissions Scenario)	RCP8.5 (High Emissions Scenario)
Annual	2.8% (-4.3, 10.1)	3.2% (-4.7, 13.5)
Winter (DJF)	5.4% (-5.6, 16.3)	7.2% (-10.6, 19.8)
Spring (MAM)	4.3% (-6.8, 18.8)	6.5% (-10.6, 26.6)
Summer (JJA)	-5.6% (33.6, 18.0)	-7.5% (27.8, 12.4)
Fall (SON)	3.2% (-8.5, 13.1)	1.5% (-11.0, 12.3)

Notes: DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November

Source: Dalton et al. 2016, adapted from Mote et al. 2013

Precipitation projections for the Reservation are similar and include increased winter precipitation, decreased summer precipitation, increased potential evapotranspiration, and increased precipitation intensity (Halofsky et al. 2011, as cited in Dalton et al. 2016). Midcentury precipitation projections for the Queets and Quinault watersheds are shown in Figure 3-4. Projections are shown for four time periods for low (RCP4.5) (left) and high (RCP8.5) (right) emissions scenarios. Note the 30 CMIP5 model average is indicated by the solid lines and shaded areas represent standard deviations.

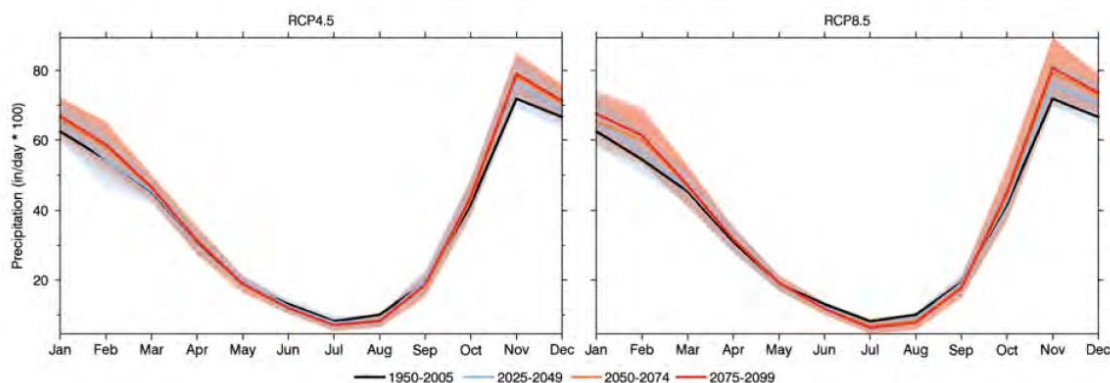


Figure 3-4. Midcentury Precipitation Projections for the Queets and Quinault Watersheds

Source: USFS National Climate Change Viewer Summary of Queets-Quinault, as shown in Dalton et al. 2016

Figure 3-5 depicts mean summer precipitation (shown in inches) downscaled to the 1/16 degree or approximately 6 km in grid size. The predictions shown are based on CMIP5 global climate models for the baseline (1970 to 2000), midcentury, and late-century, under the low (RCP4.5) and high (RCP8.5) emission scenarios. The image on the left shows the baseline image. The top middle and top right images show the 2050 and 2099 predicted mean summer precipitation based on the low (RCP4.5) emissions scenario. The bottom middle and bottom right images show the 2050 and 2099 predicted mean summer precipitation based on the high (RCP8.5) emissions scenario.

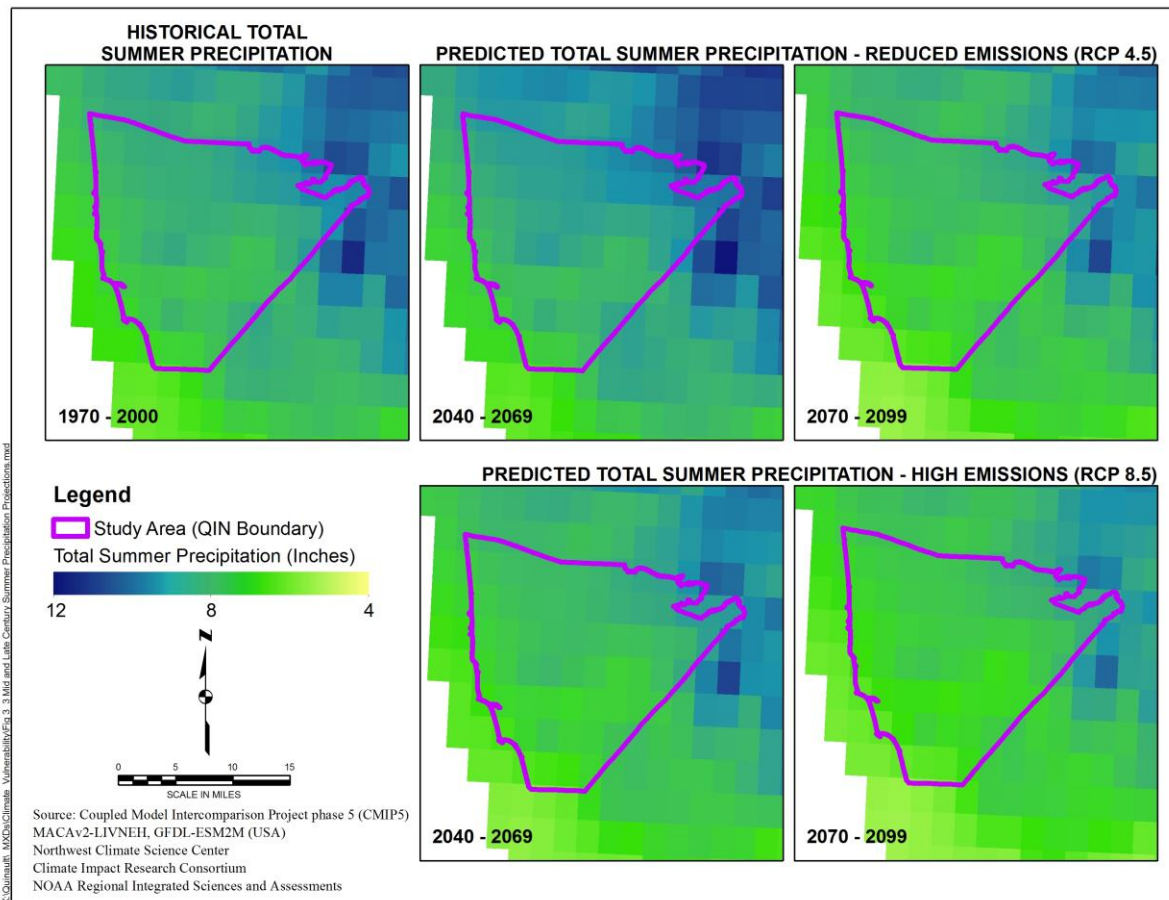


Figure 3-5. Predicted Mean Summer Precipitation on the Reservation under the Low (RCP4.5) and High (RCP8.5) Emission Scenarios

Source: Coupled Model Intercomparison Project Phase 5 (CMIP5)

While mean summer precipitation is projected to decline, no clear trends in the Reservation can be interpreted from this figure, which speaks to the dynamism of the models. The degree of detail and uncertainty in the models make it more difficult to isolate specific assets within the broader regional context. Note that precipitation east of the Reservation shows a projected decrease, where the dark blue fades to lighter blue over time under both scenarios.

Streamflow

Climate trends have been noted, including a reduction in winter snowpack, more winter precipitation falling as rain rather than snow, and spring snow melting earlier (Dalton et al. 2016). These events have resulted in higher winter stream flows and reduced summer flows, leading to decrease in June streamflow over the past 60 years on the Olympic Peninsula (Dalton et al. 2016). The Anderson Glacier that once fed the Quinault River has melted, which also contributes to a lower annual flow, particularly in the dry season. Largest changes are anticipated in areas with mild snowpack, leading to impacts on salmon and other aquatic species, potentially reducing fishing success and water quality (Dalton et al. 2016). As shown in Figure 3-6 below,

projected changes to total runoff in the Reservation are between -30 and <-50 percent for 2040, when compared to the period of 1915 to 2006.

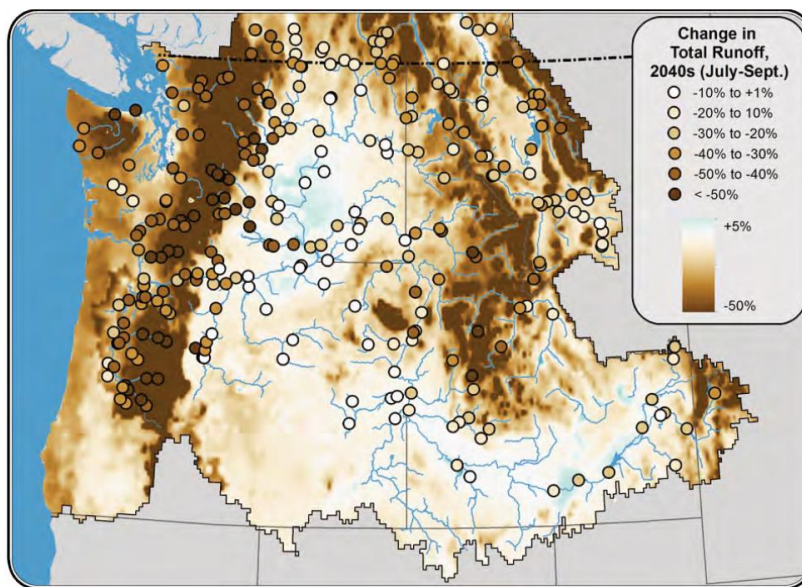


Figure 3-6. Projected Changes in Local Runoff (Shading) and Streamflow (Colored Circles) Under the Medium (A1B) Emissions Scenarios

Source: Columbia Basin Climate Change Scenarios Project, in Dalton et al. 2016

Figure 3-7 shows the combined monthly average total runoff and baseflow for the Queets River basin (USGS ID 12040500) and Quinault River basin (USGS ID 12039500) expressed as average depth in inches. The blue line shows the simulated historical values, the light red shading shows the range of ten GCMs for the 2080s and the Medium (A1B) scenario, and dark red lines show the average of the ten GCMs.

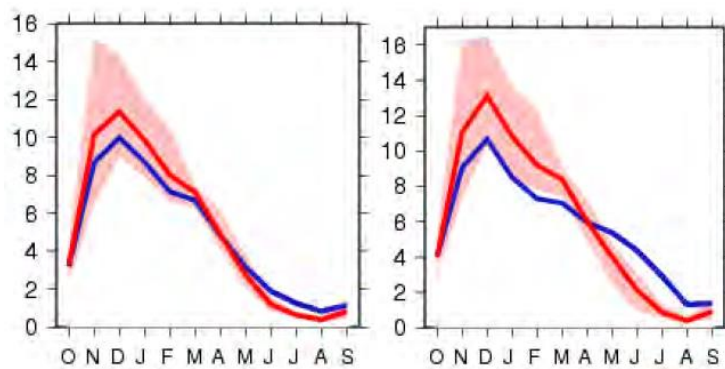


Figure 3-7. Combined Monthly Average Total Runoff and Baseflow (inches) for the Queets River Basin (left) and Quinault River Basin (right)

Source: Columbia Basin Climate Change Scenarios Project, as shown in Dalton et al. 2016

A study titled the *Effect of Climate Change on the Hydrology of the Chehalis Basin* (Mauger et al. 2016) has found that adverse impacts currently affecting water resources and aquatic habitat in the basin are anticipated to worsen as a result of climate change. The findings were consistent with Dalton et al. (2016) and other references cited in this report. With reference to potential impacts to wetlands, these include projected increases in spring/winter precipitation resulting in increased spring/winter high flows and decreased summer precipitation resulting in decreased summer low flows. Hydrology of the Chehalis Basin is classified as “rain dominant,” with relatively little winter precipitation falling as snow. Hydrology of the Queets/Quinault Basin is proportionately more dependent on snow melt so will react to climate change slightly differently.

The *Draft Chehalis Basin Strategy Programmatic EIS* (Ecology 2016) recognizes the potential importance of wetlands for reducing flood flows, improving water quality, and providing habitat for aquatic species. The “Restorative Flood Protection” alternative is intended to rebuild the lost natural flood storage capacity of the basin, much of which would be provided by restoring or reconnecting wetlands within the floodplain (Ecology 2016).

Soil Moisture

Soil moisture is a key indicator of wetland impacts to climate change. Figure 3-8 below displays total soil moisture change for summer on the Reservation, for midcentury (2040 to 2099) and late-century (2070 to 2099), as compared to the change in baseline conditions (1971 to 2000). Soil moisture is projected to decrease throughout the twenty-first century.

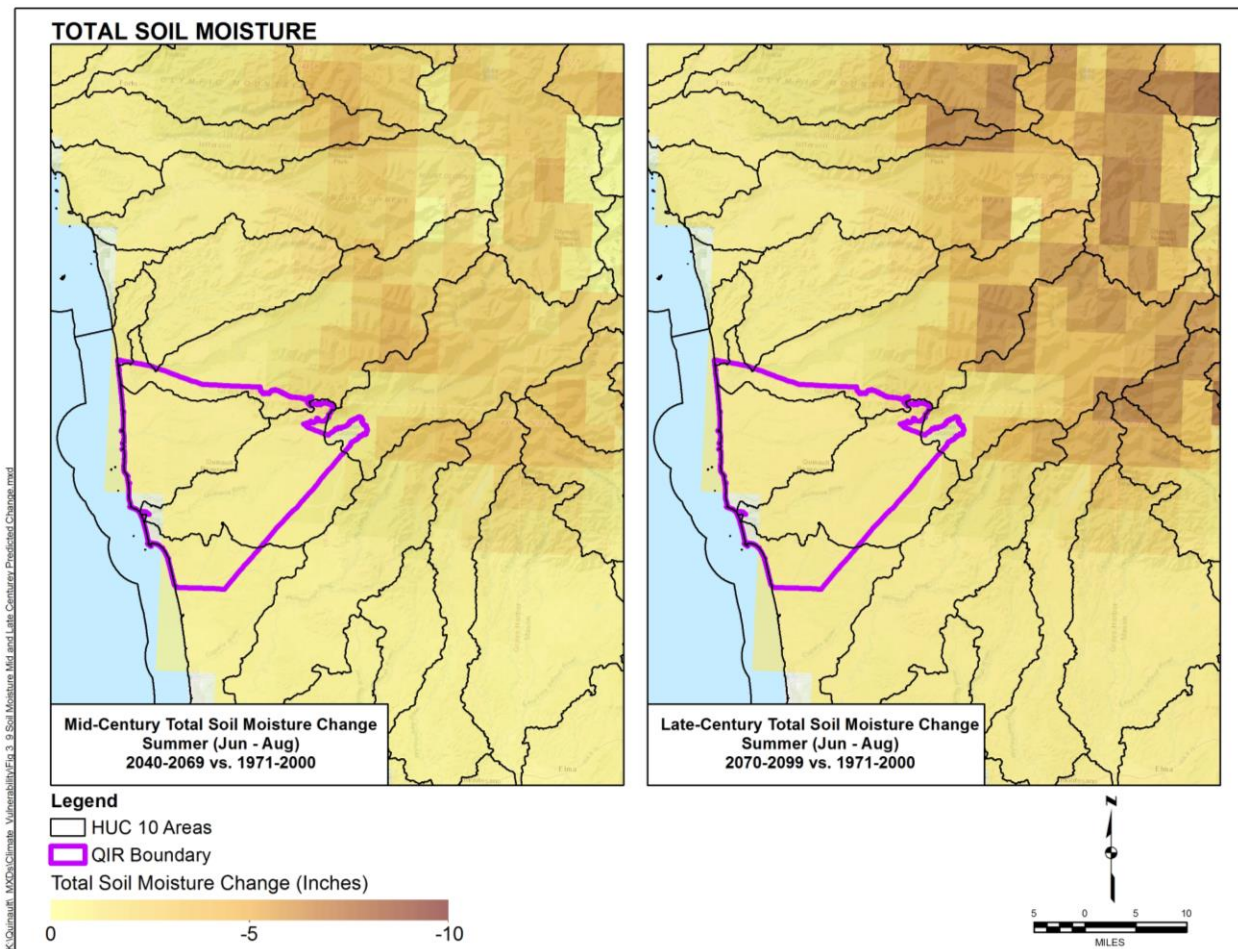


Figure 3-8. Soil Moisture Change in the Twenty-First Century

Source: Integrated Scenarios: <https://climate.northwestknowledge.net/IntegratedScenarios/>

Data exported from the VIC Hydrology model for the total soil moisture during the summer timeframe variable based on the CCSM4 climate model.

3.4 Snowpack

Snowpack on the Olympic Peninsula is expected to decrease over time as temperature warms. The warmer temperatures lead to precipitation falling as rain rather than snow events, particularly at elevations typically considered snowfall areas, resulting in widespread declines of spring snowpack across the Western U. S. (Mote et al. 2005, Dalton et al. 2016). Figure 3-9 shows the trends in regional snowpack from 1955 to 2015 measured in snow water equivalent; blue circles represent increased snowpack and red circles represent a decrease. Significant declining trends are shown for the Pacific Northwest.

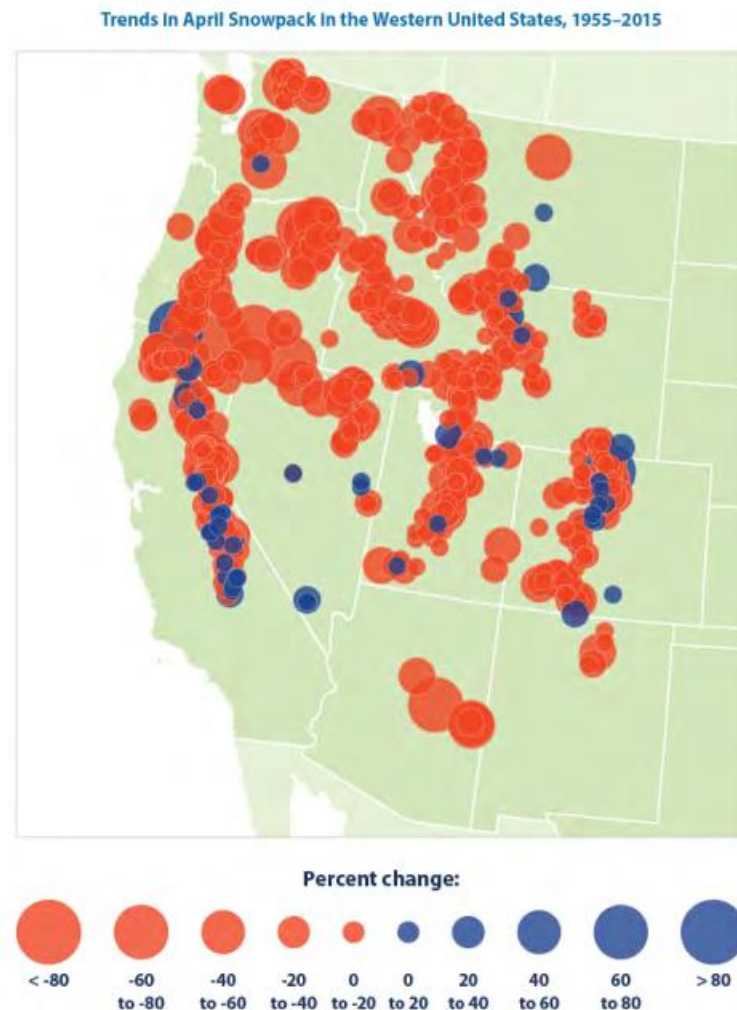


Figure 3-9. Trends in April Snowpack in the Western U.S.

Source: Mote and Sharp 2015, from Dalton et al. 2016

Table 3-5 below shows the projected changes in April 1 snow water equivalent in Washington State for the 2020s and 2080s for the Low (B1) and Medium (A1B) scenarios.

Table 3-5. Projected Changes in April 1 Snow Water Equivalent for Washington State

April 1 Snowpack Projections	SRES B1 (Low Emission Scenario)	SRES A1B (Medium Emission Scenario)
2020s (2010-2039)	-27%	-29%
2040s (2030-2059)	-37%	-44%
2080s (2070-2099)	-53%	-65%

Source: Elsner et al. 2010, shown in Dalton et al. 2016

Figure 3-10 shows the average snow water equivalent (quantifies natural storage as snowpack) for the Queets and Quinault River basins expressed as average depth in inches. The blue line shows the simulated historical values, the light red shading shows the range of 10 GCMs (Global Circulation Models) for the 2080s and the Medium (A1B) scenario, and dark red lines show the average of the 10 GCMs.

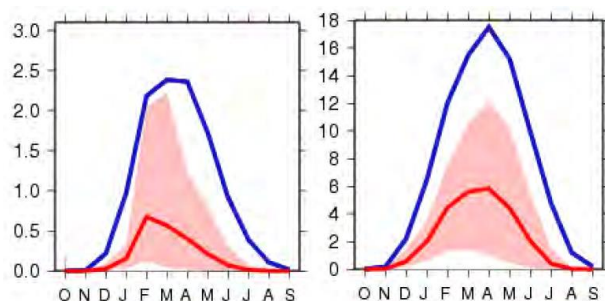


Figure 3-10. Snow Water Equivalent in Inches for 2080 on Queets River (left) and Quinault River (right), by Month

Source: Columbia Basin Climate Change Scenarios Project, as shown in Dalton et al. 2016

3.5 Wildfire

Wildfire on the Olympic Peninsula and across the west has increased, with large fires occurring in recent years, such as the Paradise Fire along the Queets River in the Olympic Mountains in 2015 (Dalton et al. 2016). The Pacific Northwest is projected to have a 400 to 500 percent increase in median fire size (Figure 3-11) (NRC 2011, and as shown in Dalton et al. 2016). This increase is exacerbated by fire suppression, because areas that historically burned but have not for an extended period of time have built up fuels that increase fire size and duration.

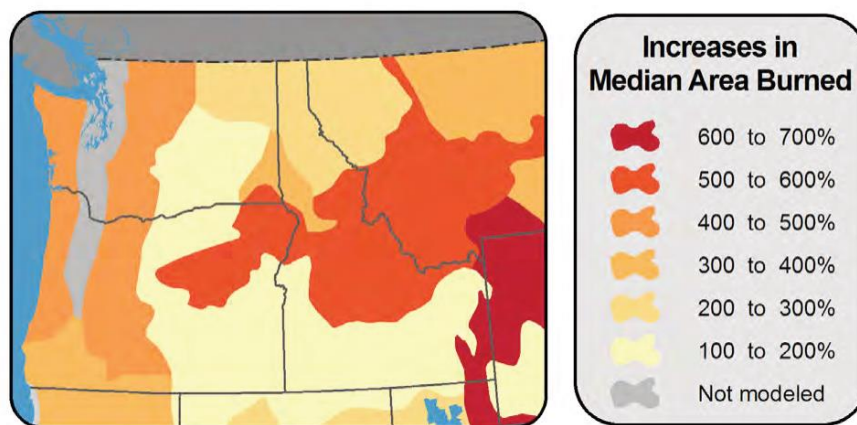


Figure 3-11. Wildfire Sensitivity based on Projected Temperature and Precipitation Changes.

Figure depicts sensitivity of area burned to a 2.2°F increase in global warming, including both the expected temperature and precipitation change. The divisions are areas that share broad climatic and vegetation characteristics.

Source: NRC 2011, as shown in Dalton et al. 2016

3.6 Sea Level Rise

Sea level rise on the Olympic Peninsula is projected to increase by 4 to 56 inches by 2100 (NRC 2012, as cited in Dalton et al. 2016). Sea level rise, along with storm surge, high tides, and wind waves pose a threat to coastal wetlands systems within the Reservation.

The National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management has modelled sea level rise and has made the data available to the public (<https://coast.noaa.gov/slr/>). The data show the inland extent and relative depth of inundation from 0 to 6 feet above mean higher high water. Within the boundary of the Reservation, only the mouth of the Quinault River was modelled. See Figure 3-12 for predicted sea level rise of the Quinault Estuary. The figure demonstrates how a 3- or 6-foot rise in sea level would raise estuary elevations such that wetlands mapped by the Reservation model wetland inventory would become inundated. Wetlands are often associated with shallow water. As these wetlands become exposed to progressively deeper water, it is likely that they would transition from wetland to open water habitat. This trend has already been documented by the Coastal Change Analysis Program, which noted that the majority of wetland losses in Grays Harbor County between 1996 and 2010 were due the transition of wetland to open water (NOAA 2017).

AECOM reviewed the mid-range and high estimates of sea level rise and mapped these areas in relation to the Reservation modelled wetland inventory to provide a visual representation of sea level rise in relation to existing wetland areas. The sea level rise model data show areas that are hydrologically connected based on a digital elevation model created by NOAA using LiDAR (Light Detection and Ranging) remote sensing data that meet Federal Emergency Management Agency (FEMA) standards for flood mapping (0.6-foot root mean square error threshold).

The sea level rise model data also provide areas with a high potential for flooding in association with the relevant increase in sea level. Although limited in geography, the data show the large area of land that may be exposed to oceanic inundation that may occur with a 3- to 6-foot rise in sea level.

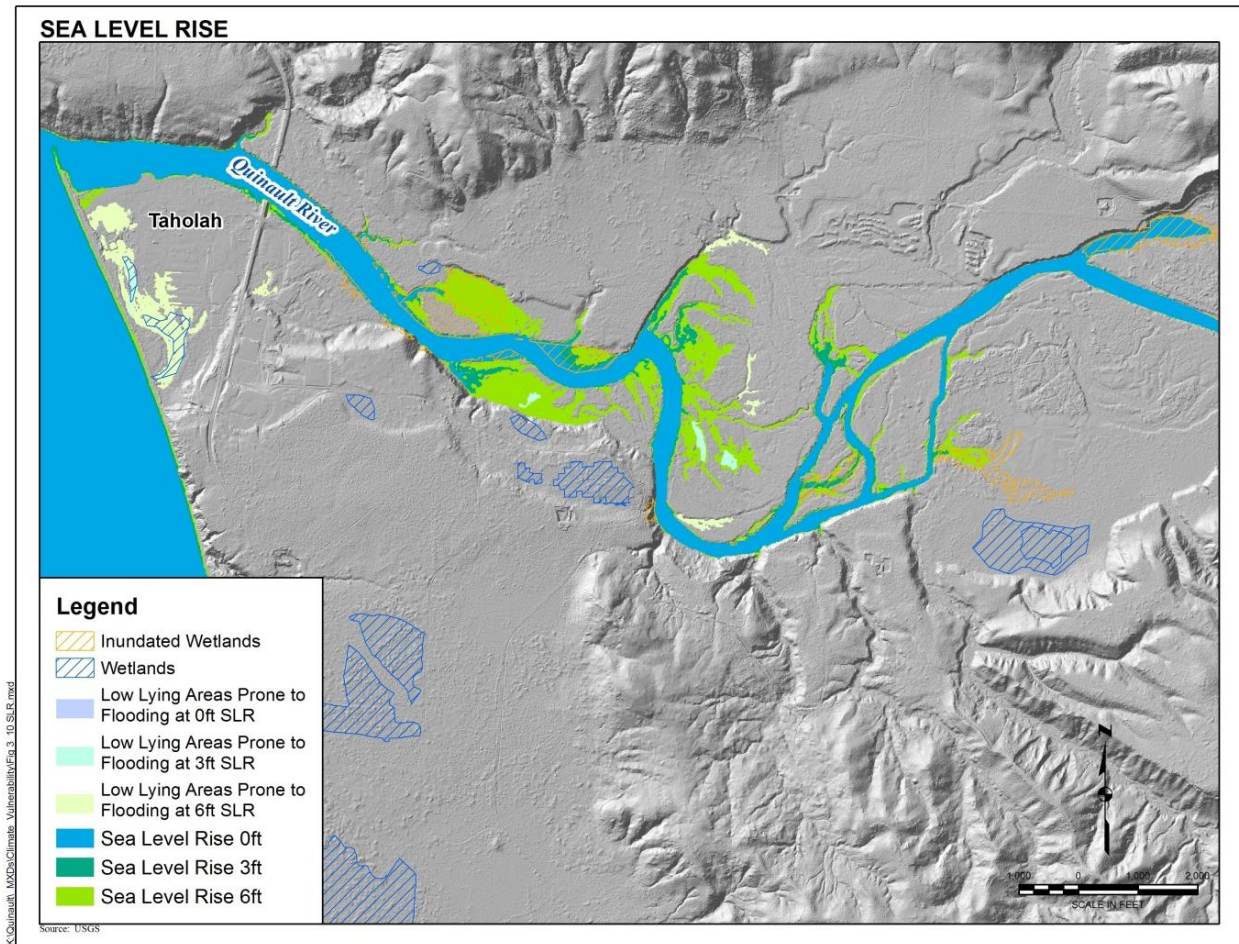


Figure 3-12. Predicted Sea Level Rise for Quinault River Estuary

4. WETLAND RESOURCES IN THE STUDY AREA

Abundant precipitation and geomorphic conditions have resulted in a relatively high proportion and diversity of wetlands on the Reservation (study area). The descriptions of the wetland resources provided below are based on the estimated wetland layer and verified stream layer that were prepared by AECOM for the QIN in 2015, as described in Section 5.1. Seven wetland asset classes were then chosen that make up the majority of the wetland area on the Reservation and best represent the diversity of wetland habitats across the landscape. It is estimated that these classes represent roughly 90 percent of the vegetated wetlands on the Reservation, as shown in Figure 4-1. The wetland asset classes are described in detail below.

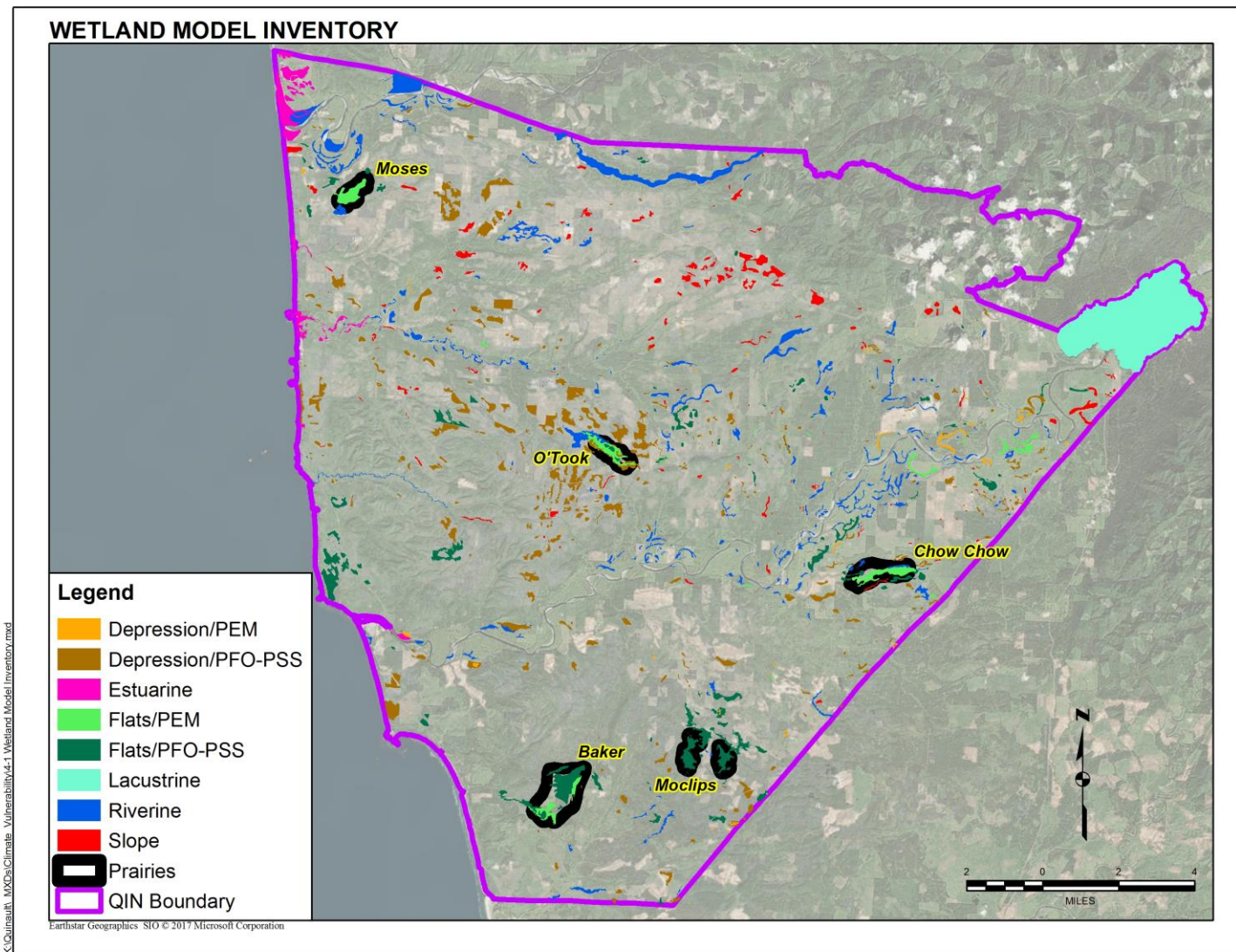


Figure 4-1. Wetland Model Inventory showing Wetland Asset Classes

4.1 Estuarine (Tidal Fringe or Surge Plain Wetland)

Estuarine wetlands are a type of fringe wetland that occurs at the margins of deep water systems. Surface water depth and movement is controlled by tidal flows. Estuarine wetlands provide important juvenile salmonid habitat that is of limited extent in the study area, confined mainly to the mouths of large river systems. These wetlands were observed along the tidally influenced portions of the Quinault (below river mile [RM] 3), Queets (below RM 5), and Raft Rivers.

Due to their limited extent, all vegetation types are included under this asset class. These wetlands include freshwater, brackish, and saltwater systems. Saltwater and brackish wetlands are generally dominated by emergent vegetation, especially Pacific silverweed (*Potentilla anserina* ssp. *pacifica*) and Lyngbye's sedge (*Carex lyngbyei*). Species richness is generally low due to salinity. These systems are frequently inundated during high tides.

Freshwater Estuarine wetlands, also known as surge plain wetlands, occur upstream of the salt wedge that forms in the major rivers. These wetlands include those inundated by freshwater during periods of high tides and high river flows, as well as infrequently flooded wetlands that have a shallow water table that fluctuates with tides.

Freshwater Estuarine wetlands include Scrub-Shrub and Forested classes. The Scrub-Shrub class is dominated by willow (*Salix* spp.), including Sitka willow (*Salix sitchensis*), Hooker willow (*Salix hookeriana*), and Pacific willow (*Salix lasiandra*). Dominant trees in the Forested class include red alder (*Alnus rubra*) and Sitka spruce (*Picea sitchensis*). The understory has a rich variety of woody and herbaceous species including salmonberry (*Rubus spectabilis*) and slough sedge (*Carex obnupta*).



Figure 4-2. Raft River Estuary



Figure 4-3. Queets River Estuary (Pacific silverweed)

4.2 Riverine, Forested/Scrub-Shrub (Floodplain Swamp)

Riverine wetlands occur in the active floodplains and riparian corridors associated with intermittent or perennial streams throughout the Reservation. The dominant sources of water are periodic overbank flooding and/or subsurface flow between the stream and the wetland (hyporheic flow). Surface runoff and groundwater discharge from valley sides may also contribute to hydrology. Movement of surface water is generally from the valley sides toward the stream channel, except during flood events. Where hyporheic flow is also present, there is also a vertical movement as the water table rises and falls.

Flooding is normally present at least once every 2 years in these systems, though there is no precise flood frequency. Soil stratification is a primary indicator of flooded sites. Other indicators include scour marks, drift lines, water marks, and sediment deposits on vegetation, and bent vegetation. Wetlands on stream terraces that are only infrequently flooded are more properly classified as Depressional. In headwater positions, these wetlands may transition into Slope or Depressional classes where distinct bed and bank morphology disappears. In the lower reaches of large rivers, Riverine wetlands may transition to the Estuarine class.

The duration of flooding varies greatly depending on the position in the floodplain. This class includes the flowthrough, impounding, and closed Riverine wetlands. The former do not retain flood waters significantly longer than the duration of the flood event (usually for several days). They are usually within or adjacent to the active stream channel. Impounding wetlands occur in backwater channels, oxbows, and swales; retain water significantly longer than the duration of flooding; and have a surface water outlet to a stream. Closed Riverine wetlands occur in depressions on the floodplain that lack an outlet and retain surface water the longest.



Figure 4-4. Upper Raft River



Figure 4-5. Queets River Side Channel



Figure 4-6. Quinault River Flowthrough Wetland with Willows and Alder



Figure 4-7. Quinault River Impounding wetland with Aquatic Bed, Emergent, Scrub-Shrub, and Forested Vegetation

Riverine wetlands are dynamic systems subject to erosion, sedimentation, and channel migration events that shape the vegetation. This class includes both Forested wetlands that occur on the more stable parts of the floodplain, and Scrub-Shrub wetlands.

Red alder is the dominant tree, with or without Sitka spruce, black cottonwood (*Populus balsamifera*), and western hemlock (*Tsuga heterophylla*). The understory can be quite rich and diverse. Common shrub species include salmonberry, stink current (*Ribes bracteosum*), vine maple (*Acer circinatum*), and devil's club (*Oplopanax horridus*). Common herbaceous species include slough sedge, skunk cabbage (*Lysichiton americanus*), lady fern (*Athyrium filix-femina*), Cooley's hedgenettle (*Stachys cooleyae*), youth-on-age (*Tolmiea menziesii*), and water parsley (*Oenanthe sarmentosa*).

Riverine Scrub-Shrub wetlands are most commonly dominated by mixed willow communities (Hookers, Sitka and Pacific willow). Other communities are dominated by stink currant, Douglas spirea (*Spiraea douglasii*), salmonberry, western crabapple (*Malus fusca*), black twinberry (*Lonicera involucrata*), and high-bush cranberry (*Viburnum edule*).

Aquatic bed vegetation [yellow pondlily (*Nuphar polysepala*) and floating-leaved pondweed (*Potamogeton natans*)] is present in deeply ponded backwater areas. A fringe of emergent vegetation is also usually present in these areas.

Closed and impounding Riverine wetlands can provide important short- and long-term storage of surface water, thereby moderating peak flood flows. They also maintain base flows in streams as surface and groundwater flows back to the streams. Impounding Riverine wetlands provide off-channel feeding and resting habitat for juvenile salmonids. Retained and detained flows contribute to nutrient cycling and the removal or transformation of dissolved elements including pollutants.

Riparian forests can provide important corridors for movement of plant and animal species. These woody communities also provide production and export of organic carbon, which is the base of the aquatic food chain; stabilization of stream banks and sediment; shading to regulate water temperature; and large woody debris that plays an important role in fish and amphibian habitat and stream channel morphology. Several plants with cultural uses by the Quinault peoples are found primarily or most abundantly in Riverine wetlands on the Reservation (Deur et al. 2017). These resources include numerous berries used for food; willows used for weaving, wood, and medicine; red alder and black cottonwood used for carving and building; and many others.

4.3 Flats, Forested/Scrub-Shrub (Coastal Swamp)

Flats generally occur on remnant lake beds and glacial outwash plains at elevations of 100 to 450 feet. Although small streams and ponds may be present, the dominant source of hydrology is direct precipitation. Soil and topographic conditions contribute to perched water tables that are hydrologically isolated from surrounding groundwater and surface water. Soils can be organic or mineral. Organic soils developed from sedges, mosses, and wood fibers can be over 8 feet deep. The depth of organic matter generally thins from the center to the edges of the Flats, where they transition to mineral Flats and then uplands. Organic Flats are often saturated much of the year. Mineral Flats generally dry out by June. In some landscapes, there are peat hummocks that are saturated and small depressions that are seasonally ponded.

Flats have been divided into dominantly Forested/Scrub-Shrub wetlands (described here) and wet prairies (described in Section 4.4). Dominant trees, where present, are shore pine (*Pinus contorta* var. *contorta*), western redcedar (*Thuja plicata*), and western hemlock. Trees can be quite dwarfed and scattered in very wet and acidic soils, usually becoming taller and denser toward the edges of the Flats. The shrub layer is dominated by plants in the *Ericaceae* family, which have thick, leathery leaves adapted to low nutrient sites. Common shrubs include salal (*Gaultheria shallon*), Labrador tea (*Rhododendron groenlandicum*), bog laurel (*Kalmia microphylla* var. *occidentalis*), fool's huckleberry (*Menziesia ferruginea*), bog blueberry (*Vaccinium uliginosum*), evergreen huckleberry (*Vaccinium ovatum*), bog cranberry (*Vaccinium oxycoccos*), and sweet gale (*Myrica gale*). Peat moss (*Sphagnum* spp.) and other mosses are abundant.



Figure 4-8. Flats Wetland with Shore Pine, Western Redcedar, and Labrador Tea



Figure 4-9. Flats Wetland with Labrador tea, Bog Laurel, and Sphagnum Moss

4.4 Flats, Emergent/Scrub-Shrub (Coastal Wet Prairie)

This class tends to be more prevalent on organic Flats than mineral Flats on the Reservation. They are seasonally to semi-permanently saturated, with areas of seasonal ponding. These wetlands correspond to the prairies that are unique to the Olympic Peninsula. All five named prairies on the Reservation (O'Took, Moses, Chow Chow, Baker, and Moclips) fall into this category. Many other smaller natural openings in the forest also fall within this class.

The interior of many Flats wetlands have small ponds that are semi-permanently to permanently inundated. Yellow pondlily commonly grows in these ponds. Seasonally ponded portions of the Flats are dominated by a variety of sedges, forbs, mosses, and low-growing shrubs. Common sedges include inflated sedge (*Carex utriculata*), pale sedge (*Carex livida*), water sedge (*Carex aquatilis*), and cottongrass (*Eriophorum chamissonis*). Common forbs include great burnet (*Sanguisorba officinalis*), deer cabbage (*Fauria crista-galli*), blue camas (*Camassia quamash*), and sundew (*Drosera rotundifolia*). Low-growing shrubs include bog laurel, Labrador tea, bog cranberry, bog blueberry, and sweet gale.

These Flat wetlands also contain two plant species that are endemic to the Olympic Peninsula and/or rare in Washington. Alaska plantain (*Plantago macrocarpa*) is only known from a small number of occurrences in Washington, with small number of individuals in each population. It is also rare in Oregon. It grows on lakeshores, wetlands, bogs, and seasonally flooded sites near the coast (Camp and Gamon 2011). It has been observed on Moses Prairie. Thompson's wandering daisy (*Erigeron peregrinus* var. *thompsonii*) is an endemic to the Olympic Peninsula. Its habitat is moist sphagnum bogs and swamps with peaty, organic soil. This species has been observed on several of the named prairies on the Reservation. It is the only endemic taxon of the Olympic Peninsula that grows exclusively at lower elevations (Camp and Gamon 2011).



Figure 4-10. O'Took Prairie Aerial View (©Larry Workman)



Figure 4-11. Flats Emergent Wetland with Sedges and Burnet

Coastal wet prairies are unique wetlands in Western Washington and of special cultural significance for the QIN. Historically, encroachment of trees in the prairies was reduced by periodic burning (Deur et al. 2017). Low-intensity fires favored the growth of culturally important plants such as Labrador (Indian) tea, bog blueberry, bog cranberry, beargrass (*Xerophyllum tenax*), and camas. Burning also maintained habitat for Roosevelt elk (*Cervus canadensis roosevelti*), which are attracted to the new growth of herbaceous plants following fires.



Figure 4-12. Cottongrass in O'Took Prairie (©Larry Workman)



Figure 4-13. Sundew Growing in a Wet Prairie

The wet prairies sustain a high diversity of native plants and animals. Some of these species are confined to the unique soil and hydrologic conditions that are found in these sites. A wide variety of mammals, birds, and amphibians make use of these areas during at least part of their life cycles. The water quality and hydrologic functions of Flats wetlands are less well studied. Studies of other bog and acidic fen systems in Western Washington (Kulzer et al. 2001) may be applicable. Flats wetlands are expected to have a high potential to improve water quality based on the prevalence of either organic soils or mineral soils with high organic matter and/or clay



Figure 4-14. Low Shrubs and Sedges in O'Took Prairie (©Larry Workman)



Figure 4-15. Beaver Lodge in O'Took Prairie (©Larry Workman)

content. At the same time, plant species adapted to acidic Flats wetlands are sensitive to inputs of nutrients, which can elevate the low base status of these systems. Organic Flats especially are expected to hold a tremendous amount of water that may ameliorate downstream flooding and maintain stream base flows. They also store large amounts of organic carbon.

4.5 Depressional, Forested/Scrub-Shrub (Basin Swamp)

These wetlands occur in topographic depressions with surface runoff as the dominant source of hydrology. On the Reservation, these wetlands are scattered throughout the study area, but occur mainly on 1) alpine glacial till plains lacking well developed drainage; 2) glacial outwash plains underlain by slowly permeable lake bed sediments; and 3) low spots on alluvial terraces above the active floodplain.

These wetlands are generally seasonally ponded in the interior and seasonally saturated on the periphery, although there can be a wide range of water regimes depending on topography and whether or not an outlet is present. A stream channel is present in some Depressional wetlands, but overbank flooding is not a significant source of hydrology (unlike Riverine wetlands). Groundwater discharge is also a source of hydrology in some Depressional wetlands, but unlike in Slope wetlands, there is at least some storage of surface water at some time of the year.

Forested wetlands in this class contain both coniferous and deciduous communities. The dominant conifers are western redcedar, western hemlock, and Sitka spruce. These wetlands tend to have a large amount of microtopography due to windthrow and downed wood. The conifers tend to be rooted on raised hummocks or on nurse logs. This is also true of traditionally upland understory species such as salal, sword fern (*Polystichum munitum*), bunchberry (*Cornus canadensis*), evergreen huckleberry, false huckleberry, and red huckleberry (*Vaccinium parvifolium*). Other common shrubs include salmonberry, vine maple, and cascara (*Frangula purshiana*). Common herbaceous species include skunk cabbage, slough sedge, lady fern, deer fern, bracken fern, and false lily-of-the-valley.



Figure 4-16. Cedar-Hemlock / Salal Community



Figure 4-17. Skunk Cabbage in Low Spots

Deciduous wetland forest communities are dominated by red alder, black cottonwood, Scouler's willow (*Salix scouleriana*), and western crabapple, with lesser amounts of conifers. Red-osier dogwood (*Cornus sericea*), salmonberry, stink currant, vine maple, black twinberry, and high-bush cranberry are the common shrubs. The herbaceous layer includes skunk cabbage, slough sedge, lady fern, false lily-of-the-valley, sword fern, water parsley, deer fern, and redwood sorrel (*Oxalis oregana*).

Douglas spirea thickets occur in Depressional wetlands with a highly fluctuating water table and inundation regime.

4.6 Depressional, Emergent/Aquatic Bed (Basin Marsh)

In semi-permanently to permanently ponded depressions, the vegetation is dominated by floating-leaved species such as yellow pondlily and pondweed. Open water is present in some of the deeper ponds, where water depths of around 6 feet have been observed during the dry season (pers. comm. G. Eide, December 21, 2017). Seasonally ponded wetlands are generally dominated by emergent species including slough sedge, water sedge, big inflated sedge (*Carex exsiccata*), and inflated sedge. Depressions with highly fluctuating surface water levels tend to be dominated

by dense stands of common cattail (*Typha latifolia*). This class has been observed on the Reservation near road crossings with blocked or elevated culverts.

Depressional wetlands often provide the best water quality improvement and flood attenuation functions due to their potential to store surface water. Sediment in surface runoff falls out in the water column. Dissolved nutrients and pollutants are physically or biologically fixed or transformed. Open depressions that discharge to a stream channel also provide base flow maintenance. In some landforms, these wetlands also have the potential to seasonally recharge groundwater aquifers.

Habitat functions vary widely. Many of the plant species are not unique. However, many of these wetlands provide important breeding habitat for amphibians and turtles, including sensitive species such as the western toad (*Anaxyrus boreas*). Resident fish also make use of some of the ponded wetlands associated with streams. Waterfowl feed and rest in some of the ponds.



Figure 4-19. Seasonally Ponded Depression with Sedge (Foreground) and Douglas Spirea (Background)



Figure 4-18. Yellow Pondlily Surrounded by Sedges and Rushes

4.7 Slope, Forested (Seepage Swamp)

These wetlands occur on hill or valley slopes with steep to gentle gradients. Most of the slope wetlands are in the northern part of the study area, known locally as the “North Boundary Area,” and are commonly associated with the headwaters of streams, foot slope and toe slope positions, and compact glacial till soils. Dominant hydrology is from groundwater seepage. The water regimes can vary greatly depending on the groundwater source. Some Slope wetlands remain saturated throughout most of the year, as evidenced by deep organic soils.

Water moves perpendicular to the topographic contour lines and does not pond except in very small depressions on the slope. Small seepage channels may be present on the slope, but water flow is in one direction (downslope) as opposed to Riverine wetlands with overbank flooding.

This class is overwhelmingly dominated by coniferous forest vegetation. Western redcedar and western hemlock are the dominant trees. Western white pine (*Pinus monticola*) is occasionally present. Understory shrubs include salal, Labrador tea, evergreen huckleberry, false huckleberry, red huckleberry, and bunchberry. The herbaceous layer includes skunk cabbage, deer fern, lady fern, slough sedge, and bracken fern.

These wetlands generally provide limited flood attenuation or water quality improvement compared to other wetlands that store surface water. However, Slope wetlands in headwater positions often provide the primary support for stream base flows. Slope wetlands that are saturated nearly year-round provide important refugia when other habitats are dry in the late summer and early fall. This is of particular importance for some frogs and salamanders.

5. METHODS

Climate vulnerability is defined by the exposure of a given species, resource, area, or system to climate changes, the sensitivity or response to such climate changes, and the adaptive capacity or inherent safeguards or coping mechanisms (Glick et al. 2011). AECOM conducted a climate vulnerability assessment of the exposure, sensitivity, and adaptive capacity of wetland habitat types to climate change variables with the Reservation wetlands. Vulnerability can be described as:

$$\text{Vulnerability} = \text{Exposure} + \text{Sensitivity} - \text{Adaptive Capacity}$$

Definitions of vulnerability, exposure, sensitivity, and adaptive capacity, in relation to natural resource climate vulnerability assessments, as defined by Dawson et al. (2011) and adopted in the Treaty of Olympia Tribes CCVA (Dalton et al. 2016), are provided below.

Vulnerability “is the extent to which a species or population is threatened with decline, reduced fitness, genetic loss, or extinction owing to climate change.”

Exposure “refers to the extent of climate change likely to be experienced by a species or locale. Exposure depends on the rate and magnitude of climate change (temperature, precipitation, sea level rise, flood frequency, and other hazards) in habitats and regions occupied by the species. Most assessments of future exposure to climate change are based on scenario projections from GCMs often downscaled with regional models and applied in niche models.”

Sensitivity “is the degree to which the survival, persistence, fitness, performance, or regeneration of a species or population is dependent on the prevailing climate, particularly on climate variables that are likely to undergo change in the near future. More sensitive species are likely to show greater reductions in survival or fecundity with smaller changes to climate variables. Sensitivity depends on a variety of factors, including ecophysiology (biological discipline that studies the adaptation of an organism's physiology to environmental conditions), life history, and microhabitat preferences. These can be assessed by empirical, observational, and modeling studies.”

Adaptive capacity “refers to the capacity of a species or constituent populations to cope with climate change by persisting in situ, by shifting to more suitable local microhabitats, or by migrating to more suitable regions. Adaptive capacity depends on a variety of intrinsic factors, including phenotypic plasticity (refers to the changes in an organism's behavior, morphology and physiology due to its adaption to a unique environment), genetic diversity, evolutionary rates, life history traits, and dispersal and colonization ability. Like sensitivity, these can be assessed by empirical, observational, and modeling studies.”

For the purposes of this report, *adaptive capacity is further defined as a two-part component*, the first being the *inherent natural adaptive capacity* as defined by Dawson et al. (2011) above, and the second being the *policy adaptive capacity*, which refers to the resource management of the natural system by humans. Human land use management and practice, such as the usage of

herbicide, supplemental watering of vegetation, and fire fuels management are all examples of this second part of adaptive capacity.

In a CCVA, assets are assessed for their particular vulnerability to a specific climate variable. In this assessment, the assets being assessed are defined as wetland habitat types. The assets and climate variables used in this report are defined below.

Assets: Wetland habitat types occurring on the Reservation, classified by Cowardin and HGM classes, as described in detail in Section 4.

Climate variable: The climate variables assessed are discussed in Section 3.0 and include temperature, precipitation, storms and riverine flooding, snowpack, wildfire, and sea level rise.

Figure 5-1 below demonstrates the climate vulnerability assessment process for a particular asset (in this case, flooding).

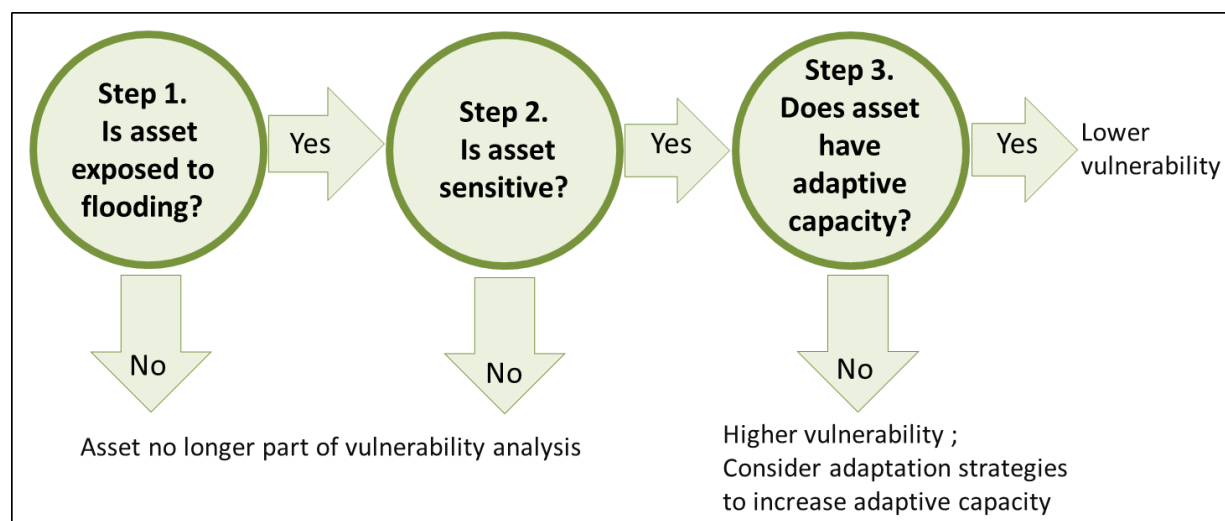


Figure 5-1. Climate Vulnerability Assessment Process

5.1 Wetland Assets and Mapping

In order to determine the wetland assets on the Reservation, AECOM utilized the estimated wetland layer and verified stream layer that were prepared for the QIN (AECOM 2015a, 2015b). The estimated wetland layer provides an improvement upon the accuracy and precision of the NWI produced by the U.S. Fish and Wildlife Service (USFWS) and the Coastal Change Atlas (wetlands) prepared by NOAA (2017). The estimated wetland layer was created by using recently available LiDAR and other Geographic Information System (GIS) spatial data to develop a Wetland Suitability Index (WSI) model. The model was used to classify and map wetlands on the Reservation by stacking various data layers that predict wetland presence, such as hydric soils, and selecting those areas where there are many high-probability layers stacked together. The relative accuracy of the WSI results was estimated by conducting limited field verification, and the model results were partially refined through ortho-rectification based on the verification study.

The WSI model output resulted in mapped polygons with a range of scores indicating low to high probability of being wetland. Wetlands described in this report are based solely on the “high probability” polygons and therefore represent a conservative estimate of the total extent of wetlands on the Reservation (AECOM 2015a; Eide 2017).

The estimated wetland layer relies primarily on the wetland classification system developed by the USFWS (Cowardin et al. 1979). All wetlands were classified to the class or subclass level. Water regimes and special modifiers are provided for some wetlands. It is important to note that the NWI classification system includes numerous aquatic habitats that lack vascular plants and soils, and therefore do not meet the technical definition of “wetlands” used by the U.S. Army Corps of Engineers (USACE 1987; 2010). Only vegetated wetlands will be analyzed for the current study.

Per the NWI system, most vegetated wetlands in Western Washington are placed in the Palustrine system, regardless of different geomorphic or hydrologic settings. Classes within the Palustrine system are based on the growth forms of the dominant vegetation. As a result, the NWI classes are not very useful by themselves for assigning wetland asset classes for climate change vulnerability analysis.

Some of the wetlands in the estimated wetland layer were also attributed with the HGM classification (Brinson 1993, as modified by Hruby 2014). This system classifies wetlands based on water source and transport vector; geomorphic setting; and hydrodynamics. During the initial review of the wetland data for the current study, it was determined that wetland asset classes would best be assigned based on a combination of the HGM and NWI classification. A robust analysis of a wetland’s vulnerability to climate change requires information on the dominant hydrology sources and dynamics (ecosystem processes), as well as vegetation structure.

The remaining wetland polygons from the estimated wetland layer were attributed with an HGM class by utilizing relevant GIS spatial data. The only major HGM class that is not included in this assessment is Lacustrine Fringe wetlands. Similar to the Estuarine class, these wetlands occur at the margins of deep water systems. Surface water movement is also bidirectional, in this case due to seiche (typically caused when strong winds and rapid changes in atmospheric pressure push water from one end of a body of water to the other), wind, or seasonal water fluctuations. No Lacustrine Fringe vegetated wetlands were identified in the estimated wetland layer, although there are a few surrounding Lake Quinault. Ponds in the study area do not appear to meet the Lacustrine Fringe minimum size threshold of 20 acres, so any wetlands associated with the ponds are classified as Depressional. Although most of the shoreline of Lake Quinault is sloping and lacks wetland vegetation, some narrow Lacustrine Fringe wetlands have been identified and are briefly discussed in Section 6.7.

5.2 Exposure

The exposure analysis evaluates an asset’s susceptibility to climate variables. In this assessment, each asset was assessed for its susceptibility to each climate variable independently. The

exposure analysis identifies the ecosystem asset (e.g., Estuarine wetlands) with exposure to projected changes in climate variables.

A GIS-based data analysis was conducted to determine exposure. A wetland habitat map was created using the Cowardin and HGM classification systems, as described in Section 5.1. Where high resolution climate change data were available (e.g., sea level rise), exposure maps were overlain onto wetland areas to determine overlap between wetland type and sensitivity.

For climate variables relating to surface water effects, such as sea level rise and riverine flooding, exposure is defined as the inundation of water and is therefore a binary metric. For these variables, mapping can more specifically target the locations where exposure is projected to occur. For climate variables relating to direct atmospheric conditions, such as air temperature and precipitation, exposure is more difficult to quantify by asset type, because the entire surface will be impacted, and the degree of detail and uncertainty in the models make it more difficult to isolate specific assets within the broader regional context. For an illustration of this, compare the large pixel quilt of temperature displayed in Figure 3-3 with the specifically isolated areas of sea level rise on the Quinault River displayed in Figure 3-12.

5.3 Sensitivity

The sensitivity analysis evaluates the degree to which the asset is affected by exposure to a particular climate variable. For example, a freshwater wetland habitat is more sensitive to sea level rise than a saltwater wetland habitat because of potential saltwater intrusion into the freshwater wetland. For this assessment, sensitivity factors were selected based on the primary ecosystem functions normally attributed to wetlands (Hruby 2014; Adamus 2001).

For each asset, sensitivity was qualitatively assessed based on the natural history of each wetland type and wetland-dependent species, according to the professional knowledge and experience of wetland scientists familiar with the Reservation. To determine whether a wetland asset is sensitive, each was assessed under three subcomponents:

- **Vegetative Community:** The dominant and common growth forms, habitat types, and plant species that are representative of each wetland asset class.
- **Fish and Wildlife Habitat:** Permanent or seasonal habitat provided by elements of the wetland asset classes for anadromous and resident fish and wetland-dependent wildlife such as waterfowl and some amphibians and reptiles.
- **Water Quality and Hydrology:** Structures and processes within the wetland asset classes that improve water quality and hydrologic function, such as thermoregulation of the water column from tree canopies and maintenance of beneficial stream/sediment dynamics through inputs of large woody debris and shoreline stabilization.

Each wetland asset subcomponent was assessed and scored on a scale of 1 to 3 for sensitivity. The scoring method includes the following categories: no impact (0), low impact (1-3), moderate impact (4-6), and high impact (7-9). The scores were then summated into a total wetland habitat sensitivity score. Wetland habitats that score a moderate or higher score were further assessed for

their exposure and adaptive capacity. Sensitivity is defined as shown in Table 5-1. Results are shown in Table 6-1 in Section 6.

Table 5-1. Sensitivity Analysis, Scale, and Definitions

	None - <i>No impact to asset function</i>	Low - <i>Asset still functional</i>	Medium - <i>Asset function compromised</i>	High - <i>Asset no longer functional</i>
Wetland Assets and Subassets	Negligible or no change to ecosystem function	Short term, minor but reversible interruption to ecosystem function	Significant but not permanent loss of ecosystem function	Widespread and permanent loss of ecosystem function.

5.4 Adaptive Capacity

The adaptive capacity analysis evaluated the asset's inherent ability to adjust to each climate variable in order to maintain its primary function. For natural ecosystems, adaptive capacity can be divided into natural adaptive capacity, which is the inherent ability or resiliency of a particular habitat to respond to climate variables, and policy adaptive capacity, which are policies and measures in place to protect that habitat. For each asset, adaptive capacity was assessed qualitatively based on a set of considerations unique to each asset category. Adaptive capacity was assessed based on the natural history of each wetland type, using the expert knowledge of wetland scientists. For the policy/natural resource management component of adaptive capacity, expert opinion was provided by Greg Eide with the QIN (pers. comm. G. Eide, October 24, 2017, and December 21, 2017).

5.5 Climate Data

To expand upon the predictive climate data available from the Treaty of Olympia Tribes CCVA (Dalton et al. 2016), readily available climate data were obtained through online sources. To ensure that AECOM was using the most current available data, a conference call was held with Dr. Michael Case, a climate research scientist at the University of Washington (October 18, 2017). Dr. Case confirmed that the study plan proposed by AECOM was consistent with the methods used by the Pacific Northwest Climate Vulnerability Assessment Project (VAP), which was a collaborative, multi-agency effort to provide resource managers and decision makers with basic and important information about how species and ecological systems will likely respond to climate change. The VAP did not look specifically at wetlands, but it did use a similar structure for assessing various other habitat vulnerabilities to climate change. Based on that conversation and other online searches, AECOM identified and incorporated the following climate prediction data into this report.

NOAA Sea Level Rise

As described in Section 3.6 above, NOAA has modelled and mapped inundation areas and associated flood-prone "low-lying" areas that may occur based on each foot of anticipated sea level rise (2017). Because estimates are currently variable (less than 1 foot to 56 inches), middle

and high sea level rise scenarios were mapped for visualization purposes. This visualization demonstrates the potential for sea level rise to inundate existing wetlands to a degree that would result in a process of marsh migration. Marsh migration occurs when water levels rise to a height that is too deep for wetland vegetation to survive and, as a result, the area transitions to open sea water. Upland terraces existing in the floodplain may become wetland as groundwater rises in response to sea level rise. Thus the marsh areas migrate to higher terraces. Where existing wetlands are bordered by valley walls, there is nowhere for the marsh to migrate, which results in a loss of wetland habitat. NOAA data were used to review the sensitivity, vulnerability, and adaptive management capacity of Riverine and Estuarine wetlands to sea level rise.

Integrated Scenarios Climate Data

The Integrated Scenarios website (NWCSC et al. 2017) contains current Pacific Northwest climate change simulation data that are freely available for download. It includes simulated changes to hydrology and vegetation in response to predicted climate change. The model data available from Integrated Scenarios includes several visual layers created from a variety of models. In relation to wetland vulnerability, estimates of snow water equivalent and soil moisture change were determined to be most helpful in considering climate vulnerability for wetlands. Changes in estimated snow water equivalent and soil moisture were created using the Variable Infiltration Capacity (VIC) model (Liang et al. 1994). This model is a large-scale, semi-distributed hydrologic model that simulates the hydrology in land-surface processes by incorporating variable vegetation, soil types and topography. The VIC data is provided on a 1/16-degree (~6 km) grid for snow water equivalent and soil moisture during the months of November through May. Because the anticipated climate changes will result in lower summer precipitation and higher summer temperatures, the May timeframe was selected to evaluate predicted changes in both snow water equivalent and soil moisture. These data were evaluated in relation to wetlands that depend on snowmelt (Riverine) and groundwater (Flats) to help assess vulnerability.

USGS Regional Climate Models (Precipitation and Temperature)

The USGS completed an array of high-resolution simulations for present and future climate in the Western U.S. General circulation models were run over a 15 km grid for the present and recent past period, as well as for each decade throughout the current century. The predictive models were found to accurately predict current conditions, thus their future prediction capabilities are estimated to be high but the input data may be very different depending on population, technology, and economic scenarios (Hostetler et al. 2011).

Stakeholder Concerns

A kick-off meeting was held on August 25, 2017. At this meeting, the AECOM team discussed wetland-associated species/habitats and other factors that would be of particular interest to QIN members. This assessment addresses wet prairies, camas habitat, fire regimes, elk habitat, and salmon habitat/water quality.

6. RESULTS

This section describes the results of the climate vulnerability assessment. Assets determined to have high vulnerability include Estuarine; Riverine; Flats, Emergent Scrub-Shrub; and Flats, Forested Scrub-Shrub. Assets scoring as having high vulnerability are further discussed in management implications for how adaptive management could potentially decrease the vulnerability rankings of these to a lower score, thereby reducing the climate vulnerability of these wetland types.

6.1 Sensitivity Matrix

The matrix shown in Table 6-1 illustrates the results of the exposure and sensitivity analysis, broken down by climate variables in the columns and wetland assets and subassets in the rows. All wetland assets were scored as “Low,” “Moderate,” or “High” for a particular climate variable. If an asset scored as “None,” that particular asset was determined to not be exposed to that particular climate variable. A wetland’s natural adaptive capacity is inherently tied to its sensitivity to a particular climate variable. As such, natural adaptive capacity is included in this sensitivity assessment.

For adaptive capacity related to resource management and policy, the QIN has begun to take steps towards reducing the climate vulnerability of wetlands through the following:

- **Wetland Program Plan (WPP)** (QIN 2016). The WPP facilitates collaboration to preserve and enhance wetland structure, function, and cultural significance through the development of several documents, including a Climate Change Adaptation Plan.
- **Tribal Code Title 48 Land Use and Development.** Title 48 discusses Fish Sensitive Areas and Sensitive Areas Chapters.
- **Tribal Code Title 61 Natural Resource Management.** As part of Title 61, a Hydraulic Project Approval (HPA) must be completed for any natural resource practice that takes place within 200 feet of a waterbody.
- **Forest Management Plan (FMP).** As part of the FMP review process protection for wetlands and streams have been identified.

While these policy efforts take important preliminary steps toward reducing the vulnerability of wetlands on the Reservation, they are limited in their implementation to successfully protect discrete wetlands that may be vulnerable to climate change (pers. comm. G. Eide, October 24, 2017, and December 21, 2017). As a result, no procedures or policies were immediately identified that would reduce the sensitivity scoring down a category. Therefore, assets scoring with high sensitivity were determined to have high vulnerability. These assets include the following:

- Estuarine – high vulnerability to sea level rise
- Riverine – high vulnerability to changes in snowpack

- Flats, Emergent/Scrub-Shrub – high vulnerability to changes in precipitation
- Flats, Forested/Scrub-Shrub – high vulnerability to changes in wildfire regime

Table 6-1. Sensitivity Matrix

 Quinault Wetlands Sensitivity Analysis													
Wetland Assets	Subhabitat Value Assets		Air Temperature		Precipitation		Storm Events - Riverine Flooding, Storm Surge		Snowpack		Wildfire		Sea Level Rise
ESTUARINE - Tidal Fringe or Surge Plain Wetland	<i>Vegetative Community</i>	1	LOW	1	LOW	2	MODERATE	1	LOW	1	LOW	3	HIGH
	<i>Fish and Wildlife Habitat</i>	1		1		2		1		1		3	
	<i>Water Quality and Hydrology</i>	1		1		2		1		1		3	
RIVERINE, FORESTED/SCRUB-SHRUB - Floodplain Swamp	<i>Vegetative Community</i>	1	MODERATE	1	LOW	2	MODERATE	2	HIGH	1	LOW	2	MODERATE
	<i>Fish and Wildlife Habitat</i>	2		1		2		3		1		2	
	<i>Water Quality and Hydrology</i>	2		1		2		2		1		2	
FLATS, EMERGENT/SCRUB- SHRUB - Coastal Wet Prairie	<i>Vegetative Community</i>	3	MODERATE	3	HIGH	1	LOW	0	NONE	2	MODERATE	0	NONE
	<i>Fish and Wildlife Habitat</i>	1		2		1		0		2		0	
	<i>Water Quality and Hydrology</i>	2		2		1		0		2		0	
FLATS, FORESTED/SCRUB- SHRUB - Coastal Swamp	<i>Vegetative Community</i>	2	MODERATE	2	MODERATE	1	LOW	0	NONE	3	HIGH	0	NONE
	<i>Fish and Wildlife Habitat</i>	1		2		1		0		3		0	
	<i>Water Quality and Hydrology</i>	2		1		1		0		3		0	

Quinault Wetlands Sensitivity Analysis													
Wetland Assets	Subhabitat Value Assets	Air Temperature		Precipitation		Storm Events - Riverine Flooding, Storm Surge		Snowpack		Wildfire		Sea Level Rise	
DEPRESSIONAL, FORESTED/SCRUB-SHRUB - Basin Swamp	Vegetative Community	1	MODERATE	2	MODERATE	1	LOW	0	NONE	2	MODERATE	0	NONE
	Fish and Wildlife Habitat	2		1		1		0		2		0	
	Water Quality and Hydrology	1		1		1		0		2		0	
DEPRESSIONAL, EMERGENT/AQUATIC BED - Basin Marsh	Vegetative Community	1	MODERATE	1	MODERATE	1	LOW	0	NONE	1	LOW	0	NONE
	Fish and Wildlife Habitat	2		2		1		0		1		0	
	Water Quality and Hydrology	2		1		1		0		1		0	
SLOPE FORESTED - Seepage Swamp	Vegetative Community	1	LOW	1	LOW	1	LOW	0	NONE	2	MODERATE	0	NONE
	Fish and Wildlife Habitat	1		1		1		0		2		0	
	Water Quality and Hydrology	1		1		1		0		2		0	

6.2 Estuarine (Tidal Fringe or Surge Plain Wetland)

Estuarine wetlands occur along the Pacific coastline, Puget Sound, and in the lower Columbia River in Western Washington. On the Reservation, these wetlands were observed along the tidally influenced portions of the Quinault (below RM 3), Queets (below RM 5), and Raft Rivers. In the study area, Estuarine wetlands include Tidal Fringe or Surge Plain wetland habitats. This class of wetlands has been most frequently studied due to the projected effects of sea level rise. Assessments of climate change vulnerability specific to this class are known for Western Washington (Thorne et al. 2015). Estuarine wetlands in the Stillaguamish watershed of Western Washington were rated moderate to high for vulnerability to climate change (Krosby et al. 2016). Modelled Estuarine wetlands are depicted on Figure 6-1.

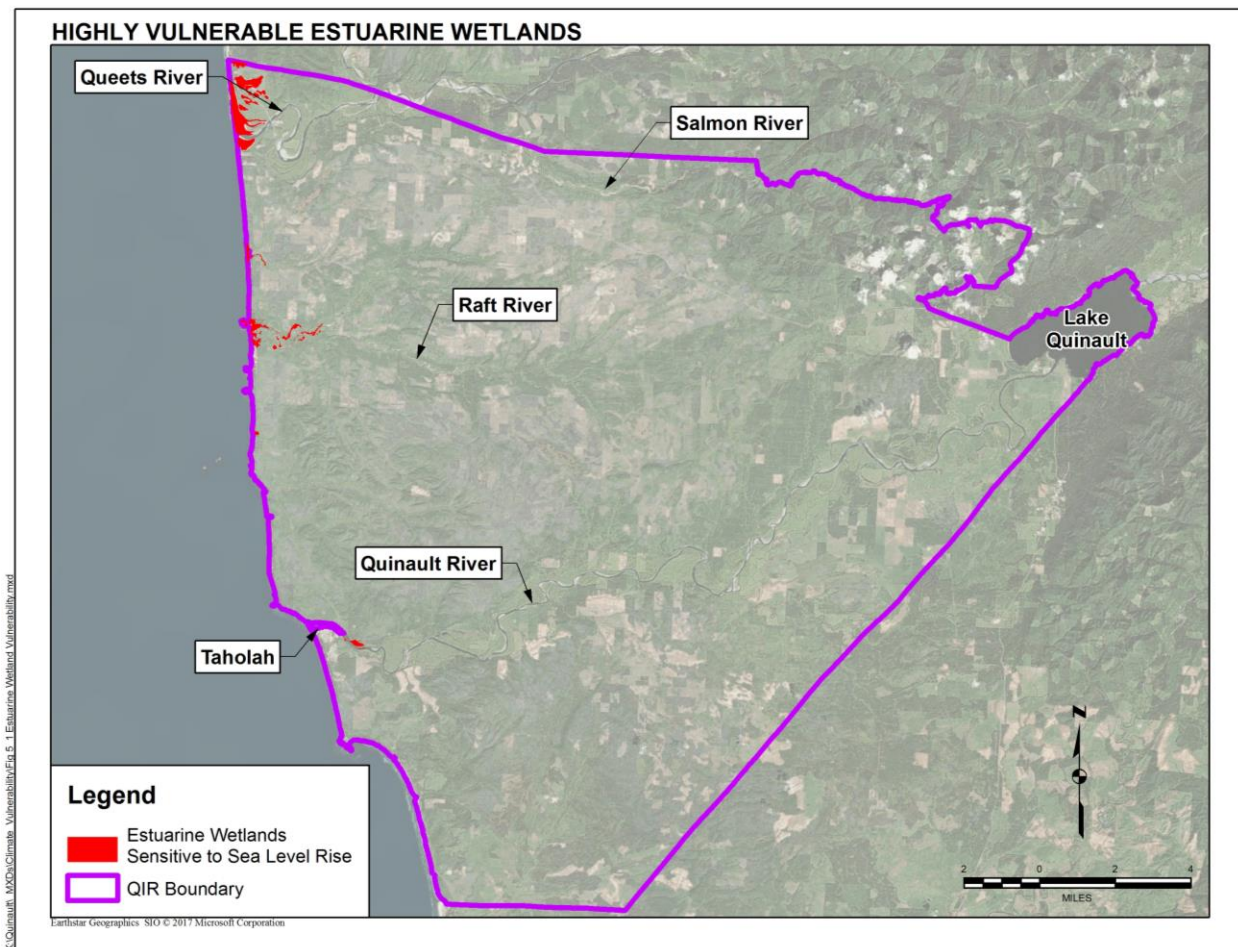


Figure 6-1. Modelled Estuarine Wetlands.

Air Temperature

Estuarine wetlands were rated low for vulnerability to changes in air temperature. Tidal waters will be subject to warming, which could reduce oxygen availability and alter the distribution of fish species. Impacts are buffered by the large inputs of freshwater in the study area.

Precipitation

Estuarine wetlands were rated low for vulnerability to changes in precipitation. These wetlands are driven primarily by tidal exchange and river flows.

Riverine Flooding and Tidal Storm Surges

Estuarine wetlands were rated moderate for vulnerability to riverine flooding and tidal storm surges. The potential effects of increased riverine flooding are more fully assessed for the Riverine wetlands.

Vegetative Community

Under various climate change scenarios, riverine flooding and tidal storm surges are projected to become more frequent and more intense in the Pacific Northwest. This will create the potential for increased bank instability and erosion, as well as scouring of wetland vegetation. In addition, flood events can bury wetlands with sediment and woody debris.

Fish and Wildlife Habitat and Water Quality

High sediment loads and turbidity in the water column adversely impact fish and wildlife habitat. Water quality is expected to be adversely impacted by the increase of erosive flows throughout the watersheds, the increase in sediment loads, and the increase in turbidity. The influence of the tides would help ameliorate some of these effects by flushing out debris and sediment.

Snowpack

Snowpack can be an important component for the hydrology of some wetland types, especially during drought months. Estuarine wetlands were rated low for vulnerability to changes in snowpack. These wetlands most often occur at the mouths of the major rivers on the Reservation. Flow in these rivers can be dependent on snowmelt during part of the year. However, tidal exchange mutes the potential effects from the changes in snowpack. Tidal influence is anticipated to maintain the hydrology of the wetlands. In addition, sea level rise (discussed in Section 6.2.6) will likely be the more crucial factor in changes to hydrology (and therefore vegetation and fish and wildlife habitat) of Estuarine wetlands.

Wildfire

Estuarine wetlands were rated low for vulnerability to changes in wildfire regime. These wetland types are generally not subject to fires due to daily inundation and/or saturation.

Sea Level Rise

Estuarine wetlands were rated high for vulnerability to sea level rise. Mid and late-century projections for sea level rise along the Washington coast range from -3.9 inches to 19.7 inches, and 4 to 56 inches, respectively. There is a high degree of uncertainty in sea level rise projections for the study area due to regional differences including uplift through glacial isostatic adjustment and tectonics (Dalton et al. 2016). Sea level rise will exacerbate the impacts of coastal flooding,

wave energy, storm surge, and erosion, with a corresponding loss or migrations of coastal habitats, including Estuarine wetlands (Whitely Binder et al. 2017).

Vegetative Community

Estuarine wetlands include both saltwater and freshwater systems. Vegetation communities in both are highly correlated to tidal elevations, sediment dynamics, and the wind wave and storm surge environments in which they exist. Vegetation types tend to be highly stratified based on frequency and depth of tidal inundation, salinity gradients, and inputs of freshwater. Tidal marshes can be resilient in response to changing environments, retreating or migrating to higher elevations as sea levels rise or sediments erode, or colonizing mud flats as sea levels drop or sediments accrete.

At the lower end of sea level rise projections, tidal marshes in the study area are expected to adapt to slowly changing conditions where they are able to migrate upslope. At the higher end of projections, the degree of tidal inundation, the speed of change, and the inherent topography of the coast may prevent tidal marshes from fully adapting to higher sea levels. The coastal landforms in the study area are dominated by steep bluffs, which prevent upslope migration of tidal marsh. Drowned marshes would transition to tidal flats or subtidal habitats without vascular plants. The initial effects of sea level rise on vegetation may be somewhat offset where there is a corresponding increase in sedimentation (WDFW and NWF 2011a; Thorne et al. 2015; Kirwan et al. 2010).

Under projected sea level rise, a significant proportion of freshwater and brackish Estuarine wetlands would likely be converted to either salt marsh or tidal flats (Mauger et al. 2015). These wetlands occur in the lower reaches of the main rivers on the Reservation. They would also be subject to many of the changes identified for Riverine wetlands. Important changes for vegetation include the volume and timing of freshwater flows, and nutrient and sediment loading.

Fish and Wildlife Habitat

Shifts and losses in Estuarine wetlands are expected to have a negative effect on fish habitat. Tidal marsh provides important rearing and migration habitat for juvenile salmonids. This habitat is already limited along the Washington coast due to shoreline development and will become increasingly scarce. The impacts could be exacerbated by seasonal increases in water temperatures. Other fish, shellfish, and populations of wintering waterfowl also depend heavily on Estuarine wetlands and could be negatively impacted by a loss or reduction in these habitats.

Water Quality

Salinity is expected to increase with sea level rise. Salinity in summer will likely increase the most due to lower projected base stream flows and higher evapotranspiration rates.

6.3 Riverine, Forested/Scrub-Shrub (Floodplain Swamp)

The Riverine class of wetlands is fairly common in Western Washington. They are most commonly found within floodplain terraces along rivers and creeks where semi-annual flooding is common. Their water source comes from a combination of groundwater and floodwater from associated streams. Due to their strong hydrologic association with waterways, they are most susceptible to climate factors that have the potential to alter flow characteristics. No assessments of climate change vulnerability specific to this class are known for Western Washington. Assessments do exist for freshwater aquatic habitat (focused on stream hydrology and salmon habitat) and riparian habitat (Dalton et al. 2016; Krosby et al. 2016; WDFW and NWF 2011b). Figure 6-2 depicts modelled Riverine wetlands.

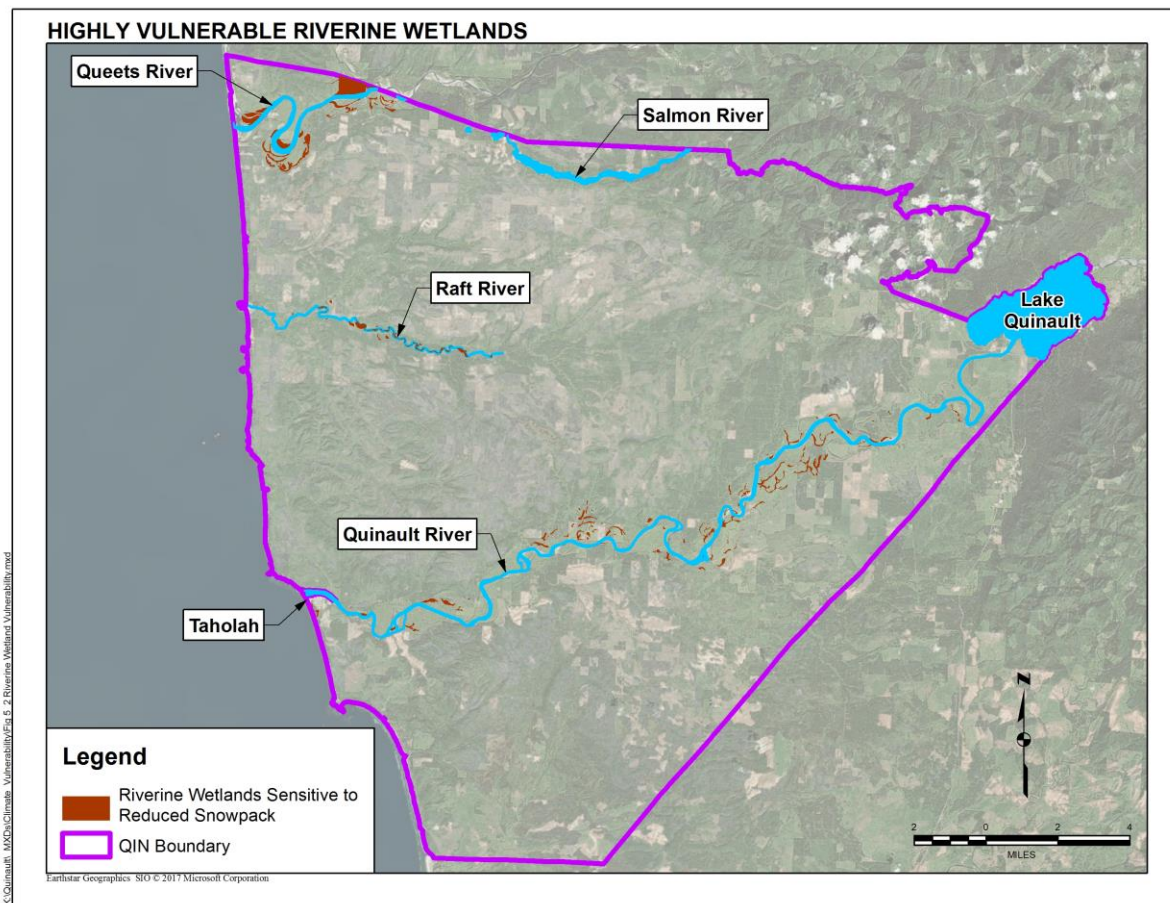


Figure 6-2. Modelled Riverine Wetlands in the Queets, Raft, and Quinault River Basins

Air Temperature

Riverine wetlands were rated moderately vulnerable to changes in air temperature.

Vegetative Community

It is expected that warming temperatures will shift species composition over time towards more warm weather-tolerant species (Devine et al. 2012). Wetland species that have wide geographic ranges and broader thermal and precipitation ranges are expected to be most adaptable (Kaye et al. 2013). Most of the common tree species in the low valley Riverine wetland class (western redcedar, willows, alder, and cottonwood) are moderately adaptable to changes in air temperature relative to species that grow higher in the mountains. Forested Riverine wetland classes are also expected to be less vulnerable to higher air temperatures than the Emergent and low Scrub-Shrub classes because of the thermal insulation provided by the tree canopy. Many of the plant species in Riverine wetlands are fairly adaptable and move through the river systems through flood-related seed dispersal. Because of these factors, Riverine wetland vegetation was ranked as having a low sensitivity to changes in air temperature.

Fish and Wildlife Habitat

Seasonally to permanently ponded riverine wetlands occur in areas that are seasonally connected to the main river, including remnant channels and scour (low) areas within seasonally flooded floodplain areas. These wetlands provide breeding and feeding habitat for numerous fish, amphibians, and reptiles. Sensitive anadromous fish, including chinook and steelhead, use these off-channel habitats for flood refuge and rearing (Mantua et al. 2009). Anadromous fish are particularly sensitive to changes in water temperature (NWIFC 2016). Because of the potential for water temperature to rise in association with rising air temperature, riverine wetlands were ranked as having moderate sensitivity to changes in air temperature.

Water Quality

In Riverine wetlands that are less frequently flooded, or where hyporheic/groundwater flow does not rapidly recharge the wetland, water quality may be degraded due to increased air temperature. In areas of relatively stagnant water, warmer air temperatures may increase algal blooms, which remove dissolved oxygen from the water column, making it less suitable for aquatic organisms. For these wetland types changes in air temperature will have a moderate impact on water quality. In Riverine wetlands with more free-flowing water, the quality will be less compromised by increased air temperature. Water quality impacts associated with increases in temperature would be much more probable in the Emergent and low Scrub-Shrub classes that lack shading. Higher water temperatures may exceed the thermal threshold of anadromous and resident fish, amphibians, and reptiles associated with this habitat.

Precipitation

Due to the relatively low reliance on direct precipitation, Riverine wetlands were ranked as having a low sensitivity to anticipated changes in precipitation. Due to the resilient nature of Riverine wetlands, they are adapted to both heavy rainfall and drought. Precipitation influence on riverine flooding is discussed below.

Storm Events, Riverine Flooding, and Tidal Storm Surges

Riverine wetlands are rated as having a moderate sensitivity to storm events, riverine flooding, and tidal storm surges. This is primarily due to their exposure to riverine flooding and storm surges, which can result in erosion and increased sedimentation in the water column. They were not ranked as highly sensitive because rivers are naturally dynamic systems, with the geomorphology changing in response to annual or semi-annual high flow events. As channels avulse and occupy new areas of their floodplain, associated wetland locations adapt.

Vegetative Community

Riverine flooding is highly associated with erosional activity, which increases turbidity (suspended sediment), decreases water clarity, and increases total suspended solids within the river water. During large storm events, bedload (coarse river substrate material) is moved rapidly. Due to both of these factors, riparian vegetation, particularly emergent wetland vegetation, can be buried or scoured out by sediment-laden water and high energy flows, respectively. However, many plant species in these wetlands are adapted to this disturbance regime and are tolerant of flooding and sedimentation.

Fish and Wildlife Habitat and Water Quality

Similarly, turbid water is a limiting factor for fish recovery and, as a result, is a factor of water quality. As salmonids use coastal rivers to rear and adjust to saline water, rapid changes in sedimentation can degrade habitat and result in short-term or long-term injury or mortality (Bash et al. 2001).

Snowpack

With more precipitation falling as rain, less water is stored as snow in the upper reaches of contributing watersheds for the Quinault and Queets Rivers. What snow is stored there would melt more quickly and earlier in the year under predicted climate scenarios. This loss or reduction of snowpack is expected to result in increasingly flashy hydrology associated with more intense and frequent storm events and reduced summer base flows (WDFW and NWF 2011b; Dalton et al. 2016). Because of these factors, Riverine wetlands were ranked as having high sensitivity to changes in snowpack. These factors would primarily affect wetlands along the Queets and Quinault Rivers, which are tied to snowmelt in the Olympic Mountains east of the Reservation. Riverine wetlands that are associated with smaller streams, particularly streams that originate within the Reservation boundary, would be relatively unaffected.

Vegetative Community

Increased winter/spring peak flows associated with rain on snow (rapid melting) events are likely to result in bank erosion and sedimentation that will exacerbate impacts on riparian vegetation through either scouring or burial by sediment.

Fish and Wildlife Habitat

In addition to the potential for increases in suspended sediments and turbidity, and potential declines in salmonid habitat associated with erosive high flows, reduced base flows in fall are likely to limit available spawning habitat for resident and anadromous fish (Mantua et al. 2009; NWIFC 2016).

Water Quality

In addition to increased erosion and sedimentation during peak winter and spring storm events, reduced base flow in summer months is likely to result in elevated water temperatures (Mantua et al. 2009; NWIFC 2016).

Wildfire

Due to the hydrogeomorphic characteristics of Riverine wetlands, including groundwater inputs from river systems and their location within low-lying moist valley bottom areas, they have a relatively low exposure and sensitivity to wildfire.

Sea Level Rise

Riverine wetlands were ranked as having a moderate sensitivity to sea level rise. In essence, the climate sensitivity factors are similar to those described in Section 6.2.6 for Estuarine wetlands. However, the effects are muted relative to Estuarine wetlands because Riverine wetlands are located above the coastal estuaries that stand to be most affected by rising sea level. Despite this muted effect, rising sea levels will likely influence river elevations further up into the river system. For example, NOAA's sea level rise estimates for the 6-foot rise scenario show increased inundation effects extending as far as the Chow Chow Creek confluence area in the Quinault River. Inundation would result when water flowing out to sea is impounded by higher sea levels. Similar to Estuarine wetlands, this sea water constriction has the potential to move river water out of its banks and into new flood hazard areas.

Vegetative Communities

Wetlands located lower in the river valley near the coast have the potential to be altered by changes in salinity as rising sea levels push the salt wedge further up into the Queets, Raft, Quinault, Wreck, and Moclips Rivers systems. Increases in salinity can cause die-off of freshwater vegetation and transition to salt-tolerant vegetation. Sitka spruce, red alder, redosier dogwood, salmonberry, Sitka willow, Pacific willow, and slough sedge are commonly occurring species in Riverine wetlands that have low tolerance for salinity. Salt-tolerant species such as Lyngbye's sedge, Pacific silverweed, saltgrass (*Distichlis spicata*), and woody saltwort (*Sarcocornia perennis*) are expected to become more prominent in Riverine wetlands exposed to sea level rise.

Fish and Wildlife Habitat and Water Quality

Marsh migration also has the potential to alter habitat for fish and wildlife as freshwater systems transition to brackish wetland or open water habitat. As trees die off due to saltwater conditions,

shoreline stability and microclimate moderation would decrease, and water temperature may increase.

6.4 Flats Wetlands (Coastal Wet Prairie and Coastal Swamp)

Flats wetlands are unique in Western Washington and the Pacific Northwest in general. Outside of the study area vicinity, they are most commonly found associated with wet prairies on broad flat glaciolacustrine terraces in the Willamette Valley of Oregon (Adamus 2001). Their locations and topography have made them exceedingly susceptible to agricultural and urban development in this area. No assessments of climate change vulnerability specific to this class are known for Western Washington. Kaye et al. (2013) assessed vulnerability of wetland species for the West Eugene Wetlands (wet prairies) in the Willamette Valley.

In the study area, flats wetlands include Coastal Wet Prairie (Flats Emergent) and Coastal Swamp (Flats Forested) habitats. Both mineral and organic Flats are included in these classes. Organic Flats encompass both fens and bogs. Fens, bogs, wet meadows, and isolated ponds are all listed as the wetland types most vulnerable to climate change by the CCVA for national forests in Western Washington (Aubry et al. 2011). Figure 6-3 depicts modelled flats wetlands.

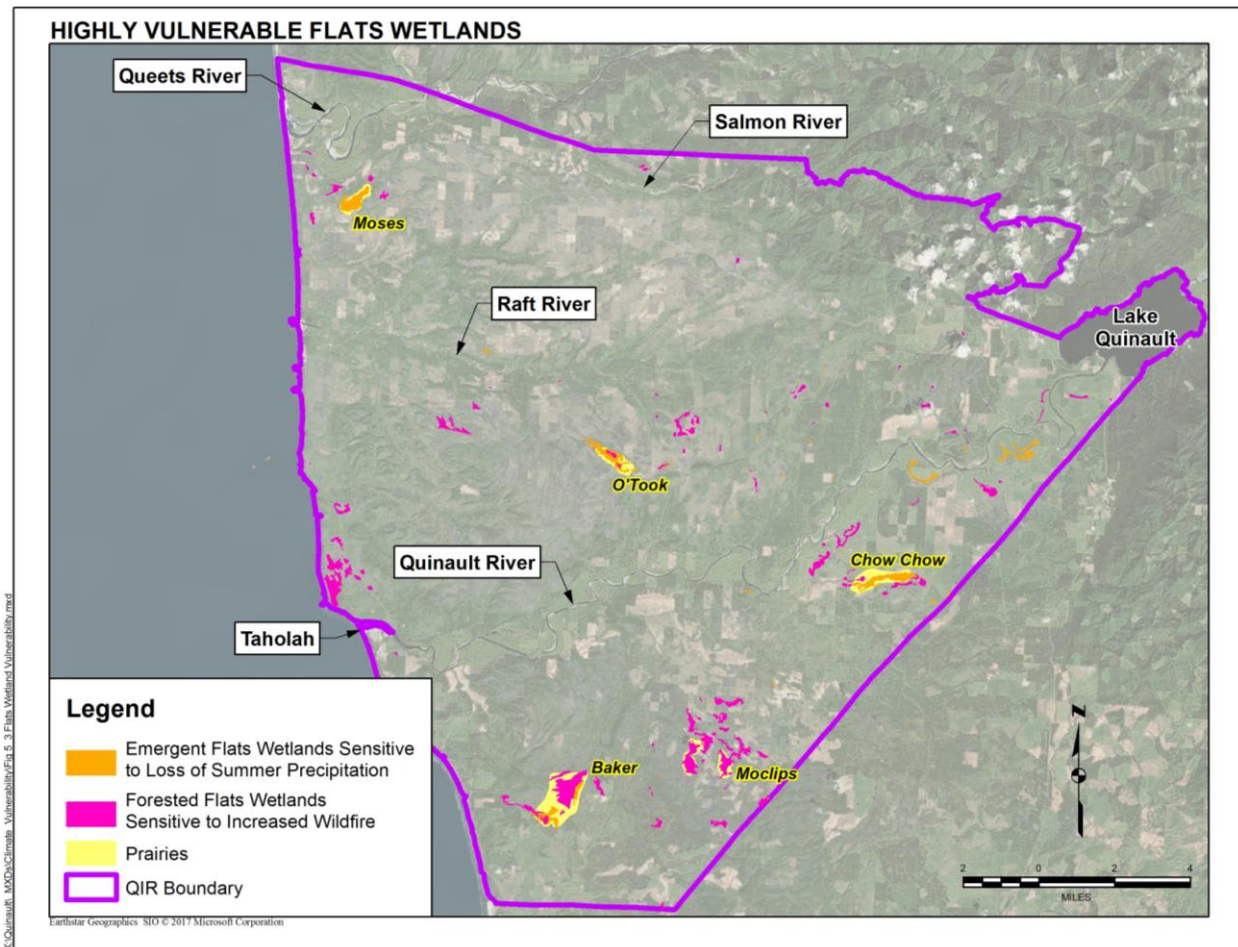


Figure 6-3. Modelled Flats Wetlands

Air Temperature

Flats wetlands were rated moderately vulnerable to changes in air temperature.

Vegetative Community

Although the thermal niche of most component plant and animal species is not precisely known, it is expected that warming temperatures will shift species composition over time towards more adaptable species. Wetland species that have wide geographic ranges and broader thermal and precipitation ranges are expected to be most adaptable. The common tree species (western redcedar, western hemlock, and shore pine) in the Forested/Scrub-Shrub wetlands have been ranked as having low to moderate sensitivity to climate change (Devine et al. 2012).

Not much is known about sensitivity of the understory species. Forested classes would be expected to be less exposed to higher air temperatures than the Emergent and low Scrub-Shrub classes due to thermal insulation provided by the canopy and the organic duff layer. Plant species associated with the Forested class also tend to be more widespread than those in the Emergent class.

Many of the plant species in the Flats Emergent/Scrub-Shrub class are commonly found in more northern latitudes and are expected to be sensitive to increasing air temperatures. Many of these species also have more precise site requirements that would make migration to other sites less likely. Bog cranberry and many of the other ericaceous shrubs common in this habitat require acidic soil conditions that could change as a result of increased temperature and other secondary effects of climate change (Krosby et al. 2016). Flats wetlands may only occur on certain geomorphic surfaces that are very flat and have subsurface soil conditions that result in a perched water table.

Wildlife Habitat

Seasonally to permanently ponded depressions within the Flats wetlands provide breeding and feeding habitat for numerous amphibians and reptiles. Projected increases in air temperature are expected to result in increased water temperatures, more evapotranspiration, and potentially reduced extent and duration of ponding in late summer and early fall. Amphibians are cold-blooded, and thus particularly sensitive to changes in temperature. Climate change may also cause mismatches of the timing of peak predator and prey abundances, which would alter food web dynamics (Mauger et al. 2015). Effects of climate change will vary among species and populations, and may include desiccation stress, increased mortality or reduced growth (Mauger et al. 2015).

Western toad is one species that utilizes shallow water habitat for breeding. This species is already in decline, and it has been rated in Washington as very sensitive to climate change for numerous reasons, including changes in water temperature, hydroperiod, and pH (Raymond et al. 2014). The dispersal capacity of this species is not well known.

Roosevelt elk graze seasonally in the wet prairies. This species has been assessed as having low sensitivity to climate change due to a rather flexible diet and high mobility (Dalton et al. 2016). However, secondary effects of climate change, such as increasing extent and intensity of wildfire and invasion of prime habitat by invasive plants, could reduce food resources and nutrition. It has also been theorized that an increase in the length of the freeze-free period may facilitate spread of diseases such as hoof disease (Dalton et al. 2016).

Water Quality

Small isolated ponds and streams within the Flats wetlands are expected to experience an increase in water temperature. This effect would be much more probable in the Emergent and low Scrub-Shrub wetland classes that lack shading. Higher water temperatures may exceed the thermal threshold of amphibians and reptiles associated with this habitat. The precise threshold is unknown for most of these species.

Precipitation

Flats Emergent and Forested wetlands were rated high and moderate, respectively, for vulnerability to precipitation changes.

Vegetative Community

Overall, the Flats wetlands are likely the most sensitive to changes in precipitation since their source of water is overwhelmingly from precipitation. The vulnerability of wetlands to climate change depends primarily on their water source (Winter 2000). The effects of climate change are more buffered in wetlands that receive water from other sources, especially discharge from regional groundwater systems.

Projected increases in spring and winter precipitation could result in the increase in extent, depth, and duration of ponding that could favor species more tolerant to ponding. Decreased summer precipitation, when combined with increases in temperature and evapotranspiration, are likely to result in increasing dry periods that could also change the character of the vegetation toward more drought tolerant species (Dalton et al. 2016; Mauger et al. 2015).

The specific relationship between air temperature, evapotranspiration, precipitation, and effective soil moisture is not well known for the study area. Other studies of climate change vulnerability of wetlands have used the following rule of thumb to approximate this relationship: “A 10 percent increase in precipitation is needed to offset the increases in evapotranspiration associated with 1 °C of warming” (Chu et al. 2014). If applied to the study area, this would translate to an additional 24 to 32 percent precipitation on an annual basis needed to offset increased evapotranspiration. Annual precipitation is projected to increase by only 2.8 to 3.2 percent by midcentury (Dalton et al. 2016). The increase in water deficit is even greater when assessed for summer. Based on midcentury projections for mean summer air temperatures, an additional 26 to 36 percent increase in precipitation would be needed to offset the increased summer evapotranspiration. Mean summer precipitation is expected to decrease by 5.6 to 7.5 percent (Dalton et al. 2016). While the exact outcomes will likely differ for the study area, this rule of thumb calculation does indicate the potential for significant decreases in moisture availability.

Changes in the Flats vegetative community as a result of drying are expected to be more pronounced in the Emergent wetlands since this class is dominated by more obligate and facultative-wetland species than the Forested/Scrub-Shrub class. Soil moisture deficit during the mid to late growing season would favor more facultative or facultative-upland species that are predominant in the Forested/Scrub-Shrub class. Plants in the Forested communities are somewhat buffered from climate change due to thermal insulation provided by the tree canopy and deep duff layers.

The edges of Flats wetlands would also be more susceptible to changes in plant species since these areas are already transitional to uplands. Invasive plant species also tend to be favored by more fluctuating water regimes that accompany more intense winter storms and longer drought periods.

Camas

Camas is one of the culturally important, traditional food plants highly valued by the Quinault people. It is also largely associated with Flats wetlands, although the plant seems to have a wide tolerance of different soils and water regimes. In Western Washington, camas (both *Camassia*

quamash and *C. leichtlinii*) is found in a wide variety of habitats, including rocky, shallow soils in the San Juan Islands; deep sandy outwash plains in southern Puget Sound; and seasonally wet soils in both coastal and valley locations. It is possible that genetic variability accounts for this adaptability. The genetic makeup of the camas plants on the Reservation, and how they would respond to climate change, has not been studied.

Camas fields are also apparently highly associated with active management by the Quinault people (Deur et al. 2017). The largest fields were actively burned, as well as seeded and transplanted. Since the last intentional fires over a century ago, camas fields have apparently become reduced in size.

Camas was rated for climate change vulnerability for the wet prairies in the Willamette Valley of Oregon (Kaye et al. 2013). It was ranked as moderately to highly vulnerable, depending on the climate change scenario used. This assessment was based on dispersal mechanisms, natural and anthropogenic barriers to movement, pollinators, and historical thermal niche. Camas seeds form in dry capsules that fall close to the parent plant. The lack of a dispersal mechanism makes them less able to adapt to changing climate conditions.

Camas growing in the Flats wetlands does appear correlated with a specific hydrologic niche of spring saturation and summer dryness. It is not known how flexible the plants are to variation on either end of this hydroperiod.

Wildlife Habitat

Changes in wildlife habitat would be coincident with changes to the hydrologic regimes and vegetative communities. Many amphibians and reptiles would be especially vulnerable to a combination of increased temperature and reduced summer precipitation. Although the overall length and extent of seasonal ponding may remain constant or even increase, there could be a mismatch between when this habitat is available and when dependent species require it.

Climate change effects in Flats wetlands may be compounded by past land use on the Reservation. Timber harvest and road building has historically reduced microtopography, altered hydrology, reduced habitat connectivity, and provided a vector for invasive species in some of these wetlands. Less mobile species such as amphibians are especially impacted by these changes, contributing to even greater vulnerability to climate change.

Water Quality

Flats wetlands receive very little surface water runoff from adjacent basins. Precipitation is the dominant water source, which contributes to the generally low nutrient status and low pH of these wetlands. For this reason, they are considered highly sensitive to changes in soil and water chemistry, and any increase in nutrient-enriched surface water entering these wetlands could result in a significant change in the plant community. Sediment in surface runoff could also fill microtopographic depressions, which are essential for plant and animal diversity in these wetlands.

Storm Events

Flats wetlands are rated low for vulnerability to storm events, primarily due to their lack of exposure to riverine flooding or storm surges.

Snowpack

Existing and projected snowpack is negligible in the Flats wetlands. They also do not receive stream flow dependent on snowmelt. For these reasons, they are not vulnerable to changes in snowpack.

Wildfire

Flats Emergent and Forested wetlands were rated moderate and high, respectively, for vulnerability to changes in wildfire regime.

Vegetative Community

Flats wetlands appear to alternate over time between woody and herbaceous vegetation (Historical Research Associates 2017). This cycle is related to long-term climate-driven changes in both hydrology and fire regime. Fires have been both natural and human-caused. Over the last century, suppression of natural fires, and cessation of intentional fires, has resulted in increasing encroachment of woody species in Emergent wetlands, and build-up of fuels in Forested wetlands. Both Flats wetland classes are expected to dry out more thoroughly in the summer and remain dry longer into the fall, making them more susceptible to wildfire.

Fire is a natural element of these ecosystems, and not all fire is considered detrimental. Shore pine and other common species in these habitats depend on fire for regeneration. Increasing low to moderate intensity burns in the prairies and Forested Flats could result in increased area and quality of prairie habitat (Dalton et al. 2016). However, high-intensity fires, or too-frequent fires, could also result in long-term changes to the habitat. When combined with increasing temperatures and prolonged summer water deficits, plant species composition and habitat quality could change significantly in the prairies.

Flats wetlands with deep organic soils present a unique sensitivity to wildfire. Normally these wetlands remain saturated for most or all of the year. However, during prolonged periods of drought, the organic soils can dry out and become susceptible to ignition. Once ignited, they can continue to burn for a long time, releasing carbon dioxide into the atmosphere.

Wildlife Habitat

More frequent fires in the Flats wetlands would reduce encroachment of woody species and favor herbaceous species. This could improve habitat for species associated with the wet prairies, such as elk. However, high intensity or very frequent fires, when combined with other climate change impacts, could also result in a long-term shift in the vegetative community which could impact the habitat needs of wildlife.

Water Quality

More frequent and intense wildfires would alter the nutrient cycling process and nutrient status of Flats wetlands soils. It is uncertain how this would affect downstream water quality.

Sea Level Rise

Flats wetlands are not vulnerable to sea level rise.

6.5 Depressional Wetlands (Basin Swamp and Basin Marsh)

Depressional wetlands are common and widespread in Western Washington. Their plant species also tend to be more adaptable and wide-ranging compared to Flats wetlands. No assessments of climate change vulnerability specific to this class are known for Western Washington. University of Washington and SAH Ecologia (2017) assessed vulnerability of Depressional wetlands in the Columbia Plateau of eastern Washington. In the study area, Depressional wetlands include Basin Swamp (Depressional Forested/Scrub-Shrub) and Basin Marsh (Depressional Emergent/Aquatic Bed) habitats.

Air Temperature

Depressional Forested/Scrub-Shrub and Emergent/Aquatic Bed wetlands were each rated moderate for vulnerability to temperature changes.

Vegetative Community

Dominant plants in the Depressional wetlands are not expected to be especially vulnerable to projected increases in air temperature. Common tree species in the Forested class (red alder, black cottonwood, western hemlock, and western redcedar) have been rated low to moderate for sensitivity to climate change (Devine et al. 2012). Sitka spruce is the only tree species in this class that was rated as having a high sensitivity to climate change. This sensitivity is largely due to this species being restricted to coastal areas with relatively cool, foggy summers, as well as its poor dispersal ability and sensitivity to disturbance (Devine et al. 2012). Relatively small changes in climate could restrict Sitka spruce in the study area.

Effects of temperature changes on common understory and emergent species are not well known. However, most understory species in the Depressional wetlands have a wide latitudinal distribution and would be expected to adapt to projected temperature changes. Less common species at the southern edge of their ranges could be affected, with the result that plant species diversity would decrease slightly.

The Forested class would be expected to be least exposed to higher air temperatures due to thermal insulation provided by the canopy and the organic duff layer. Plant species associated with the Forested class also tend to be more widespread than those in the Emergent class. Depressional wetlands can occur on many different geomorphic surfaces and soil types, which make them more adaptable than wetlands with strict site requirements, such as some types of Flats wetlands.

Fish and Wildlife Habitat

Shallow open water and vegetated ponds and pools in the Depressional class provide habitat for amphibians, reptiles, and resident fish. Projected increases in air temperature are expected to result in more evapotranspiration and potentially reduced extent and duration of ponding in late summer and early fall. Painted turtle (*Chrysemys picta*) is associated with the Depressional Emergent/Aquatic Bed wetlands. It is one of only two native turtle species in the state. The thermal niche of this species is not well known. It is potentially vulnerable to climate change since it has poor dispersal ability. Natural barriers to dispersal, such as areas lacking aquatic or wetland habitat and unsurpassable terrain, are not common in the study area. However, anthropogenic barriers such as roads and clearcuts are present.

Water Quality

Ponds and shallow, seasonal pools are expected to experience an increase in water temperature, especially during periods of draw-down in the summer. Smaller inundated areas are expected to be more sensitive than larger areas, as well as Depressional wetlands that receive most of their water from surface runoff. Depressional wetlands that receive some of their water from groundwater discharge are expected to be buffered to some extent from extreme water temperatures. Pools within Forested wetlands are also buffered from water temperature increases by shading. Higher water temperatures may exceed the thermal threshold of amphibians, reptiles, and resident fish associated with this habitat. The precise threshold is unknown for most of these species.

Precipitation

Depressional wetlands were rated moderate for vulnerability to precipitation changes.

Vegetative Community

Depressional wetlands receive water from surface runoff and direct precipitation, with or without groundwater discharge. Their vulnerability to changes in precipitation depends to a large degree on both the proportion of each water source and the characteristics of the basin and/or aquifer. Depressional wetlands with little or no groundwater inputs are expected to be significantly more vulnerable to precipitation changes than those with groundwater inputs (University of Washington and SAH Ecologia 2017; WDFW and NWF 2011b). Groundwater from regional aquifers is also more reliable than from local aquifers and provides additional buffering from climate impacts. Likewise, wetlands with large hydrologic basins are more buffered from the effects of climate change than those with smaller basins.

Hydroperiods of surface-runoff driven Depressional wetlands are likely to become more “flashy” due to more intense precipitation events in the wet season, and faster draw-down and a longer dry period in the summer/early fall. This flashiness may result in a shift in the dominant plant species towards generalists that can adapt to a wider range of hydrologic regimes. Within the Forested class, this shift may select away from trees that are sensitive to disturbance and flooding, such as western hemlock, western redcedar, and Sitka spruce, towards ones that can tolerate a wider range of hydrology and disturbance, such as red alder, black cottonwood, and

willow. A similar shift may occur in the Scrub-Shrub and Emergent classes towards species such as Douglas spirea and common cattail, which tolerate a wide range in hydrology and disturbance. This type of hydrologic regime would also tend to favor some invasive species such as reed canarygrass (*Phalaris arundinacea*), which currently is of limited extent in undisturbed wetlands in the study area.

The combined effect of reduced summer precipitation and higher summer air temperatures could result in a shift toward facultative-upland or upland species in wetlands or portions of wetlands that are currently at the drier end of the wetland hydrology range. This shift could occur even on sites that experience increased wetness during the winter, since most plant species typically respond more to moisture that occurs during the growing season than during periods of dormancy or very slow growth.

Fish and Wildlife Habitat

Depressional wetlands encompass a wide variety of hydrologic regimes that determine the depth, duration, frequency, and timing of inundation. Wetland-dependent fish and wildlife species utilize many of these wetlands based on their unique habitat needs and according to their own life cycles. Waterfowl are perhaps the most ubiquitous species-groups that make seasonal use of the Emergent and Aquatic Bed habitats. Wetland-dependent bird species in the study area include trumpeter swan (*Cygnus buccinator*), wood duck (*Aix sponsa*), great blue heron (*Ardea herodias*), western grebe (*Aechmophorus occidentalis*), several migratory ducks and geese, and many others.

Many waterfowl species are ranked as Presumed Stable for their vulnerability to climate change (Krosby et al. 2016). This ranking is based on their flexible diet and high mobility. Some species, however, are not as adaptable. The western grebe, for instance, has been ranked as potentially highly vulnerable to climate change based on its dependence on a very narrow hydrologic niche. Its breeding success is dependent on stable water levels. It is highly sensitive to flooding, wind, and drought (Krosby et al. 2016).

Water Quality

Projected increases in summer water deficit and prolonged periods of drought will result in smaller pools of water that heat up faster in the Depressional wetlands.

Storm Events

Depressional wetlands are rated low for vulnerability to storm events, primarily due to their lack of exposure to riverine flooding or storm surges. However, some Depressional wetlands are primarily driven by surface water runoff from the surrounding upland basin. Projected increases in precipitation intensity and frequency during the wet season could result in increased soil erosion with sedimentation in the wetlands. This effect could be compounded by timber harvest activities in the upland basins, which increase surface runoff. Depressional wetlands are less sensitive to changes in soil and water chemistry than Flats wetlands.

Snowpack

Existing and projected snowpack is negligible in the Depressional wetlands. They also do not receive stream flow dependent on snowmelt. For these reasons, they are not vulnerable to changes in snowpack.

Wildfire

Depressional Forested/Scrub-Shrub and Emergent/Aquatic Bed wetlands were rated moderate and low, respectively, for vulnerability to changes in wildfire regime. Forested and Scrub-Shrub wetlands are expected to dry out more thoroughly and for longer periods during the dry season, which will make them more susceptible to high intensity fires. These habitats are considered adaptable to low to moderate intensity fires with low frequency. High intensity fires, or too-often-recurring fires, could result in long-term changes to the habitat. When combined with increasing temperatures and prolonged summer water deficits, plant species composition and habitat quality could change significantly in these wetlands

Sea Level Rise

Depressional wetlands are not vulnerable to sea level rise.

6.6 Slope, Forested (Seepage Swamp)

Slope wetlands are common in Western Washington, though less widespread than Depressional wetlands. No assessments of climate change vulnerability specific to this class are known for Western Washington. In the study area, Slope wetlands are dominated by coniferous Forest vegetation.

Air Temperature

Slope wetlands were rated low for vulnerability to air temperature changes.

Vegetative Community

Conifer tree species dominant in this class are expected to have low vulnerability to changes in air temperature. Sitka spruce is the only tree species that has been rated as high for sensitivity to climate change (Devine et al. 2012). However, projected increases in air temperature are expected to be somewhat moderated for slope wetlands since they tend to occur in cooler microclimates at the base of slopes and in concave basin and headwater positions. Soil temperatures are also controlled by cooler groundwater.

The thermal niche of understory species is less well understood. However, most of the common species in this class appear to have a wide geographic range and are not expected to be highly sensitive to climate change, with the possible exception of some late successional species, which tend to have more precise and stable habitat requirements. Climate change impacts to such species are also compounded by past and current timber harvest on the Reservation.

Wildlife Habitat

Wildlife species that utilize these habitats and that could be negatively impacted by changes in temperature and hydrology include Cascades frog (*Rana cascadae*), Olympic torrent salamander (*Rhyacotriton olympicus*), Van Dyke's salamander (*Plethodon vandykei*), long-toed salamander (*Ambystoma macrodactylum*), northwestern salamander (*A. gracile*), and garter snake (*Thamnophis sirtalis*) (Halofsky et al. 2011). Slope wetlands with permanent or semi-permanent saturation provide cool, moist refugia for these species during extended periods of hot dry weather.

Water Quality

Slope wetlands receive limited surface runoff and lack extensive areas of ponding that would be subject to warming. The tree canopy and thick duff layers also provide shade and insulation to moderate temperature increases.

Precipitation

Slope wetlands were rated low for vulnerability to changes in precipitation.

Vegetative Community

The water source for these wetlands is overwhelmingly from groundwater. Slope wetlands occur in locations on the landscape that receive concentrated groundwater discharge as seeps or springs. For this reason, they are expected to be buffered from changes in local precipitation, even more so than Depressional wetlands (Winter 2000). The degree of buffering, however, depends on the nature of the groundwater aquifer that feeds the wetlands. Wetlands that receive groundwater solely from local aquifers are more sensitive to climate change than those sourced by regional aquifers.

Not enough is known about the groundwater hydrology of the study area to make precise determinations on groundwater sources. It is assumed that there is a diversity of sources within this class. Slope wetlands that currently remain saturated throughout the year are likely connected to groundwater sources that are more regional in nature. Many of these wetlands are characterized by having organic soils and a higher proportion of obligate or facultative-wetland species in their understories. Very little change to the vegetative community is expected for these wetlands. Slope wetlands with a less reliable groundwater source are expected to be more at risk for changes to the vegetative community.

Slope wetlands are not subject to inundation, except in very small depressions on the slope. This lack of inundation also provides a degree of stability to the vegetation.

Wildlife Habitat

Wildlife that utilizes these wetlands is not dependent on surface water ponding, which is more sensitive to changes in precipitation and evapotranspiration than groundwater. Habitat is expected to remain mostly stable.

Storm Events

Slope wetlands were rated low for vulnerability to storm events. They do not receive abundant surface runoff and are not subject to erosive flows.

Snowpack

Existing and projected snowpack is negligible in the Slope wetlands. They also do not receive stream flow dependent on snowmelt. For these reasons, they are not vulnerable to changes in snowpack.

Wildfire

Slope wetlands were rated moderate for vulnerability to changes in wildfire regime. These wetlands sustain conifer forests that can have large amounts of fuel. Increases in air temperature and summer drought have been correlated with increases in certain disease and pest infestations that could in turn create additional fuels (Mauger et al. 2015; Dalton et al. 2016). Warmer and drier summers are expected to create conditions for more frequent and intense wildfires that could have long-lasting impacts on the vegetative community.

Sea Level Rise

Slope wetlands are not vulnerable to sea level rise.

6.7 Usual and Accustomed Areas off the Reservation

The QIN U&A consists of the usual and accustomed fishing areas confirmed in the original U.S. v. Washington case, 384 F. Supp. 312 (1974). They include the “Clearwater, Queets, Salmon, Quinault (including Lake Quinault and the Upper Quinault tributaries), Raft, Moclips, and Copalis [Rivers] and Joe Creek.” They also include “Grays Harbor, and all those streams which empty into [it],” the entire Chehalis River system including all of its tributaries as well as the saltwaters “adjacent to their territory” (QIN 2016). These areas are generally located within WRIAs 21 (Queets/Quinault), 22 (Lower Chehalis), and 23 (Upper Chehalis). Although the U&A extends beyond these areas, these WRIA boundaries are used for general U&A reference in this report and associated figures.

Wetland loss has been substantial outside the Reservation boundaries. Estimates of pre-European settlement wetland acreage in Washington range from 1.17 to 1.53 million acres, depending on the historical information and research assumptions used. Based on a 1988 estimate by the USFWS, about 20 to 39 percent of Washington's wetlands have been lost during the past two centuries. Other estimates place the total loss as great as 50 percent, and some urbanized areas of the Puget Sound area have experienced losses of from 70 to 100 percent. Estimates of continuing wetland loss range from 700 to 2,000 acres per year. In addition, most of the state's remaining wetlands have been significantly degraded (Lane and Taylor 1997).

Montane Wetlands

The wetland asset classes that have been discussed for the Reservation are expected to extend throughout the U&A. Their assessment for vulnerability to climate change is also expected to remain valid within the U&A. However, at least one wetland asset class (Montane wetlands) is not represented on the Reservation itself, due to its generally low elevation. Although not a separate HGM class, seasonal wetlands that are fed primarily by snowmelt or glacial melt present a special assessment class. These Montane wetlands are generally in headwater positions at elevations above 2,000 feet where snowmelt or glacial melt is the primary source of water.

Montane wetlands are expected to be highly sensitive to climate change (Mauger et al. 2015). Warming will cause a greater proportion of winter precipitation to fall as rain rather than snow. Snowpack is projected to decline, and snowmelt and peak streamflow will occur earlier in the year. The combination of early snowmelt, increased temperature and evapotranspiration, and reduced summer precipitation is expected to result in extended periods of water deficit that could shrink wetland area and/or significantly change the vegetative communities. Wetlands that receive a significant proportion of their water from glacial melt are more buffered from the impacts of climate change, as increased icemelt associated with warming temperatures may compensate for reduced moisture availability in the summer (WDFW and NWF 2011a).

Montane wetlands in the U&A have not been intensively studied, so the precise nature of climate change induced hydrologic and vegetative changes is not well known.

Lacustrine Wetlands

A small area of vegetated Lacustrine wetlands do occur on the shore of Lake Quinault. A narrow fringe with mostly Emergent vegetation was identified on the south shore of the lake near the fish hatchery. These wetlands were not included in the vulnerability assessment due to their very limited extent on the Reservation and the fact that the WSI cannot delineate these out apart from the lake. However, other lakes and ponds that meet the 20 acres size threshold do occur within the U&A that are expected to support a larger area of Lacustrine wetlands. These wetlands are expected to be dominated by Emergent vegetation (sedges, rushes, grasses, and wetland forbs). Aquatic bed vegetation would be expected in calm water areas. Scrub-Shrub communities dominated by willows, red-osier dogwood, and other wetland shrubs may occur landward of the Emergent communities.

These wetlands will vary in their vulnerability to climate change, but as a group they are expected to be among the least sensitive since their source of hydrology is a large body of water. Lakes and ponds of this size likely have large catchment areas and receive both surface and groundwater discharge. Many plant species common in Lacustrine wetlands are also adapted to wet and dry climate cycles and accompanying periods of inundation and drought. Vegetative communities may be able to migrate waterward or landward as the lakes slowly expand or contract.

7. MANAGEMENT IMPLICATIONS

Management implications for the QIN wetland CCVA are meant to target wetlands that scored with a high vulnerability and to identify how those particular wetlands can be managed in the future to reduce their vulnerability to a specific climate parameter. Wetlands that scored with a high vulnerability in the Results, Section 6.1, include the following:

- Estuarine – high vulnerability to sea level rise
- Riverine – high vulnerability to changes in snowpack
- Flats, Emergent/Scrub-Shrub – high vulnerability to changes in precipitation
- Flats, Forested/Scrub-Shrub – high vulnerability to changes in wildfire regime

The following sections identify the specific climate concern or opportunity and then identify management actions that could be implemented to reduce the vulnerability of each wetland asset type.

7.1 Climate Concerns and Opportunities

All Wetlands

Concern/Opportunity: Increasing protection of wetlands on the Reservation

Action: Further development and implementation of the policies on the Reservation for protecting wetlands, including:

- Further development of climate change vulnerability in the Wetland Program Plan's 2020 update;
- Assessment of the enforcement of Tribal Code Title 48 Fish Sensitive Areas and Sensitive Areas chapters, in order to identify areas of improvement and to further enhance the implementation of wetlands protection;
- Assessment of Tribal Code Title 61 Natural Resources Management HPA process, to avoid, minimize, and mitigate wetland impacts under the HPA process.
- Assessment of the QIN FMP process, to further identify measures that would decrease wetland impacts by avoidance, minimization and mitigation opportunities for projects under the FMP process.
- Assessment of the QIN Shoreline Management Plan (SMP) process, to further identify measures that would decrease wetland impacts by avoidance, minimization and mitigation opportunities for projects under the SMP process.

Estuarine and Riverine

Concern/Opportunity: Water quality and habitat with sea level rise

Action: After relocating inhabitants to higher ground to reduce impacts from sea level rise, ensure areas are cleared of any household toxic items like paints, cleaners, old machinery, etc. to ensure better water quality and habitat.

Concern/Opportunity: Raising dikes with sea level rise

Action: Acknowledge that raising dikes causes direct impacts to wetlands. Carefully consider opportunities to facilitate changes in residential areas that may occur in low-lying areas, to reduce the need to raise dikes, thereby protecting the wetlands. Incorporate practices to be sensitive to the needs and culture of residents.

Concern/Opportunity: Gill net fishing and salmon fisheries

Action: Implement practice of removing old gill nets after use and cleaning up snagged gill nets to maintain Riverine/Estuarine habitat quality. Climate change affects salmon habitat, and this action would help to ensure that salmon runs within the Reservation, along with other aquatic species, are not inhibited to movement by discarded debris in the waterways.

Concern/Opportunity: Nonnative invasive species management

Action: Under various climate scenarios, there is expected to be an increase in potential habitat for nonnative invasive species to establish. Knotweeds (*Polygonum bohemicum*, *P. sachalinense*, *P. cuspidatum*, *P. polystachyum*) are already displacing native wetland species, especially in Riverine wetlands. Management of invasive plants under a changing climate is even more important in order to maintain native plant communities that are under other threats. Continuing an existing funding and plans for knotweed removal and native plant restoration projects.

Flats, Emergent, Scrub-Shrub, and Forested Scrub-Shrub

Concern/Opportunity: Incorporate wetlands into riverine setback buffering for timber practices

Action: Consider incorporating wetlands into definition for setback for timber practices, in order to protect wetlands and water quality in addition to riverine and riparian areas currently protected.

Concern/Opportunity: QIN ceremonial practices

Action: Consider planting or managing parcels for plants of cultural significance that grow in wetland habitats that are vulnerable to climate change.

Concern/Opportunity: Roadways and wetlands

Action: Roads are closely tied to wetlands because of flooding and the amount of rain on the Reservation. Consider prioritizing removal of old roads and structures in wetland areas to protect and increase habitat quality rather than modifying existing structures or building new roads. The development of new roads through wetland habitat areas should be avoided as it fragments wetland habitat and may make it more vulnerable to climate change as a result.

Concern/Opportunity: Prairie habitat

Action: Consider adopting burn management approaches to prairies. The burn study and implementation of the burn plan conducted at Moses Prairie could be adopted at other prairies on the Reservation. A burn management plan for the Reservation could be developed and implemented.

7.2 Next Steps

The management implications introduced herein will be developed further into a Wetland Climate Adaptation Plan (CAP). This CAP will outline step-wise, specific goals and objectives for the QIN and will draw on climate concerns and opportunities identified in Section 7.1, along with additional local knowledge, to create wetland adaptation strategies. It will be important to update the existing Wetland Protection Plan during the 2020 review and further review implementation of tribal codes pertaining to wetlands Title 48, Title 61, the FMP, the SMP and the HPA processes. The CAP will play an active role in reducing climate vulnerability and fostering wetlands resiliency under the changing climate.

8. KNOWLEDGE GAPS AND NEXT STEPS

Data gaps and uncertainties have been categorically identified during the preparation of the QIN wetland CCVA. These are grouped by model limitations, data gaps and technological considerations, and future research opportunities.

8.1 Model Limitations

The QIN wetland CCVA was focused in time and scope; therefore, the following limitations are identified:

- Vulnerability is assessed for individual climate variables; however, the variables are not truly independent from each other. Accounting for cumulative or interactive effects of all variables would be much more complex to assess.
- The relationship of changes in air temperature, evapotranspiration, precipitation, and available moisture is not known precisely for each wetland class in the study area, which complicates the assessment for wetland contraction and species shifts.
- The wetlands in the study area have been grouped into seven classes that are expected to have generally similar responses to climate change. However, each class represents a range of environments, and individual wetlands at either end of the range may respond differently than expected on the ground.

8.2 Data Gaps and Technological Considerations

The following gaps were identified during data collection and analysis for the QIN wetland CCVA:

- NOAA sea level rise data is not available for portions of the Reservation north of the Quinault River; the Washington coast north of this river is shown as “no data” on the Sea Level Rise Viewer. Sea level rise data for the Raft and Queets Rivers would also be useful.
- Much of the available data from Integrated Solutions and other climate data clearinghouses are at a coarse scale, typically 1/16 degree (or about 6 km) grid size. This coarse resolution was necessary to provide readily available depictions of general regional areas that face the greatest climate change vulnerability; however, these data sets would be much more useful if developed specifically for the scale of the Reservation and associated, contributing watershed areas.
- The wetland layer used for this analysis is a coarse model that improves on wetland detection relative to the NWI and NOAA’s coastal Change Atlas; however, as a model it is limited to the quality of its inputs. As such, it should not be considered adequate to capture all wetland areas within the Reservation. Improvements could be made with heads-up digitizing and additional field verification.

- Shoreline mapping of potential areas of expansion and contraction of Estuarine wetlands would be necessary for a finer-scaled vulnerability assessment.

8.3 Future Research Opportunities

The data gaps summarized above offer opportunities for further study:

- The true resiliency of native ecosystems is not fully known. Further study is needed to understand how wetlands respond to increased frequency and intensity of perturbations or disturbances.
- There is limited research on the distribution of Montane wetlands or their physical, chemical, and biological dynamics, making future projections challenging.
- Wetland amphibians are expected to be highly sensitive to climate change, but the species- and population-specific influence of climate change is uncertain. Further research would serve to improve future projections.
- Several culturally important species are associated with wetlands. Research on these species would improve future climate management strategies. These culturally important species may include camas, elk, salmon, beargrass and waterfowl.

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