LOWER ELWHA KLALLAM TRIBE

CLIMATE CHANGE VULNERABILITY ASSESSMENT

February 2022

Natural Systems Design

Prepared for
Lower Elwha Klallam Tribe
2851 Lower Elwha Road
Port Angeles, WA 98363

In Collaboration With

adaptation international

Sea Grant Washington

Funding: This project was generously funded by Bureau of Indian Affairs, Climate Resilience Program.

Recommended Citation Format
Lower Elwha Klallam Tribe. 2022. Lower Elwha Klallam Tribe Climate Change Vulnerability Assessment. Prepared for the Lower Elwha Klallam Tribe by Natural Systems Design, Adaptation International, and Washington Sea Grant.

Cover Image: By John Gusman.

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Glossary of Key Terms*

***adaptive capacity*—**The ability to adjust to potential impacts, take advantage of opportunities, and respond to extreme weather events and changing climate conditions.

***climate exposure*—**An extreme weather event or changing climate condition that could adversely affect people, livelihoods, species, ecosystems, environmental functions, services, resources, infrastructure, and economic, social, and cultural assets.

***climate projections*—**The simulated response of the climate system (e.g., temperature, precipitation, etc.) to a scenario of future emissions or concentrations of greenhouse gases and aerosols, generally derived using global climate models.

***key concerns*—**The natural and built resources, assets, and issues that are most important to the Tribe, have the potential to be affected by climate change, and can be addressed within the scope of available resources and capacity.

***sensitivity*—**The degree to which a species, asset, or resource is affected by an extreme weather event or changing climate conditions.

vulnerability—The degree to which a key concern is susceptible to adverse effects of climate change as determined by climate exposure, sensitivity, and adaptive capacity.

*As defined by Dalton et al. (2018).

1 INTRODUCTION

The Lower Elwha Klallam Tribe (LEKT) maintains a deep connection to their traditional homeland that encompasses much of the north Olympic Peninsula, including the Elwha River. A changing climate has the potential to impact natural, built, and cultural elements that are important to the LEKT, so the Tribe has developed this Vulnerability Assessment to establish a baseline of knowledge that will support future planning to preserve and strengthen the Tribe's treaty rights.

The LEKT is a federally recognized tribe that is part of the 1855 Treaty of Point No Point (Hahduskus). The Treaty of Point No Point documents the LEKT's rights to maintain traditional lifeways, including taking fish at usual and accustomed grounds and stations. The LEKT has weathered substantial changes to their traditional lifeways that have resulted in decreased access to the land and once bountiful resources. Climate induced changes to those already diminished resources will have a disproportionate impact to the LEKT, so identifying and planning for these changes is a key step in maintaining and strengthening the LEKT's protected treaty rights both now and generations into the future.

This Lower Elwha Klallam Tribe Climate Vulnerability Assessment was developed by Natural Systems Design, Inc. (NSD) and Adaptation International (AI). The project team also included Dr. Ian Miller of Washington Sea Grant, who provided local expertise on sea level rise, coastal hazards, and local geomorphic processes.

The overall approach to this assessment was based on a climate adaptation planning framework, illustrated below on Figure 1. This effort focused on the first three steps shown in the figure, culminating in an understanding of overall vulnerability that can be used to develop and focus adaptation actions.

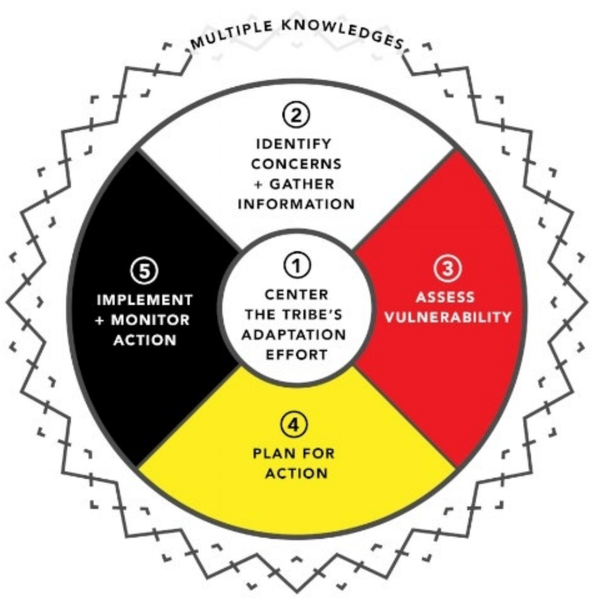


Figure 1. Steps of a Climate Adaptation Effort (From *Tribal Climate Adaptation Guidebook,* November 2018)

The Vulnerability Assessment is organized into six sections. Key pieces of information are included in multiple sections to support a reader who is interested in only one or two sections. Below is an outline of the LEKT Climate Vulnerability Assessment:

- Section 1 – Provides the introduction, background for the LEKT, and a climate change overview
- Section 2 – Documents the centering of the Tribe’s Adaptation Effort
- Section 3 – Identifies the key concerns used to guide the analysis
- Section 4 – Identifies the overall climate exposures for the LEKT
- Section 5 - Provides the Vulnerability Analysis for key concerns
- Section 6 – Conclusions and Next Steps

1.1 Background

The LEKT Reservation is located 8 miles west of Port Angeles, Washington, which is on the south shore of the Strait of Juan de Fuca and on the north side of the Olympic Peninsula. It is accessible by both road and a ferry which comes into Port Angeles. The main reservation was secured in trust for the Tribe by the US federal government in 1936 and was formally deeded in 1968. The Lower Elwha Reservation and Trust Lands include 850 acres at the mouth of the Elwha River. The Tribe also owns property within Port Angeles, and the surrounding area as well. The climate of this area is dominated by the rain shadow effect of the Olympic Mountains and the moderate temperatures of a maritime climate. For time immemorial, the Elwha River valley has provided the Tribe with food, shelter, and sustenance, as well as access to the interior of the Olympic Peninsula. It is the cultural and spiritual home and heart of the Lower Elwha Klallam Tribe. This climate vulnerability assessment was focused on the Lower Elwha Klallam Tribe Reservation.

The LEKT is a party to the 1855 Treaty of Point No Point and is a sovereign federally recognized Indian Nation with its own constitution and government. The Tribe is led and governed by the Lower Elwha Tribal Council, or Business Committee, comprised of five elected officials with staggered terms of three-years. The Tribal Council has full and ultimate responsibility for managing all Tribal programs operating on an annual budget. The Community Council of all eligible voting Tribal members is responsible for enacting laws for the governances of land and people under its jurisdiction and performs the duties of the Tribal Council in the absence of a Council quorum. About 580 Tribal members live on the reservation or nearby (Lower Elwha Klallam Tribe, 2011).

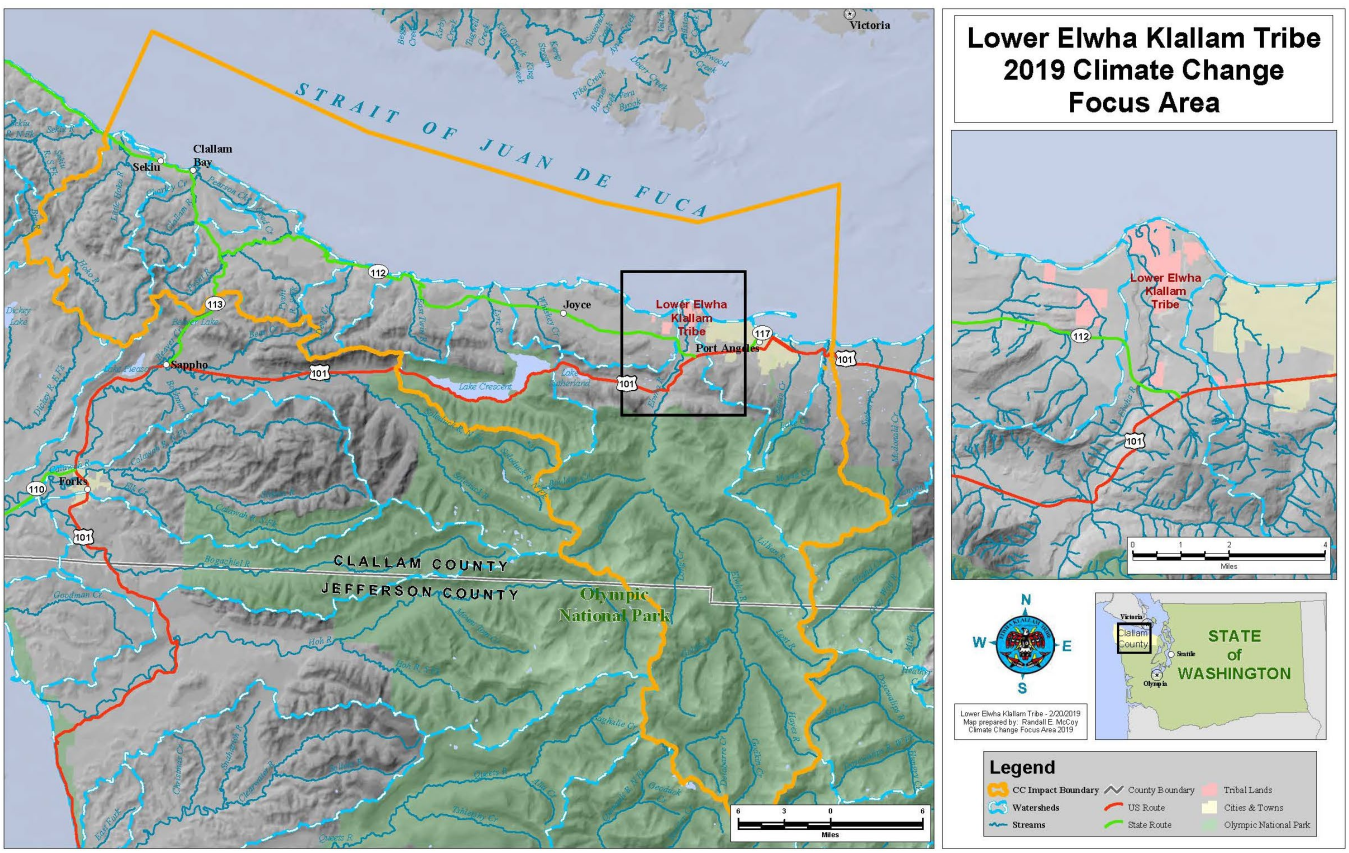


Figure 2. Lower Elwha Klallam Tribe climate change vulnerability assessment focused analysis area outlined in black (map created by Randall McCoy, LEKT staff, 2019).

1.2 A Changing Climate

Since the beginning of the Industrial Revolution in the mid-1800s, humans have been releasing carbon dioxide, previously locked in the Earth, into the atmosphere through the burning of fossil fuels. The increase in carbon dioxide, and other greenhouse gases (GHGs), in the atmosphere is causing the Earth to warm. Warming has been documented already and will continue to cause far-reaching impacts to natural systems and human populations.

The average annual global temperature has increased by about 1.8˚ Fahrenheit from 1901 to 2016, with the majority of warming occurring in recent decades (Vose et al., 2012). The majority of the warmest years on record have occurred in the last two decades. Heat waves are becoming more frequent and extreme cold temperatures are less frequent. Warming temperatures not only affect the air temperature, but also warm the ocean, lakes, and rivers; melt glaciers and ice sheets; decrease snow cover; change precipitation and river flow patterns; raise sea levels; and increase the acidity of the oceans. According to a recent comprehensive assessment of observations and analysis, *"It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century."(Wuebbles et al., 2017)* Burning fossil fuels, which release heat-trapping greenhouse gasses (e.g., carbon dioxide, CO_2) into the Earth's atmosphere, is the primary contributor to these impacts that have been measured and observed around the world (Walsh et al., 2014).

The Pacific Northwest is already experiencing drier summers, decreases in snowpack and glacial mass, higher wet season and lower dry season river flows, increases in coastal erosion, sea level rise, and a more acidic ocean. These are not isolated incidents, but part of a larger regional and global trend of changing climate conditions that is driven primarily by human activity (U.S. Global Change Research Program, 2014).

Climate is the long-term average of weather over a given area; whereas *weather* is what is happening in the atmosphere at a given place and time. For example: in Port Angeles, the temperature and amount of rain on a given day is the *weather*, while the average temperature and precipitation in December (typically over a 30-year span) is the *climate*. Climate can be calculated across different spatial scales: globally, regionally, and locally. Each scale is useful for understanding a component of the climate system. Global climate model (GCM) outputs can be combined with historical observations to assist with translating large-scale patterns into more localized projections at a smaller scale, a process called downscaling. For this assessment, the climate analysis uses both GCMs and analysis of downscaled climate data provided by the Climate Impacts Group at the University of Washington, and the National Climate Change Viewer (NCCV) by the U.S. Geological Survey (Alder and Hostetler, 2013; Krosby et al., 2020).

1.2.1 Climate Projections

The exact amount of greenhouse gasses the world will emit over the next century is unknown, so scientists have to create climate change projections using several different scenarios based on plausible societal responses to climate change and other factors. The multiple emissions scenarios describe future trajectories of GHG emissions that capture the relationship between human decisions, global population growth, economic development, technological advancement, and global temperature change throughout the 21st century.

Climate modeling uses a range of future scenarios to simulate how future emissions will occur. The International Panel on Climate Change (IPCC) uses a series of scenarios termed Representative Concentration Pathways (RCPs) created in 2010. The scenarios range from RCP 2.6[1], a stringent mitigation scenario that achieves a net negative

[1] The RCP scenarios are related to emissions trajectories until 2100 and the numerical name is based on the projected increase in radiative forcing, or 'warming', in watts per meter on the Earth's surface.

emission by the end of the century to RCP 8.5, a "business-as-usual" scenario with no effort to constrain emissions (Figure 3). The current emissions trajectory more closely follows RCP 8.5, so climate exposures and projections throughout this work, are based on RCP 8.5, unless otherwise noted.

The RCP 8.5 scenario corresponds to a future where carbon dioxide and other GHGs continue to rise over the rest of the century (Hayhoe et al., 2017). Average temperature is likely to increase by at least 3.6°F (2°C) under RCP 8.5 and lead to substantial warming across the planet and especially in the Arctic and northern latitudes. This warming is likely to cause rapid and extensive melting of glaciers and land ice, with global implications and consequences.

It is important to take action to reduce emissions and limit the long-term impacts of climate change. The more emissions are reduced (globally), the less severe climate change exposures will be over the long term. So, while it is still possible that the world will take action to reduce carbon emissions and limit the worst impacts of climate change, it is important to plan for the "business-as-usual" scenario.

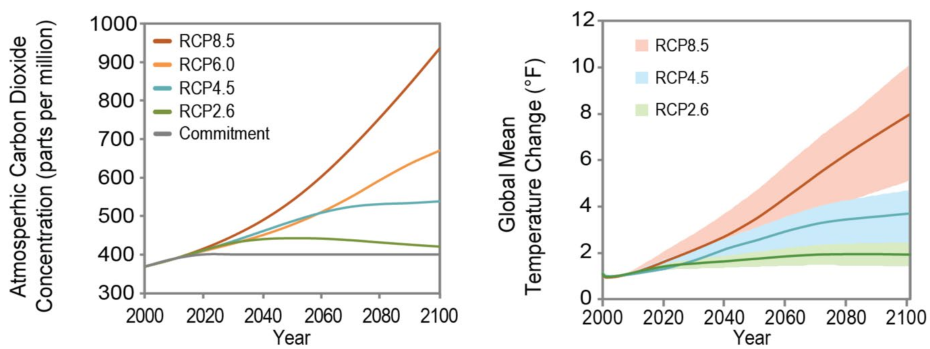


Figure 3. Future scenarios of atmospheric carbon dioxide concentrations (left) and global temperature change (right) resulting from several different emissions pathways, called Representative Concentration Pathways (RCPs), which are considered in the fourth and most recent National Climate Assessment (Source: https://science2017.globalchange.gov/chapter/4/)

2 CENTERING THE ASSESSMENT

2.1 Tribal Community Input

The Climate Change Vulnerability Assessment process began by engaging the LEKT project team and the broader community to identify overall goals of the project. As part of the centering process, the project team (LEKT, NSD, AI, and Washington Sea Grant) worked together to solicit input from the community to inform the scope of the analysis. At the outset of the project, LEKT organized and held a community survey in the summer of 2019. This survey was followed by a community luncheon at the Tribal Center on August 7, 2019. These conversations resulted in the development of the following vision statement for the vulnerability analysis:

> The Lower Elwha Klallam Tribe climate change vulnerability assessment shall support the Lower Elwha Klallam Tribe in understanding vulnerability and risk to natural resources, cultural practices, economy, and health and wellbeing in a changing climate.

The project team used the vision statement to organize the assessment to focus on:

- Natural Resources
- Built Environment
- Cultural Places and Practices
- Community Health and Wellness

Due to the Covid-19 pandemic, community input and sharing was somewhat curtailed, and partially limited to remote methods.

2.2 Climate Vulnerability Assessment Approach

The overall assessment of vulnerability is based on a combination of three factors - the *Climate Exposure*, *Sensitivity*, and *Adaptive Capacity* of a specific asset, resource, or issue of concern (Figure 4).

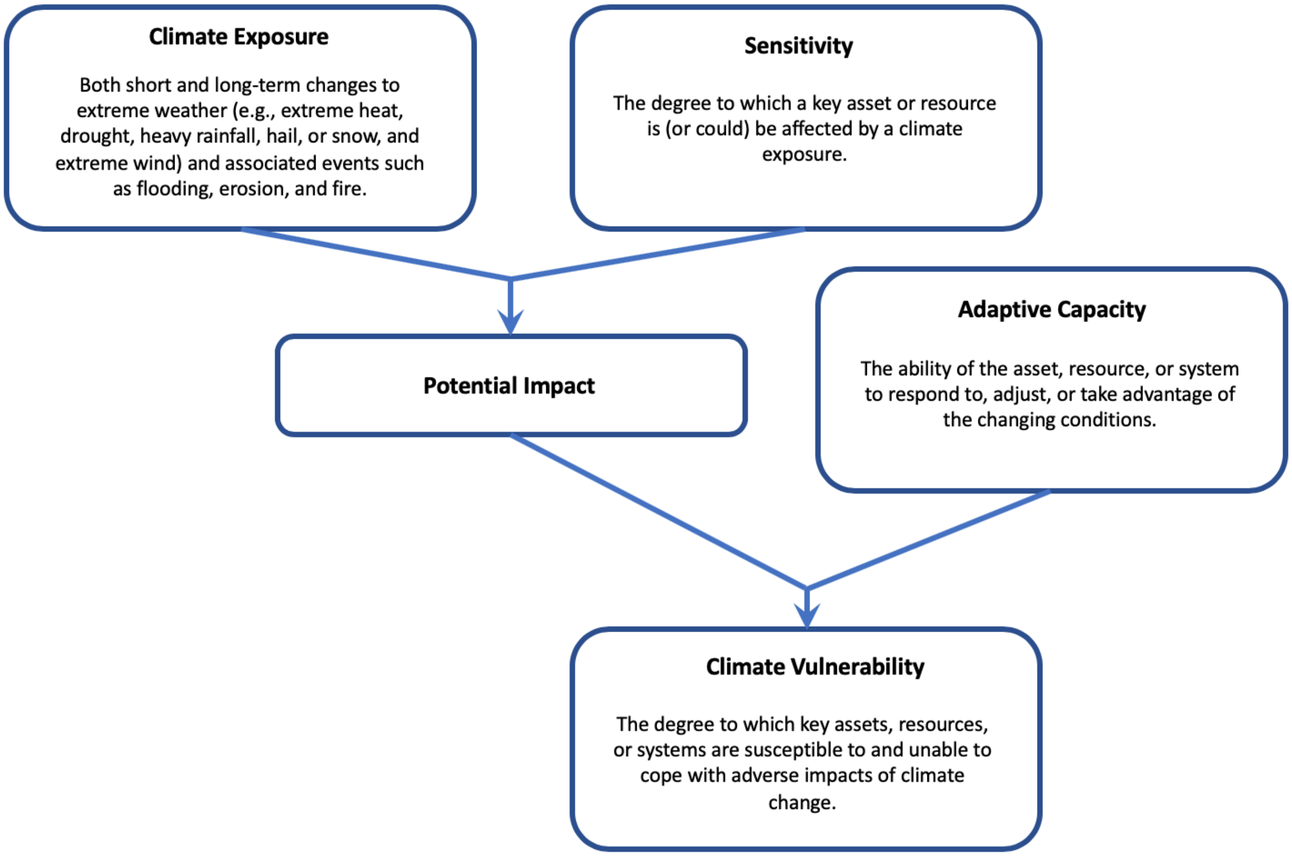


Figure 4: Definitions and relationships of Climate Exposure, Sensitivity, and Adaptive Capacity, all of which contribute to climate vulnerability. Source: (US Climate Resilience Toolkit, 2017).

2.3 Use of Existing Resources

While the Vulnerability Assessment presented here is unique to LEKT, it is not the first of its kind in the region. Examples of previous climate change and vulnerability studies used to provide background for this assessment include:

- Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes (2016)
- Stillaguamish Tribe Natural Resources Climate Change Vulnerability Assessment (2016)
- Climate Change Preparedness Plan for the North Olympic Peninsula (2015)
- Jamestown S'Klallam Tribe Climate Vulnerability Assessment and Adaptation Plan (2013)
- Olympic National Park Action Plan for Climate Friendly Parks Program
- Climate Change in Puget Sound (2015)
- Projected Sea Level Rise for Washington State (2018)

3 KEY ISSUES OF CONCERN

To focus the vulnerability analysis, the project team jointly developed a list of key issues of concern that provide specific examples that represent examples within each of the four overarching questions identified during the centering process. Focusing on example key issues of concern was a means of efficiently working through complex climate change vulnerability analyses, over a diverse built and natural landscape, with available time. While we chose to examine one resource over another, it does not imply that one is more important than the other.

The following sections provide the background and overview of the selection of these key issues of concern.

3.1 Natural Resources

During the tribal luncheon and in the online survey, LEKT community members and staff expressed concern about potentially harmful effects of climate change exposures on the major landscapes of the area: forest, river, and nearshore, which have long sustained LEKT people. Based on that feedback, ten key species were identified for vulnerability assessment that will serve as examples of how changes could occur to the three landscapes:

- For Forests: western red cedar, salal, and devil's club
- For Rivers: a discussion of the Elwha River and Chinook Salmon
- For Nearshore: Dungeness crab, geoduck, eulachon, and eel grass

There are many other species that are important to the LEKT. The ten examples used in this assessment were selected to provide examples of a range of potential vulnerabilities. The project team met with natural and cultural resource experts within the Tribe to discuss changes in quality of harvestable materials, harvest timing, and availability, as well as estimate of current and desired traditional use of species of cultural importance to the Tribe. This initial research and discussion provided important insights and cultural context for this analysis.

3.2 Built Environment

The vulnerability of the built environment to sustain people during extreme weather events, or to evacuate in times of emergency, was another dominant theme of the luncheon and survey. Emergency preparedness in the form of passable evacuation routes, updating or relocating buildings and facilities for sheltering-in-place and providing for frontline populations, such as the young/old and medically fragile, were all important areas to assess for climate change vulnerability. Ensuring long-term access to functional utilities, specifically power, water and sewer, were also identified as a priority.

Tribal Facilities

Potential climate exposure, coastal flood risk, river flood risk, channel migration and bluff erosion, risk to the water overflow treatment pump (on beach near dike), dike structure & tribal housing, the new downtown hotel, the Elwha Health Clinic, Elwha Food and Fuel, Daycare, Tribal Hatchery, Tribal Center, and Emergency operations/IT/Justice center were analyzed using best available topography. The water overflow treatment pump and levee system were analyzed in more detail, since critical elevations for the pump and levees are known, and they provide a critical drainage function for the LEKT.

Transportation Analysis

Transportation routes have potential to be impacted by climate changes. The LEKT identified critical transportation infrastructure:

- **Transportation Routes within LEKT Reservation & Elwha Watershed:** Kacee Way/ Stratton Road, Lower Elwha Road, Highway 101, Ediz Hook Boat Launch, Boat Haven Marina, Fairchild International Airport, Olympic Discovery Trail
- **Elwha River bridges:** Elwha River Road, Highway 112, Highway 101 (note – WSDOT is in the process of designing a new bridge)
- **Dry Creek bridges:** Olympic Discovery Trail, Edgewood Drive
- **Morse Creek bridge:** Highway 101

Water Distribution System and Alluvial Water Storage Capacity in our Natural Systems

The process for analyzing the vulnerability of the water distribution system was to create a description of the existing system related to potential threats from climate change, including post wildfire or flood. This analysis includes spatial analysis relating climate risks to the water system, particularly as it pertains to river hydrology and summer water supply. The current hazard management plan was consulted to identify known resources or needs.

Solid Waste, Wastewater Collection System, Septic Systems, Stormwater Management

The assessment included a general description of existing solid waste, wastewater, septic and stormwater systems relating to potential threats from climate change.

Power Delivery, Cell Towers and Emergency Communications

The assessment included a general description of existing power delivery systems, cell towers and emergency communications systems relating to potential threats from climate change.

3.3 Cultural Places and Practices

Sacred Places and Cultural Practices

The vulnerability assessment process for sacred places was to provide a general written description of potential threats to, and vulnerability of, culturally important sites and cultural practices discussed with the Tribe. The project team interviewed cultural resources department staff and worked with Tribal representatives to review and refine the written descriptions of important places and impact summaries to provide sufficient information for Tribal use without sharing sensitive cultural information or locations.

Villages

Village sites were/are commonly found at the confluences of rivers and streams. Tse-whit-zen, one of the largest of the Klallam villages, is used as an example for assessing the relative vulnerability of important cultural places to climate change.

3.4 Community Health and Wellness

Dr. Powell at the LEKT Health Clinic was interviewed to support the climate vulnerability assessment of the key concerns listed below. Community-specific data, for the community and wellness key concerns, listed below, were not available when research was conducted for this assessment. Much of the climate vulnerability assessment was primarily based upon a literature review.

Respiratory Stress and Allergies

The project team conducted a literature review of how climate change can impact the respiratory health of communities. Allergy and respiratory complaint data was limited within the community.

Diabetes (Type II)

The project team conducted a literature review-based description of the links between climate change, loss of traditional food sources and lifeways, and increases in Type II Diabetes in the community.

Communicable and Vector Borne Diseases

LEKT community members and staff have reported a concern that tickborne diseases may increase due to climate change. Lyme disease and West Nile Virus have been included in the analysis as examples to investigate relative vulnerability to climate change exposures and links to vector-borne disease. The project team conducted a literature review-based description of the links between climate change, Lyme disease, West Nile virus, and harmful algal blooms. This topic did come up in an interview with Dr. Powell, the LEKT Health Clinic doctor, however, this analysis used available literature on tick species distribution and historical/current range and habitat use, as well as available data on disease rates.

Mental Health and Social Relationships

The project team conducted a literature review of the links between climate change and mental health and impacts on social relationships within the community. The level of analysis remains general and focused on a regional scale where applicable.

4 CLIMATE EXPOSURES OVERVIEW FOR THE LOWER ELWHA KLALLAM LANDS

Future projections from climate models provide an opportunity for community and Tribal planners to consider and explore a range of plausible outcomes, while also taking into consideration the complexity of the climate system. It's important to remember that projections should not be thought of as predictions of what the weather will be like at a specified date in the future, but rather viewed as the long-term aggregate of weather, if greenhouse gas concentrations follow a specified trajectory.

Projections of climate variables in this report are best used in reference to historical climate conditions, both measured and observed. Comparing historical and projected future periods allows us the perspective to envision how the current systems of interest would respond to climate conditions that are different from what they have been. In some instances, projected changes fall within the realm of events that occur in the present, however, events that are now rare may become commonplace. In other cases, the projected change may be large enough that they are beyond our experience.

Understanding climate projections themselves is only the starting point for assessing the impacts that climate change may have on a community. Community experts and knowledge-holders are encouraged to think carefully about how those projections could translate into impacts on things that the community values. For example, it's one thing to grasp the abstract meaning of a 2 degree Fahrenheit change, but the real impacts of such an increase in temperature to wildlife are complex; the impacts on natural resources depend on temperature thresholds of individual species, or stresses they experience during summer high temperatures, and the cascading effects through the ecosystem.

4.1 Developing Climate Exposures

Climate change projections were used to assess exposure to climate-related impacts and were based primarily on data developed by Washington Sea Grant and the University of Washington Climate Impacts Group (CIG) (Krosby et al., 2020). The regional analyses from Washington Sea Grant and CIG were augmented with other information from the literature or more detailed local information where available. Climate protections vary with assumptions about timeframe, future trends, and spatial scale. Our general approach for the analysis was the following:

1. **Timeframe**: The assessment focused on mid-century (2050) and end of century (2100) projections, with modifications in some cases tailored to available data.
2. **Future trends**: Projections associated with the Representative Concentration Pathway (RCP) 8.5 emissions scenario, which represents the "business as usual" scenario, where greenhouse gas emissions continue at their current rate well into the future, was utilized most frequently to assess potential future impacts.
3. **Spatial Extents**: This assessment focused primarily on the core reservation area, generally extending from the Elwha River to the City of Port Angeles (see Figure 2), but extended to the climate change impact boundary in limited cases.

4.2 Climate Exposures and Future Changes in the Lower Elwha Region

Changes in temperature and precipitation, both type and amount, can drive complex changes to physical systems in the region that interact with one another in a variety of ways. These changes in environmental conditions further drive biological responses of species, on an individual level, as well as interactions with one another. Organisms respond to changing environmental conditions by altering their behavior, moving to more favorable conditions, changing the timing of their life phases, or otherwise adapting. These changes to natural resources, in turn, can greatly affect the culture and traditions of the Tribe and surrounding communities.

The icons at the start of each climate exposure description are used in the climate vulnerability assessment (Section 5) to identify these detailed exposure results.

Temperature

The Pacific Northwest warmed about 1.3°F (0.7°C) between 1895 and 2011, with statistically significant warming occurring in all seasons except for spring (Mote et al., 2013b). Warming is expected to continue to occur throughout the 21st century; temperatures averaged across the Pacific Northwest are projected to increase by between 3 and 8°F under the lower climate scenario (RCP 4.5) and by as much as 7 to 14°F for the higher climate scenario (RCP 8.5) by the end of the century (Mote et al., 2013a). This rate of warming is noteworthy, as it is the same order of magnitude of change, as the warming that occurred between glacial and interglacial periods (Mote et al., 2013a).

For the Lower Elwha Reservation, average annual temperature is projected to increase by about five degrees Fahrenheit by the middle of the century and more than 8°F by the end of the century. Projected changes in seasonal temperatures are arguably more important for projecting impacts for both species, habitats, and humans and human systems. Warming is expected to occur during all seasons, with the largest temperature increases, of as much as 10°F, projected for the summer months by the end of the century (Table 1).

Table 1. Average historical and projected changes in average annual temperature, average maximum summer temperature, and average number of days a year that will be warm (above 86 Degrees Fahrenheit) on the Lower Elwha Reservation. Projected increases are for the higher future scenario (RCP 8.5) for both the 2050s (2040-2069) and the 2080s (2070-2099).

Changes in Temperature (RCP 8.5)			
	Historical	**2050s**	**2080s**
Average Annual Temperature	49.0°F	+ 5.0°F	+ 8.3°F
Average of daily maximum Summer Temperature	66.4°F	+ 6.1°F	+ 10.0°F
Number of Days per year with daily maximum temperature above 86°F	0.1 days	+ 4.1 days	+ 11.6 days

As temperatures continue to increase, the number of extreme heat days do as well. Days above 86 degrees Fahrenheit are historically uncommon across the region, averaging much less than one day per year. These warm days are projected to increase to more than 4 days a year by mid-century and more than 11 days by the end of the century (Table 1).

Increasing seasonal temperatures leads to subsequent increases in the length of the growing season, defined by the number of days between the last frost in the spring to the first frost in the fall. The historical growing season on the reservation was about 8 months long and by the end of the century could extend to just short of a full year (346 days) (Table 2).

Table 2. Changes to the growing season for the Lower Elwha Reservation based on historical observations and future projections for the 2050s (2040-2069) and 2080s (2070-2099) under the higher future scenario (RCP 8.5).

Length of Growing Season (RCP 8.5)		
Historical	**2050s**	**2080s**
240 days	321 days	346 days

Heat Waves

The North Olympic Peninsula may be generally protected from truly extreme temperatures over the next century due to its close proximity to the moderating influence of the Pacific Ocean (Petersen et al., 2015b). Nighttime heat events have become more frequent in areas west of the Cascade Mountains of Washington and Oregon since the early 1900s (Bumbaco et al., 2013). While extreme heat is historically uncommon in the area, the number of days above 86 degrees Fahrenheit is projected to increase.

Precipitation

Precipitation in the Pacific Northwest (PNW) naturally varies over different temporal scales from years to decades. However, heavy rainfall events have increased in frequency and intensity beyond the natural variability. For example, the extreme rainfall events that fall in the top 1 percent of all daily events increased in frequency by 12 percent in the PNW during the 20th century (Global Climate Change Impacts in the United States, 2009).

Local projections for changes in the precipitation in the region vary, with some models projecting increases in average annual precipitation and some projecting decreases. For the Lower Elwha Reservation, average annual precipitation is projected to increase by 2.3 inches or about 9% (by the end of the century). The winter seasonal precipitation (October – March) is projected to increase by nearly 3 inches and fall more often as rain than snow. In contrast, already relatively dry summers (April – September) are generally projected to be drier by the end of the century (Table 3).

Table 3. Changes in average annual, winter seasonal (October – March), and summer seasonal (April – September) precipitation for the Lower Elwha Reservation based on historical observations and future projections for the 2050s (2040-2069) and 2080s (2070-2099) under the higher future scenario (RCP 8.5).

Changes in Precipitation (RCP 8.5)			
	Historical	**2050s**	**2080s**
Average Annual	26.1 in	+ 1.4 in (+ 5.4%)	+ 2.3 in (+ 8.8%)
Winter seasonal	20.3 in	+ 1.5 in (+ 7.4%)	+ 2.7 in (+ 13.3%)
Summer seasonal	5.7 in	- 0.2 in (- 3.5%)	- 0.4 in (- 7.0%)

Hydrology

The flow regime of the Elwha River follows seasonal fluctuations in temperature and precipitation, characterized by warm, dry summers and cool, wet winters. The presence of the Olympic Mountains strongly influences spatial precipitation patterns within the watershed, as snow-dominated high elevation areas can receive over ten times the amount of precipitation compared to along the coast. Precipitation falls as snow in upper elevations and predominantly as rain below approximately 4,000 feet. Annual average precipitation in the lower watershed is 26.1 inches and increases with elevation to over 240 inches near the headwaters (Duda et al., 2011). Figure 5 shows monthly averages for temperature and precipitation at the Elwha Ranger Station (elevation 360 ft.) for 1971-2000.

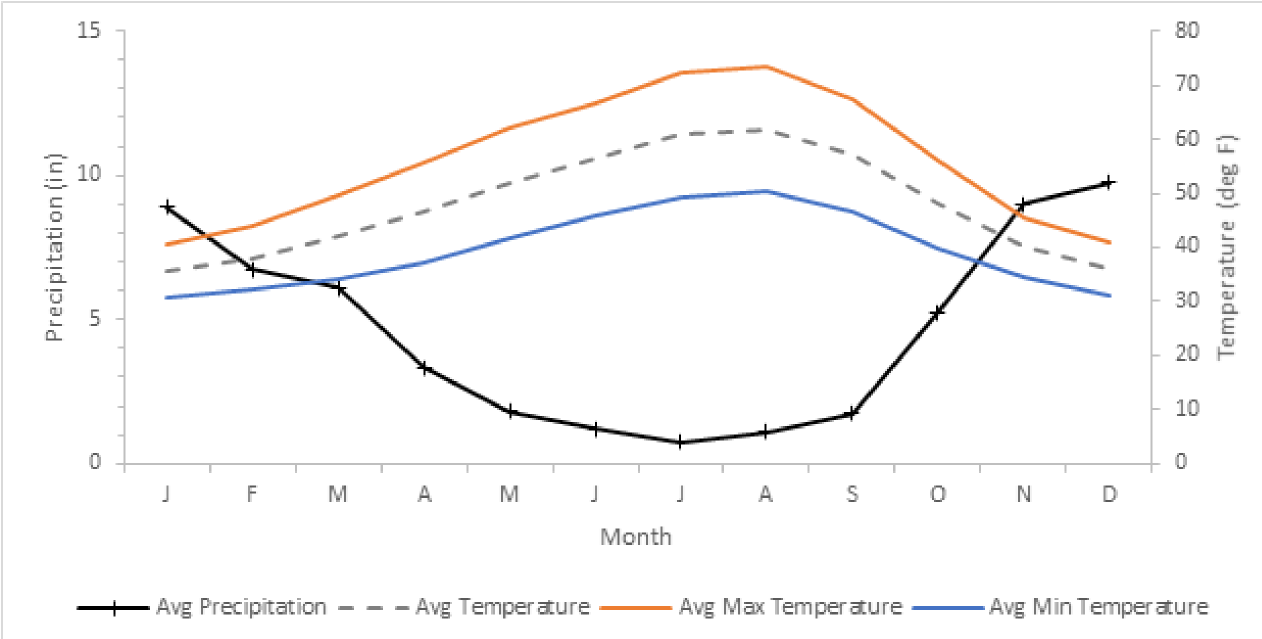


Figure 5. Monthly average precipitation and temperature recorded at Elwha Ranger Station gage from 1971-2000. Data source: Western Regional Climate Center (2000).

Increases in air temperature will have a disproportionate effect at higher elevations within the Elwha watershed due to impacts on snowpack and glaciers. By the end of the century, the number of freeze-free days in the upper watershed is projected to increase by 110 days based on the CIG Tribal Climate Tool, signaling a significant shift in precipitation type and storage as snow. By comparison, the number of freeze-free days within the LEKT Reservation at low elevations near sea level is projected to increase by only 36 over the same time period. (Figure 6).

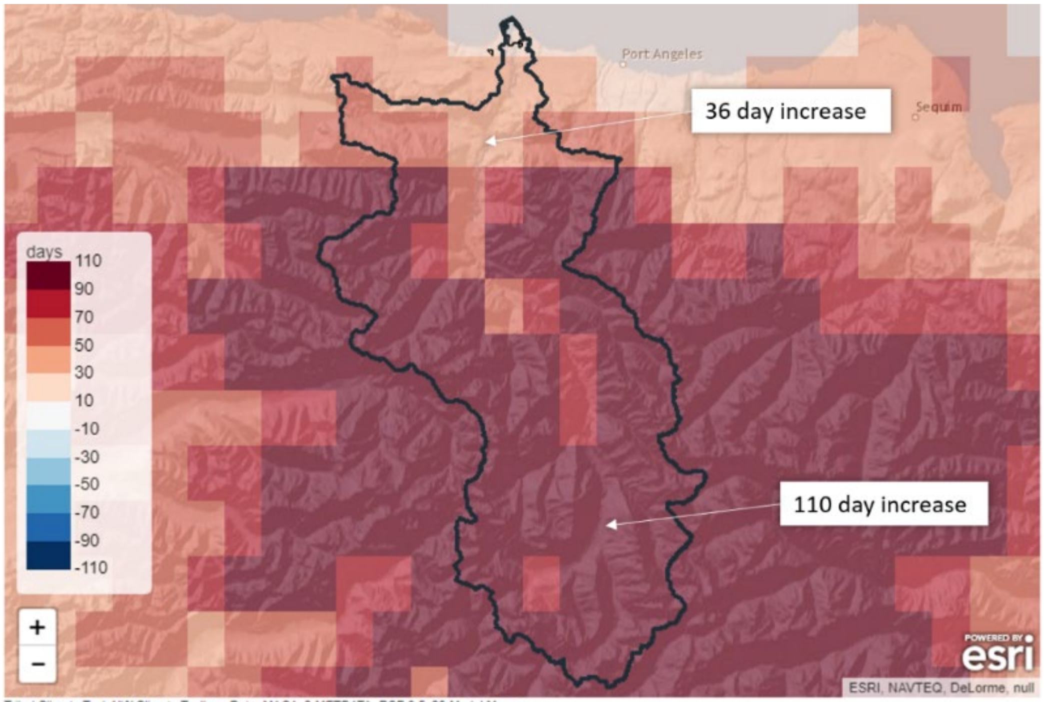


Figure 6. Map view of the increase in freeze-free days under the RCP 8.5 emission scenario (by 2099). Data source: UW Climate Impacts Group and NW toolbox accessed June 2020 (Krosby et al., 2020).

Snowpack and glaciers act as storage for precipitation that falls as snow during the winter and is gradually released as melting occurs in the spring and summer months. Warmer temperatures will shift an increasing amount of precipitation to rainfall, instead of snow during winter months, and will increase the rate at which the snowpack melts during summer months. As snowpack declines and glaciers recede across the Olympic Peninsula due to climate change, the Elwha River will experience intensified summer lower flows and higher stream temperatures.

These changes are compounded by projected increases in winter precipitation and decreases in summer precipitation, which have the potential to negatively affect salmon, and other riverine species that rely on them, at critical life stages (Grah and Beaulieu, 2013). As winter precipitation increases, average streamflow and peak flood flows will also increase in magnitude (Elsner et al., 2010) . Projected increases in winter precipitation are 4 inches and 20 inches for the lower and upper areas of the Elwha watershed on an annual basis, respectively. Decreased summer precipitation will exacerbate the issue of low flows in the Elwha River.

Snow-water Equivalent (SWE)

Snowpack volume is commonly represented by the snow-water equivalent (SWE), or the amount of water held in the snowpack on April 1 of a given year. Snowmelt supplies cool baseflow for the Elwha River during summer months when streamflow is at its lowest levels of the year. In the western United States, the SWE has decreased by approximately 20% between 1950 and 2000, and an even greater decline in the Elwha River Basin of 57%. Warming temperatures are attributed to the decline of April 1-SWE compared to precipitation and non-climatic factors (Mote, 2006).

Past seasonal anomalies can provide a glimpse of what a climate-altered future may look like. During the winter of 2014-2015, record-breaking temperatures occurred from October to March, 4.7°F above the 20th century average. By May 2015, Governor Jay Inslee declared a statewide drought emergency as the average snowpack in

Western Washington was at 10% of the median value for 1981-2010, with the lowest levels measured in the Olympic and Central Puget Sound basins (USDA NRCS, 2015). As recently as 2019, the City of Port Angeles prepared for a voluntary water conservation under a Stage I water shortage due to an early melt of average snowpack conditions (Leach, 2019).

Glaciers

Mountain glaciers are unique ecosystems in themselves and provide an especially vital source of baseflow for river systems during warm, dry periods. In the Elwha watershed, glaciers account for 2.5 to 4.0% of May-September streamflow. Glaciers of the Olympic Mountains are relatively small and thin, and with less snow accumulation, they adjust rapidly to changing climatic conditions over a multi-decadal timescale (Riedel et al., 2015). Since 1980, there has been a loss of 82 individual small glaciers and a decrease of 34% in the total combined area of glaciers on the Olympic Peninsula. The total area of glaciers within the boundaries of the Elwha watershed has declined by approximately 25% in the same time period (Pelto, 2010).

Streamflow

River flow and sediment transport in and through the Elwha River is highly dynamic, varying by season and year. Its response to climate change will be sensitive to this natural variability, as well as the geologic and topographic controls, that define its form. The mainstem Elwha River has an approximate length of 45 miles while tributaries total over 100 miles, much of which is in the upper watershed. For this reason, tributaries in particular, will be most heavily impacted by changes in air temperature and precipitation. Figure 7 plots the annual hydrograph in terms of mean daily flow.

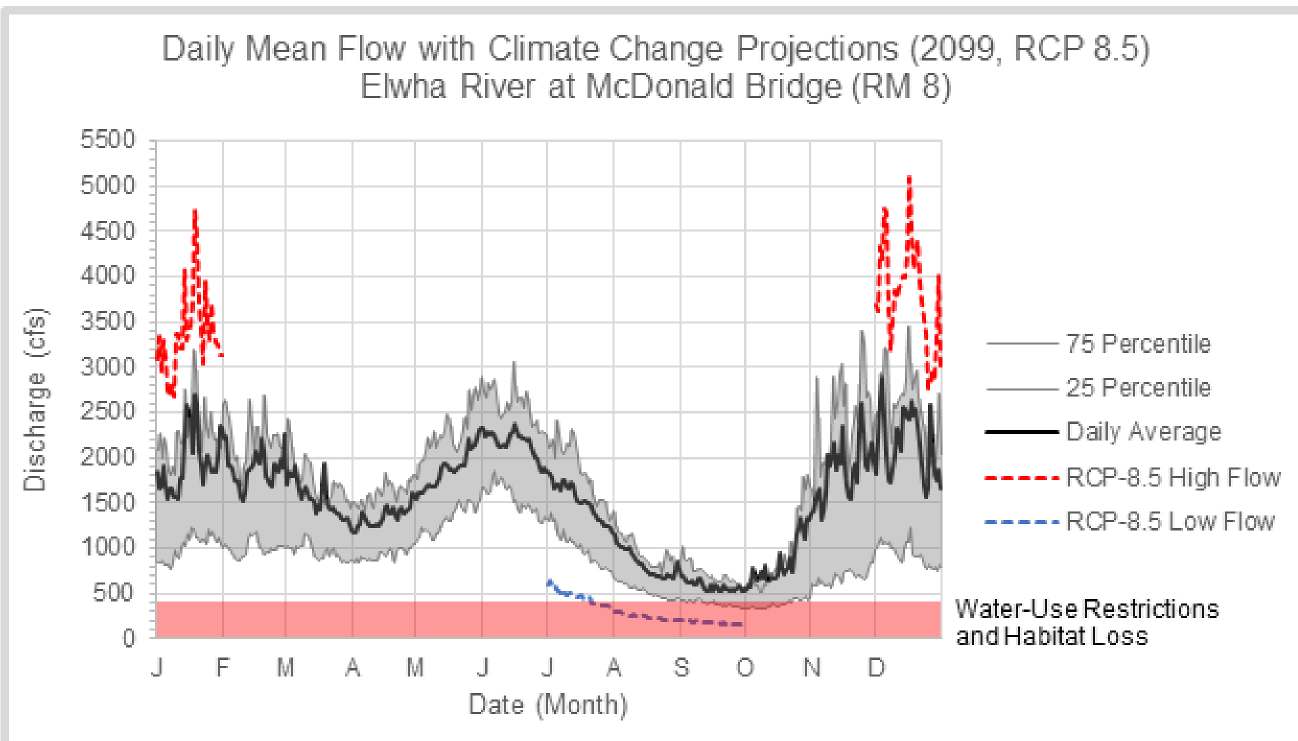


Figure 7. Annual hydrograph of the Elwha River showing daily mean flow recorded at USGS 12045500 (1971-2000). The gray hatch indicates daily mean flows between the 25th and 75th percentiles. Red lines indicate the projected increase in winter maximum flows (Dec-Jan), and blue line shows the decrease in summer low flows (Jul-Sep).

The Elwha River has a bimodal hydrograph, Figure 7, defined by a peak in the winter months due to rainfall and a peak in the early summer due to snowmelt. The average daily mean flow is shown by the solid black line and bounded by the 75^{th} and 25^{th} percentile flows shown in gray. Under the RCP 8.5 emission scenario, winter maximum flows are expected to increase by 48% (red lines) by the end of the century. Increase in winter peak flows will increase the frequency and duration of channel bed disturbing events in the mainstem Elwha River and its tributaries.

The gray area represents the 25^{th} percentile of flows, which just reach the threshold of City-imposed water use restrictions and levels that induce habitat loss for aquatic species (shown by red area in Figure 7). During summer months, minimum flows are expected to decrease by 56**%**, under the RCP 8.5 scenario, by year 2099. Projected reductions in summer streamflow will directly decrease aquatic habitat with less depth and wetted area. Water availability, including for the City of Port Angeles' sole water intake facility along a side channel of the Elwha River, will also be reduced, likely to levels that will require water use and timing restrictions.

Extreme high and low flow events are important drivers of geomorphic and habitat-forming processes and threaten human-built infrastructure. Changes in channel form often occur at peak flows, or flood events, in areas with broad fine-grained floodplains, such as the Lower Elwha River. Under historical conditions, the 50-yr and 100-yr flood magnitudes are 38,500 cubic feet per second (cfs) and 43,700 cfs, respectively, though the removal of the Elwha River dams may have increased the magnitude of the 100-yr flow by 10-15%, to ~49,000 cfs) (Duda et al., 2011). Climate change is likely to increase peak flows; under the RCP 8.5 emission scenario, the 50-yr and 100-yr flows are expected to increase by approximately 30% to 50,000 cfs and 64,000 cfs, respectively.

Low flows in the Elwha River are expected to be significantly lower in the coming decades. Currently, a measure of typical low flows calculated as the 10 percent exceedance probability of low flows averaged over 7 days (known as the 7Q10 flow) is 247 cfs. The projected 65% reduction means that the future 7Q10 would be approximately 160 cfs (Duda et al., 2011). Habitat loss in the Lower Elwha River is expected at flows less than 400 cfs, and current water rights allow for withdrawals of more than 200 cfs (City of Port Angeles, 2017). **Therefore, future low flow levels will have severe impacts on water availability to support aquatic habitat and industrial and municipal water withdrawals**. Sustaining in-stream flows for salmonids will require reducing human water demands or finding alternative sources.

Another projected future change in streamflow is the loss of the snowmelt runoff peak. Under the RCP 8.5 scenario, the Elwha River is expected to lose its snowmelt driven summer peak by year 2099 (May through August, Figure 7) primarily due to warming air temperatures. Loss of snowmelt will result in a systematic shift of the watershed from a transient-type to a rain-dominated system (Duda et al., 2011). Peak streamflow events will be primarily driven by precipitation events early in the winter, making the system less resilient to periods of drought.

August stream temperature in the Lower Elwha River is projected to increase from 60.8 to 64.4 degrees Fahrenheit under the moderate emission scenario for 2099. Annual maximum of weekly stream temperatures is typically used to evaluate limiting conditions for thermal stress. Increases in stream temperature will be most severe in the lowest reaches of the Elwha River during summer months.

Wildfire Risk

Projected decreases in summer precipitation coupled with increases in summer temperatures will reduce the moisture content in existing fuels, which facilitates fires. In addition, earlier snowmelt could lead to an earlier onset of the fire season. The median annual area burned in the Northwest from 1916-2006 is 500,000 acres; models for the end of the century (under medium GHG emissions scenarios) project an increase to 2 million acres by the 2080s.

Because the Olympic Peninsula has a low historical annual area burned, it is harder to project future fire risk for the region; however, the projected seasonal changes in temperature and precipitation could lead to lower soil moisture levels and higher evaporation rates, **resulting in higher wildfire risk in areas that have not traditionally been considered fire-prone**.

Large fires in Western Washington typically occur on steep south-facing slopes and often are a result of a combination of factors and circumstances: a source of ignition in areas of dry, heavy fuels; an extended period of drought; and dry east winds. The fires usually occur during the months of July, August, and September, but can occur between April and October under the right conditions. Clallam County rarely has conditions that lead to low enough moisture levels in fuel for major fires, yet smaller fires occur frequently. Most fires burn themselves out at less than one-quarter acre due to higher fuel moisture and topographic barriers (Clallam County, 2009).

For the reservation area, the number of days per year where fire danger is “very high” or “extreme” is projected to increase. “Very high” fire danger days are days where the moisture in the 100-hour fuel (dead vegetation with one to three-inch diameter trunks/stalks available to burn) is in the lowest 10% of days observed. These days are expected to increase about 35% by the 2050s, to about 50 days total per year. “Extreme” fire danger days are days when the moisture level is in the lowest 3%. These days are expected to increase about 57% to almost 20 days total per year under the higher future scenario (RCP 8.5) (Table 4).

Table 4. Projected change to the number of “very high” and “extreme” fire danger days per year for the Lower Elwha Reservation by the 2050s (2040-2069).

Changes in Fire Danger (RCP 8.5)		
	Historical	**2050s**
“Very High” Fire Danger	36.5 days	49.2 days (+ 12.7 days)
“Extreme” Fire Danger	11.0 days	17.3 days (+ 6.3 days)

Coastal Flooding and Sea Level Rise

Coastal areas and the marine waters of the LEKT’s usual and accustomed areas are a critical component of the Tribe’s sense of place and play an irreplaceable role in their traditions and cultures. Coastal areas are also economically vital. Coastal and marine ecosystems provide valuable ecosystem services that support both human and natural communities. Sea level rise will exacerbate existing risks and vulnerabilities along the shoreline, such as bluff erosion, storm surge, coastal flooding, and groundwater intrusion (Miller et al., 2018). Sea level rise and coastal flooding will impact infrastructure and ecosystems both through permanent inundation of lower-lying areas and by increasing the frequency and intensity of coastal flooding.

Changes in global sea level are closely linked to increasing mean global air and ocean temperatures. Sea level rise is driven primarily by two main factors: 1) increased volume of sea water due to thermal expansion as the water warms, and 2) increased total amount of water in the ocean due to the addition of meltwater from glaciers and land-based ice sheets (i.e. Antarctic and Greenland Ice Sheets) (Sweet et al., 2017). To a lesser extent, the total mass of water in the ocean is also affected by changes in land-water storage, through groundwater depletion and reservoir impoundment (Kopp et al., 2014).

Mean global sea level has risen by a total of 7-8 inches (16-21 cm) since 1900; however, the rate of sea level rise has increased since the early 1990s due to the increased melting of land-based ice. Consequently, about half of the observed global average sea level rise of 7-8 inches has happened since 1993. Relative to the year 2000, global average sea level is very likely to rise by 0.3–0.6 feet (9–18 cm) by 2030, 0.5–1.2 feet (15–38 cm) by 2050, and 1–4 feet (30–130 cm) by the end of the 21st century (Hayhoe et al., 2018).

Local sea levels along the coast of the Pacific Northwest are also expected to rise, though at different rates than the global average due to natural variability in climate patterns that influence ocean currents and wind patterns (e.g. El Niño–Southern Oscillation and the Pacific Decadal Oscillation). Another factor affecting local sea level rise is vertical land motion—rising or sinking of land—due to geologic processes, including the subduction of oceanic plates and isostatic rebound of the land from compressive weight of Ice Age glaciation (Dalton et al., 2017; Reeder et al., 2013) (National Research Council (NRC), 2012).

Sea level rise can be presented in two different ways, as absolute sea level change (the height of the ocean surface relative to a fixed reference point) and relative sea level change (the combination of sea level change and vertical land movement) for a specific location. Relative sea level rise is most applicable for community adaptation planning, since it will determine the most localized impacts of sea level rise on the coast. Therefore, relative sea level rise projections and likelihoods are used throughout this analysis.

The Washington Coastal Resilience Project (WCRP) produced relative sea level projections for different parts of the state that incorporate differences in vertical land motion. The projections are probabilistic, meaning that for each scenario, a set of probabilities describe the likelihood that sea level will meet or exceed a particular threshold (Miller et al., 2018). There is often a wide range of variability among projections, even within the same scenario, which is primarily due to the complexity of Earth's climate systems and how the components of that system interact. For example, it is not well understood how quickly glaciers and large land-ice sheets (such as the West Antarctic ice sheet) will melt. This creates variability and uncertainty in sea level rise projections (Miller et al., 2018).

Local relative sea level in Port Angeles is rising at a rate of about 0.016 inches (0.4 millimeters) per year, using sea level data from 1975 to 2019, which is equivalent to a change of just 0.1 feet (4 centimeters) if extrapolated over the last century (NOAA, 2020). Local relative sea level rise is *likely* (83-17% probability of exceedance) to rise by 1.2 to 2.5 feet from the 1991-2009 sea level average by 2100 under RCP 8.5 (Table 5). Under the very low (0.1% probability of exceedance), sea levels could rise by as much as 8 feet by the end of the century. The data for each time period represent the average sea level change over a 19-year period centered around the date listed.

Table 5. Relative sea level change projections, through 2150, for a high greenhouse gas scenario (RCP 8.5) for Port Angeles, WA. All projections are relative to the average sea level for 1991-2009, and the probability values are "probabilities of exceedance", i.e., the best assessment of likelihood that sea level will rise by at least a given change in elevation. (Data from Washington Coastal Resilience Project: https://wacoastalnetwork.com/chrn/research/sea-level-rise/).

Projected Relative Sea Level Change (feet, averaged over 19-yr period centered on year)						
Time Period	Virtually Certain (99%)	Central Estimate (50%)	Likely Range (83-17%)	Higher Magnitude, but lower likelihood possibilities		
				5%	1%	0.1%
2030	0	0.2	0.1 - 0.3	0.4	0.5	0.6
2040	0	0.4	0.2 - 0.5	0.6	0.8	1.1
2050	0	0.5	0.3 - 0.7	0.9	1.2	1.9
2060	0.1	0.7	0.5 - 1	1.2	1.6	2.7
2070	0.2	0.9	0.6 - 1.3	1.6	2.2	3.8
2080	0.2	1.2	0.8 - 1.6	2.1	2.9	5
2090	0.3	1.4	0.9 - 2.0	2.6	3.6	6.4
2100	0.3	1.7	1.2 - 2.5	3.2	4.5	8
2150	0.6	3	1.9 - 4.5	6.1	9.5	17.9

It is important to note that the probabilities associated with the sea level rise projections are fundamentally different from probabilities associated with coastal flooding, such as a 100-year flood event (see Table 6 for water level associated with extreme storm events). The 100-year flood is defined as a level of flooding having a 1% chance of occurring in any given year and is derived from historical data and observations using the frequency of past high-water events and the occurrences of drivers of those events (e.g., high winds). In contrast, the probabilities of the different sea level rise projections are derived using models to project changes over time. Thus, the probabilities incorporate uncertainties from both the models and the observations used to refine the models.

Table 6. Extreme still water levels measured at Port Angeles, WA, tide gauge shown relative to mean higher high water (MHHW) across a range of storm event probabilities. Source: Station 9444090, (NOAA, 2020).

Extreme Storm Event	Probability of Occurring in 1 year	Water Level above MHHW (ft)
1-yr	99%	2.4
10-yr	10%	3
100-yr	1%	3.4

Bluff Erosion

Retreat of the coastal bluffs between the Elwha River and Port Angeles (hereafter referred to as the Elwha Bluffs) occurs as waves and currents erode the base of tall glacial deposits. Bluff retreat is an important source of sediment to the nearshore, supporting ecosystems and habitats. Bluff retreat also presents risks to infrastructure at the top of the bluff, as evidenced by bluff stabilization at the former landfill west of Port Angeles. The unarmored portions of Elwha Bluffs have eroded at average rates of approximately 1.3 feet/year (Parks, 2015). Sea level rise is likely to increase the rate of bluff erosion as the probability of water levels and wind waves eroding the bluff toes increases. To estimate the potential amount of bluff retreat by 2150, historical erosion rates were increased by 20%, after Section D in Petersen et al. (2015a) to 1.6 feet/year, with an added 25 foot buffer, per Parks (2015), to account for uncertainties and sudden bluff failures (Figure 8).

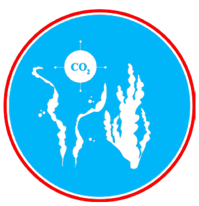
Figure 8. A bluff erosion risk zone for the unarmored sections of the Elwha Bluffs bordering the LEKT Reservation. The risk zone is intended to convey areas that could be exposed to erosion by 2150 due to expected increases in erosion rates, which have historically averaged ~1.3 ft/yr (Parks, 2015)

The Climate Change Preparedness Plan for the North Olympic Peninsula (Petersen et al., 2015b), provides an excellent overview of the relationship between nearshore health and climate change:

> *"The health of the nearshore is currently influenced by environmental conditions such as ocean chemistry, temperatures, dissolved oxygen levels, phytoplankton blooms, and water circulation patterns. Climate change will influence these conditions, as well as introduce changes to the amount and timing of freshwater inputs, shift erosion patterns, altered sediment delivery and transport, and increased opportunities for invasive plants and animals. Sea level rise may encroach and even inundate coastal marshes and wetlands, unless these ecosystems are able to migrate landward, an opportunity dependent on topography, upland land uses, and the presence of shoreline armoring. Coastal inundation to rural-residential areas adjacent to nearshore ecosystems could impact the areas of the Dungeness River delta, the Elwha River delta, Beckett Point, and Diamond Point. High Feeder bluffs may be subject to increasing rates of erosion and their importance to the region has been calculated as providing over three times the value of shoreline protection compared to engineered armoring (Flores et al., 2013)."*

The Climate Change Preparedness Plan for the North Olympic Peninsula (Petersen et al., 2015b) identified the Elwha Bluffs as a priority area for conservation of intact nearshore ecosystem.

Ocean Warming and Acidification



In addition to rising sea levels, ocean warming causes many direct and indirect impacts to marine ecosystems. Warming oceans increase water temperatures at all depths, which can affect water circulation and salinity and change water chemistry. Ocean heat storage has implications for all global systems, including seasonal and regional climate variability, ocean circulation and stratification, and heat transport. Climate change is also causing changes in chemical processes in warming ocean waters, making waters more acidic and influencing oxygen availability for natural processes. These changes in turn affect coastal and marine ecosystem composition and dynamics and impact the availability and sustainability of important natural resources for traditional, ceremonial, commercial, and recreational uses. All of these physical and chemical changes affect the distribution and abundance of marine life throughout the ecosystem and impact the livelihoods and cultural traditions that depend on the ocean.

The world's oceans have absorbed about 30 percent of the atmospheric carbon dioxide emitted by anthropogenic sources. As CO_2 dissolves in water, it undergoes a series of chemical reactions that ultimately increases the acidity of the ocean water (decrease in pH). This process is called ocean acidification (OA). The acidity of a substance is measured by the concentration of hydrogen ions, or the pH; the lower the pH of a substance, the more acidic it is. The change in pH units is logarithmic, so a whole number increment represents a tenfold difference in hydrogen ion concentration. Ocean water pH can vary temporally and spatially due to local factors, such as the daily uptake and release of carbon dioxide of aquatic vegetation during photosynthesis and respiration.

The same chemical processes that lead to the decrease in ocean pH also reduce the saturation state of the minerals aragonite and calcite, two forms of calcium carbonate that are essential for marine species such as crabs, clams, oysters, and certain types of plankton to build their shells and skeletons. The saturation state of a mineral describes a set of conditions in which the mineral will either form or dissolve in seawater. Decreased saturation states interfere with the ability of organisms to form shells, which can greatly impact their survival.

Since the beginning of the industrial era, the pH of ocean surface water has decreased by 0.1 pH units in the North Pacific and is projected to decrease by another 0.3-0.4 pH units by the end of the century. This change translates to a 26 percent increase in hydrogen ion concentration, or acidity levels in surface waters approximately 150% higher than pre-industrial levels by the end of the century. Colder waters, such as those of the North Pacific and along the northern Olympic Peninsula, can absorb more CO2 gas than warmer waters and are typically more vulnerable to acidification than lower latitude waters. In addition, coastal waters off Washington and Oregon are quite productive and strongly influenced by the California Current system, due to a combination of seasonal upwelling and freshwater inputs from rivers that deliver high levels of nitrogen and phosphorus from terrestrial sources. Nitrogen acts as a fertilizer for intense algae blooms that die and sink into deeper water and are decomposed via microbial respiration. This process leads to the release of large amounts of CO2 directly into the water column, lowering the pH and aragonite saturation rates, and also reducing the amount of oxygen that would otherwise be available to other organisms in the surrounding area.

Ocean acidification has the potential to negatively affect a variety of culturally and economically important marine species in the Pacific Northwest; however, some species are more studied than others. The direct biological impacts of OA can result in changes to development, growth, reproduction, and behavior of a variety of species. The extent of these changes varies by species. Ocean acidification has been demonstrated to significantly reduce the size of shrimp and mussel larvae, degrade shell integrity (strength and thickness) in mussels, and cause developmental delays in oyster larvae. In general, the most negative impacts of OA are observed in marine organisms with calcium carbonate structures (shellfish); however, changes in water chemistry may also disrupt nerve function in fish, while other species that use CO2 to photosynthesize (like seagrasses and algae) may benefit. These coastal species have important significance in the livelihoods and cultural practices of the Western Washington tribes and understanding the potential impacts on priority species and the broader ecosystem can help the Tribe better prepare for future changes.

4.3 Non-climate Exposures

The United States Geological Survey (USGS) estimates that the Lower Elwha Klallam Tribe's Reservation lands have a 60-80% probability of experiencing an earthquake of 6.0 magnitude or greater in the next 100 years. Historically, there have been five deep earthquakes of magnitude 6 and one of magnitude 7 since 1900 in the vicinity of the LEKT Reservation and Port Angeles. Crustal quakes occur at a depth of 5 to 10 miles beneath the earth's surface and are associated with fault movement within a surface plate. There have been four crustal earthquakes of magnitude 7 or greater in the last 1100 years, including two since 1918, on Vancouver Island. Of particular concern, though, is an earthquake on the Cascadia Subduction Zone (CSZ) of sufficient magnitude to generate a large tsunami. According to the 2011 LEKT Hazard Mitigation Plan (HMP), for a 9.0 CSZ event, the lower reservation will be,

> *"subjected to strong shaking, landslides, and tsunamis. Buildings, roads, bridges and utility lines will suffer varying amounts of damage. Some will be destroyed. Extensive injuries and fatalities are likely. Within minutes, a tsunami will arrive, making it essential that residents and visitors understand the need to head for higher ground or inland as soon as the shaking stops. Coastal Highways 101 and SR 112 will be impassable over large stretches, and landslides through the Olympic Mountains and foothills will sever highway travel in Clallam County, particular east-west traffic. Destruction of roads, runways, ports, and will leave individual communities isolated. Residents and visitors will have to do much of the work of rescuing those trapped in the rubble and will be responsible for the immediate clean-up and organization to distribute relief supplies." (Cascadia Region Earthquake Workgroup (CREW), 2005).*

The 2019 Lower Elwha Klallam Tribe All-Hazards Mitigation Plan found that the infrastructure in the Lower Elwha Reservation was at high to very high risk from combined earthquake hazards (Clallam County Emergency Management, 2019). Below is a list of Lower Elwha Reservation critical facilities from the 2011 draft LEKT HMP, which were also listed in the 2019 Clallam County All-Hazards Mitigation Plan. Many of which have been relocated to the bluff since 2011.

- Tribal Center
- Lower Elwha Klallam Casino
- Tribal Health Clinic
- Tribal Police Station – relocated to bluff
- House of Salmon Hatchery
- Emergency Operations Center – relocated to bluff
- USACE Flood Control Levee
- Bureau of Indian Affairs Roads (37.4 miles)

It is important to note that the probability of the type of earthquake sufficient to generate a tsunami is independent of climate change, however, the magnitude of impact would be so severe that this process is included in this planning document.

Lowlands along the Elwha River and Port Angeles, including portions of the reservation, are within the landward limit of expected inundation from a large tsunami associated with a Cascadia Subduction Zone (CSZ) earthquake of magnitude 9.1 (Walsh et al., 2002). This scenario does not include the influences of tidal changes and uses an assumed tide height of 4 feet. Tsunami inundation maps were recently developed for the Olympic Peninsula that confirm the risk, particularly along the Elwha Estuary and portions of downtown Port Angeles (Dolcimascolo et al., 2022).

The Cascadia Subduction Zone (CSZ) is located along the outer coast, and the last major earthquake, which is thought to be about a magnitude 9.1, occurred in 1700 (Atwater et al., 2005; Jacoby et al., 1997; Kilfeather et al., 2007; Satake et al., 1996; Williams et al., 2005). Petersen et al. (2002) predict a 10 to 14 percent chance that another could occur in the next 50 years. The rarest events are subduction zone earthquakes like the one which occurred in 1700.

As of 2019, a new school and Head Start building were being constructed on high ground, and an evacuation plan was completed. With mitigation actions taken since 2011, the LEKT is officially a tsunami and storm-ready community.

5 VULNERABILITY ASSESSMENT

The overall climate vulnerability for each of the Key Concern areas is presented below. Each Key Concern section includes a discussion of local context and relates the overall climate exposures to the 1-5 numerical scale. The sensitivity and adaptive capacities are presented, both scored on 1-5 numerical scales. The three scores are then combined to develop the overall vulnerability of high, medium, or low, summarized in Figure 9.

Key Concern		Vulnerability Category
Forest Environment	Salal	Low Vulnerability
	Devil's club	Medium Vulnerability
	Western red cedar	Medium Vulnerability
River Environment	The Elwha River	High Vulnerability
	Chinook Salmon	High Vulnerability
Nearshore Environment	Dungeness Crab	High Vulnerability
	Geoduck	High Vulnerability
	Eulachon	Medium Vulnerability
	Eelgrass	Medium Vulnerability
Built Environment	Reservation Facilities and Homes	Medium Vulnerability
	Downtown Port Angeles Assets	Medium Vulnerability
	Elwha River Facilities	Medium Vulnerability
	Roads and Bridges to/from Reservation	Low Vulnerability
	Power delivery	Medium Vulnerability
	Water availability & distribution	High Vulnerability
	Wastewater Collection System	Low Vulnerability
	Cell towers and emergency comm.	Low Vulnerability
	Solid waste management	Low Vulnerability
Cultural Places and Practices	Village locations & Sacred Places, Cultural Practices	Medium Vulnerability
	Allergies, Asthma, & Respiratory Stress	Medium Vulnerability
	Communicable & Vector Borne Diseases	Low Vulnerability
	Diabetes Type II	Medium Vulnerability
	Mental Health & Social Relationships	*Unknown*

Figure 9. Summary table of vulnerability rankings for all key concerns.

5.1 Vulnerability Ranking Approach

To determine the relative vulnerabilities of each key concern, exposure and sensitivity, and adaptive capacity were assessed and assigned a relative rating according to the rationale summarized in Figure 10. The vulnerability ratings are relative and are intended to provide insights about where the Tribe can prioritize adaptation plannning efforts.

Key concerns determined to be high vulnerability may be a clear area to start adaptation planning efforts; however, some low vulnerability concerns may be significant enough to require adaptation planning as well. The icons at the start of each key concern section are used to reference detailed exposure results in section 4.

Climate Exposure		
Exposure and Sensitivity	High	Climate change is affecting Key Concern now and/or will significantly influence Key Concern in the future.
	Medium	Climate change is projected to cause some negative effects on Key Concern by the middle of the 21st century. OR there is high degree of uncertainty in exposure and sensitivity.
	Low	Climate change is projected to negatively affect Key Concern by end of 21st century.

Adaptive Capacity		
Adaptive Capacity	Low	Key Concern is not able to accommodate or adjust to impact.
	Medium	Key Concern is somewhat able to accommodate or adjust to impact. OR there is a high degree of uncertainly in the key concern's adaptive capacity.
	High	Key Concern is able to accommodate or adjust to impact in a beneficial way.

Figure 10 . The rationale for the relative ratings for climate exposure/sensitivity and adaptive capacity.

The relative vulnerability of each key concern was then determined using the combination of the exposure/sensitivity and adaptive capacity results (Figure 11). The relative rankings provide information about which concerns will be affected first and worst by changing climate conditions and can help the Tribe determine where to begin adaptation planning efforts.

		Exposure/Sensitivity		
		Low	*Medium*	*High*
Adaptive Capacity	*High*	Low Vulnerability	Medium Vulnerability	Medium Vulnerability
	Medium	Low Vulnerability	Medium Vulnerability	High Vulnerability
	Low	Low Vulnerability	High Vulnerability	High Vulnerability

Figure 11. Vulnerability ranking based on combination of exposure/sensitivity and adaptive capacity.

5.2 Natural Environment Key Concerns

Forest Environment

The LEKT describes the lower part of the Elwha River watershed as a place of extraordinary abundance that provided food, medicine, shelter, livelihood, and spiritual practices (Valadez, 2011). Forest resources included western red cedar, red alder, big leaf maple, western yew, douglas fir, labrador tea, ocean spray, devil's club, stinging nettle, salal, sword and bracken fern, cattail, bear grass, oregon grape, horsetail, tiger lily, red huckleberry, snowberry, thimbleberry, salmonberry, black gooseberry, soap berry, strawberry, blackberry, red elderberry, bunchberry, and camas (Valadez, 2011).

The vulnerability of forest ecosystems was assessed by evaluating the vulnerability of three indicator species: áqaʔ (salal), x̣paʔčí̓ɬč (western red cedar), and púʔqʷɬč (devil's club). Western red cedar, salal, and devil's club were chosen as focal species for this vulnerability assessment to represent species used for shelter and travel, food, and medicine, respectively, and represent a range of habitats. Vulnerabilities for these indicator species ranged from low to medium. The most vulnerable aspect of the forest environment are species which rely upon summer water availability from the Elwha River. The least vulnerable are the species which thrive under more varied environmental conditions and have more drought tolerance.

Changes in temperature, precipitation, hydrology and wildfire risk are the biggest climate change exposures for forest landscape and the three indicator species.

Wildfire, drought, and diminishing snowpack are directly connected to **increases in daily temperature** and **shifts in the timing and type of precipitation.**

Since 1973, there have been been four large wildfires in the Ewha River watershed, three in July 2016 and one in August 2019, all caused by lightening and ranging in size from 43 acres to 2,390 acres (Washington State Geospatial Open Data Portal, 2019). According to Clallam County's Community Wildfire Protection Plan (Clallam County, 2009), there will be an increased wildfire hazard particularly along the wildland-urban interface in eastern Clallam County.

Increased drought stress on soils and plants has been documented over the last 40 years (Clallam County, 2009). Extreme droughts, like the one experienced in summer 2015, lead to increased risk of wildfire (Kunkel et al., 2013) and low summer streamflows (USGS, 2015). Longer growing seasons and higher temparatures lead to increased evapotranspiration which further exacerbates drought stress on soils and plants (Abatzoglou et al., 2014).

All of these changes are predicted to affect plant species distribution and increased mortality due to wildfire, insect outbreaks and disease, which in turn effects the compositon of habitats and ecosystems. For example, species unaccustomed to drought stress, such as Sitka spruce and Western hemlock, could decline and be replaced by Douglas fir, western red cedar, lodgepole pine and western white pine (Halofsky et al., 2011).

áqaʔ, Salal, *Gaultheria shallon*

áqaʔ, or salal, received a **low** overall vulnerability score. The same conclusion can be extended for many of the other edible berry species.

Salal was chosen to represent the berry species important to the LEKT. Salal grows in a full range of moist to dry conditions, as well as a variety of mineral and organic soils. Salal berries were historically harvested in large quantities and stored as dried cakes (Valadez, 2011). The leaves may be used for a medicinal tea for coughs, tuberculosis, and diarrhea (Halverson et al., 1986).

Exposure and Sensitivity - Low

No impacts from changing climate conditions have been observed in salal. Salal is adapted to a range of understory conditions and can tolerate moist to dry soil moisture levels. Therefore, changing temperatures and rainfall conditions are unlikely to alter conditions for establishment by end of 21st century.

Salal is resilient to moderate fires as it readily resprouts from roots, rhizomes, or stem bases (USDA, 2019). More intense fires lead to below-ground plant mortality. Because salal generally occurs outside of the floodplain, it is less susceptible to changes in river processes, such as changes in Streamflow Patterns and Flood Risk. This species may be resilient to the hotter and drier summers predicted under climate change, and increased episodes of drought stress.

Changes in the forest overstory due to drought or wildfire could have a significant effect on understory species by changing light conditions and increasing competitive stress.

The 2016 Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes assigned salal a low to moderate climate change sensitivity (Dalton et al., 2016). Dalton et al.'s assessment focused on salal's limited seed dispersal ability and relatively good drought tolerance, and identified the future role of pests and pathogens as a data gap (Dalton et al., 2016).

Adaptive Capacity – High

Salal thrives in the understory of conifer forests within a range of growing conditions that are likely to continue to occur in the future, giving it a high adaptive capacity to projected climate changes. Salal is likely to be mostly able to accommodate or adjust to future conditions.

púʔqʷɬč, Devil's Club, *Oplopanax horridus*

púʔqʷɬč, or devil's club, received a **medium** vulnerability score. Devil's club is vulnerable to reductions in soil moisture with rising temperatures, reduced summer streamflow, and increased channel migration.

Devil's club grows in moist to wet conditions and is used here as an indicator species for wet areas. It often grows on streambanks and provides shade for salmonid fishes and their eggs (USDA, 2019). From a spiritual and medicinal perspective, devil's club is highly valued and an important component of medical treatment and spiritual practices. According to the United States Forest Service (USFS) plant database, this species was valued by many tribes as a key component of important medical treatments and spiritual practices too numerous to list in that database (USDA, 2019). It was also used to create fishing lures (Valadez, 2011).

Exposure and Sensitivity - Medium

The projected 10 degree Fahrenheit increase in average maximum summer temperature and a 65% decrease in summer low are likely to reduce soil moisture levels which can influence the establishment and persistence of devil's club. Changes in peak streamflow patterns may result in reduced establishment locations due to increased erosion in stream corridors.

There are no known current impacts from climate change to devil's club. Devil's club may be sensitive to increased fire, but its adaptations to fire are not well documented.

A recent study by Case et al. (2020) used devil's club and salal as representative species of Maritime coniferous forest in a dynamic global vegetation model (DGVM). The DGVM results indicated no changes are expected for either species.

Adaptive Capacity - Medium

Devil's club evolved in a naturally disturbed environment in and adjacent to streams which indicates that it has the potential to adapt to future conditions.

x̣paʔčí̓ɬč, Western Red Cedar, *Thuja plicata*

x̣paʔčí̓ɬč, Western red cedar, received a **medium** vulnerability score.

Western red cedar establish and thrive in moist, shaded areas, and in areas with richer soils. Increasing air temperatures and summer drought will reduce soil moisture levels in these areas during the summer dry season which may be partially offset by increased winter precipitation and flooding. Integrated over the water year, these effects may off-set each other, resulting in minor impacts to remaining Western red cedar populations with climate change. Historical records state that a large Elwha River tributary, Little River, was home to a western red cedar which was almost as big in diameter as the largest Giant Sequoia in Sequoia National Park, which is greater than 25 feet in diameter (US Geological Survey (USGS), 1902).

Western red cedar was used for everything from shelter and clothing, to canoes and containers (Valadez, 2011). Western red cedar is highly valued as a vital aspect of modern tribal culture. For example, today cedar bark strips are used to construct canoes for use by the Tribe in the annual Canoe Journey. Unfortuntately, large trees are no longer available for traditional canoe construction out of whole logs.

Western red cedar was logged and removed from river floodplains in Western Washington. It has been replaced in many areas by early successional species such as red alder, ulitmately reducing western red cedar's current distribution. Halofsky et al. (2011) mapped the distribution of key vegetation zones on the northern Olympic Peninsula. Western red cedar is included in the western hemlock vegetation zone which was expected to shift toward a drier forest type, such as the Douglas fir vegetation zone.

Several regional climate change vulnerabilty studies have included cedar in their assessments:

- In 2013, the Jamestown S'Klallam Tribe assigned western red cedar a "medium" vulnerability to climate change due to increased drought stress, fewer trees and altered bark harvest times as potential climate change impacts (Jamestown S'Klallam Tribe, 2013). According to this report, tribal harvesters have noticed that springtime harvest of cedar bark for basket-making has been shifting earlier in the year.
- The Climate Change Vulnerability Assessment for the Treaty of Olympia Tribes (Quinault, Hoh) assigned western red cedar a vulnerability ranking of "low" (Dalton et al., 2016). This score was based on a ranking by Devine et al. (2012) and a projection of percent changes in suitable habitat over the Olympic Peninsula. This low vulnerability score was likely influenced by the significantly wetter climate on the west side of the peninsula.
- The analysis for the Stillaguamish Tribe assigned a "medium" vulnerability score to western red cedar.

Exposure and Sensitivity - Medium

Cedars were observed to be negatively impacted during the summer 2015 drought, with observations of increased mortality and disease. Drought events, like in 2015, are likely to become more frequent with climate change. Evidence from 2015 confirms that likely results of warming temperatures will change soil moisture levels and cedars are not resistant to drought. Western red cedar also has limited seed dispersal ability. Wildfires are also fatal to all but the larger trees (USDA, 2019). According to CIG modeling, vegetation composition will shift from 100% conifer forest to 62-65% warm mixed forest, 7-12% cool mixed forest, and 5% woodland/savanna.

The susceptibility of Olympic Peninsula western red cedar populations to disease and pests remains largely unknown. Susceptibility to top kill and mortality associated with drought stress are documented by the Region 10 of the Forest Service in Southeast Alaska. This region also found that drought-stressed trees are vulnerable to secondary injury from insects and pathogens, such as the cedar bark beetle, *Phloeosinus sequoiae*, which typically only attacks trees stressed by other factors, and cedar leaf blight (Service, 2020). It is uncertain whether the cedar bark beetle (*Phloeosinus sequoiae*) is present in the study area but, this insect could further impact healthy western red cedar populations.

Adaptive Capacity - Medium

Western red cedar populations have already been reduced by past land use practices. Western red cedar is intolerant to drought and large fires and likely not able to adapt to these conditions which are expected to become more frequent.

Western red cedar is being actively planted in the Elwha watershed as part of the post dam removal river and floodplain restoration program to recover a significant population of western red cedar in the Elwha River floodplain. Future conditions may mean that additional maintenance will be necessary to support establishment of cedars.

River Environment

The Elwha River supports many aquatic species which the LEKT tradtionally use for food, livelihood and spiritual practices (Valadez, 2011). The lower part of the Elwha River watershed was once a place of extraordinary abundance, including five salmonid species; coho, sockeye, chinook, chum, and pink, many of which were harvested using fishing weirs in the rivers, streams and estuary (Valadez, 2011).

The potential for the **Elwha River to lose its distinctive snowmelt-driven annual hydrology is a significant impact from climate change**. A changing Elwha River will have a cascading series of impacts to the many species that rely on the river, including Chinook salmon. The Elwha River itself will adapt, provided that adequate space is provided, and healthy forests are established and maintained, but will represent a very different ecosystem than the one that supported the LEKT in the past.

Changes in temperature, precipitation, hydrology and sea level rise near the coast are the biggest climate change exposures for river landscape and species which rely upon it. Ocean acidification will also affect salmon; these effects are discussed in the nearshore environment section of this report.

ʔéʔɬx̣ʷaʔ, The Elwha River

The Elwha River is **highly** vulnerable to climate change impacts. Changes in snowpack and annual hydrologic regime will fundamentally change the geomorphic and ecological character of the Elwha River. These shifts in natural processes will change the River's character.

"The Elwha River valley is the cultural and spiritual home of the Lower Elwha Klallam Tribe. The Klallam people have continually resided here for many centuries. The river and surrounding land fed, sheltered, and sustained the people, as well as provided access to the interior of the Olympic Peninsula."

The Elwha River and its tributaries were historically known for their abundance and diversity of salmon. The Elwha was one of the few rivers in the lower 48 states known to support all native Pacific Northwest anadromous salmonids; and there was no month of the year when salmon were not migrating upstream, spawning, rearing, or passing juveniles out to sea (Duda et al., 2008; Wunderlich et al., 1994). The Elwha dams, built in the early twentieth century without fish passage, greatly dimished salmon populations.

The Elwha River watershed is 321 square miles in size with 45 miles of mainstem river channel and 100 miles of tributary chanel (Figure 12). From top to bottom, there is 4500 feet of vertical relief and 83% of the watersehd is owned and managed by the National Park Service.

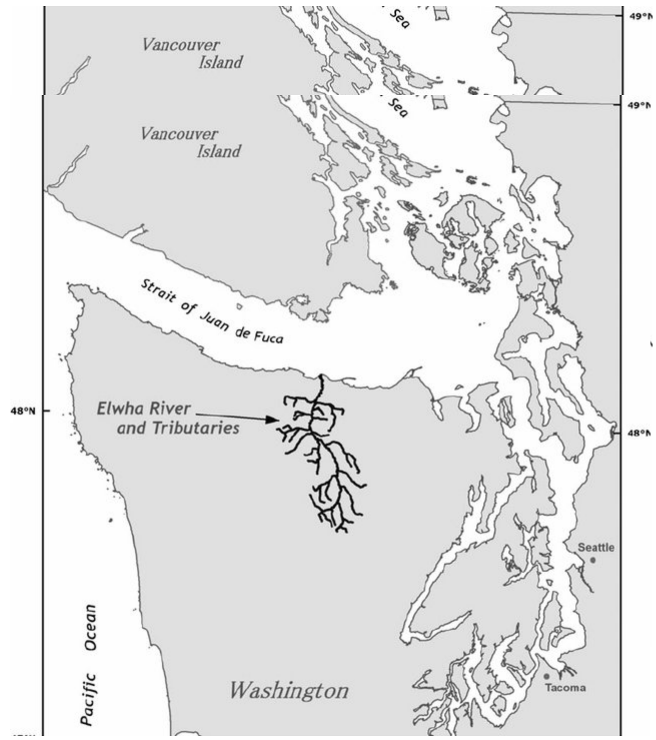


Figure 12. Location map for Elwha River and tributaries.

In 2012, Elwha Dam was removed from the Elwha River, followed by Glines Canyon Dam in 2014. Today, the Elwha River flows freely from the headwaters to the estuary. The LEKT is a key player in the various restoration projects that are being conducted following these dam removals, including revegetation projects to restore riparian and floodplain forest, and river restoration projects installing engineered log jams on the river to restore diverse in-channel salmon habitat until the planted saplings naturally mature and fall into the river, replacing the engineered jams. Salmon populations are beginning to return to the watershed.

Dam removal has restored connectivity between the headwaters and lower reaches of the Elwha River. The delivery of wood to the lower reaches of the Elwha River will help the system store gravels in the channel, raise the water table, and reconnect historical floodplain areas with the mainstem. Over 80% of the watershed is protected within the Olympic National Park. Healthy and productive riparian forests are key to maintaining clean water and supplying nutrients and sediment downstream.

Climate projections predict a shift from a transient-type basin to a rain-dominated flow regime. The Elwha River's watershed now has a dramatic gradient in precipitation from sea level up into the mountains with snow-dominated areas receiving up to 30 times more precipitation than lower elevations (Figure 13).

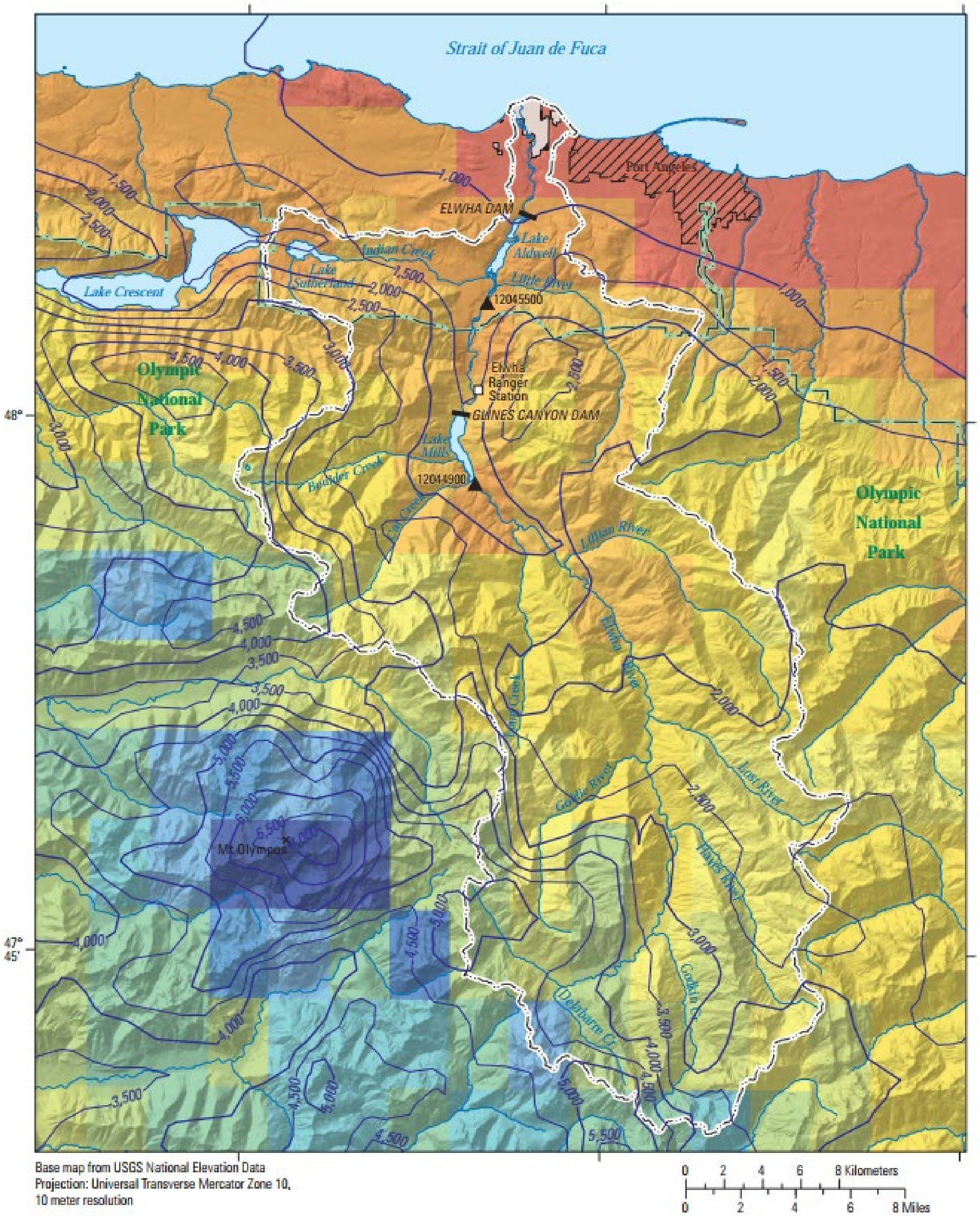


Figure 13. Map of existing precipitation gradients within Elwha River watershed where blue represents 275 to 295 inches of precipitation and red represents 10 to 39 inches of precipitation (Duda et al., 2011).

The annual hydrograph of the Elwha River currently reflects a balance of flow derived from a combination of rainfall and snowmelt (Figure 14).

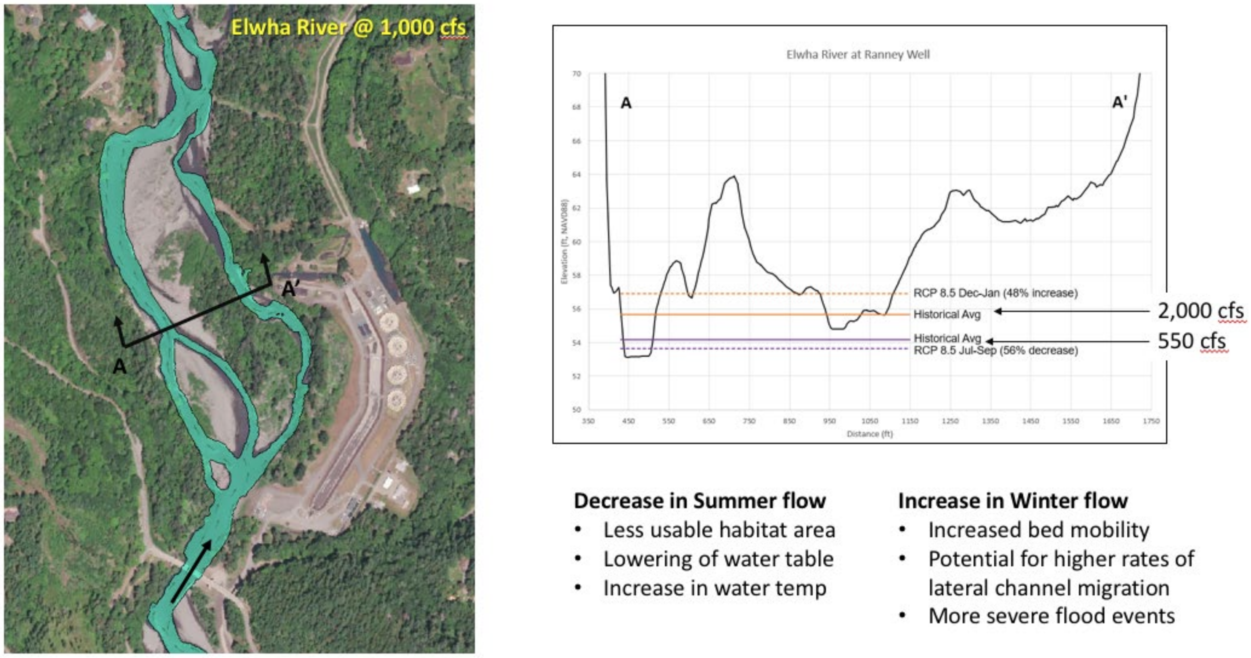


Figure 14. Estimated changes in Elwha River water surface elevation during high flows along a representative reach in the lower river (~ RM 3) with projected changes by 2099.

Exposure and Sensitivity- High

The Elwha River is particularly sensitive to predicted changes in temperature and precipitation. Anticipated changes in air temperature are expected **to reduce the amount of precipitation that falls as snow, fundamentally changing the amount, timing, and quality of water flow throughout the basin by the end of the century.** As more winter precipitation falls as rain than snow, flood peaks that drive erosion and channel migration are anticipated to increase. So where broad alluvial valleys exist, including the LEKT Reservation, intensified flooding and erosion are expected, and levee systems constructed using historical hydrologic conditions will be less effective over time. Without the spring snowmelt, summer baseflows are anticipated to be lower and more prone to warming.

The Elwha River is sensitive to climate change in a number of ways:

- **Stream Flow**. Over the last half-century, April snowpack has been declining, leading to reduced streamflow in summer months (University of Washington College of the Environment, 2018). Glaciers are also shrinking with continued warming and while they contribute a relatively small percentage of annual flows to the Elwha River, glacier melt occurs during the summer where it is most important for minimum stream flows.
- **Water Quality.** Warming air temperatures coupled with decreases in summer streamflow will cause an increase in water temperature, particularly in the lower reach of the Elwha River.
- **Sea Level Rise.** Increases in sea level will change the interaction between the lower Elwha River, its estuary and nearshore environment. Bluff erosion along the Strait is likely to increase in response to higher sea levels. Changes in water surface elevations, water quality, and delta shape will impact both built and natural systems.

- Low flows in late summer and fall will become critical and current industrial & municipal water withdrawals are likely incompatible with protecting aquatic habitat for Pacific salmon.

Adaptive Capacity- Medium

The Elwha River will adapt and persist under a new hydrologic regime. However, the degree of changes mean that the river will not retain some characteristic elements, notably the snowmelt runoff that drives physical and biological processes in the basin.

In terms of adaptive capacity to Sea Level Rise (SLR), the Elwha River will adapt to new typical water levels, and the magnitude of future change within the estuary is likely to be less than the changes to the estuary and delta that recently occurred post-dam removal. For the Elwha estuary, the dam removals and subsequent delta progradation moved the extent of tidal influence in the river shoreward to such a degree that locations within the river channel that had the full tide range of close to 10 feet, now have much less than a foot of vertical tidal influence (Foley et al., 2017). Therefore, SLR on the order of a foot, representing the central estimate fromTable 5, will affect the extent of tidal influence, but the magnitude of that change will likely remain within the newly formed delta.

kʷítšən, Chinook Salmon, *Onchorhunchus tshawytscha*

kʷítšən, or Chinook salmon, are **highly vulnerable** to climate change, largely due to predicted changes in hydrology in terms of Elwha River streamflow.

Primary climate change exposures for Chinook salmon include:

- Increased peak flows that are expected to increase mortality of salmonid eggs and juveniles due to redd scour and loss of refugia habitat.
- Reductions in summer low flows and increased water temperatures that are expected to increase mortality of juvenile and adult salmon in the lower river (Abdul-Aziz et al., 2011; Atcheson et al., 2012).
- Changing timing and magnitudes of tributary flow regimes that are likely to influence spawning and migration patterns.
- Changing marine conditions that are expected to be less suitable for Pacific salmon with warmer, more acidic, sea water (Orr et al., 2005).

Secondary Impacts to Chinook come from changes in nearshore habitat conditions with sea level rise, changes in alluvial water storage and floodplain connectivity, and climate change effect on the nutrient and food web cycles in both river and marine environments.

Many of the above effects are documented in leDoux et al. (2017), and Puget Sound Partnership (2017) provides regional case studies and guidance on restoration and preservation projects in the context of climate change predictions.

Since monitoring began in 2005, Chinook 0+ salmon outmigration abundance has increased dramatically (McHenry et al., 2020a) (Figure 15). Historically, the Elwha River had 10 runs of native anadromous salmon and trout, including Chinook salmon. As an anadromous species, critical reproductive life stages occur in the river and these life stages each require specific combinations of flow conditions, channel bed substrate conditions and stability, and water quality (e.g., temperature, clarity). Increases in temperature and changes to precipitation patterns are expected to affect the amount, timing, and quality of flow within the river in ways that will change conditions for all Chinook life stages that occur within the river (Figure 17).

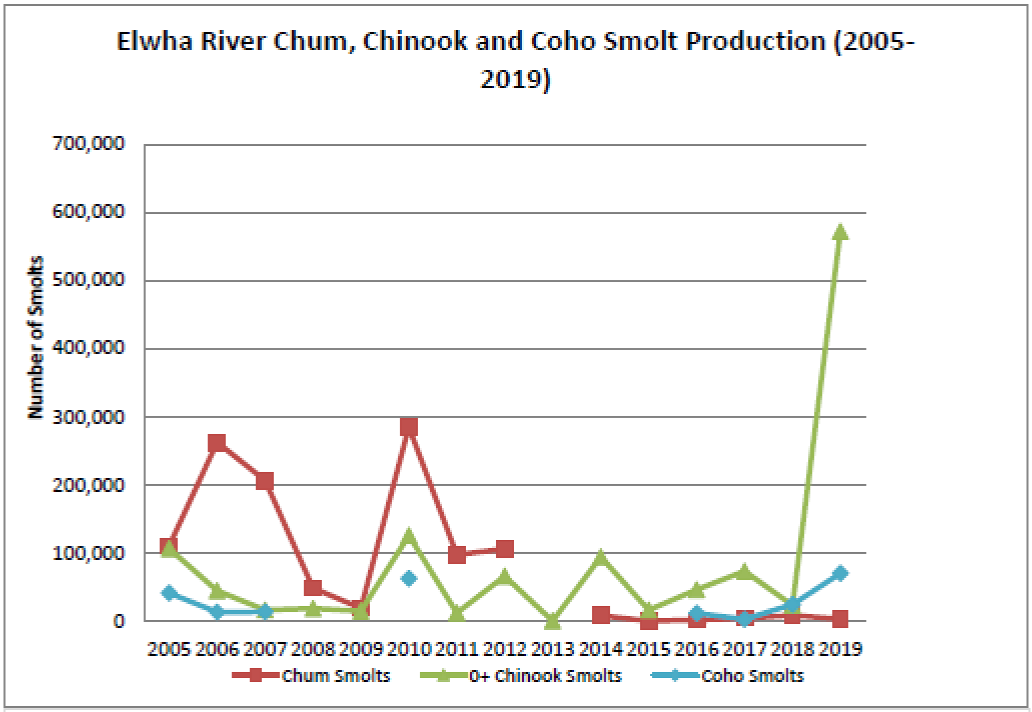


Figure 15. Estimated Elwha River Chinook, Chum, and Coho salmon smolt production from 2006 – 2016 (McHenry et al., 2020a).Two Elwha River dam removals occurred in 2011 and 2014.

Since the removal of the Elwha River dams in 2011 and 2014, Chinook have begun re-colonizing the watershed and both spawners and out-migrating smolts, as well as redds (Figure 16), have been in increasing abundance (McHenry et al., 2020a; McHenry et al., 2020b). This renewed access to historical habitat may mask any effects from climate exposures that this Chinook population may already be experiencing.

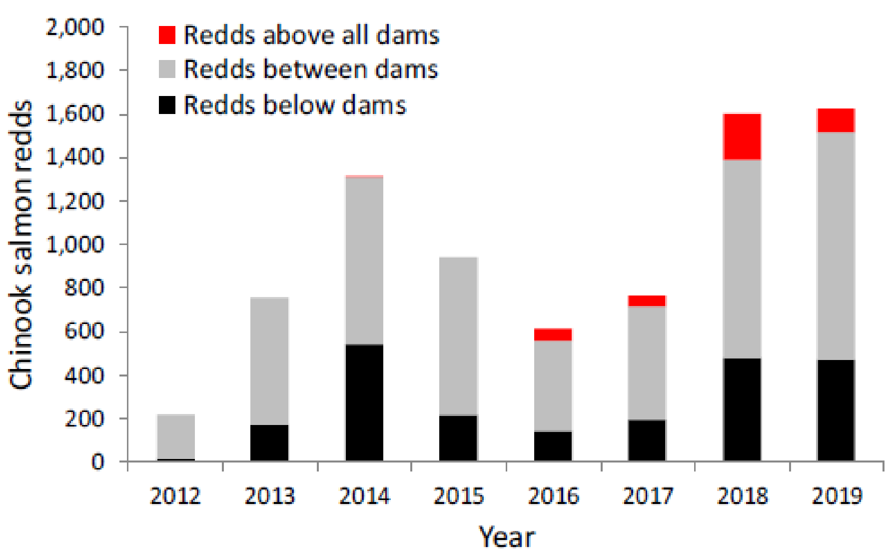


Figure 16. Lower Elwha Klallam Tribe Chinook redd monitoring data from 2012 to 2019 (McHenry et al., 2020b).

The Elwha River historically had two Chinook runs, one in the spring and another in the summer/fall life. Chinook use of the lower and middle river reaches has been slowly increasing. Spring Chinook run timing is associated with snowmelt. However, spring Chinook are currently extirpated from the Elwha River watershed, and because the run timing is genetically controlled, it may take a very long time for this run to return. As the watershed shifts to a rain-dominated basin, snowmelt signals for spring Chinook recovery will decrease. In the near-term, access to greater habitat today may make these populations more resilient to future climate change, but adaptive capacity of these species to the impacts of changing hydrology and stream temperatures are challenging to estimate.

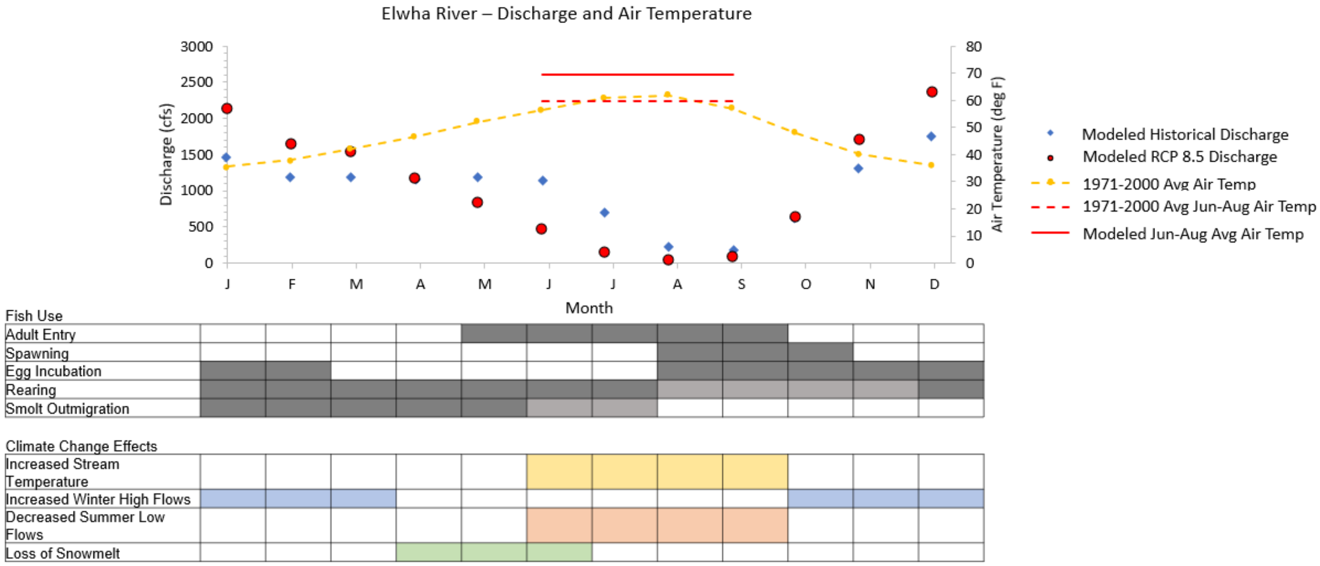


Figure 17, Effects of increased air temperature and winter high flows and decreased summer low flows on Chinook salmon life stages (NSD, 2020).

The Stillaguamish Tribe found Stillaguamish River Chinook to be moderately to highly vulnerable in the mid and late century scenarios, respectively, with a very high confidence (Krosby et al., 2016).

The Jamestown S'Klallam Tribe also afforded Dungeness River Chinook a high vulnerability score (Jamestown S'Klallam Tribe, 2013).

Exposure and Sensitivity- High

The removal of the Elwha River dams has overshadowed any potential observations of climate change on Chinook. The river's recovery after dam removal shows how the river and the habitat it provides responds to dramatic changes in hydrology and hydraulics, including the movement of sediment, erosional and aggradational processes, and the presence or absence of woody debris in the river. While dam removal was essential to ecosystem recovery in the Elwha and had positive effects, **climate change impacts in the old reservoir areas will be exaggerated until a mature floodplain forest and natural wood loading quantities are re-established.**

Episodic years of summer low flow in recent years (2015, 2019) highlight the increasing stress on water availability during dry periods. In valleys of the river and its tributaries that have been impacted by historic disturbance, such as forest and channel clearing, road construction and diking, climate change impacts will put further stress on habitat recovery. Over the last half-century, April snowpack has been declining, leading to reduced streamflow in summer months.

Increased winter high flows will increase channel bed scour depths which will result in higher egg mortality as redds become more susceptible to erosion. Higher peak flows could also result in channel widening, increases in wood mobility and a reduction in rearing and spawning habitat. The loss of spring and summer snowmelt will reduce instream habitat and may affect sub-species that specifically time outmigration during these times. Increased summer stream temperature and low flows may affect adult entry into the river and increase mortality.

Adaptive Capacity- Medium

Chinook have adapted to millions of years of change to climatic and geologic cycles so they have intrinsic adaptive capacity. Human actions, such as dam construction and removal, have resulted in broad changes to the river and floodplain in a relatively short time frame. The project team considers Chinook's adaptive capacity to be medium, acknowledging that we will learn more about Chinook's ability to adapt in the coming years.

Actions that support the Elwha River, such as preservation and restoration of riparian forest, will improve Chinook's adaptive capacity over time.

Nearshore Environment

The vulnerability of the LEKT nearshore environment was assessed using indicator species of Dungeness crab (*Metacarcinus magister/Cancer magister*), Geoduck (*Panopea generosa*), Eulachon (*Thaleichthys pacificus*), Eelgrass (genus *Zostera*). The most vulnerable species in the nearshore was found to be focused on species which rely upon consistent ocean chemistry, such as pH for shell production (Dungeness crab and Geoduck). The least vulnerable key concern in this study was eelgrass, which may benefit from increased dissolved carbon dioxide. It is worth noting that increased dissolved carbon dioxide may also favor non-native aquatic plants and algae, potentially creating an imbalance in local water chemistry and seasonal fish kills.

Nearshore environments are extremely important to the economy of the North Olympic Peninsula. A recent valuation for them in Clallam County by Earth Economics found that:

> *"Carbon storage and sequestration, creation of habitat, and forage fish supportive value of Clallam's nearshore ecosystems contribute more than $15 million annually to the local and regional economies. Commercial and recreational fishing provide $20 million annually. Services provided by feeder bluff ecosystems contribute between $99,000 and $506,000 every year within the Dungeness and Elwha drift cells. The large range in economic values for nearshore ecosystems reflects the health of the shoreline and the presence or absence of shoreline armoring" (Flores et al., 2013)*

ʔáʔčx̣ , Dungeness Crab, *Cancer magister*

ʔáʔčx̣, or Dungeness crab are highly vulnerable to climate change, due to ocean acification. Dungeness crab includes a life stage that is highly sensitive to pH with likely limited evolutionary adaptive capacity (Hodgson et al., 2016). We acknowledge that there is significant uncertainty for Dungeness crab.

Dungeness crab was historically an important summertime food for the Lower Elwha Klallam Tribe, harvested using crab pots and eaten fresh or preserved for winter use and trade. The Pysht estuary , Deep Creek, Dungeness Bay and Green Point were all favored harvest locations (Valadez, 2011). This species remains an integral part of Klallam life and is economically very important (Valadez, 2011). Commercial and subsistence Dungeness crab fishery regulations are carefully managed by state and tribal co-managers.

There is a connection between sediment processes and habitat function in the Elwha River nearshore environment. The relatively recent removal of two dams on the Elwha River resulted in a significant realease of sediment from the former dam locations, and an increase in nearshore and estuary habitat (Peters et al., 2017) and a rapid return of Dungeness crab to the Elwha estuary and nearshore for the first time in the memory of many Tribal fishers. This is attributed to sediment delivery to the nearshore environment and the associated change in habitats.

Exposure and Sensitivity - High

The primary climate exposure for Dungeness crab is changing ocean pH through ocean acidification. Dungeness crab larvae and megalops life stages are impacted from exposure to low pH (Figure 18). Pteropods are one of Dungeness crab’s food sources, and Pteropods are highly vulnerable to ocean acification.

However, there is a high degree of uncertainty in distibution data for both larvae and magalops life stages column (Hodgson et al., 2016). This uncertainty is important because pH varies widely from the nearshore to the deeper ocean and vertically in the water. For sensitivity, there is a moderate degree of confidence in the sensitivity of larvae to pH exposure, there is greater degree of certainty in the relative effects on the megalops life stage, with more than one study coming to similar conclusion (Hodgson et al., 2016).

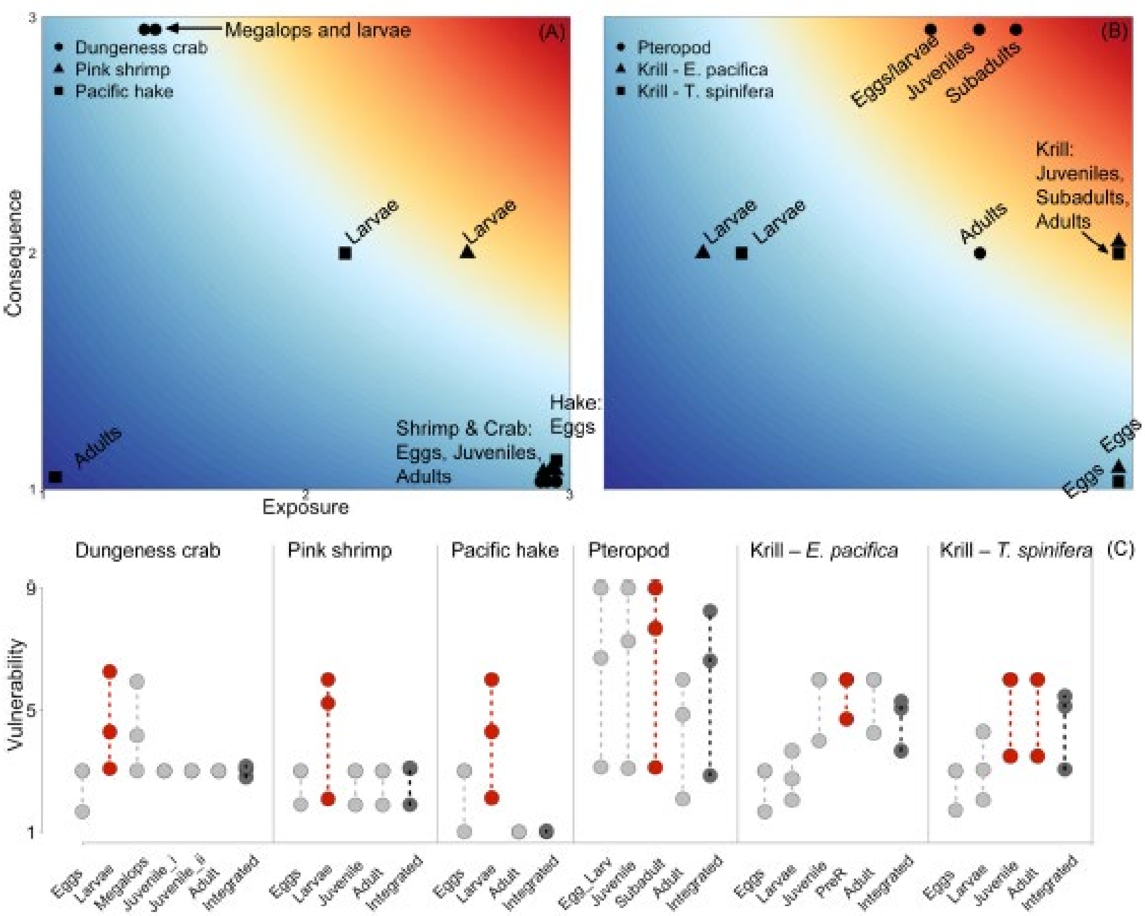


Figure 18. Vulnerability plots for six species, including Dungeness crab (Hodgson et al., 2016).

Dungeness crab eggs, juveniles, adults demonstrate tolerance to exposure to low pH. There is also low uncertainty in known distribution of eggs, juveniles and adults. Little is known about the sensitivity of eggs and juveniles to relative pH exposures however, there is greater degree of certainty in the relative effects on the adult life stage, with more than one study coming to similar conclusions (Hodgson et al., 2016).

Changing streamflow patterns due to decreasing snowpack will also likely have an effect on the salinity of the Elwha estuary.

Adaptive Capacity – Low

While Dungeness crab reside in a dynamic nearshore and marine environment, it is uncertain as to how Dungeness crab may adapt to long-term changes in ocean pH. The low adaptive capacity determination is based on a recent NOAA vulnerability assessment that made the assumption that these species do not have the capacity to "evolve an adapted response to low pH" (Hodgson et al., 2016).

Geoduck, *Panopea generosa*

Geoduck are highly vulnerable to climate change, due to ocean acidification.

This species was part of a large list of shellfish, including mussels, cockles, steamers, butter clams, bent-nose clams, surf clams, oyster clams, scallops, limpets, dogwinkles, acorn barnacle, chiton, and sea urchins which were harvested and eaten fresh or cured, and used for future trade (Valadez, 2011).

Decreases in ocean pH due to increases in atmospheric CO_2 concentrations are particularly affecting marine species which rely on calcium carbonate for shell production, such as geoduck. Recent studies on the effects of pH on geoduck indicate that larval growth and development, as well as burrowing behavior, are negatively influenced at lower pH levels (Huo et al., 2019).

The 2016 Stillaguamish Climate Change Vulnerability Assessment noted that there is a significant need for natural history information relating to specific families and genera within the large and diverse Bivalvia class (Krosby et al., 2016). These data are necessary to refine the specific vulnerabilities of clam, oyster, mussel, and scallop species in coastal Washington.

Geoduck was qualitatively assessed in the bivalve category of the 2016 Stillaguamish Climate Vulnerability Assessment (Krosby et al., 2016). This assessment found that while bivalves have a relatively flexible diet and reside in coastal and estuarine habitats, sea level rise could inundate coastal habitat areas important for bivalve reproduction and survival. Bivalves are filter feeders and consume phytoplankton and zooplankton species ((WDFW, 2020)). Impacts to phytoplankton and zooplankton could effect bivalve populations. It was also noted that once bivalve larvae have developed into the mature life stage, they attach to gravel, shell, or sand grains, and burrow below the sediment surface (WDFW, 2020). Conversely, larval clams spend a significant amount of time drifting in the water before settling and burrowing beneath the sediment surface. Therefore, larvae may disperse several miles from the parental origins (WDFW, 2020).

Exposure and Sensitivity - High

Geoducks are exposed to both changing ocean pH and altered coastal sedimentation patterns.

By the end of the century, ocean acidification is projected to result in a 40% reduction, globally, in the rate at which mollusks (e.g., mussels and oysters) form shells, as well as a 17% decline in growth, and a 34% decline in survival. The Stillaguamish Tribe's Climate Change Vulnerability Assessment (Krosby et al., 2016) identified changes in available food (zooplankton and phytoplankton), changes in sediment size and structure, and larval dispersal and movement as key sensitivities relative to climate change impacts (Figure 19).

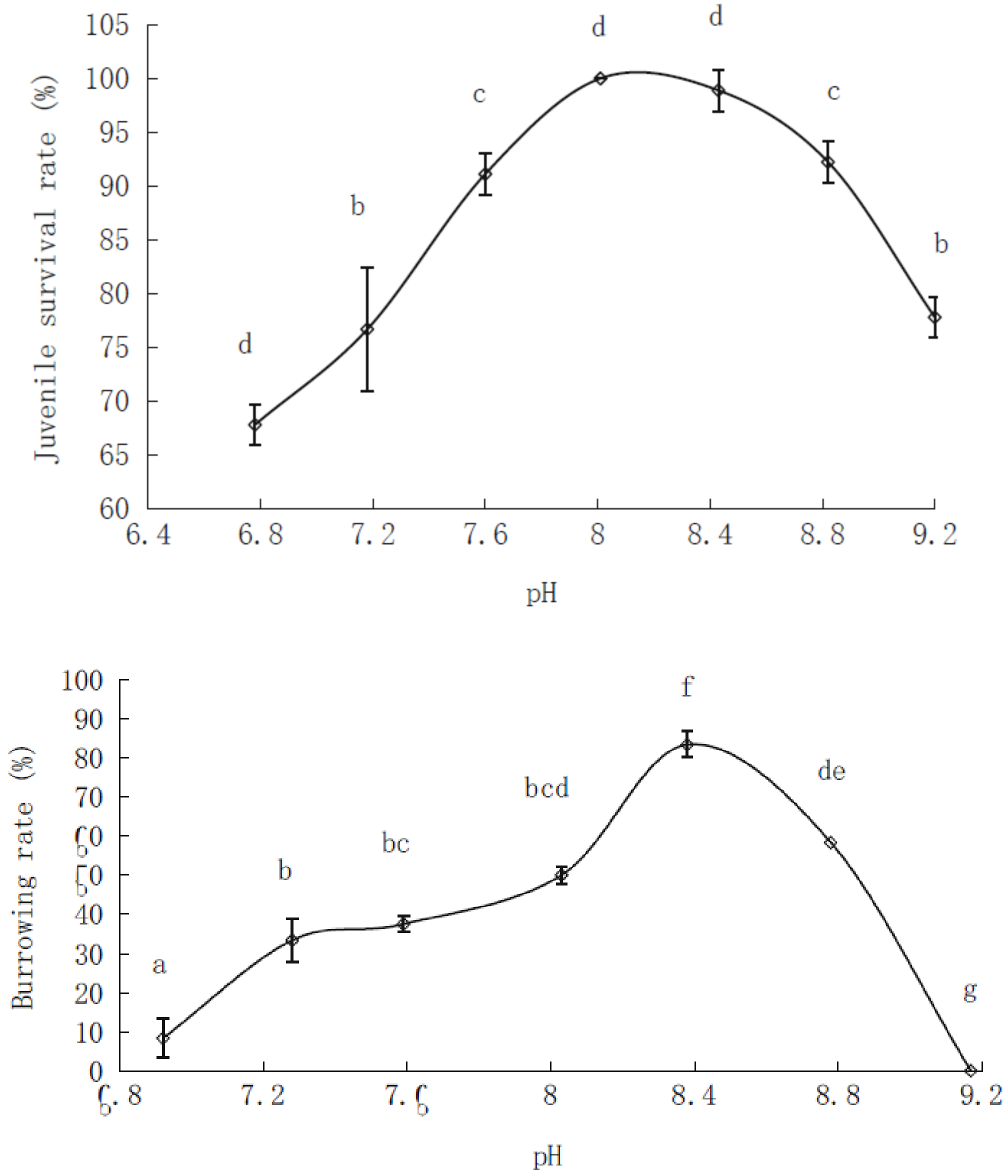


Figure 19. Survival rates (top) and burrowing rates (bottom) of juvenile geoducks under different pH conditions from (Huo et al. 2019). Burrowing rates are key for predation avoidance and are sensitive to pH.

Conversely, Spencer et al. (2019) found that aquacultured juvenile geoducks may be able to tolerate a wide pH range, ranging from 6.7 to 8.3, in their study. These results differ from Huo et al. (2019). However, aquacultured populations may not experience the same survival stressors as wild populations. Both studies do acknowledge that studies of the effects of ocean acidification on this species are in their infancy.

Juvenile geoduck are also sensitive to temperature. Spencer et al. (2019) noted that juvenile geoducks deployed for aquaculture in warmer bays (16 – 19 degrees Celsius) did not grow as well as juveniles deployed at temperatures less than 16 degrees Celsius; optimal hatchery temperature for reproduction are about 11 degrees Celsius.

Adaptive Capacity – Low

We are uncertain as to how geoduck may adapt to these changes, so we are conservatively estimating that they are minimally able to accommodate or adjust to these impacts.

Pacific geoduck aquaculture is growing as an industry. This industry is not an intrinsic adaptive quality but may function like the hatchery programs for salmonid species and may be useful for research. Spencer et al. (2019) posed that the diverse responses exhibited by clam species may be partially attributed to local adaptation to varying environmental drivers and that, being native to the Puget Sound where episodes of low pH are experienced regularly by some populations, these species may be able to withstand periods of low pH.

qʷəlístiyuʔ , Eulachon, *Thaleichthys pacificus*

qʷəlístiyuʔ , Eulachon have **medium** vulnerability to climate change.

Eulachon are anadromous and a member of a long list of fish species which the LEKT relied upon for food and trade, including the five species of salmon, as well as steelhead, halibut, lingcod, flounder, herring, smelts, and many other species.

Eulachon and longfin smelt spawn on fine grained deposits in lower rivers through winter and spring. The population around the Elwha River delta is a part of the southern Distinct Population Segment, which extends from the Nass River in British Columbia to the Mad River in California (Gustafson et al., 2012). This population has been in significant decline and was listed as threatened under the Endangered Species Act in 2010 (National Marine Fisheries Service, 2017). NOAA has designated portions of the Elwha River as Critical Habitat for eulachon.

The Elwha River dam removals have likely increased Eulachon habitat in the delta through increased areas of sand and gravel substrate necessary for spawning. LEKT has observed adult Eulachon in their rotary screw trap installed near the mouth of the Elwha River in 2005. As of 2021, LEKT is in the process of conducting a eulachon study where eulachon eggs have been found at least 5 miles up the Elwha River from the mouth.

Existing and ongoing threats to this species include habitat degradation, habitat impediments, fisheries interaction and bycatch, water pollution (Table 7).

The Stillaguamish Tribe found forage fish to to be moderately vulnerable to climate change due to modifications in diet availiabilty, habitat shifts, and a potential increase in regional seawall development as sea levels rise. (Krosby et al., 2016)

Exposure and Sensitivity - Medium

Eulachon will be exposed to changes in temperature, stream flow, sedimentation, wind patterns, and sea level height that all have implications for survival of eulachon (Table 7) (National Marine Fisheries Service, 2017).

Threats	Subpopulation Klamath	Columbia	Fraser	BC
	Severity			
Climate change impacts on ocean conditions	high	high	high	high
Dams /water diversions	moderate	moderate	very low	very low
Eulachon bycatch	moderate	high	moderate	high
Climate change impacts on freshwater habitat	moderate	moderate	moderate	moderate
Predation	moderate	moderate	moderate	moderate
Water quality	moderate	moderate	moderate	low
Catastrophic events	very low	low	very low	low
Disease	very low	very low	very low	very low
Competition	low	low	low	low
Shoreline construction	very low	moderate	moderate	low
Tribal/First Nations fisheries	very low	very low	very low	low
Non-indigenous species	very low	very low	very low	very low
Recreational harvest	very low	low	very low	very low
Commercial harvest	very low	low	low	very low
Scientific monitoring	very low	very low	very low	very low
Dredging	very low	moderate	low	very low

Table 7. Level of threat severity in four subpopulations of Southern Distinct Population Segment of eulachon (NMFS 2017).

Lower freshwater flows in late spring and summer may lead to upstream extension of the salt wedge, possibly influencing the distribution of eulachon prey and predators (National Marine Fisheries Service, 2017). Increased temperature of freshwater inflows and seasonal expansion of freshwater habitats may extend the range of non-native, warm-water species that are normally found only in freshwater (National Marine Fisheries Service, 2017). The sensitivity of forage fish also depends on the effects of ocean acidification and higher ocean temperatures on food sources, such as insects and crustaceans.

Adaptive Capacity - Medium

Eulachon have adapted to millions of years of change to climatic and geologic cycles. Eulachon have a flexible diet of forage fish that may enable the species to respond to climate mediated shifts in prey abundance and availability. However, there is significant uncertainty about Eulachon's adaptive capacity, so was assigned a medium capacity.

támәx̣ , Eel Grass, *Zostera marina*

Eelgrass was rated as having **medium vulnerablility** to climate change.

Eelgrass is one of the most abundant seagrasses in PNW estuaries and is a food source for micro-invertebrates which are an important part of juvenile salmonid diet. Eelgrass beds are also nursery habitat for juvenile and young adult crab, as well as all species of juvenile salmon and forage fishes (Blackmon et al., 2006). In a recent aquaculture geoduck study, which considered environmental heterogeneity on geoduck production, eelgrass beds were found to be higher pH (less acidic) relative to unvegetated areas (Spencer et al., 2019), particularly in the warm summer months of June and July.

Climatic exposures for Eelgrass include:

- Increased water temperatures
- Changes in salinity patterns related to changes in seasonal river discharge
- Increased CO_2 in marine waters

Sensitivity- Medium

Eelgrass's primary sensitivity is to the potential increase in disease due to plant stress induced by increased water temperatures and altered salinity patterns (Blackmon et al., 2006). Eelgrass desiccation may increase due to increases in air temperature, especially in low tide systems.

Adaptive Capacity - Medium

We are uncertain as to how eelgrass may adapt to climate changes so was assigned a medium capacity. Eelgrass establishes in dynamic nearshore environments so, we are assuming that eelgrass has some intrinsic ability to adjust to these impacts.

5.3 Built Environment Key Concerns

Key elements of the LEKT's built environment, including tribal facilities and homes, reservation ingress/egress roads and bridges, and utilities were assessed for climate change vulnerability. The most vulnerable aspect of the built environment to climate change is the Tribe's water supply. Systems that have undergone recent updates or receive ongoing investment, including the new LEKT wastewater collection system, the cell tower and emergency communication system and solid waste management, are the least vulnerable.

The LEKT built environment is exposed to a number of hazards, as documented in a 2019 Hazard Mitigation Plan jointly developed with the Tribe and Clallam County. Hazards which may be affected by climate change, such as winter storms, windstorms, and wildfire were ranked with medium priority, and flooding and tsunami hazards were ranked with low priority (Figure 20).

	Magnitude (1=lowest, 5=highest)	Onset (1=slowest, 5=fastest)	Duration (1=shortest, 5=longest)	Frequency (1=lowest, 5=highest)		Average	Rank
Earthquake	5	5	5	1		4	1
Cascadia Earthquake	5	5	3	1		4	2
Landslide	2	5	3	5		4	3
Winter Storm	2	3	3	5		3	4
Windstorm	2	4	2	5		3	5
Wildfire	3	5	2	3		3	6
Flooding	1	4	2	2		2	7
Tsunami	2	4	2	1		2	8

Figure 20. Lower Elwha Klallam Tribe hazard ranking (Clallam County Emergency Management, 2019).

Tribal Facilities and Homes

The ~ 1,780 acre Lower Elwha Klallam Tribe Reservation includes two large parcels of land containing most of the residential areas. These two areas are typically referenced as the Upper Reservation, which is about 26 acres with homes and a community center called 'the Gathering Place'; and the larger Lower Reservation which is located in the Elwha Valley and contains most of the Tribal facilities, including the Tribal Center, and more homes (Lower Elwha Klallam Tribe, 2011).

The Tribe also has several properties along Highway 101, including the health clinic and gas station, as well as some property on the bluff adjacent to the Lower Elwha River valley with homes, police station, daycare/headstart, and some holdings in Port Angeles, including Tse-whit-zen, Ediz Hook, and a new hotel site.

Reservation Facilities and Homes

The LEKT Reservation facilities and homes received a **medium** climate change vulnerability score. There are some facilities that have higher vulnerabilities, these facilities are generally closer to Elwha River or the nearshore.

The on-reservation facilities and homes are currently in the historical floodplain protected by a levee. The levee designed by the Corps of Engineers to provide a level of protection that allowed for post-dam removal sedimentation but did not include future increases in peak flows. Future peak flow events are predicted to increase in magnitude and frequency towards the end of the century to levels that could increase the chances that the levee will be overtopped or fail via erosion and scour.

In 2010, the Federal Levee to the east of the Elwha River was updated to accommodate channel changes associated with dam removal. The Federal Levee was armored with riprap, elevated two to four feet and extended to the south by more than 1,600 feet. Similarly, a levee west of the river which was built by Clallam County after residents on Place Road formed a flood protection district, was improved and updated in advance of dam removal. The water overflow treatment pump station near the beach was also updated as part of the 2010 Federal Levee improvements.

Figure 21 identifies an actively eroding bluff on the west side of the Lower Elwha River, and illustrates current 100-year flood zone, tsunami hazard zone, and estimated 2-ft increase in Mean Higher High Water (MHHW) with relative increases in sea level toward the end of the century. The locations of the west side levee, lower reservation homes and buildings, the east side Federal Levee and major roads are also mapped (Figure 21).

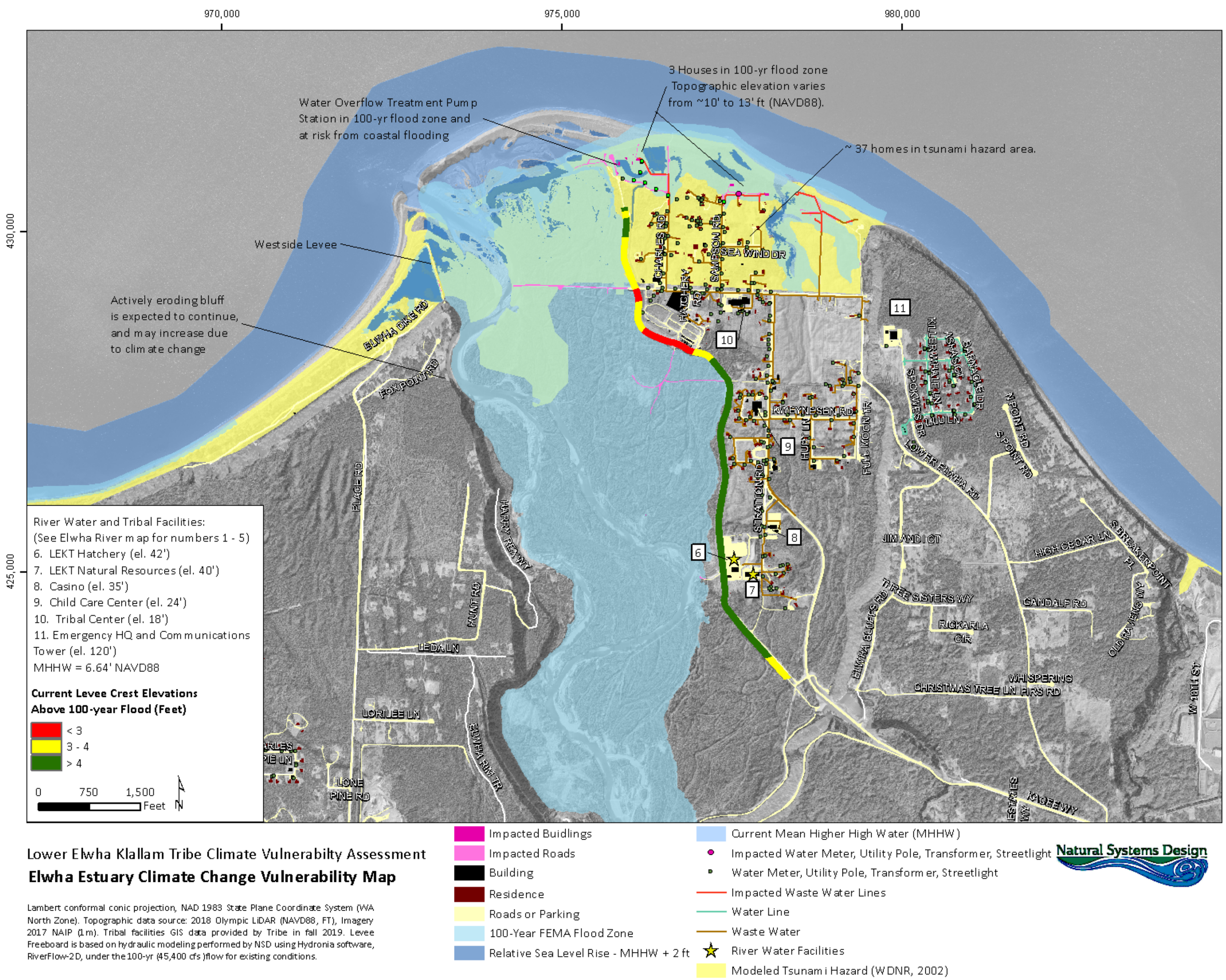


Figure 21. Lower Elwha Climate Change Vulnerability Map.

Sensitivity – Typically Medium (Varies)

The safety of these facilities is tied to the condition of the Federal Levee. All levees present some level of risk to the low-lying areas that they protect. The Federal Levee, along the LEKT Reservation, did not include an analysis of potentially increased future flows resulting from climate change so any increases in the magnitude of peak flows will reduce the level of protection provided by the levee system. We do not have quantitative estimates of future level of protection, so further analysis and coordination with the Corps of Engineers to better establish the risk is included, as a recommendation discussed at the end of the report.

There are variable levels of sensitivity surrounding the river, keyed to location in or out of the historical floodplain. Specific elements are described below, organized by overall sensitivity:

- **High sensitivity:** The water overflow treatment pump station is located in the 100-year flood zone and at risk from coastal storms and flooding now and in the future.
- **Medium sensitivity:** The new LEKT hatchery and natural resources facilities, the tribal center, social services building, approximately 12 homes, and the casino are protected by the Federal Levee. The Federal Levee's level of protection will be reduced over time with increased peak flow magnitudes.
- **Low sensitivity**: The newly relocated Lower Elwha Justice Center, with emergency management and communications, as well as the new Head Start and childcare building, is well outside of the tsunami and flood hazard areas. The tribal gas station and associated businesses (4773 S Dry Creek Rd) are also located outside of flood areas.

Adaptive Capacity - Medium

The Federal Levee includes the standard three feet of freeboard above the 100 year flood elevation, providing some adaptive capacity over time. Flood modeling in 2014, to evaluate possible restoration scenarios, found that aggradation of the lower river may have reduced freeboard to less than three feet near the old Tribal hatchery. The Federal Levee could be raised and/or strengthened in the future, similar to what was done in 2010 (Corum and Ball, 2014). In 2010, both the Federal Levee to the east of the lower reservation and the "west" levee along the west bank of the Lower River were improved to maintain flood protection following removal of the Elwha dams. With the predicted increases in winter flooding caused by climate change, similar improvements may be required in the coming decades. The hazard mitigation planning process may be a good mechanism for maintaining or increasing adaptive capacity (see Conclusions).

The levee improvments made as a result of the Elwha River dam removal projects are a good example of how this system can be adaptively managed. These projects do come with a high level of multi-agency coordination and effort. The vulnerabilty of these facilities depends on the availability of funding for these renovations over time.

Downtown Port Angeles Assets

Downtown Port Angeles, Ediz Hook and Tse-whit-zen have **medium vulnerability** to climate change.

The LEKT Heritage Center and regional airport appear to be well outside of the area influenced by changes in relative sea level rise, storm surges or tsunamis so have a low vulnerability to climate change.

Downtown Port Angeles is home to Tse-Whit-Zen village, the LEKT Heritage Center, the future site of a LEKT hotel, several key boat launches (serving LEKT commercial, recreational and subsistence fisheries) on Ediz Hook, the ferry terminal, and the Boat Haven Marina (Figure 22).

The facilities along the Port Angeles waterfront are not at risk from flooding during an average high tide, even at the highest magnitude sea level rise scenario considered (Figure 22). However, as sea level rises, extreme water levels associated with storms may become more impactful over time. Ediz Hook and Tse-whit-zen are less protected and may be more exposed to flooding during extreme events.

The Climate Change Preparedness Plan for the North Olympic Peninsula (2015b) found that, since the downtown area of Port Angeles was built on pilings and fill, it is above the annual coastal flood risk zone even with sea level rise. However, their analysis did not account for erosive forces or the impacts of wind driven waves. Petersen et al. (2015b) predicts that the industrial waterfront, including Ediz Hook, will be affected by coastal flooding, but not until the latter half of this century.

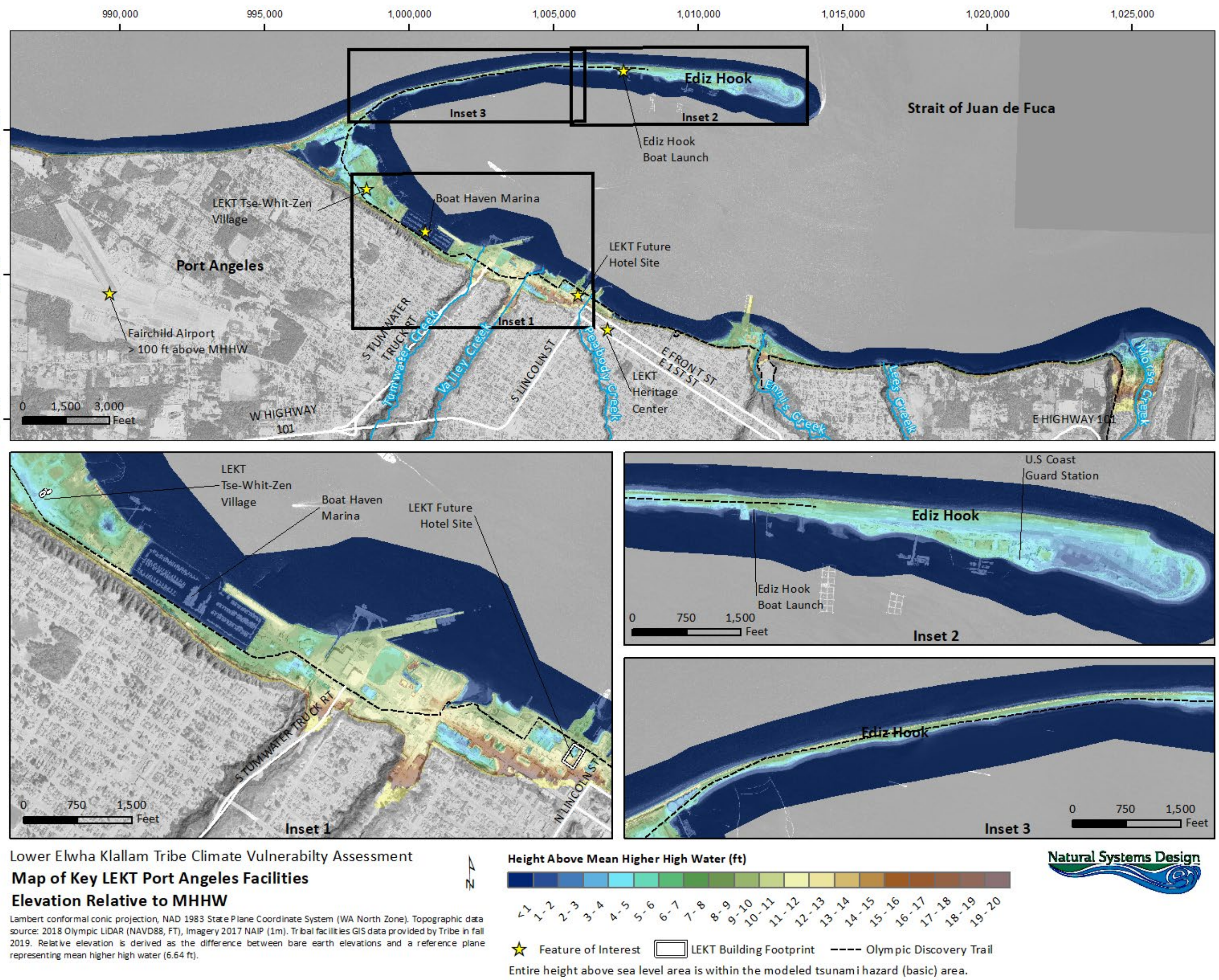


Figure 22. Map of key Port Angeles facilities relative to MHHW elevation (ft).

Sensitivity - Medium

In general, these facilities are subject to flooding and damage from storm events with decreasing risk with increasing elevation. Ediz Hook is more sensitive to Relative Sea Level Rise (RSLR) and erosive forces. It has been eroding and is currently protected by a large engineered rip-rap rock structure. RSLR and storm surge changes associated with future increases in sea level are the primary climate change related threats to these facilities.

Tse-Whit-Zen is currently approximately 5 feet above MHHW and will likely become more exposed to coastal flooding over time but is unlikely until later in the century. The road to Ediz Hook boat launch and the US Coast Guard Station ranges from 5 to 12 feet above MHHW. The future LEKT hotel site is at a similar elevation, about 11’ above MHHW.

Boat Haven Marina in downtown Port Angeles is exposed to sea level rise and is susceptible to tsunami damage (Clallam County Emergency Management, 2019). The marina may require modifications and/or repairs and the parking lot may become flooded, and both may be affected by any increase in severe storms. According to the 2019 draft Clallam County HMP, Ediz Hook and parts of Port Angeles may become inundated with high tides and storm surges (Clallam County Emergency Management, 2019).

The airport (elevation 276 feet NAVD 88) and LEKT Heritage Center (elevation 94 feet NAVD 88) are outside of the tsunami zone and the sea level rise exposure zone.

Adaptive Capacity – Medium

These facilities include villages and other water dependent uses that cannot feasibly relocate. There is, however, some opportunity for on-site modifications to reduce future risk. Similar to the LEKT Reservation, the boat launches and parking areas may need to be adaptively managed to maintain function with increases in sea level. Adaptive capacity is dependent on space to move to and available funding for structural improvements. On-site actions could include temporary flood walls, raising buildings and roads, and taller floating piers.

The 2019-2025 Clallam County Multi-Jurisdictional Hazard Mitigation Plan (2019) lists the following hazard mitigation or adaptation measures:

- Update flood assessment at an unknown estimated cost funded by FEMA, DOE (action PA05)
- Upgrade shorelines at a cost of $150,000 from FEMA/DNR grants/private funding (PA06)
- Evaluate options to make new hotel in Port Angeles tsunami resistant, to be funded by FEMA (LEKT03)

Elwha River Facilities:

Hatchery, Levees, and Water Overflow Pump Station

The LEKT hatchery, levees and pump station have **medium vulnerability** to climate change.

All of these facilities are located within the floodplain and channel migration zone of the Elwha River, so they are susceptible to future increases in peak flows. Winter maximum flows are anticipated to increase by 46%, so would change current erosion and inundation patterns. The hatchery water supply is separate from Elwha River water intake, currently supported by six independent wells, with a seventh scheduled for construction in 2021 (GeoEngineers, 2011; GeoEngineers, 2016).

The Federal Levee and Westside Levee are both designed to hold back floodwaters. Peak flows are predicted to increase in frequency and magnitude by the end of century, which will reduce the level of protection provided by the levee system. Both levees are at heightened risk of erosion or overtopping which would be exacerbated with increased future peak flows.

The water overflow pump system is designed to allow for drainage of the low-lying reservation area during periods of high water in the river (Corum and Ball, 2014). The functioning of the pump system is predicated on the Federal Levee providing protection from river flooding. According to the Corps as-built drawings, the levee elevation at the pump station is approximately El 14 NAVD 88, which represents approximately 4 feet of static Sea Level Rise (SLR) with 3.4 ft of additional storm surge. This is a lower probability, towards end of the century level of SLR.

Exposure and Sensitivity - Medium

The hatchery is currently protected by the Federal Levee and is not directly exposed to flow from the Elwha River (Corum and Ball, 2014). There are no known impacts from climate change to the levees since they were upgraded in 2010. The delta has changed significantly post-dam removal with aggradation and activation of side channels. Increased winter high flows and magnitude of extreme flood events will subject the levee, more frequently, to erosive forces. Side channels adjacent to the levee have become more frequently engaged, in the vicinity of the old hatchery, which may place additional stress on the levee structure. The Federal Levee is sensitive to increases in peak flows and associated water surface elevations.

The pump station was installed in 2010 and designs did not incorporate an assessment of climate change impacts. If the Federal Levee was to overtop or fail, the pump station would similarly fail to function, resulting in flooding in the lowland portions of the reservation.

Adaptive Capacity – Medium

The Federal Levee currently provides flood and erosion protection and at the time of construction in 2010, included considerations of post-dam removal sedimentation, but the levee design analysis did not consider future changes in peak flow magnitudes. Modifications to the Federal Levee or hatchery operations would be necessary to address projected changes. These modifications, such as raising the height or increasing strength to the Federal Levee, will take time and multi-agency cooperation.

Transportation

Due to its remote isolated location, with limited ingress and egress, the LEKT Reservation is vulnerable to severe weather, such as high winds, landslides, record snowfall, and flooding. During severe weather events, power outages and road closures place significant burdens on the Tribe (Lower Elwha Klallam Tribe, 2011).

Increased winter maximum and peak flows will increase risk to primary transportation routes in two ways; flooding and erosion. Elevated winter flows may flood access roads more often, and increase the risk to roads in the Lower Elwha River valley that are located behind the Federal Levee. Increases in flow may also increase risk of erosion for infrastructure that is located adjacent to the Elwha River and its tributaries, most notably the Olympic Hot Springs Rd, Highway 101, and the Federal Levee. Increasing summer air temperatures may affect pavement conditions & maintenance needs; and all of these facilities are at risk with increased wildfires. Increases in RSLR will increase exposure to flooding by increasing the base flood elevations in the Lower Elwha River floodplain.

Roads and Bridges to/from Reservation

Egress and ingress routes to the reservation, including bridges, received a **low** relative vulnerability assessment score.

These routes are currently impacted by the existing regulatory floodplain, such as Highway 101, Highway 112 and Elwha River Road, and/or, they are protected by the Federal Levee (**Figure** 23). These routes include Kacee Way, Stratton Road and Lower Elwha Road. The projected increase in peak winter flows will increase the potential for flooding and/or erosion of these locations (see Section 4 for more information).

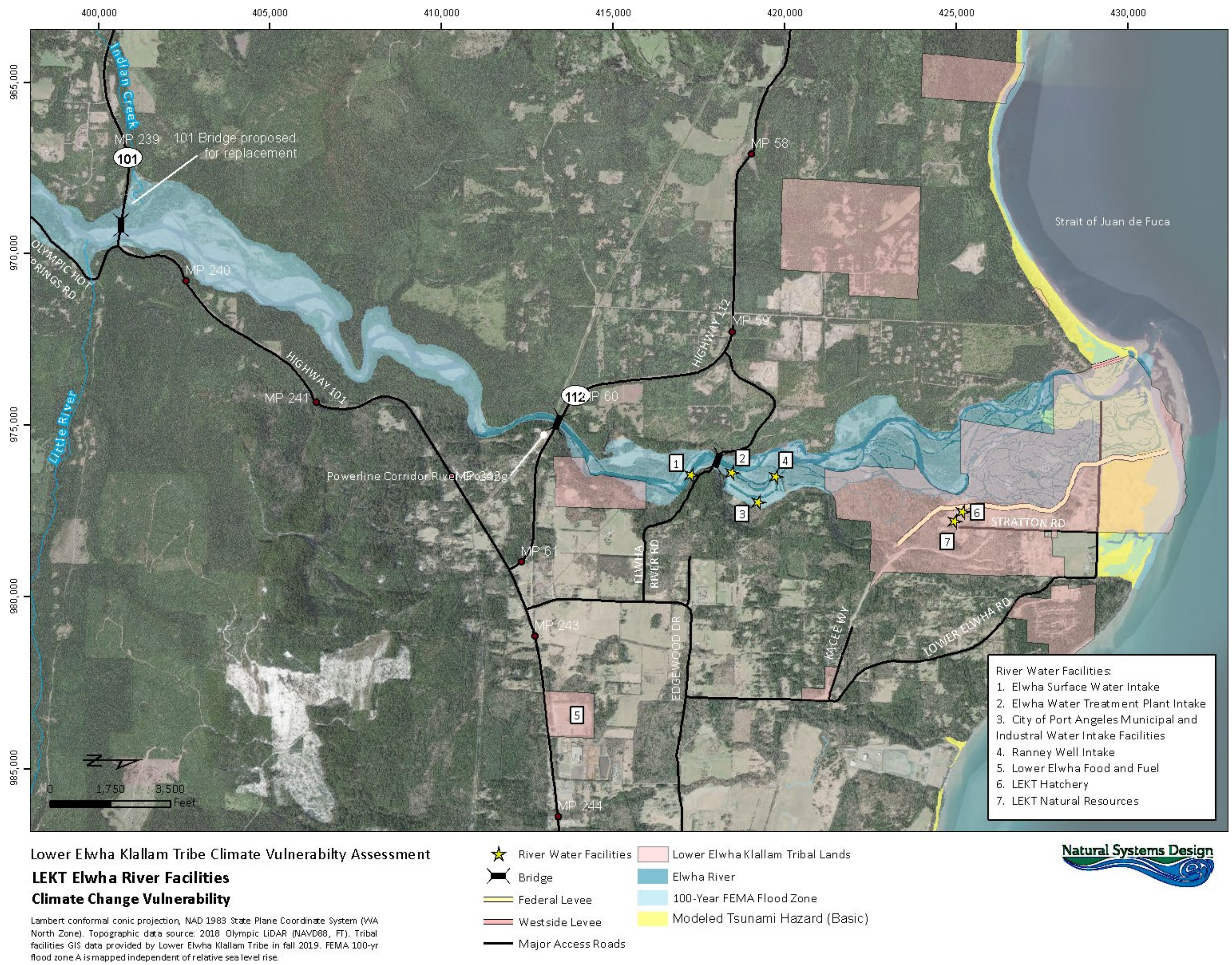


Figure 23. **Map of key roads, bridges and Elwha River facilities.**

Exposure and Sensitivity - Low

Three residential Lower Reservation roads, accessing three homes near the coast, would be affected by 2-ft of RSLR. While the Lower Elwha Road on the west side of the Federal Levee is also within the Elwha River floodplain, it is not being actively maintained and will eventually become a part of the Elwha River floodplain (see Figure 21. Lower Elwha Climate Change Vulnerability Map.)

No significant climate change impacts to state highways or bridges were identified by WSDOT in this area. The Highway 101 bridge is currently proposed for replacement (Figure 24) (WSDOT, 2016).

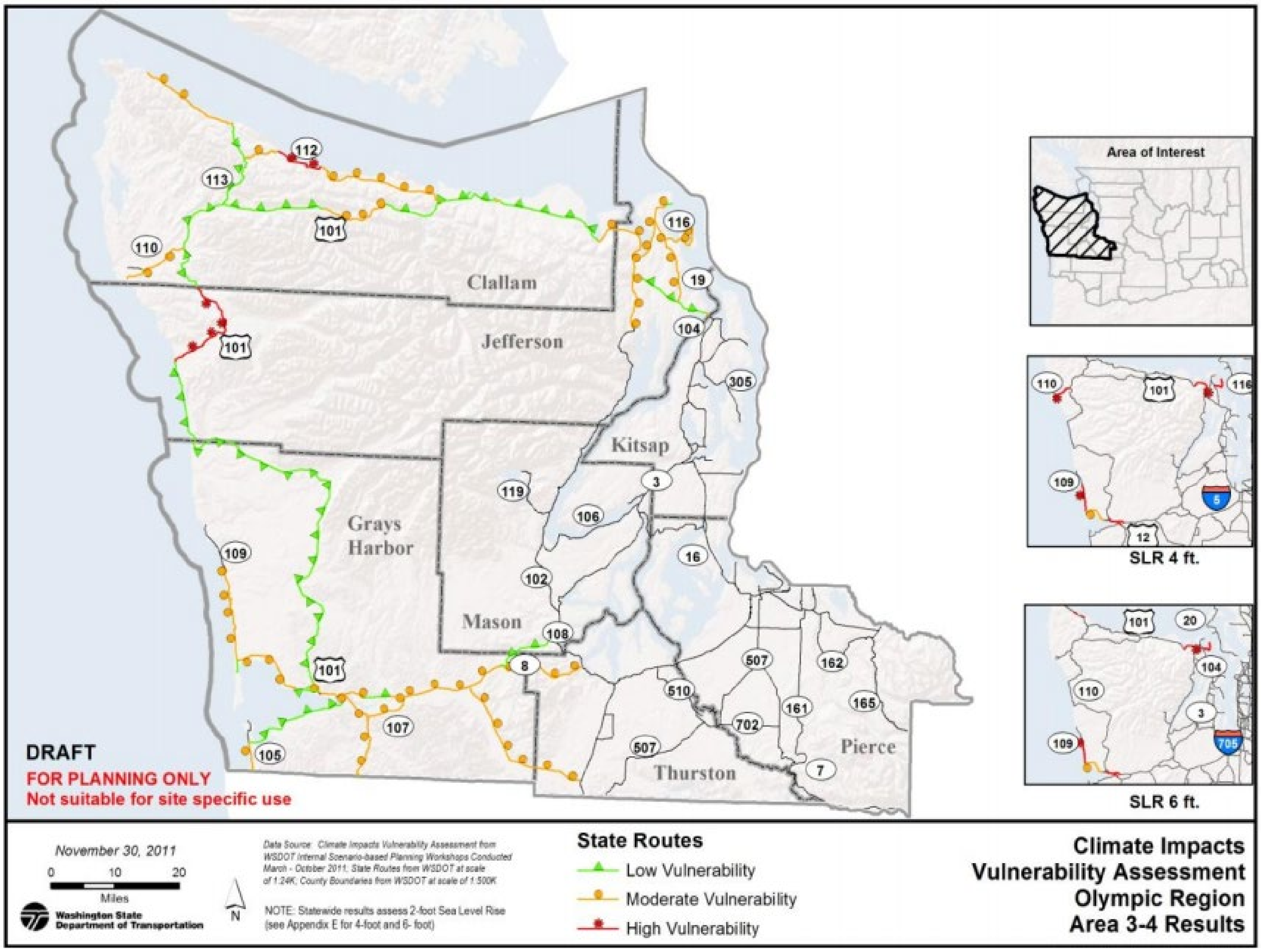


Figure 24. Map of climate impact vulnerability assessment of Olympic Peninsula state routes (WSDOT, 2016).

The Olympic Discovery Trail is sensitive to landslides outside of the study area. It was closed by a slide in 2014 (Clallam County HMP, 2019).

Adaptive Capacity – Medium

Existing roads and bridges crossing the Elwha River floodplain can likely withstand current flood and erosion risk. These structures may already be engineered to withstand some impact beyond current conditions. Over time, the roads and bridges may be moved, elevated, and strengthened to adapt to climate change conditions. Planning for these improvements is not easy but, critical road and bridge conditions crossing the Elwha River and within the tsunami and earthquake impact areas, are routinely evaluated as a part of the hazard mitigation planning process and may be improved over time with multi-agency coordination.

Utilities

Power Supply and Delivery

Power supply and delivery have a **medium** vulnerability to climate change.

The interruption of power to the LEKT, particularly during severe weather, is a proximate risk to human health and safety. Electrical power supports climate control, water distribution, pump driven sewer systems, and communication for the LEKT. Power supply to the LEKT and Port Angeles is provided by the Clallam Public Utilities District (PUD) and is reliant on the regional power grid.

Power outages are the top concern of the 2019 Clallam County HMP and are ranked and included in the “winter storm” and “windstorm” analyses in the LEKT portion of the HMP, ranked #4 and #5 hazard mitigation concerns for the LEKT Annex of this 2019 plan. Power outages during winter and windstorms can last anywhere from several hours to several weeks, and these outages could have significant human health impacts (Clallam County Emergency Management, 2019). Water supply service is also generally shut down without power. Widespread utility failures occurred during the December 2018 wind storms and during Hurricane Songda in 2016 (Clallam County Emergency Management, 2019).

Should power fail, all forms of communication will be intermittent and unreliable, and affected systems will include cellphones, land lines, internet, cable TV, AM/FM radio.

Exposure and Sensitivity - Medium

Exposure and sensitivity of the power system to climate change occurs via an increase in severe storms, wildfire, SLR, and increase in peak heat events.

- **Increase in severe storms and wildfire**: Power is supplied to the study area via Clallam Public Utility District via long above-ground transmission corridors. These corridors extend beyond our detailed study area, but have inherent vulnerability to severe weather events.
- **SLR**: A handful of utility poles near the coast are within the area predicted to be affected by SLR toward the end of the century. Above-ground power lines are also exposed to wildfires, with predicted increased risk by 2050.
- **Increased peak heat events**: The potential for increased summer power outages, during peak heat events, is predicted to increase by 2035 (Turner et al., 2019). The 2019 DRAFT Clallam County Multi-Jurisdictional Hazard Mitigation Plan identified potential climate change sensitivity, where increased demand during high-intensity heat, could result in widespread outages, similar to what was seen in California during summer 2020.

Adaptive Capacity – Medium

The Tribe’s local distribution system may be adapted as existing power lines in flood prone areas may be relocated or protected.

The regional power delivery system is more complex, so adaptations will take more time. Development of independent power supply, such as solar or wind, could provide more energy independence, if regional power grid were to fail for an extended period.

Water Availability and Distribution

Future water availability and distribution from the Elwha River is highly vulnerable to climate change. Reductions in future low flows in the river by 56% means that today's infrequent drought years, that impair habitat and result in water use restrictions, will become a typical future condition in the summer and early fall. For context, the projections suggest that the drought year of 2015 will be closer to the typical condition later in the century.

The Elwha River is the primary source of water for the City of Port Angeles and LEKT Reservation. Water is withdrawn from a groundwater well, near the Ranney side channel of the Elwha River, which recharges the well. There are several backup-systems in the same location as the well, a surface water diversion and pumped intake system, called the Elwha Surface Water Intake (ESWI). The LEKT fish hatchery is serviced by the ESWI and a series of groundwater pumps in the vicinity of the hatchery (Figure 25).

Water from the Elwha River is used by industrial, domestic, agricultural, and fish hatchery users. Water users from the river include:

- The LEKT water rights held in trust by the federal government, which are not quantified (City of Port Angeles 2018). These rights guarantee sufficient water to support treaty fisheries and the purposes of the Lower Elwha Klallam Reservation.
- 200 CFS total held by the City of Port Angeles. The City obtains water from a surface diversion and from subsurface collection in the Ranney side channel.
    - 50 CFS for municipal potable system
    - 150 CFS for non-potable uses including industrial and fish hatcheries. This 150 CFS includes the 100 CFS for Industrial Uses and 50 CFS in use by Washington Department of Fish and Wildlife and LEKT used at the tribal hatchery.
- 6 CFS held by property owners along the river.
- Black Diamond Water District holds water rights on Little River, a tributary to the Lower Elwha.

There are currently no minimum flow requirements for the Elwha River. Water rights allocations in the Lower Elwha were summarized by (Federal Energy Regulatory Commission (FERC), 1993) (Orsborn and Orsborn, 1999).

Water shortages are currently managed according to the Water Shortage Response Plan (City of Port Angeles, 2017). A voluntary conservation program (stage 2) is triggered when the river flows are 400 cfs or less for three consecutive days. As drought worsens, outdoor water use becomes restricted (stage 3), indoor water use is then conserved (stage 4), and then water rationing (stage 5). All of these actions are based off of the Elwha River flows measured at USGS gauge station number 12405500, located at the McDonald Bridge on the Elwha River.

In their low flow assessment of the Lower Elwha River, Orsborn and Orsborn found that habitat conditions were reduced anytime the flow goes below 300 cfs at each of the four sites they examined. They also concluded that during low flows, fish would need to find adequate cover (depth) (Orsborn and Orsborn, 1999).

Given the physical changes to the Lower Elwha River since dam removal and future decreases in low flows due to the warming climate, the current industrial water right allocation may not be compatible with sustaining minimum flows for salmonids. Past studies and water right allocation processes have not considered reductions in summer availability, so we recommend that LEKT pursue a new minimum in-stream flow study for the Elwha to establish whether minimum flow requirements are warranted and if water rights allocations need to be renegotiated.

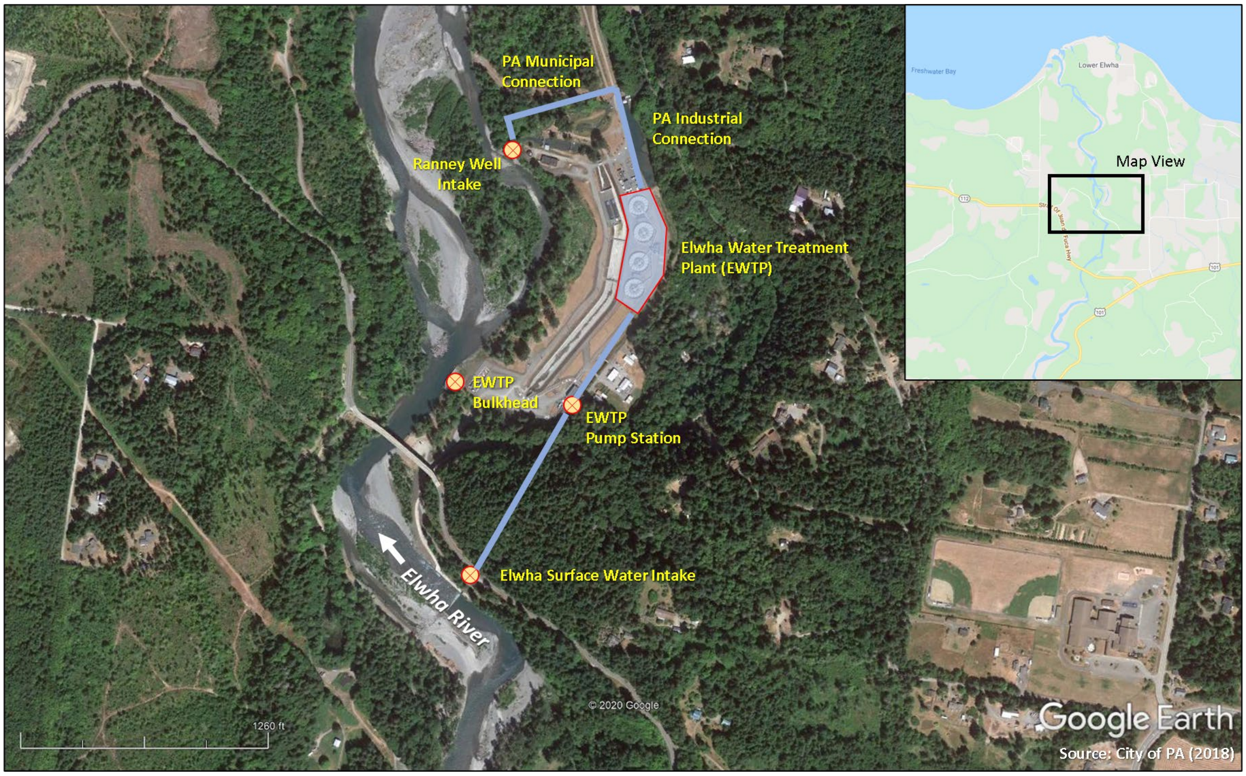


Figure 25. Map of Elwha River water supply system with allocated water rights (City of Port Angeles, 2018). Industrial water supply consists of surface water diversion upstream of Elwha River bridge and municipal drinking water supply comes from a Ranney groundwater intake.

Exposure and Sensitivity - High

LEKT's water supply is directly tied to Elwha River streamflow. Climate projections predict a shift from a transient-type basin to a rain-dominated flow regime, which will result in the loss of the late spring and early summer flow peak. Low flows, in late summer and fall, are expected to be reduced to levels that will threaten both the amount of water available for human use and the amount and quality of aquatic habitat in the river.

Water supply is already an issue in warmer years, with voluntary water conservation measures implemented due to low flows in the river in 2015, 2019 and 2020. According to Clallam County Multi-Jurisdictional HMP (2019), Clallam County has experienced 8 moderate to extreme droughts over the last 17 years.

From a water distribution perspective, the water treatment plant and pump station are highly susceptible to earthquake damages, but not tsunami, flood, wildfire, or landslide damages (Clallam County Emergency Management, 2019).

Adaptive Capacity - Low

With projected hydrologic changes and the water distribution system, there is limited adaptive capacity for the existing system. The City of Port Angeles has secondary sources (e.g., Morse Creek and groundwater wells) identified. The LEKT may use the hatchery as a source of water in times of crisis. There were 6 wells at the time that this report was written, running at a capacity of 3,500 gallons per minute, with a seventh planned for construction in 2021 (GeoEngineers, 2011; GeoEngineers, 2016).

Over time, the LEKT may need to identify new sources of water and/or modify water rights, particularly the large water right allocated to industrial consumption to support future residential use and maintaining sufficient flows in the river for fish and wildlife. Changing water rights is a lengthy process and identifying new sources may be difficult, so developing a planning strategy should begin as soon as possible.

Adaptation measures typically involve construction of new wells or distributions systems, or desalinization plants; in the short-term, water may be supplied via large tankers (Clallam County Emergency Management, 2019). Financial resources for some of these potential adaptation measures are listed in the Clallam County HMP (2019) and include community development block grants, capital improvement project funding, insurance, user fees for utility services, state-sponsored grant programs, FEMA, and the potential to incur debt.

Wastewater Collection and Treatment System

The relative climate change vulnerability of the LEKT wastewater collection and treatment system is **low**.

Prior to the removal of the Elwha River dams, all of the Lower Reservation had been integrated into the City of Port Angeles wastewater and sewer systems. Septic systems on the reservation were functioning, until they were removed prior to Elwha Dam removal, due to predicted increases in groundwater elevation caused by changes in hydrology and the river channel.

None of the public wastewater treatment systems are subject to floods, fire, or landslide risks (Clallam County Emergency Management, 2019). Destructive earthquakes were the only threat listed in the Emergency Management Report. Damage from earthquake would result in a disruption of service for an unforseeable amount of time.

Exposure and Sensitivity – Medium

The current wastewater collection and distribution systems may be impacted by increased river or coastal flooding. The sewer system is a vacuum sewer system and may be vulnerable to changes in the groundwater table (Petersen et al., 2015b). The projected 48% increases in peak winter Elwha River flows increases the potential for groundwater affecting the new vacuum-based sewer system. The system is also sensitive to power outages.

The wastewater treatment plant and pump station are highly susceptible to earthquake damages but not tsunami, flood, wildfire, or landslide damages (Clallam County Emergency Management, 2019).

There are some wastewater lines, near the beach, which may be affected by sea level rise, but the vast majority are outside of the influence of SLR and protected by the Federal Levee.

Adaptive Capacity - High

The LEKT wastewater collection is currently a part of the (2019) Clallam County Multi-Jurisdictional Hazard Mitigation Plan, which will help this system adapt over time. Additional protections (e.g., gasketed catch basins) may be necessary to prevent additional water intrusion. Back-up power for the pump station may also be needed during longer or more frequent outages.

Cell towers and Emergency Communications

The relative climate change vulnerability of the local cell tower and emergency communication system is **low**. The communications system is reliant on power, which has a medium vulnerability.

Communications systems in the county are managed by Amateur Radio Emergency Services, Marine Band, Air Band, Simplex Line-of-sight-only repeaters, portable satellite systems, and military internal tactical communications (Clallam County Emergency Management, 2019).

The KONP radio station, Clallam Transit communications system are highly susceptible to earthquake damages but not tsunami, flood, wildfire, or landslide damages (Clallam County Emergency Management, 2019).

Exposure and Sensitivity - Low

Cell towers and emergency communications appear to be out of harm's way from river flooding and SLR. The primary climate change exposure for communication infrastructure comes from wildfire and power grid reliability.

Adaptive Capacity - Medium

Increasing the level of protection for communications systems against wildfire would increase the level of future reliability of the communications systems. Adding power backup systems would decrease sensitively to power outages.

Solid Waste Management

Solid waste management system was assigned a **low** climate change vulnerability score.

Solid waste management takes place at a transfer station, located at a former land fill site in Port Angeles that has historically been impacted by bluff erosion. A $20M stabilization project in 2014 has provided protections to avoid future SLR and bluff erosion impacts.

The Port Angeles landfill was originally a regional landfill, purchased by the City in 1947. It contained about 750,000 cubic yards of municipal solid waste. Bluff erosion has been a concern since 2001 and the landfill was permanently closed in 2007, when erosion exposed the Strait of Juan de Fuca to some of the stored waste material. An emergency seawall was constructed to contain the waste, which failed again in 2011. A regional transfer station has since been constructed at the same site to gather solid waste for compaction and shipment to Roosevelt Landfill in eastern Washington (Figure 26).

Figure 26. Port Angeles landfill (closed) and transfer station (active).

Exposure and Sensitivity - Low

The landfill has historically been influenced by bluff erosion associated with tidal water levels and storm events. The landfill remediation project included a seawall that will provide protection until rising sea levels increase wave attack to beyond the current level of protection.

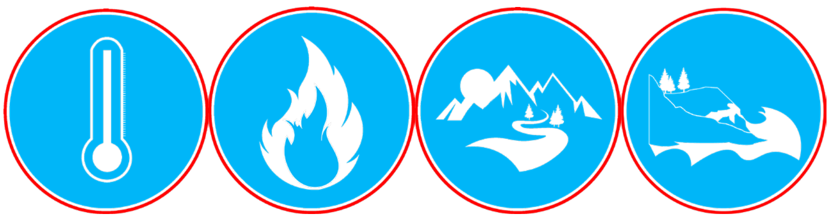
Adaptive Capacity - High

The landfill has already been moved and the portions near the bluff have been stabilized in place. Additional stabilizations may be necessary and adjusting the existing sea wall will be expensive.

5.4 Cultural Places and Practices Key Concerns

Climate change is already affecting critical cultural resources. The land, water, food sources, and important plant and animal species are threatened. Cultural heritage sites, ceremonial sites, and traditional practices that help to sustain intra- and intergenerational community relations, are built on sharing traditional knowledges, food, and ceremonies, are potentially at risk. Disruption to these traditional practices can weaken place-based cultural identities, may worsen historical trauma still experienced by many Indigenous peoples, and adversely affect mental health and the tribal values-based understanding of health.

Village Locations, Sacred Places, and Ceremonial Sites & Cultural Practices



Exposure and Sensitivity - Medium

Village Locations and Sacred Places: Located on the mainland shoreline near Ediz Hook in Port Angeles, Tse-whit-zen's elevation is approximately 5 feet above today's MHHW. Based on the Washington Sea Grant work (Miller et al., 2018), there is a 50% probability that there will be 1.7 feet of sea level rise by 2100; with the addition of storm surge (roughly 2.5 feet), the overall exposure of this site to coastal flooding is likely to occur after 2100. The exposure of the other historical villages is dependent on the elevation and coastal features that either protect or expose the sites to flooding and/or erosion (Figure 27).

The southern shore of Beach Lake is a known sacred site and a segment of berm fronting Beach Lake and protecting this site is vulnerable to coastal erosion. Over the years, the integrity of the berm has been compromised, and without intervention may soon be breached.

Ceremonial Sites and Cultural Practices: The Klallam people are resilient and have continually been adapting their cultural practices, including ceremonies and hunting and gathering activities, to changes in their environment and natural resources. However, the projected climatic changes, and subsequent impacts on culturally-important plant and animal species are unprecedented and may lead to a permanent shift in seasonal timing, abundance, and/or habitat range of different species. These shifts could ultimately lead to a loss in species essential for certain traditional practices and ceremonies.

Communities with strong social cohesion are more adaptable or less vulnerable to the impacts of climate change (Dodgen et al., 2016). Social cohesion refers to the "*strength[s] of interpersonal networks and social patterns in a community*" (US Global Change Research Program, 2016). Climate factors that can impede outdoor activities include extreme heat days, which put vulnerable individuals at risk of heat exhaustion or other health complications, and poor air quality from wildfire smoke or high pollen loads, increasing risk for asthmatics and those with allergies. In communities where opportunities to convene and gather are not priorities, isolation becomes a problem and mental health conditions, such as depression alcohol and drug dependency and aggression, worsen. Importantly, social isolation is a large indicator of heat-related illness and death vulnerability (US Global Change Research Program, 2016; US Global Change Research Program, 2018) .

Climate change also threatens the availability and abundance of culturally significant plant and animal species. In addition, climate change can potentially prohibit (or make much more difficult) access to sacred and ceremonial sites, all of which hold significant value for the Tribe and may be central to the way of life for many tribal members and communities (Lynn et al., 2013; US Global Change Research Program, 2016). These losses can have profound impacts on the community's ability to practice and share their culture, their language, and, in many cases, provide food to nourish themselves (Lynn et al., 2013). As Lynn et al. states, "*The indigenous relationship between food and people is intimately tied to the cultural, physical, emotional, psychological, and spiritual health of tribal communities. The impacts of climate change on species or ecological processes, therefore, are directly connected to climate impacts on tribal culture and the importance that traditional foods have for tribes*" (2013).

One example of a traditional activity being affected by climate change is "Journeys". Traditional tribal canoe journeys look very different today than they used to, including the duration, path, and logistics of the journeys. It was noted that the canoes themselves have changed because, due to logging, there are no large cedar trees to create the traditional dug-out canoe. Modern canoes for these journeys are made from cedar strip and fiberglass, which creates a much lighter boat that tips easier and can be pushed around more by the wind. Climate change is affecting cedar stripping, occurring earlier in the year as temperatures warm. While climate change may not be the reason for changes in traditional practices for the Tribe, the impacts of climate change on weather and seasonal climate, as well as the availability of resources, only serves to exacerbate other challenges.

Figure 27. Map of Northwest S'Klallam Villages along the Strait of Juan de Fuca (Source: https://www.elwha.org/culture-history/historical-village-sites/).

Adaptive Capacity – Medium

The Lower Elwha Klallam people have lived in the area for thousands of years, and their culture, spiritual practices, and economies have evolved over the years to be adaptive to seasonal environmental changes. Cultural ceremonies and traditional hunting and fishing practices have evolved as the abundance and seasonal return timing of salmon have changed over the years. The flexibility increased the Tribe's ability to adapt to ongoing environmental changes driven by climate change.

However, there is less adaptive capacity when it comes to historical villages and sacred sites. The physical location of these areas holds immense value and cultural significance to the Tribe, and it is not possible – and in many cases not acceptable – to attempt to relocate these areas.

Vulnerability Ranking – Medium

Overall, the cultural concerns of the Lower Elwha Tribe, including historical village sites and cultural practices, have a medium vulnerability to climate change. While the Tribe has historically adapted to environmental changes, the projected changes may cause a significant shift in ecosystems that may lead to loss of plant and animal species or the loss of historical sites that cannot be moved or rebuilt. While the vulnerability of individual sites and practices may vary, depending on the resources used and/or the specific geographic location and environmental conditions, participation in traditional cultural ceremonies and activities is already low, which exacerbates the threat of climate change to these places and activities.

5.5 Community Health and Wellness Key Concerns

Climate change can impact human health in a variety of ways both directly, from extreme events such as drought, wildfires, extreme precipitation, and storms, as well as indirectly, from loss of access to traditional foods, impacts to cultural practices and sites, and loss of overall community cohesion. More frequent or intense extreme events are expected to adversely impact the general population's health (Bell et al., 2016) by worsening underlying medical conditions and increasing overall stress and anxiety, which can all lead to adverse mental health effects (Dodgen et al., 2016). In addition to the adverse impacts to the individual, extreme weather and other climate events can disrupt the proper functioning of critical public health, healthcare, emergency, and other related systems in ways that can affect the health of the population, even long after the event took place (Bell et al., 2016).

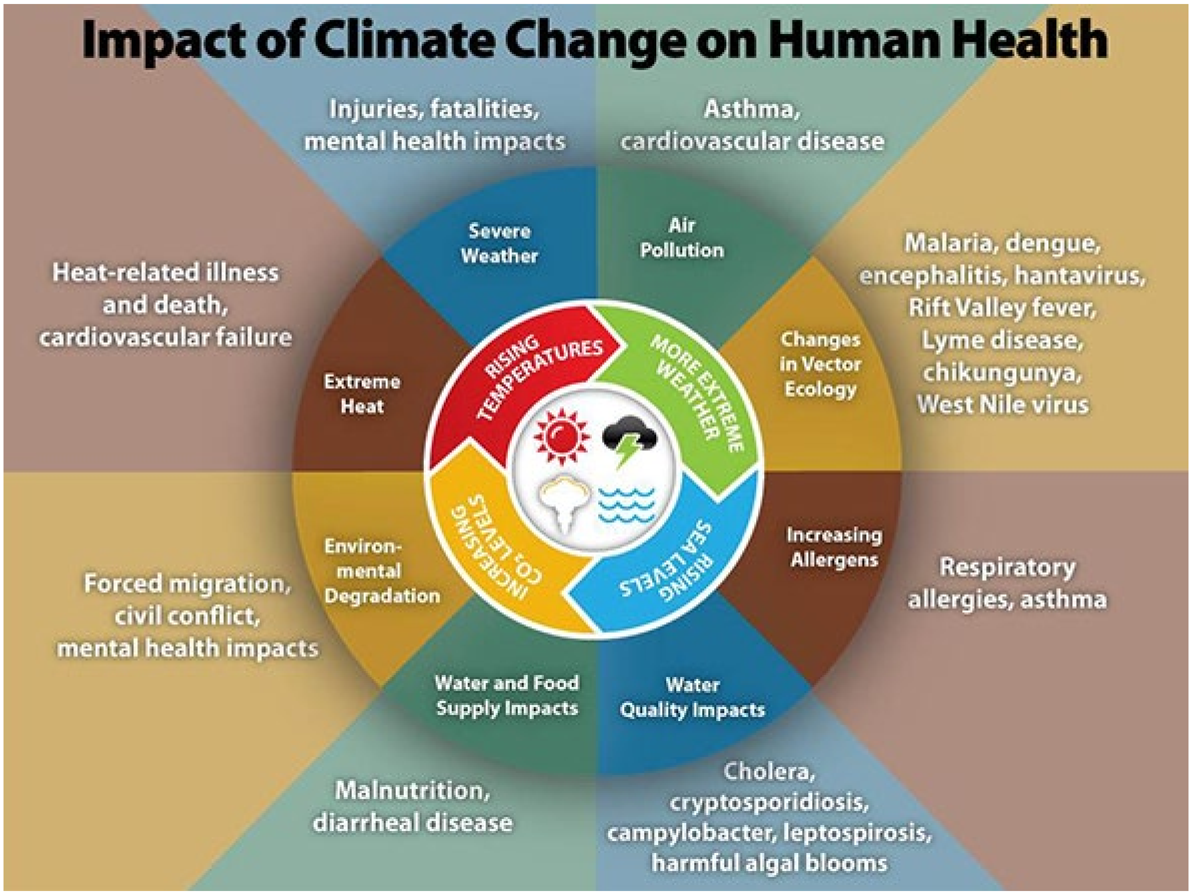
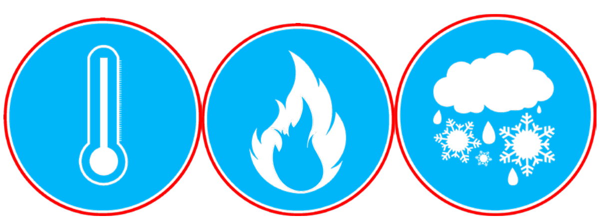


Figure 28. Climate change impacts a wide range of health outcomes. This figure illustrates the most significant climate change impacts (rising temperatures, more extreme weather, rising sea levels, and increasing carbon dioxide levels), their effect on different exposures, and the subsequent health outcomes that can result from these changes in exposures. This is a graphic that summarizes nationwide impacts of climate change on public health and is not specific to the Lower Elwha Klallam Tribe; however, many of these exposures and health outcomes are discussed in this assessment (Source: Center for Disease Control and Prevention).

Healthcare and social systems, which are already stretched thin with current demands, will likely be further challenged as acute climate events increase in frequency or when cascading events occur in the future. As the likelihood of hazards and epidemics increase, disruptions to local economies and food systems are projected to impact local health and result in more chronic health risks.

Allergies, Asthma, and Respiratory Stress



Asthma is directly connected to increases in daily temperature in a region. According to a study looking at heat-related emergency hospitalizations for asthma, a daily increase of 10°F was associated with a 4.3% increase in same-day emergency hospitalizations for respiratory diseases (Anderson et al., 2013). Further, the same study found a strong association between heat and respiratory hospitalizations (e.g., asthma, bronchitis, chronic obstructive pulmonary disease, respiratory infections) in the elderly, a particularly vulnerable population.

Particulate matter (PM) from drought and wildfire smoke represents another significant source of pollution that can exacerbate asthma and other respiratory illness and increase respiratory stress (e.g., bronchitis, chronic obstructive pulmonary disease, and respiratory infections). Studies have found that children exposed to PM over long periods of time have reduced lung growth and increased respiratory symptoms. Extended and more severe wildfire seasons, even if not directly affecting the forests of the Olympic Peninsula, can significantly decrease outdoor air quality, affect those with existing conditions, and force people to spend more time inside.

Changes to temperatures and precipitation can expand the growing season. An expanded growing season increases the growth of pollinating plants and causes them to produce more spores and pollen for a longer period of time. These changes, as well as changes in habitat conditions, can allow for existing allergy-causing plants to expand their range into new areas (Staudt et al., 2010).

People generally spend more time indoors than outdoors, thus the impact of poor indoor air on health, in particular respiratory health, is an important consideration. The effects of climate change on indoor air quality are an emerging issue. Increases in particulate pollution from wildfire smoke and increasing presence of allergens from seasonal changes worsens both outdoor and indoor air quality (Institute of Medicine, 2011; US Global Change Research Program, 2016). For the Pacific Northwest, the expanded wildfire seasons over the past few summers have meant poor and dangerous air quality in the region and have increased the amount of time people spend in the indoor air environment. Further, climate change may lead to an increase in localized flooding of homes and buildings and create conditions where more power outages may occur, which can increase the presence of mold due to increased dampness and less ventilation inside the home (US Global Change Research Program, 2018).

Exposure and Sensitivity - Medium

At present, there is a high incidence of asthma and chronic obstructive pulmonary disease (COPD) in LEKT members. Many individuals use inhalers to reduce asthma attacks; however, the use of oral steroids is sometimes necessary. Health clinic staff noted the significant increase of visits related to asthma and other respiratory illnesses during periods of high pollen events, generally in the spring season. It was also noted that the “pollen season” has become longer and more intense and appears to be connected to the climate-driven shift in the earlier arrival of the spring season, changes in rain patterns, the occurrence of pollen loads in bursts, and the impact of wildfire smoke and associated poor air quality (personal communication with Tribal Health Clinic staff).

The direct impacts of wildfire smoke in the area from the extensive wildfires that burned in Washington and Oregon in the summer of 2020 greatly limited the ability of adults and children to recreate outdoors and participate in community events or traditional hunting and gathering practices (personal communication with Tribal members). While the risk of wildfire is expected to increase in the area due to changes in precipitation and increased temperatures, smoke from wildfires burning from British Columbia to Oregon can have adverse effects on public health; therefore, increased wildfire risk in the larger scale of the Pacific Northwest can directly affect the health of tribal members.

Increased incidence and prevalence of asthma, allergies, and other respiratory illnesses can limit or decrease the ability of Tribal members to participate in traditional practices and modern events, such as hunting and gathering and school activities. Certain tribal members noted a connection between the increased prevalence of asthma and allergies and the increase in rates of diabetes and obesity within the Tribe, due to the physical limitations and reduced opportunity to participate in physical activities such as traditional hunting and fishing or gathering berries for subsistence (personal communication with tribal members).

In Clallam County, the approximate percentage of the population with asthma (~11%) is slightly higher than the state average (~10%)(WSDOH, 2015). The U.S. Centers for Disease Control and Prevention (CDC) identified Washington's asthma prevalence as among the highest in the nation, and steadily increasing (WSDOH, 2020). According to data compiled by the Washington Behavioral Risk Factor Surveillance System (BRFSS) regarding health risks of Native Americans in Washington State (from 2003-2006), about 22% of Native Americans surveyed reported they had asthma, in contrast to 14% of non-Native Americans surveyed.

Adaptive Capacity – Medium

The ability of the Tribe to adapt to increased risk and prevalence of respiratory diseases and illnesses due to climate change is limited. While the local health clinic is available to treat asthmatics, resources are limited, and climate change and extreme events are likely to put additional stress on the healthcare system. The Tribe has little control over localized and regional air quality, especially poor air quality from wildfire smoke and higher pollen levels. However, actions can be taken to improve indoor air quality in public and private buildings and homes by installing air filters and working to reduce any residual moisture following heavy precipitation or flooding events.

Vulnerability Ranking - Medium

Due to the existing high prevalence of chronic respiratory illness and projected increase in climate-related events, particularly wildfire, that reduce outdoor air quality, the Tribe is somewhat vulnerable to health risks related to asthma, allergies, and other respiratory illnesses. While outdoor conditions are expected to increase these risks, actions can be taken to improve indoor air quality conditions and educate the community on actions individuals can take to reduce their risk of asthma and other respiratory illnesses.

Communicable & Vector-Borne Diseases and Illnesses (Lyme Disease, West Nile virus, Harmful Algal Blooms)

Projected warming temperatures for the Lower Elwha Reservation and surrounding region, both in terms of increasing average temperature, increasing frequency of heat days, and decreasing number of cold nights, improves conditions for many vectors - organisms which transmit disease from one animal to another. These conditions allow vector populations to increase due to the lack of vector die off during cold temperatures and expand presence, both temporally and spatially (Ebi et al., 2018; US Global Change Research Program, 2016).

Overall, climate change is expanding the geographic range and shifting the timing of the presence of vectors that cause illness, and vector-borne pathogens not previously occurring in this area may emerge under new temperature regimes (USGCRP, 2016). Warming temperatures create ideal conditions for tick-borne illnesses to expand into new areas or persist in existing regions outside their typical season (Levi et al., 2015; US Global Change Research Program, 2016). Changing precipitation patterns and the increase of extreme weather events will influence the “distribution, abundance, and prevalence” of mosquito-borne illnesses such as West Nile Virus (Harrigan et al., 2014; US Global Change Research Program, 2016). The complexity of the systems which create ideal conditions for the spread of vector-borne illness and uncertainties about the data surrounding these conditions, however, makes projections of some vector-borne illness challenging (US Global Change Research Program, 2016) .

Lyme Disease: Lyme disease is the most common reportable vector-borne disease that can be passed from animals to humans in the United States, and its incidence has sharply increased in the last decade in the United States. Increases in average daily temperatures, a consequence of climate change, may be the contributor to the increase in tick abundance due to higher winter rates of tick survival. In addition, changes in the environment may contribute to better host availability, which is critical for tick feeding and completion of the tick’s life cycle. It has been demonstrated that tick activity and survival are dependent on temperature and humidity (Dumic and Severnini, 2018).

West Nile Virus: Climate is a major environmental driver influencing the epidemiology of West Nile Virus. Weather conditions (particularly temperature, precipitation, and humidity) affect survival and reproduction rates of vectors – mosquitoes, their habitat suitability, distribution, and abundance (Paz, 2015). In addition, climate change can impact the intensity and temporal activity of the vector throughout the year and impact the rates of development, reproduction, and survival of the pathogens within the vectors (Rogers and Randolph, 2006).

Harmful algal blooms: Increased water temperatures and changes to hydrological conditions have increased the potential for freshwater harmful algal blooms in areas of recreational and subsistence harvest (Paerl and Huisman, 2008). The affects are not limited to freshwater as the toxins from algal blooms can accumulate in shellfish and reach levels that can cause illness, sometimes severe, for humans that ingest affected organisms (Bethel et al., 2013).

Exposure and Sensitivity - Low

In recent years, the Pacific Northwest region has seen an increase in some communicable and vector-borne diseases. Increases in Lyme disease cases are associated with rising temperatures and expanding and shifting tick habitat (Beard et al., 2016).

Earlier onset of West Nile virus-carrying mosquitoes and an increasing number of human infections (some resulting in fatalities), likely associated with higher temperatures, has been observed by the Washington Department of Health's vector surveillance program (WSDOH, 2018).

According to historical data on West Nile Virus cases in Washington, there have been no documented cases of West Nile Virus in Clallam County since testing began in 2002; however, it is difficult to predict changes in cases as temperatures increase and alter the ranges of vectors for this virus in the region. The first case of West Nile Virus in Washington was detected in 2006, where 5 people were diagnosed, and the virus was detected most heavily in the state in 2009, when 38 people tested positive (Seattle Times, 2020).

The largest harmful algal bloom ever observed off the West Coast occurred in 2015 and stretched from California's coast to Alaska, and the high levels of toxins led to extensive closures of shellfish harvest in much of the Northwest (Milstein, 2015).

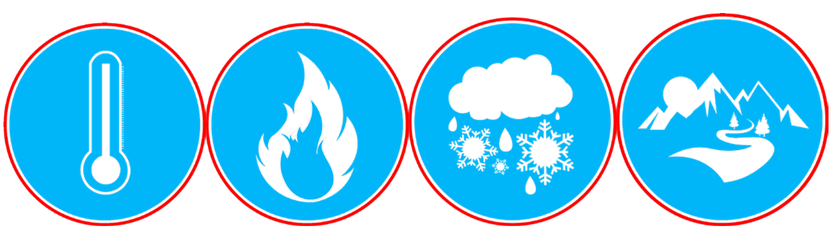
Adaptive Capacity - High

When it comes to communicable and vector-borne diseases and illnesses, the greatest means to combat current and future infections is through community education. In all instances, these health issues are treatable and, in most instances, can be prevented or caught and treated early. Tribal members can adjust their behaviors by avoiding areas with a high abundance of vectors (ticks and/or mosquitoes), wearing long-sleeved clothing when outdoors, or using insect repellants. Understanding how to look for ticks and the early signs of illness are paramount to reducing complications from these illnesses. Education, awareness, and public alerts of harmful algal blooms and fishery closures can prevent illness from ingesting affected shellfish.

Vulnerability Ranking - Low

The overall vulnerability of the Tribe to communicable and vector-borne disease and illnesse due to climate change is low. The current incidence in Lyme disease, West Nile Virus, and paralytic shellfish poisoning (health impacts from ingesting shellfish affected by harmful algal blooms) are very low, and despite projections that may create more hospitable habitat for vectors, there are many actions individuals and the Tribe can take to educate and prevent an increase in these health issues.

Diabetes (Type II)



A loss or shift in traditional plant and animal foods due to climate change or other external factors means a loss of high-quality sources of nutrition and decreases the opportunity to partake in physical exercise associated with gathering and preparation of these resources. Historically, tribal members in the region likely consumed 200 times more fish and shellfish when species were more abundant, and tribes had access to traditional fishing and gathering grounds (NWTT, 2016) This shift away from a traditional diet and toward a western diet aligns with an increase in chronic diseases, such as type II diabetes (Kuhnlein et al., 2004; Lynn et al., 2013).

The impacts of climate change can both increase the prevalence of diabetes in the tribal community, as well as exacerbate health conditions in diabetics. Diabetes complications are connected to climate change in two critical ways. First, diabetics have increased sensitivity to heat stress, and studies have shown an increase in hospital admissions and emergency room visits among diabetics during heat waves (Fletcher et al., 2012; US Global Change Research Program, 2016) . This increase in admissions during heat events can be linked to electrolyte imbalances due to dehydration and overheating (Xu et al., 2012). Secondly, extreme events make access to medications and specific dietary needs difficult, increasing morbidity and mortality among those with diabetes (Xu et al., 2012) .

Exposure and Sensitivity - Medium

Lower Elwha Klallam Tribal staff conducted an analysis focused on traditional fish consumption versus the more current suppressed fish consumption in order to determine if increased incidence of disease in LEKT members was related to the decreased consumption of salmon and shellfish. The analysis used data collected from a 2006 survey of tribal members, interviews with tribal members, and records maintained by tribal clinics and fisheries staff. Rates of obesity and Type II diabetes occur on the reservation at rates that exceed the national average, and it was concluded that if the situation of loss of traditional food consumption continues, tribal members will likely continue to experience increased rates of heart disease, Type II diabetes, and hypertension, as well as other weight-related disorders (Dunn, 2013).

The tribal diet has changed significantly from the traditional fish-dominated diet to a more westernized diet that is rich in processed foods high in fats and grains. As salmon harvest declined, the Tribe initially substituted shellfish (mostly crab) for salmon in their diet; however, as shellfish harvest also declined (mostly due to discovery of pollutants and toxins in the local waters), the Tribe has become more dependent on store-bought, highly processed foods or government-supplied foods, most of which are high fats and refined carbohydrates (Dunn, 2013). A marked increase in health disorders, such as obesity (48%) and type II diabetes (12%) appear to be associated with shifts in diet and the decrease in level of physical activity associated with moving to consumption of less traditional foods (Dunn, 2013).

Adaptive Capacity – Medium

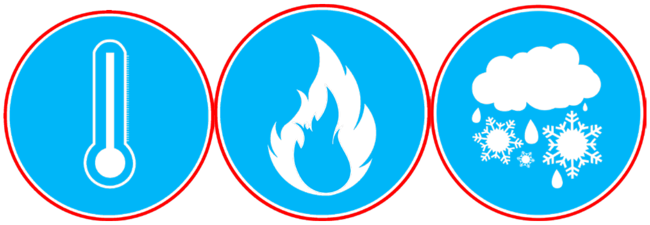
Despite increasing rates of diabetes and the significant decline in overall health in recent years, the strong association with changes in diet provides opportunities for the Tribe to reverse these health impacts in the future. The Elwha dams were removed to help restore salmon runs, which once restored, would provide opportunities to harvest salmon. The Tribe has also increased efforts to educate members on traditional foods, with the hope that even a slight shift back towards a more traditional diet could return tribal members to better health. The goal of the local First Foods program is educating members on traditional gathering practices and focus on an “awakening of the gut” in hopes to integrate more traditional foods into tribal diets.

Climate change will inevitably affect plant and animal species in a variety of ways, and there are many outside stressors, such as broader political and economic issues, which may prevent a full return to a traditional diet. However, there are likely different avenues the Tribe can pursue to help its members reduce their intake of highly processed foods and increase the amount of highly nutritious traditional foods in their diets.

Vulnerability Ranking - Medium

Due to the high prevalence of diabetes in the community and the increased vulnerability of diabetics to climate change, the Tribe has a medium vulnerability to Type II diabetes in a changing climate. While the Tribe’s ability to fully restore traditional diets is limited, there are still actions that can be taken to educate members and move towards a diet lower in fats and highly processed foods, especially in the younger generation. An increased emphasis on diet and exercise can greatly decrease the incidence of diabetes, as well as many other associated adverse health conditions that increase the population's vulnerability to climate change.

Mental Health & Social Relationships



While mental health conditions affect an individual, the impacts of those conditions have cascading effects on that individual's family, neighbors, and broader community. Climate change and its associated impacts are known to affect mental health and result in greater incidence of anxiety, alcoholism, stress, depression and possibly suicide (USGCRP, 2016; Willox et al., 2013). Climate directly impacts mental health through extreme weather events, while other impacts are subtler and result in increases in substance use disorder, depression, anxiety, and an overall sense of loss, especially as traditional landscapes change over time (Clayton et al., 2014). Some communities are more vulnerable than others. "*Factors that may increase sensitivity to the mental health impacts include geographic location, presence of pre-existing disabilities or chronic illnesses, and socioeconomic and demographic inequalities, such as education level, income, and age*" (Clayton et al., 2017).

Mental health consequences from climate change can range from symptoms of minimal stress and distress to clinical disorders, such as anxiety, depression, post-traumatic stress, and suicidality. All of these consequences can result from short-term or prolonged climate or weather-related events and the subsequent health consequences (Dodgen et al., 2016). These individual impacts can interact with existing health, social, and environmental stressors that can ultimately diminish an individual's well-being and overall mental and physical health

Exposure and Sensitivity - Medium

Extreme weather events are projected to increase on the Reservation and surrounding region, due to increasing temperatures and number of extreme heat days, increased wildfire risk, and dramatic hydrological regime shifts. Post-Traumatic Stress Disorder (PTSD) results when the acute stress responses to an event linger on beyond the time when order and calm have been restored; it can be expressed as anxiety and/or depression and potentially result in suicide (Clayton et al., 2017) . According to a recent report on the mental health impacts associated with climate change, "*climate change–induced extreme weather, changing weather patterns, damaged food and water resources, and polluted air impact human mental health. Increased levels of stress and distress from these factors can also put strains on social relationships and even have impacts on physical health, such as memory loss, sleep disorders, immune suppression, and changes in digestion*" (Clayton et al., 2017).

Climate change impacts have been demonstrated to cause a range of emotional and behavioral responses (Willox et al., 2015). There is a positive correlation between increasing temperatures and aggression (Clayton et al., 2014). "*Higher outdoor temperatures are associated with decreases in subtle aspects of well-being such as decreased joy and happiness and increased aggression and violence*" (US Global Change Research Program, 2018). Further, extreme weather events (e.g., extreme rainfall, wildfires, heat waves) isolate people in their homes, causing mental health declines that can result in increases in aggression and violence (US Global Change Research Program, 2016).

This project was unable to determine the incidence of mental illness or anecdotal information on the impact of a changing climate on the mental health of tribal members and the social relationships within the Tribe.

Adaptive Capacity – Unknown

The project team was unable to determine the adaptive capacity of the Tribe and the ability of local healthcare providers to address increasing mental health and relationship issues.

Vulnerability Ranking – Unknown

Due to the unknown adaptive capacity, the overall vulnerability of the Tribe's mental health and social relationships is unknown. This provides an opportunity for the Tribe to look into these issues within both the Tribal health staff and the tribal community. The overall health of the Tribe relies strongly on the well-being of individuals and the cohesion and sense of community within the Tribe.

6 SUMMARY AND NEXT STEPS

This Climate Change Vulnerability Assessment has been developed to provide a foundation that the Lower Elwha Klallam tribal community can build on over time as they prepare for changing climate conditions. The detailed consideration of climate exposures, sensitivity, and adaptive capacity for each of the key concerns identified by the Tribe culminates in a relative vulnerability ranking for each of the concerns (see Figure 9).

6.1 Key Findings

The vulnerability assessment resulted in the following key findings:

1. The Elwha River will persist, but the predicted loss of winter snowpack and associated late spring/early summer runoff will result in fundamental changes to the river ecosystem.
2. Lower baseflows in the Elwha River during the late summer and early fall will mean less water available for aquatic habitats and human uses. Current low flows and withdrawals already result in trade-offs between habitat and human use, so future lower low flows means that the status quo for water allocations will not be sustainable.
3. Chinook salmon are recovering now that the dams have been removed but are highly vulnerable to the seasonal flow changes predicted for the Elwha River.
4. There is adaptive capacity in many of the terrestrial plant and animal species that suggest they will persist with little overall change in frequency. Locations may shift, and there is uncertainty about how species will react over time.
5. Nearshore species will be impacted by ocean acidification which has significant implications for certain life stages and food webs.
6. With recent updates, much of the transportation and utility infrastructure that the tribe relies upon will be resilient to climate change.
7. Much of the low-lying portion of the Reservation is dependent on flood and erosion protection provided by the Federal Levee along the Elwha River. Recent improvements to the levee have been effective, but the level of protection did not consider future increases in peak flows, so the level of protection is expected to decrease over time.
8. There is little existing information regarding human health for the LEKT to support a vulnerability analysis specific to the LEKT.

6.2 Next Steps in Adaptation Planning

The information contained in the report and the details of how and why each concern will be affected by climate change can help guide if and how the Tribe chooses to plan for anticipated impacts to key concerns. The Tribe can also continue and add monitoring and data collection to fill gaps in knowledge about these key concerns. This assessment can also be used to help support and justify grant proposals and other funding requests to address these concerns.

Next steps for the Tribe to consider are community conversations and education, adaptation planning, and filling data gaps to support future decisions.

6.2.1 Community Conversations and Education

Sharing these findings with the community is a critical element to successful adaptation efforts. Broadening the conversation throughout the community will build:

- Community awareness of climate change exposures, impacts, and vulnerabilities.
- Institutional knowledge throughout tribal staff to support future adaptation.
- **Support to take actions to prepare for climate change.**

Many of the Key Concerns identified and evaluated in this report are complex and are interconnected and need awareness on many levels and within many different tribal departments. The more the community understands and owns these issues, the more likely the solutions developed to address them will be effective.

6.2.2 Adaptation Planning

Adaptation planning is the next step in building resilience to address the vulnerabilities identified in this report. Adaptation planning can take many forms, ranging from identifying stand-alone actions that the Tribe can pursue, to the integration of climate change considerations into existing tribal plans, policies, programs, or actions. The Tribe must be opportunistic and strategic about making these changes to target incremental improvements over time. We strongly recommend that adaptation effort include climate projections in the next update to the Hazard Mitigation Plan along with pursuing future funding opportunities to develop a holistic adaptation plan.

It will take creativity, innovation, and collaboration to respond to climate change. It will take commitment to continue to track current and emerging risks, develop goals and metrics of success, and continue to find or dedicate funding to take action. It will take rising to the challenges that climate change creates for natural resources, infrastructure, and community health not only on the Reservation, but throughout the region. The Lower Elwha Klallam people are resilient and have been adapting to changes for thousands of years and have shown a commitment to continuing to adapt by investing in this project and facing climate change directly. This project represents a solid next step in the community's continuing journey to adapt and build community resilience.

6.2.3 Opportunities for additional research and information gathering

- The LEKT can request the U.S. Army Corps of Engineers to re-evaluate the level of protection provided by the Federal Levee to incorporate both: (1) actual channel changes after dam removal (including progradation of the delta), and (2) predicted future changes in peak flows. The Corps has a process for supporting local sponsors for Federal levees which could be engaged by the Tribe.
- LEKT can implement an in-stream flow study to quantitatively assess aquatic habitat impacts of water withdrawals under existing and future base flow scenarios and establish minimum in-stream flow requirements. This study would support additional planning for future water sources and water rights.
- There is opportunity to further study the role of climate change in exacerbating pests, pathogens, and diseases within the Elwha River watershed and LEKT Usual and Accustomed Area.
    - While non-native European green crabs have not been found in the vicinity of the LEKT usual and accustomed fishing grounds, the LEKT have a monitoring program to track the species. A recent survey of Pysht Estuary monitoring by LEKT from 2017 to present found 13 Dungeness in 2017 and none in 2018 or 2019. No sign of green crabs were reported to date. Should this

species arrive, it may be beneficial to investigate the impact of climate change on the success of non-native European green crab, and the subsequent effect on Dungeness crab populations. In today's marine environment, European green crab tends to out-compete Dungeness crab wherever they co-exist. The European green crab may have a significant impact on Dungeness crab populations.

    - Community health data was unavailable at the time of this assessment however, data tracking of allergies, asthma, respiratory stress, communicable and vector-borne disease, type II diabetes are all identified as good opportunities to gather additional useful data to inform a good future climate change adaptation strategy for the LEKT. This dataset could also include the prevalence of vectors for vector-borne diseases, such as ticks.
    - Paralytic shellfish poison is a real concern for the LEKT as clams represent a commonly harvested traditional food. The overall trend in red tides in the LEKT fishing U&A, as well as algal bloom prone locations on the LEKT Reservation would also be useful to have for climate adaptation planning.
- Utilize available and recommended infrastructure, river, fish, wildlife, and plant monitoring data in climate adaptation planning.
    - Incorporate LEKT eulachon research into climate change adaptive management planning.
    - A map of eelgrass beds in the LEKT U&A was not located during the research phase of this assessment, which would be useful for future climate change adaptation planning.
    - Investigation of where solid waste is transferred and making waste treatment more local or decreasing waste transfer affords the opportunity to explore sustainability of the LEKT community from a "cradle to cradle" perspective on material consumption and use, rather than "cradle to grave."

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