HOOD CANAL CLIMATE CHANGE PROJECTIONS SUMMARY

Prepared for Participants of the Hood Canal Climate Adaptation Workshop

May 2015

Prepared by:

Stacy Vynne, Ecosystem Recovery Coordinator for the Hood Canal Action Area, Puget Sound Partnership

Haley Harguth, Watershed Planning & Policy Coordinator, Hood Canal Coordinating Council

Thanks to:

Port Gamble S'Klallam Tribe, Department of Ecology, Environmental Protection Agency, Adi Hanein

Climate Change in Hood Canal: A Snapshot

The earth's atmosphere and oceans are warming. Hood Canal is already experiencing changes in air temperature, stream and ocean temperature, precipitation and snowpack. These changes will alter life in the Hood Canal ecosystems and our communities built around them. We can adjust to these changes with smart planning and foresight – to preserve our way of life on Hood Canal.

Future climate projections for Hood Canal include:

- **Increase in air temperature**, including a 10-12°F increase in summer months by the end of the century.
- Increase in **extreme precipitation** over the next half-century.
- Shift from a mixed rain and snow dominant system in the mountains to a **rain dominant system** by mid to late century.
- **Shift in peak stream flow** from late spring to early winter by mid-century.
- Potential increase in **severe weather-related events**, such as flood and drought.

These changes will have consequences for natural and human resources in Hood Canal, including:

- **Impacts to salmon** as a result of declining habitat quality, shifts in migration, and reduced survivability due to unfavorable conditions.
- **Impacts to shellfish** from **Ocean Acidification**, with larval stages most vulnerable.
- **Impacts to forest processes**, such as plant physiology, establishment, growth, productivity, and mortality.
- Changes in climate may make conditions more suitable for **invasive species and pests**, pushing native species to higher ground or out of the region.
- Impacts to forestry, agriculture, infrastructure and water resources such as increased road washouts and **reduced availability of water for drinking and irrigation**.
- **Impacts on human health** such as increased respiratory disease and allergies, emergent new diseases, and increase in mental illness.
- **Tribal and cultural impacts** such as loss of culturally important food resources, reservation land and sacred sites.

The Hood Canal community will need to come together to identify opportunities and strategies to adapt to these changes.

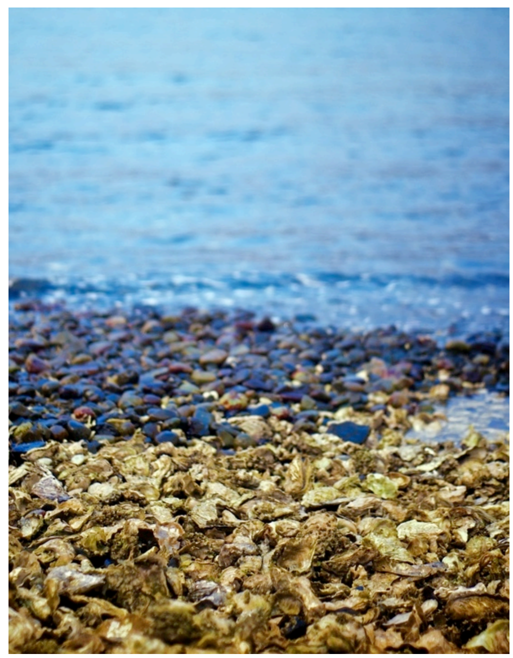

Photo by Flickr user hstender

Contents

Introduction

The Intergovernmental Panel on Climate Change (IPCC) reached consensus in 2007 that the evidence is now "unequivocal" that the earth's atmosphere and oceans are warming, and these changes are primarily due to human activities (IPCC 2007). While reducing carbon and other greenhouse gas emissions is vital to stabilize the climate in the long term, excess emissions already in the atmosphere will produce significant changes in the global climate now and throughout the next century. These changes will transform natural systems and pose new stresses on native species in Hood Canal. As a result, this transformation will modify the way the local economy functions and produce new stresses on infrastructure, human health and wellbeing, and the quality of life for Hood Canal residents and visitors. While there are efforts underway in Hood Canal that may help prepare the community, economy and natural resources for the inevitable changes, there are few initiatives that focus specifically on actions needed to prepare for climate change. By expanding existing efforts, launching climate preparation-specific actions, and continuing to develop new strategies, the Hood Canal community can build resistance and resilience to climate change in a way that also helps the region thrive.

This document presents a summary of climate change projections for Hood Canal, as a means to consider vulnerability and ultimately develop adaptation strategies. **This document is not comprehensive in terms of projected or likely impacts, but provides an overview of the key anticipated changes and resulting effects on natural and human communities.** Where available, Hood Canal specific projections are presented. To supplement information, projections for the Pacific Northwest, Puget Sound and Washington State are also included to provide the broadest spectrum of considerations for climate change. An overview of the projected change's impact on key resources in Hood Canal is also presented, but is not comprehensive: the overview is intended to stimulate discussion among local experts and residents about anticipated impacts on resources, and strategies for adapting to change.



Oyster shells on a Hood Canal beach.
Photo by Flickr user Brett Vogel

Hood Canal Overview

Geography and Climate

Hood Canal is a long, narrow, natural L-shaped fjord that separates the Olympic and Kitsap peninsulas. This marine water body extends southward from Foulweather Bluff, at the northern tip of the Kitsap Peninsula, and Tala Point to its southern terminus at Lynch Cove. Hood Canal is approximately 68 miles long and one and a half to two miles wide. The Hood Canal Action Area (as defined in the Puget Sound Action Agenda) includes the Canal itself, the uplands and streams that enter into it from both sides, and extends north to Point Wilson in the city of Port Townsend. On the west side of the Canal, major rivers including the Skokomish, Dosewallips, and Big Quilcene drop rapidly from the Olympic Mountains, while smaller streams such as the Dewatto and Tahuya drain the west side of the Kitsap Peninsula. Precipitation along the Canal varies from 75 inches annually at Skokomish, to only 19 inches in Port Townsend.

Although the average depth of Hood Canal is 177 feet, the underwater topography can be as deep as 600 feet. Marine water circulation in Hood Canal is naturally poor, particularly in the southern 20 miles. A relatively shallow, underwater sill south of the Hood Canal Bridge limits water exchange with incoming ocean water from the Strait of Juan de Fuca. Hood Canal also has poor vertical mixing as fresh water entering from rivers and streams can form a distinct layer at the surface. Dense algal blooms die off, sink, and decay – reducing the dissolved oxygen in deeper layers and degrading water quality for many marine species. In general, these oceanographic conditions present special challenges in managing nutrient and other inputs deriving from human activities, in pursuit of water quality that supports both a healthy ecosystem and a healthy economy in the communities surrounding Hood Canal.

Natural Resources and Human Dimensions

The Skokomish, Port Gamble S'Klallam, Jamestown S'Klallam, Lower Elwha Klallam, and Suquamish Tribes retain treaty rights in the Hood Canal region for hunting, fishing, and gathering. The Port Gamble S'Klallam Reservation is located at the north end of Hood Canal, while the Skokomish Reservation is located at the south end. The eastern shore of Hood Canal is home to the U.S. Navy Submarine Base at Bangor, the largest industry and development on the Canal. Populated centers in west Kitsap County include Port Gamble and Seabeck. Southern Hood Canal begins in Belfair and the Tahuya Peninsula and runs along relatively developed lower Hood Canal towards the Skokomish estuary and Potlach.

Much of the west side of Hood Canal borders the Olympic National Forest and Park. The US Highway 101 and population centers of Quilcene, Brinnon, Hoodsport, and the Skokomish Valley lie along the narrow fringe of land on the west shore of the Canal. The Hood Canal Bridge is a critical transportation link between the Kitsap and Olympic Peninsulas. The proximity to Olympic National Park and Forest, cultural attractions in Port Townsend and Union, and hunting, fishing, and camping opportunities have generated a significant tourism industry and the proliferation of recreational homes.

Gathering shellfish on Hood Canal.
Photo by Flickr user Chris Brooks

Hood Canal is famous for its shellfish as it is characterized by prime growing conditions for oysters and other shellfish species. Rivers flowing from the Olympic Mountains mix with brackish waters at ideal temperature and water conditions, supporting some of the largest shellfish hatcheries and productive growing areas in the world. The native Olympia oysters (*Ostreola conchaphila*) of Hood Canal were largely overharvested by 1870, although several small populations in the area are being nurtured back to life. Oyster growers introduced the larger, faster-growing Pacific oysters (*Crassostrea gigas)* to compensate, and shellfish farms were staked out throughout Hood Canal. Today the oysters of Hood Canal are internationally famous, and connoisseurs identify them by place names including Quilcene, Dabob, and Hama Hama, much like fine wines from specific regions and vineyards. Oysters and other bivalve species are filter feeders, processing hundreds of gallons of water daily, and are thus highly valuable for their ability to clean the water. However, this also makes them vulnerable to pollutants and toxic contaminants.

The human population of the Hood Canal region is generally low, as a majority of the uplands are managed as private and public forest lands. Relatively larger population concentrations are found along lower Hood Canal and around Lynch Cove. Though impacted by the dissolved oxygen problems and other modifications to rivers and shorelines, fisheries and aquaculture remain economically significant to the Hood Canal region. Commercial and recreational fisheries occur for salmon, spot prawn, Dungeness crab, clams and oysters, and geoduck. Fishing is closed for rockfish and flatfish, due in part to the recent low dissolved oxygen problems.

Exploring Shine Tidelands.
Photo by Flickr user George Wesley & Bonita Dannells

Hood Canal is home to several other important and unique marine and upland species. An evolutionarily significant unit (ESU) of chum salmon that return in the summer spawn only in the rivers and creeks of Hood Canal and the eastern Strait of Juan de Fuca. Other populations of Chum, Coho, Pink, and Chinook salmon spawn, rear, and migrate in Hood Canal, along with steelhead, Bull, and Cutthroat trout. Many of these salmonid species spend a large part of their early lives in the estuary, and water quality conditions in the Canal are essential to their continued survival. Hood Canal is also used by marine mammals, and has unusual timing periods for birthing and pupping of some seal species. Orca whales occasionally enter Hood Canal for short periods of time to feed on prey species indigenous to Hood Canal. In places, patches of old growth and other intact forest provide unique habitats for bird species and mammals in close proximity to the marine shoreline. Herds of elk in the eastern Olympics migrate seasonally along the river corridors.

Global Climate Change

Climate change presents a unique challenge as we plan for the future. Our current planning strategies at all scales (local, regional, and national) rely on historical data to anticipate future conditions. However, with climate change and its associated impacts, the future is no longer expected to resemble the past.

Climate Change: long term trends

Climate Variability: year-to-year or decade-to-decade variation

Weather: daily or seasonal change

How modeling works

> **Climate Models Vary By:**
> 1. Inputs
> 2. Global Emission Scenarios (SRES)
> 3. Time Period

To determine what conditions we might expect in the future, climatologists created models based on physical, chemical and biological processes that form the earth's climate system. The models vary in detail and assumptions, making future scenarios variable. Differences among models stem from an incomplete understanding of many of the Earth's processes and feedbacks. Although the model outputs may vary, taken as a group, climate models present a range of possible future conditions.

Most climate models are created at global scales, but are difficult to apply at local and regional scales because global model output does not reflect regional or local variation in climate. For managers and policymakers to make decisions at these finer scales, they need information about how climate change will impact the local area.

The Intergovernmental Panel on Climate Change (IPCC) uses numerous models to make global climate projections. The models are developed by different institutions and countries and have slightly different inputs and assumptions. Examples of different inputs include variations in greenhouse gas emissions, air and ocean currents, ice and snow cover, plant growth, particulate matter and many others (Randall et al. 2007). In addition to different assumptions, models consider different global emissions scenarios as identified by the IPCC (Figure 1). Emissions scenarios were developed with storylines to describe how the world is operating (see IPCC Special Report on Emissions Scenarios-SRES). They include scenarios such as a business-as-usual scenario (no change in emissions based on 1990 levels), a best-case or green scenario, a scenario where developing countries increase emissions, and others. The time period is a third consideration when looking at modeling results. Models typically consider a time period (e.g. a decade or two) and average the results for that period.

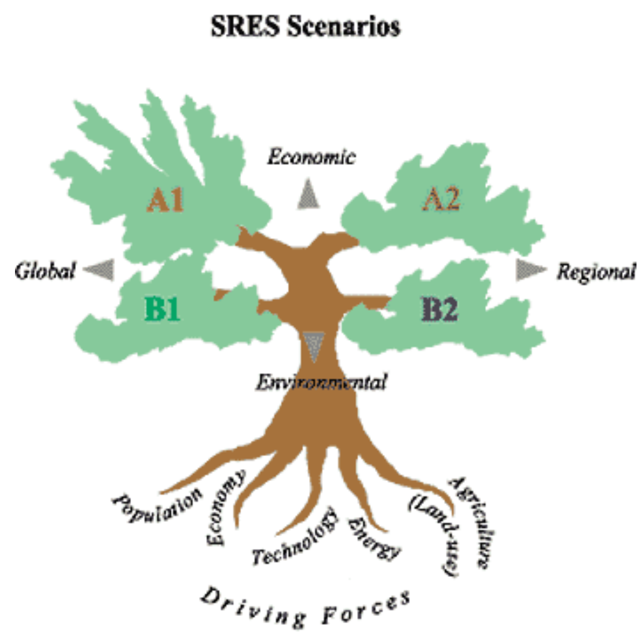


Figure 1. IPCC Climate Scenarios. The Special Report on Emissions Scenarios (SRES) team defined four narrative storylines (see Figure 1), labeled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century. Each storyline represents different demographic, social, economic, technological and environmental developments that diverse in increasingly irreversible ways.

Climate models are converted to local scales using local data on recent temperature and precipitation patterns. The climate projections and models shown in this report are intended to help communities picture what conditions and landscapes may look like in the future as well as the magnitude and direction of change. Note that due to model outputs varying in their degree of certainty, they are considered projections and not predictions. Some model outputs, such as temperature, have greater certainty than other projections. When looking at the projections, it is important to note the model (and relevant assumptions) as well as the emissions scenario used.

We urge the reader to keep in mind that the information presented here is intended to explore the types of change we may see in Hood Canal, but actual future conditions may be quite different from those depicted in this report.

Uncertainty associated with projections of future conditions is not a reason to delay action in preparing for or adapting to climate change. The likelihood that future conditions will resemble those of the past is very low, so managers and policy makers are encouraged to begin planning for change, even if the precise trajectory of that change is uncertain.

> **CLIMATE PROJECTION**: A model-derived estimate of the future climate.
>
> **CLIMATE PREDICTION OR FORECAST**: A projection that is highly certain based on agreement among multiple models.
>
> **SCENARIO**: A coherent and plausible description of a possible future state. A scenario may be developed using climate projections as the basis, but additional information, including baseline conditions and decision pathways, is needed to develop a scenario.

GLOBAL PROJECTIONS

The IPCC (2007) and the US Global Change Research Program (2009) agree that the evidence is "unequivocal" that the Earth's atmosphere and oceans are warming and that warming is due primarily to human activities including the emissions of CO_2, methane, and other greenhouse gases, along with deforestation, which decreases the earth's capacity to absorb CO_2. Average global air temperature has already increased by 1.4°F since 1880 and is expected to increase by 2 to 6.4°F within the next century (NASA 2010). Two-thirds of the warming has occurred since 1975 (NASA 2010).

Due to climate system inertia, restabilization of atmospheric gases will take many decades even if countries make drastic emissions reductions. Reducing emissions is vital to preventing the earth's climate system from reaching certain "tipping points" that will lead to sudden and irrevocable changes. In addition to emissions reductions, planning for inevitable changes triggered by greenhouse gases already present in the atmosphere will allow the Hood Canal community to maintain their quality of life as climate change progresses.

Climate Projections for Hood Canal

MODELS/ DATA USED

To identify projections specific to the Northwest, Washington state and Hood Canal, we relied on recent reports and analysis by regional modelers (University of Washington's Climate Impacts Group, Oregon Climate Change Research Institute, USGS, etc.) as well as recent published literature. Most of the projections presented in this report are: 1) an average of multiple Global Climate Models (GCMs) to reduce bias or variability in the

> **LIMITATION OF "DOWNSCALING" FOR LOCAL CLIMATE MODELS**
>
> **Computational Efforts**: Running a model scaled down to a regional or local level takes a significant amount of time. Ideally, climate change assessment should be performed on a decadal scale using multi-scenario, multi-model runs (ensembles) to address the ultimately stochastic nature of the problem. This requires the use of large-scale parallel computing or grid computing.
>
> **Accuracy of Input Data**: The regional model is forced by the Global Climate Model (GCM) output and inherits the assumptions and errors made in global model simulations.

models; 2) presented for at least two emissions scenarios to identify different paths depending on global action to address emissions; and 3) provided for different time scales (e.g. mid and late century). Models for the Pacific Northwest must also account for local variations in climate such as the Pacific Decadal Oscillation and El Nino events.

AIR TEMPERATURE

The Pacific Northwest warmed about 1.3°F between 1895 and 2011, with statistically significant warming occurring in all seasons except for spring (Mote et al.2014). Similar 20th century trends are obtained using different analytical approaches. All but five of the years from 1980 to 2011 were warmer than the 1901-1960 average (Snover et al. 2013).

Climate models project an increase in average annual Pacific NW temperature of 2°F by 2020 and warming is expected to occur during all seasons. In the Northwest, a warming rate of +.5°F per decade has been observed in the 21st century (Littell et al. 2009).

Air temperatures for the Pacific NW are projected to increase between 3.3°F and 9.7°F by 2070-2099, depending on the level of global emissions (Figure 2). The summer temperatures will experience the

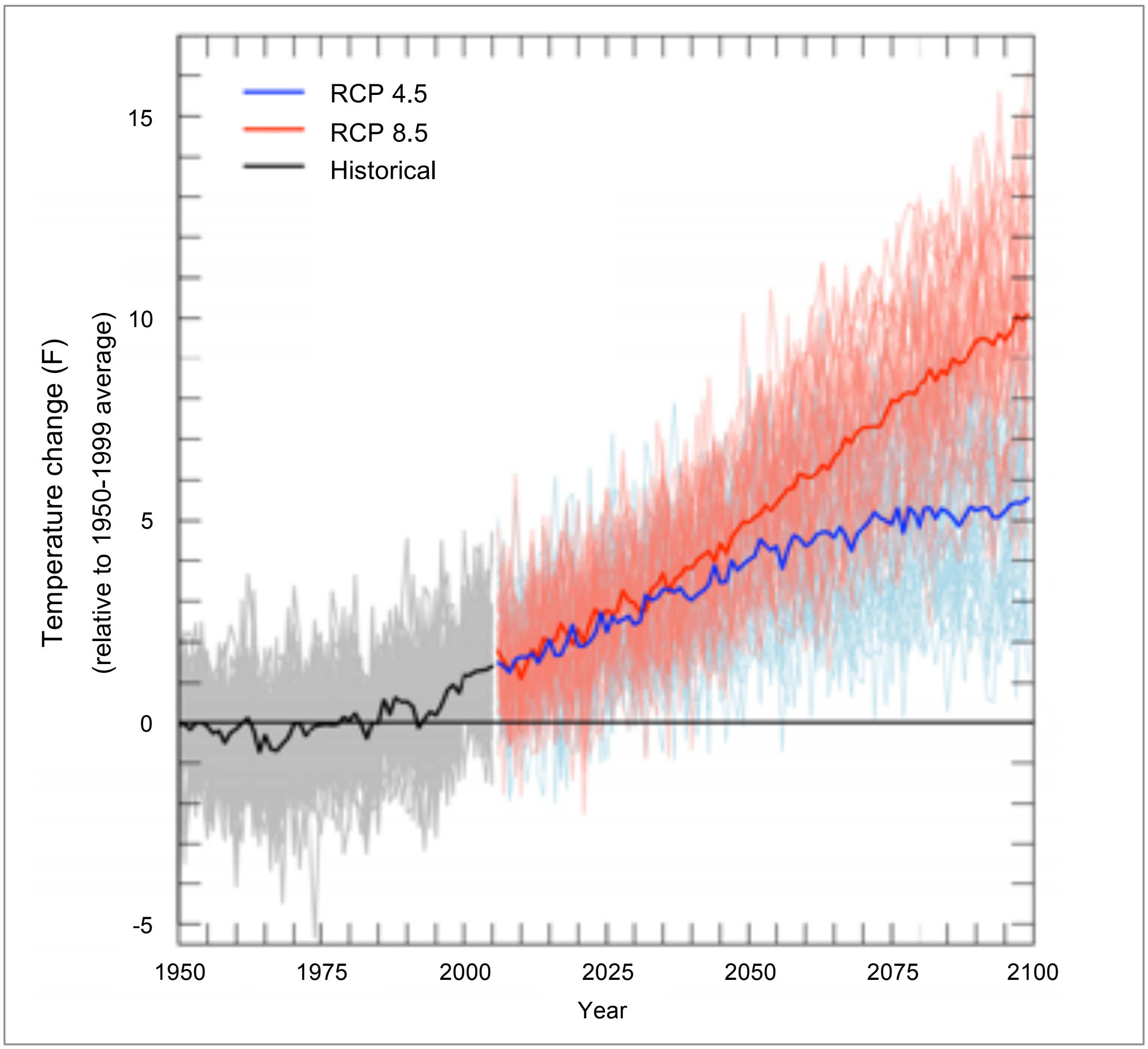


Figure 2. Observed (1950-2011) and simulated (1950-2100) regional mean annual temperature under various climate models and scenarios (high and low emissions) (Dalton et al.2013)

greatest increase (Mote et al.2014). Models predict that the number of days over 90°F will increase by 8 days (+/- 7) for the 2041-2070 period and the number of days below freezing will decrease by 35 days (+/- 6) for the Northwest region.

Figure 3 shows annual mean maximum temperatures for the three counties in Hood Canal under two different emission scenarios (RCP4.5 and RCP8.5). Under both scenarios, temperatures increase through midcentury, with an extreme increase of nearly 10°F by end of century under the high emission scenario in all counties.

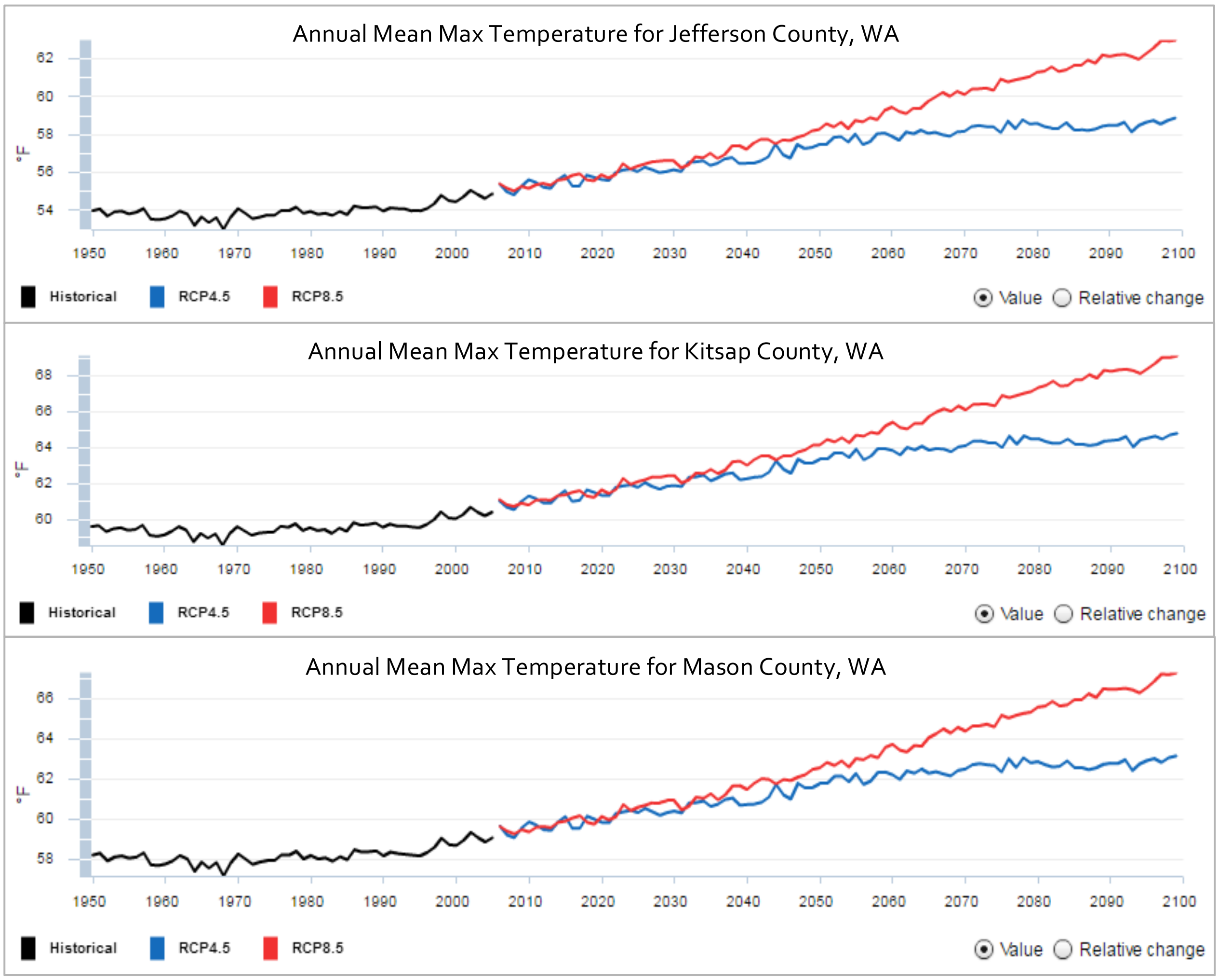


Figure 3. Annual mean maximum temperature projections in F for Mason, Jefferson and Kitsap counties under two climate scenarios (high and low emissions). (USGS 2014)

In the Skokomish watershed (Figure 4), minimal average temperature increase is expected for the 2020 period, but by the 2040's, an increase of approximately 1°F is expected throughout the year with 5-8°F increase in the summer months. By the 2080s, an increase of 3 to 4°F is expected throughout the year with a more significant increase of 8 to 12°F, depending on the emissions scenario.

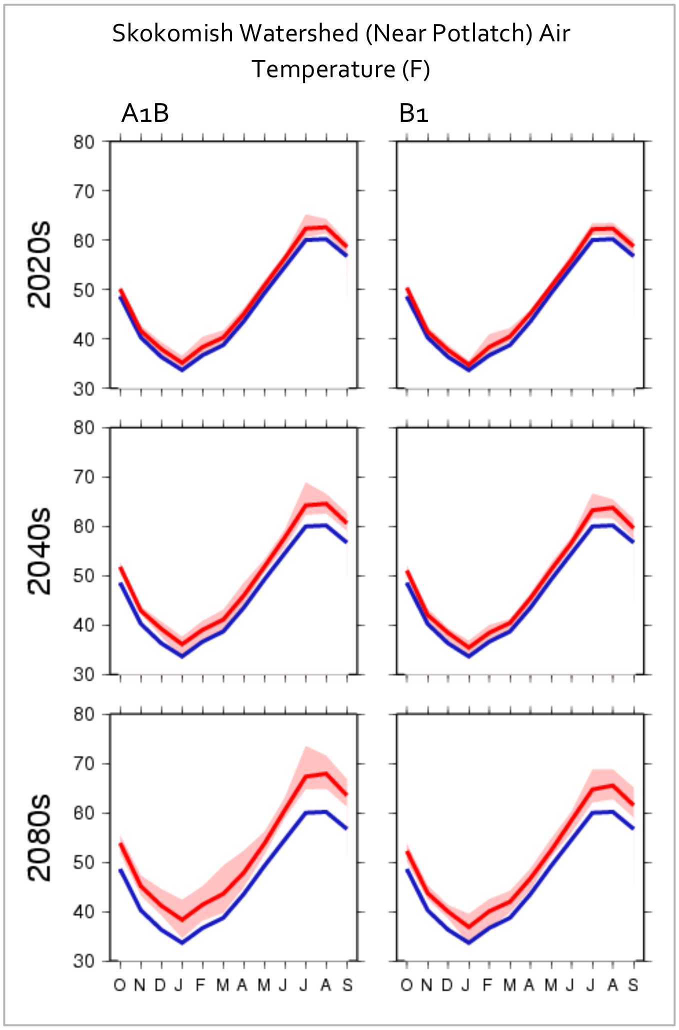


Figure 4. Skokomish Watershed (near Potlatch) air temperature projections in F using two climate scenarios- medium emissions (A1b) and low emissions (B1). Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (average of 10 Global Circulation Models). Dark red lines show the ensemble average. (CIG 2014)

Stream Temperature

Increases in air temperature have been shown to result in increases in stream temperatures (Dalton et al.2013), which has consequences for water quality (see next section). Flow rates (described below) will also influence stream temperature.

Ocean Temperature

Elevated ocean temperatures are documented for NW waters from 1900 to 2008 (Deser et al. 2010). However, projecting ocean temperature in the Northwest is challenging because of the influence from local events (El Nino, Pacific Decadal Oscillation), local conditions (such as upwelling, mixing, salinity and currents), and weather related factors (such as wind and clouds).

Precipitation

According to Littell et al.(2009), there have not yet been statistically significant changes in extreme precipitation in the Puget Sound region. However, climate model simulations project increases in extreme high precipitation for our area over the next half-century. For the three counties in Hood Canal, precipitation is expected to increase under both emission scenarios over the next century as shown in Figure 5. In the Skokomish watershed (Figure 6), the average of the models shows a slight increase in precipitation in winter months by the end of the century. However, under some models, precipitation increases significantly by midcentury under both emission scenarios.

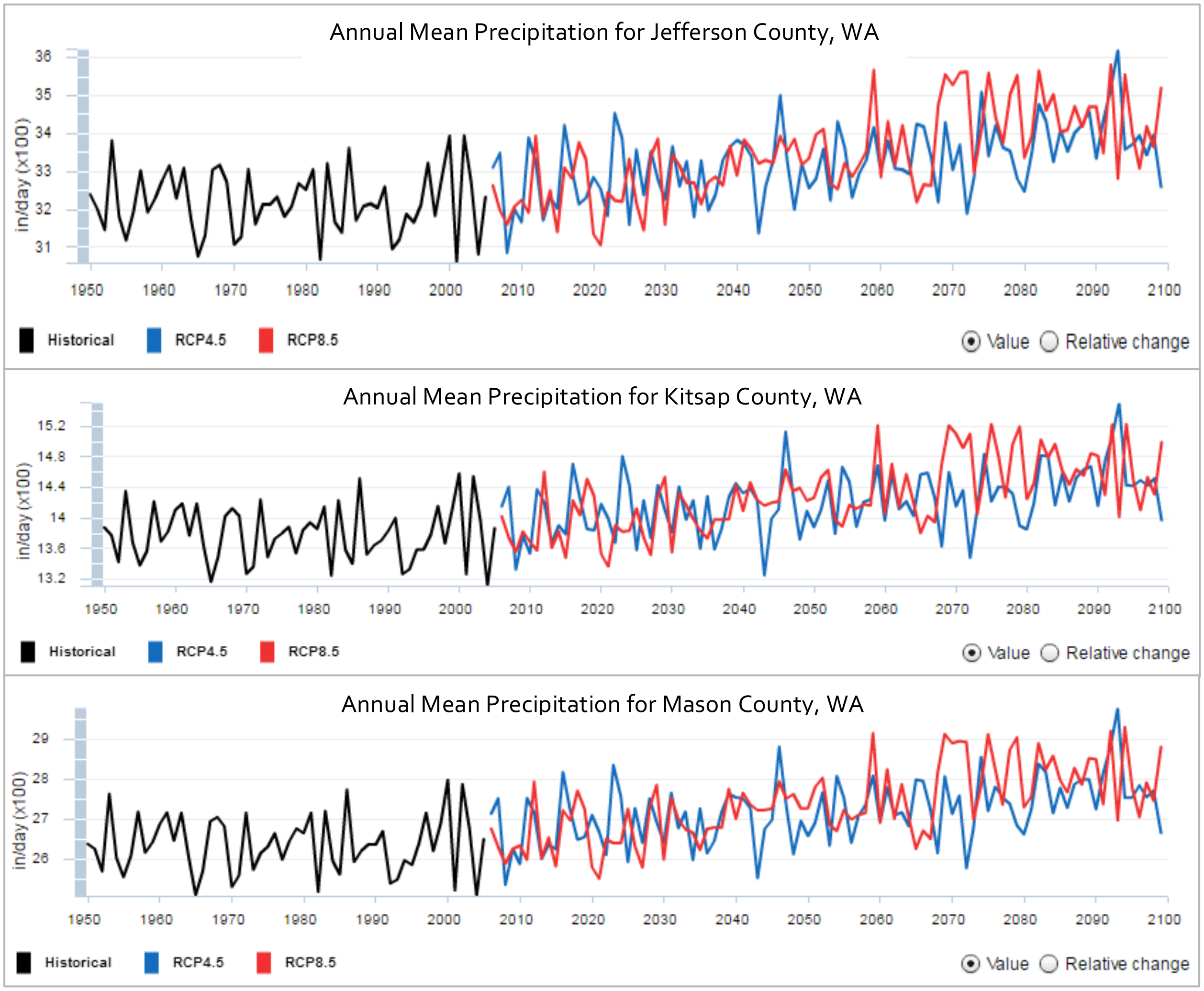


Figure 5. Annual precipitation projections (in inches) for Jefferson, Kitsap and Mason counties under two climate scenarios (high and low emissions). (USGS 2014)

Rain clouds over Hood Canal. Photo by Flickr user becotopia

Maidenhair Ferns along Duckabush River.
Photo by Flickr user brewbooks

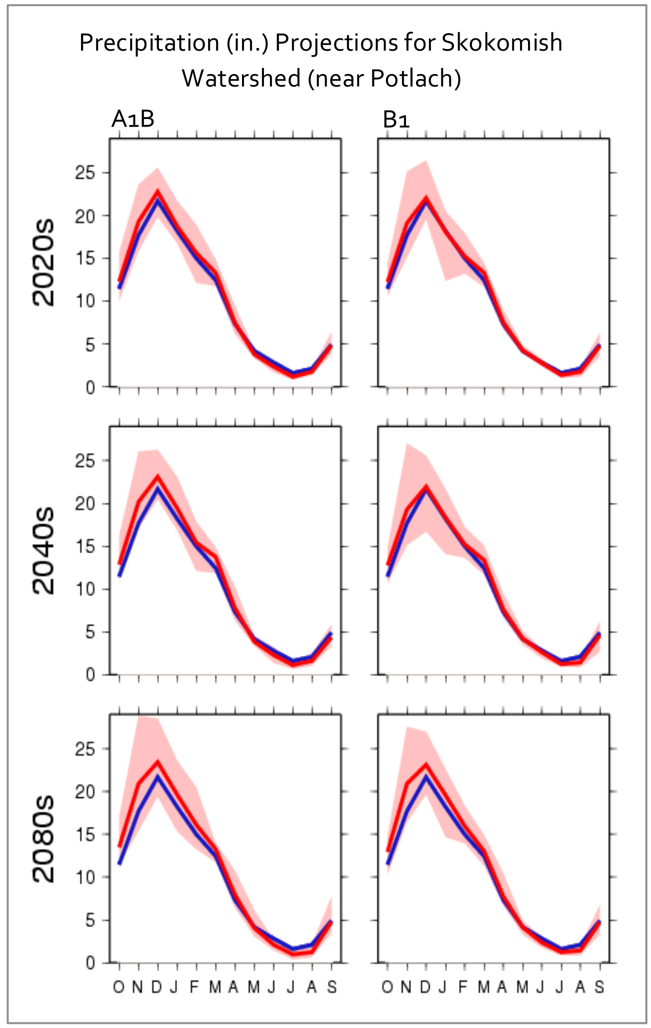


Figure 6. Precipitation projections for Skokomish near Potlatch. Monthly average total precipitation over the entire basin expressed as an average depth (Units: in). This variable is a primary component of the simulated water balance, and quantifies total precipitation as either rain or snow. Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (10 Global Circulation Models). Dark red lines show the ensemble average for the hybrid delta future projections. (CIG 2014)

STREAMFLOW

In Washington state, the major impact for stream flows will be a shift in peak rates from late spring (snow dominant) to early winter (precipitation or rain dominant) by mid century (Littell et al.2009; Dalton et al.2013). Figure 7 shows streamflow projections for the three Hood Canal counties. In the Skokomish watershed (Figure 8), the average of the models shows an increase in streamflow in winter months and a slight decrease in the late spring and early summer months (April through July). However, under some modeled scenarios, streamflow increases significantly by mid century under both emission scenarios.

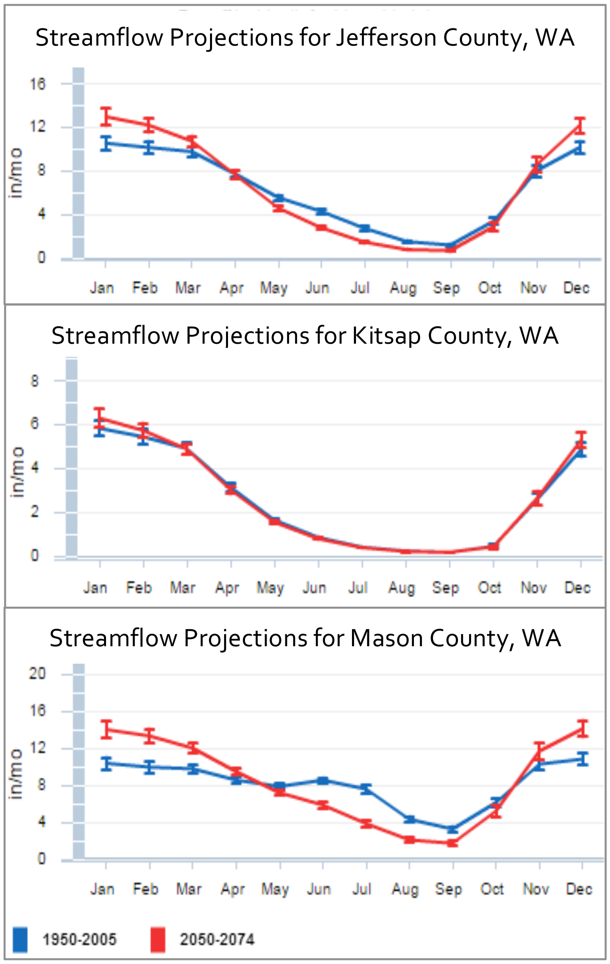
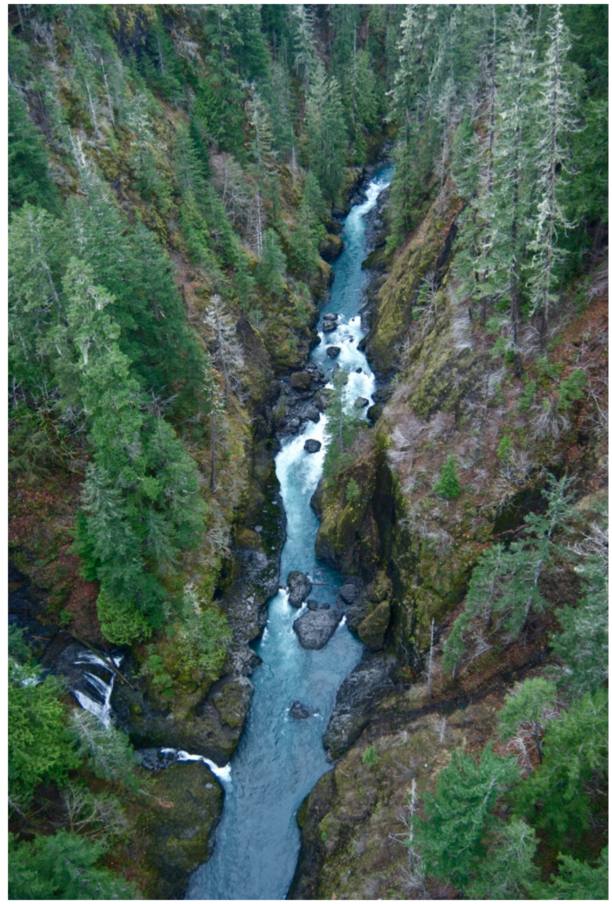


Figure 7. Monthly streamflow projections (in inches) for Mason, Jefferson and Kitsap counties under historic condition (blue line) and mid century (red line). (USGS 2014)



South Fork Skokomish River.
Photo by Flickr user wild trees

Quilcene River estuary

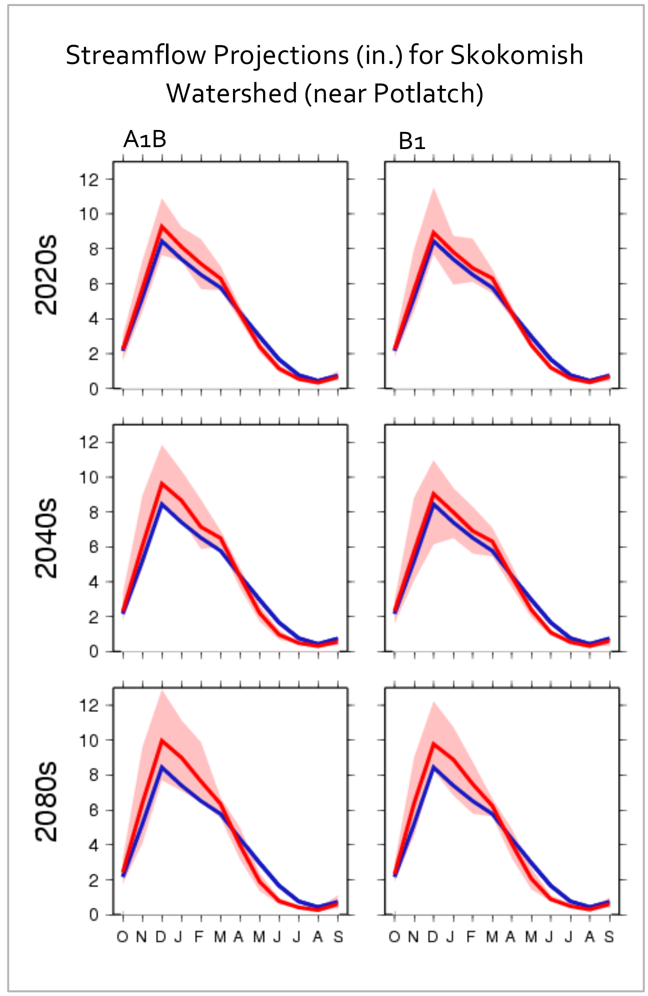


Figure 8. Combined monthly average total runoff and baseflow over the entire Skokomish basin expressed as an average depth. Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (10 GCMs). Dark red lines show the ensemble average for the hybrid delta future projections. (CIG 2014)

SNOWPACK

Watersheds in the Northwest are classified as snowmelt dominant, rain dominant or mix rain-snow based on their Snow Water Equivalent (SWE) of the April 1st snowpack. The Hood Canal watersheds have historically been rain-snow dominant. Future projections show a shift from a transitional system in Hood Canal (mix of rain and snow) to a rain dominant system by mid to late century (Figures 9 and 10). Figure 11 shows a significant decrease in snowpack in the Skokomish basin by midcentury under all models and emission scenarios.

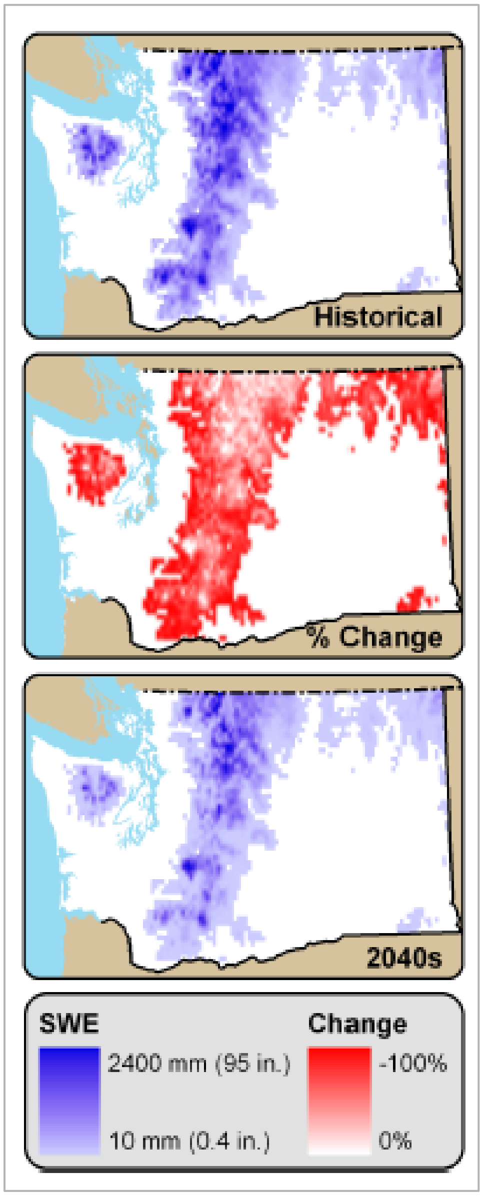


Figure 9. Snowpack is measured by Snow Water Equivalent (SWE), the amount of water snowpack would yield if melted. Summary of projected SWE change under A1b (medium emissions) scenario for 2040s. Compared to historical, future projections show a 37-44% reduction. (CIG 2009)

Olympic Mountains from Hood Canal. Photo by Flickr user Micheal B.

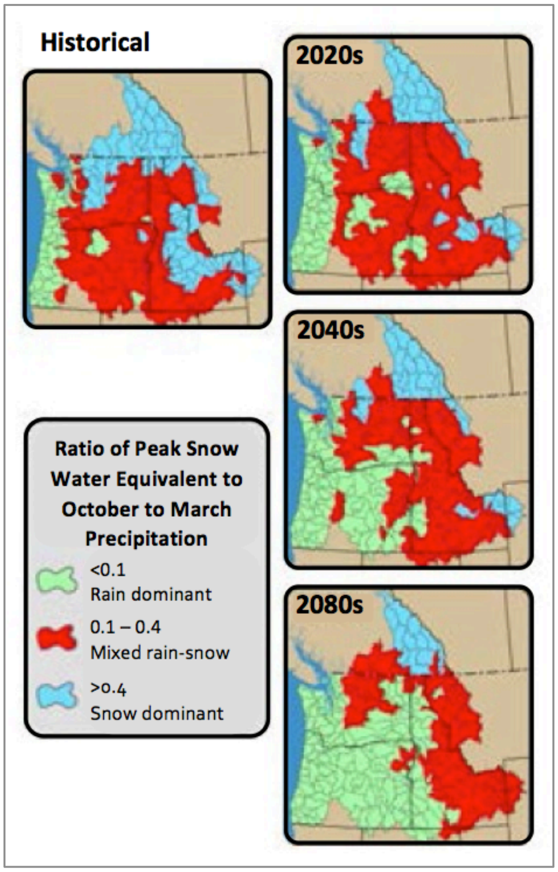


Figure 10. Transition of watershed peak snow water equivalent from historical measures. From Hamlet et al.2013 as displayed in Dalton et al.2013.

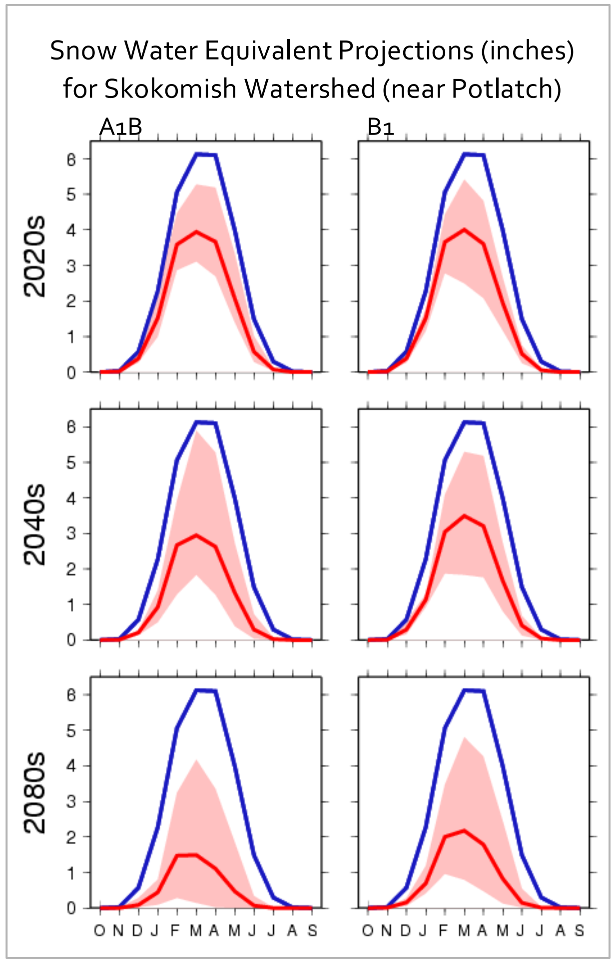


Figure 11. Snow Water Equivalent (SWE) for Skokomish watershed. Blue line shows the simulated historical values, light red bands show the range of all hybrid delta scenarios for the future time period and emissions scenario (10 GCMs). Dark red lines show the ensemble average. (CIG 2014)

Sea Level Rise

For Washington State, the median projections for sea level rise (SLR) for 2100 are 2 inches to 13 inches, depending upon location (Littell 2009). High emissions scenarios show a low probability high impact estimate of sea level rise for the NW Olympic Peninsula of 35 cm by 2050 and 88 cm by 2100 (Mote et. al 2008). Scientists predict that on the NW Olympic Peninsula sea level rise will range from 4 cm to 61 cm. Seattle is predicted to have a sea level change of -3.7 to +22.5 cm, -2.5 to +47.8 cm, and +10 to +143 cm in 2030, 2050, and 2100, respectively (Table 1). Numbers are relative to the year 2000.

Table 1: Projected Sea Level Rise for Seattle, WA

Year	SLR (cm)
2030	-3.7 to +22.5 cm
2050	-2.5 to +47.8 cm
2100	+10 to +143 cm

On the Olympic Peninsula in Washington State, global positioning system (GPS) observations generally show a rate of vertical uplift of the same order of magnitude as sea level rise, thus creating the potential for a net decrease in local observed sea level in some locations (Mote et al. 2008). However, projections for sea level rise vary dramatically and more research is needed to improve the modeling.

Extreme Weather

With increased warming and variation in precipitation, it is likely that extreme events such as droughts, flooding and other such events may occur more frequently and at a greater magnitude (Dalton et al.2013). Put simply, it is likely to get more wet and more dry.

Ocean Acidification

According to Feely et al.(2012):

> The International Panel on Climate Change (IPCC) Workshop on Impacts of Ocean Acidification on Marine Biology and Ecosystems (2011, p. 37) defines Ocean Acidification (OA) as "*a reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean.*" Washington State is particularly vulnerable to pH decline because regional drivers—upwelling, hypoxia, nitrogen oxides (NO_x)/sulfur oxides (SO_x), and watershed inputs of nutrients— can combine with the global drivers to exacerbate the acidification process. (page 3)

Like trees, oceans are an important carbon dioxide sink, meaning they absorb CO_2 from the atmosphere. OA can be more severe in areas where there are changes in the natural chemistry of the ocean and where human activities increase acidity such as through nutrient inputs. OA is linked to the human generated CO_2 in the atmosphere, which has been released primarily through fossil fuels and deforestation (Newton et al.2013). Along with climate change, OA is a major consequence of increased global emissions. Global ocean surface pH has decreased since the pre-industrial times, resulting in an increase in acidity of 30% (Feely et al.2004, Caldeira and Wickett, 2003). Ocean acidity is expected to double globally by 2100, and the current rate of acidification is nearly 10 times faster than any period over the past 50 million years (Newton et al.2013).

In Washington, acidified conditions have been observed sooner than anticipated, due to regional factors than exacerbate acidification, such as seasonal upwelling, runoff, and material decay (Newton et al.2013). In Hood Canal, some studies show that up to 40% of the increase in CO_2 in subsurface waters since the industrial revolution is linked to human activity (Feely et al.2010, 2012). However, local or regional contribution compared to global contribution varies seasonally (Feely et al.2012) and a lack of long term, high quality modeling makes it challenging to determine the exact direct impact that humans are having on local and regional acidification.

Hood Canal oysters. Photo by Flickr user Kris

Potential Climate Impacts in Hood Canal

The following section provides a brief overview of potential consequences for natural resources and human communities based on projected climate changes for Hood Canal. Note that this is an initial description intended to spark conversation. Further impacts will be identified and assessed by regional experts during the May 2015 workshop, and summarized in subsequent reports.

NATURAL RESOURCES

Salmon

Warmer water temperature in streams may push salmon past their thermal tolerance, as stream temperatures are already near salmonids' upper range. This could put these species at higher risk for disease and mortality. Changes in stream flow timing, due to a shift to a more rain dominant watershed, could impact the timing of salmon runs, particularly the ability for salmon to return upstream for spawning. Dalton et al. (2013) summarizes the key impacts to salmon as the following:

Face to face with a summer chum salmon.
Photo by Cheri Scalf

- Reduced habitat quality due to warmer stream temperatures, impacting all freshwater life stages).
- Increased difficultly for migration due to reduced summer streamflows, creating both physical and thermal obstacles.
- Increased scouring of salmon nests due to heavier rainfall and more frequent and intense flooding.
- Altered migration timing in snowmelt-dominated streams due to earlier spring runoff.
- Impacts to estuarine habitat including sea level, warming ocean temperatures and changes in freshwater flows.
- Reduced survivability of salmon due to unfavorable conditions (higher ocean temperature and ocean acidification) impacting the marine food web.

Variable freshwater flow has a bigger negative impact on Chinook salmon than any other climate impact.

Ward et al.'s recent paper looks at how climate change impacts on streamflow will impact Puget Sound Chinook (2015). They found that in all systems, increases in variability of freshwater flows has a more negative effect than any other climate signal study. Climate change models predict that this region will experience warmer winters and more variable flows, which may limit the ability of Chinook populations throughout Puget Sound to recover. Because Chinook lifestages are dependent on various ecosystem types (marine, freshwater), they may be more vulnerable than other species as they will feel direct and indirect impacts of climate change in multiple ecosystems. To combat these impacts, Ward et al. (2015) recommend focusing restoration on spawning and juvenile rearing habitat in winter as well as projects that buffer flow variability such as floodplain reconnection.

Shellfish

Dabob Bay oysters. Photo by Flickr user Alan Teo

Pacific Northwest shellfish are sensitive to ocean chemistry: small shifts in ocean acidity will cause large responses among shellfish organisms, with local species significantly impacted. Impacts include increased mortality, softer shells, reduced shell mineral availability, and impacts to Pacific oyster larvae. Changes in ocean chemistry require marine organisms to expend more energy to regulate their internal chemistry, which means less energy for growth, reproduction, and managing other environmental stresses. All life stages are impacted by OA, with larval stages most vulnerable and early exposure causing detectable impacts later in life.

Species more tolerant to acidic conditions may move in and replace those that are critical to Hood Canal's economy and food webs.

Calcified species are more likely to be replaced by non-calcified species in more acidic conditions, which has been shown in a study on Tatoosh Island (Wootton et al. 2008). Species more tolerant to acidic conditions may move into Hood Canal and replace those that are critical to Hood Canal's economy and food webs.

Forests

Waterfall along Big Quilcene River. Photo by Flickr user Joe Doe

Many forest processes are affected by climate, such as: plant physiology, establishment, growth, productivity, and mortality. Climate also indirectly affects forests through influencing disease, fire and insects. Dalton et al.(2013) cites a number of recent studies in Washington on the impacts of climate on forests (pg 111).

Direct impacts include:

- Changes in temperature, precipitation and snowpack will impact water balance and result in more water deficits in the summer, resulting in less successful seeding and increased vulnerability to disease and mortality.
- Change in productivity for some species, such as reduced growth for Douglas Fir in the drier parts of the range but possible increase in growth in the warmer parts of the range.
- Photosynthesis and respiration may both increase with raised CO_2 levels, yet water and nutrient limits may prevent enhanced growth.

Indirect impacts include:

- Shifts in abundance, distribution and function of Northwest tree species due to change in growth, phenonlogy and mortality (e.g. conditions will become less favorable for Douglas Fir and species susceptible to mountain pine beetle).
- Forests fires are likely to increase due to higher susceptibility from warmer and drier summer conditions, which may benefit some fire dependent species.
- Insects that cause mortality or affect growth may become more prominent without regular freezing, which kills insects. In addition, trees may be more vulnerable when faced with drought conditions.

Forest fires are likely to increase due to warmer and drier summer conditions.

The impacts felt by forests may result in implications for the ecosystem services they provide, such as flood protection, sedimentation loading, erosion control, and water purification.

Wildlife

Changes in climate may make conditions more suitable for invasive species, pushing native species to higher ground or out of the region. Species adapted to current mild conditions in Hood Canal may have to migrate north or higher in altitude. In the Olympics, species that rely on wetlands may see habitats dry up during periods of the year or may see an expanded wetland network during periods of intense flooding (Dalton et al.2013).

Species diversity may change as invasive species push native species out of the region.

Herd of elk in Brinnon, WA.
Photo by Flickr user Bejan

Shorebirds at Shine Tidelands.
Photo by Flickr use George Wesley & Bonita Dannells

Human Dimensions

Natural Resource Economy

Hood Canal offers a range of recreational activities, including hiking, biking, camping, kayaking, fishing, hunting, boating, wildlife viewing and others. It is unclear how climate change will impact each of the recreational opportunities, but changes to natural resources (e.g. impacts to salmon, increased wildfire) and more major weather events (e.g. heat waves, extreme precipitation) may have implications on the industry. However, warmer temperatures may lead to a longer summer recreational season, offsetting any implications from more extreme weather or forest fires. Due to

Shucking oysters at Taylor Shellfish Co.
Photo by Kristian Marson

impacts on marine species, opportunities for recreational fishing and shellfishing may be limited, resulting in loss of revenue from licenses and impacts to the hospitality industry with fewer people visiting Hood Canal.

Hood Canal's forestry industry may feel impacts from changes in productivity, increased disease, and susceptibility to wildfire. Impacts will likely be felt by the private industry, state, and the federal forest service. Forest roads may face increased flooding and erosion due to changes in precipitation, leading to greater sediment loading and possibly damage to bridges and culverts. Washed out roads will have impacts on forestry industry access and may be expensive to rebuild or replace.

The shellfish industry in Hood Canal has already begun to see the impacts of OA and is likely to experience greater economic loss in the future.

Agriculture

Impacts to agriculture will vary substantially depending upon type of crop and location. While reduced water may impact irrigation, a warmer winter may provide for a longer growing season and more crop diversification (Dalton et al, 2013). Pressures on agriculture from pests, weeds and disease are difficult to project, but typically increase with warming temperatures. The following table is adapted from Dalton et al.(2013) table 6.1.

Chimacum Corner Farmstand.
Photo by Flickr user Gypsy Gong

Table 2. Climate drivers and implications for agriculture (adapted from Dalton et al.2013, Table 6.1)

Climate Driver	Implications for Agriculture
Increase in mean summer temperature	Heat-stress related reductions in yields of crops and livestock; changes in insect, disease and pest impacts
Increase in mean cool season temperature	Increased survival of winter and cold sensitive crops; changes in insect, disease and pest impacts
Longer growing season and increase in growing days	More flexibility in crops species and crop design; changes in insect, disease and pest impacts; faster maturation of crops
Increase in mean evapotranspiration	Increased risk of drought stress
Decrease in summer soil moisture and decrease in mean summer precipitation	Increased risk of drought stress for farms that are rain or irrigation dependent
Increase in mean winter precipitation	More soil moisture available for establishing spring crops; wetter soils may impede planting of some spring crops
Increased atmospheric CO_2	May increase productivity of some crops

Water Resources

With the changes in air temperature, precipitation and a shift from rain-snow watersheds to rain dominant watersheds, impacts are expected on the Hood Canal reservoir systems and municipal drinking infrastructure. Water resources may exceed those that are needed for human use when demand is lower (winter, early spring) and may not be available during the summer when demand increases. With the Skokomish River as one of the most flood prone rivers in the northwest, an increase in frequency and magnitude of floods is expected with changes in snowpack, temperature and precipitation. More frequent and stronger floods may impact water quality as well as local infrastructure.

Lake Cushman Reservoir.
Photo by Flickr user Scott Smithson

Infrastructure

Hydropower in the Northwest produces two thirds of the region's electricity, including Hood Canal's Cushman Dam, owned by Tacoma Power. Shifting to a rain dominant system may have impacts on hydropower. For the northwest, summer hydropower production is projected to decline by about 15% by 2040 (due to decreased snowpack and less storage), while winter production may slightly increase compared to 1917-2006 levels (Dalton 2014). In addition, with shifting water resources, hydropower may face additional competing factors for water management, such as water for agriculture, flood control, and fish.

Cushman Hydroelectric Power Plant.
Photo by Flickr user Wendy House

With more frequent and intense flooding and precipitation, urban areas, roads, stormwater systems and other infrastructure (e.g. pipelines, bridges, culverts) may be more vulnerable (CIG 2012). Sea Level Rise may also damage or destroy infrastructure such as roads, docks, septic and sewer systems, buildings and homes (e.g. basements flooding). Impacts to transportation infrastructure will cause additional economic impacts by imposing delays on the movements of goods and the traveling public.

Hood Canal Bridge.
Photo by Flickr user Ann & Peter Macdonald

The Washington Department of Transportation (WSDOT) conducted a vulnerability assessment in 2011 (WSDOT 2011). Hood Canal is covered by WSDOT Olympic Region Area 2, which includes portions of Thurston, Mason, Kitsap and Jefferson counties. The study found a few segments of concern in the area, including areas of State Route 101, which is projected to be impacted by rising sea levels and from more extreme precipitation events. Sections of SR 300 and SR 3 could also see impacts from rising sea level. Figure 12 shows projected risk for Hood Canal roads.

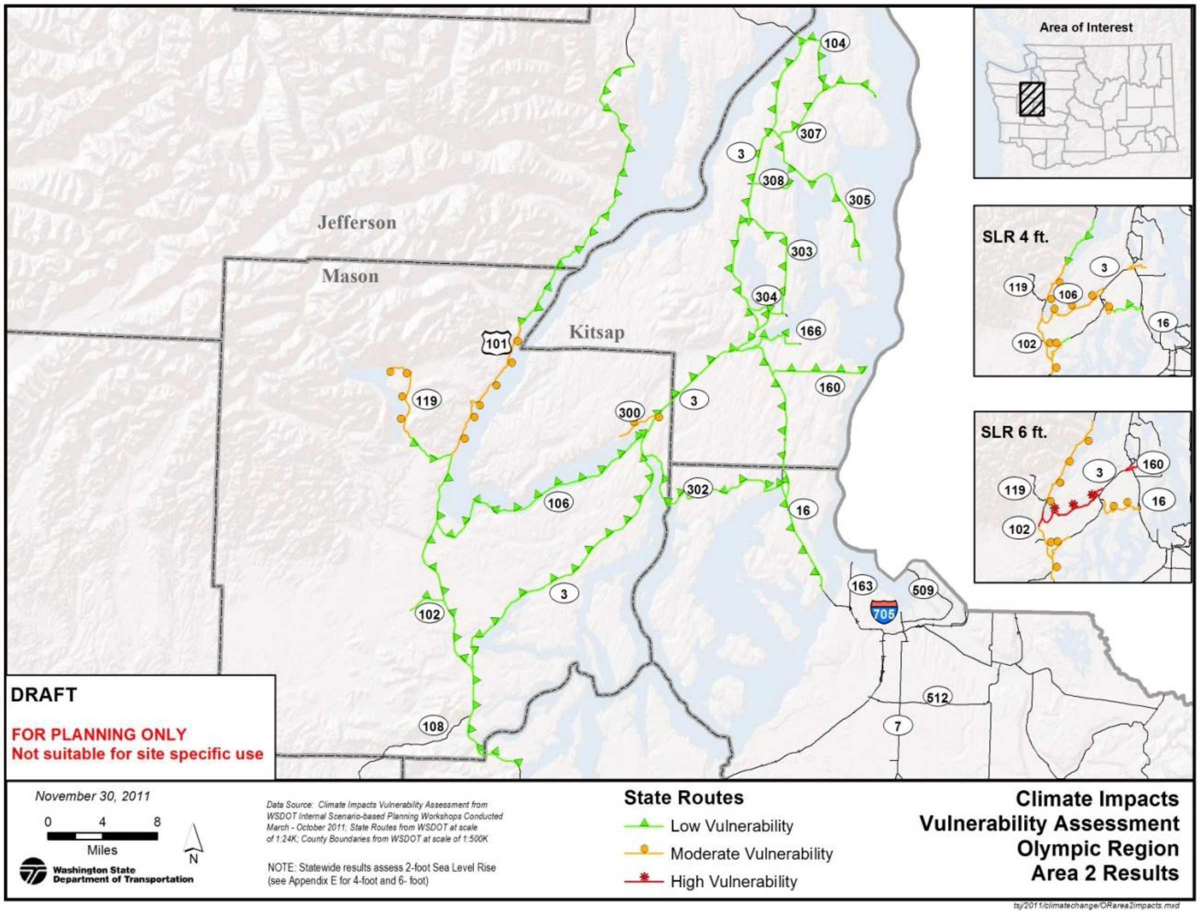


Figure 12. Climate impacts vulnerability assessment for Hood Canal roads (WSDOT 2011).

Human Health

Climate change will have direct and indirect implications on human health (Figure 13). Due to more mild temperatures than other parts of Puget Sound or the state, Hood Canal is likely to avoid extreme heat events and other effects on human health, yet other implications from warming temperatures, extreme weather, air pollution, disease and other effects are possible.

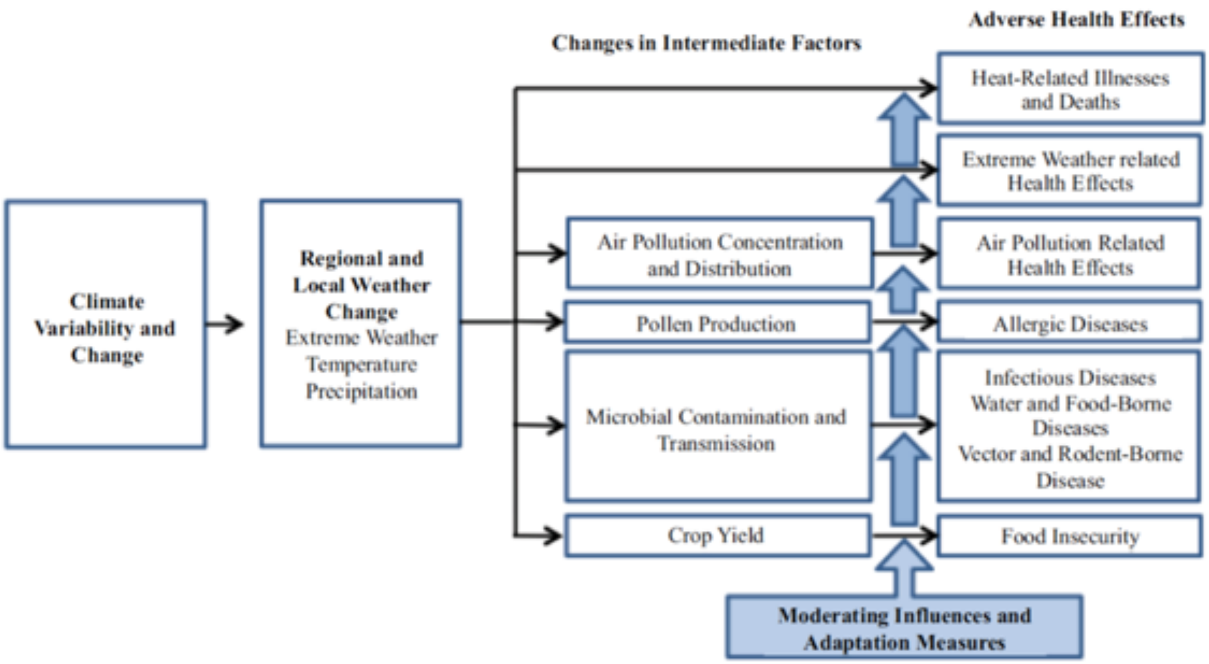


Figure 13. Climate change implications for human health. From Dalton et al.(2013) figure 7.1.

Hood Canal residents may experience climate related health impacts, including:

- Direct injury or death from flooding and storms
- Indirect impacts from flooding and storms, including implications from standing water, increased communicable diseases from crowded evacuation centers, lack of clean water for cleaning and bathing; and increased respiratory disease from mold and microbial growth
- Increased mental illness due to stress brought on by drought conditions such as reduced water quality and quantity, and food insecurity
- Respiratory conditions resulting from Increased wildfires that may lead to and direct injury or death
- Increases in asthma and allergies due to longer pollinating seasons from increased levels of CO_2 and warmer temperatures
- Epidemiological shifts in infectious diseases including vector-borne, water-borne and fungal disease (vector-borne diseases include Hantavirus, West Nile virus and Lyme disease; water-borne diseases include

A family heads home from a day at the beach.
Photo courtesy of Flickr user dolanh

Vibrio parahaemolyticus, which can increase with warmer water temperatures; an increase in *Cryptosporidium*, transported by cattle, is also possible; fungal diseases include *Cryptococcus gattii*, which was once rare in the Northwest and may become more common).

- Increased Harmful Algal Blooms from warming water temperatures, which can cause poisoning through shellfish consumption.
- Mental health impacts may occur with loss of home (from wildfire, extreme weather event), stress or concern about future climate changes, impacts to natural resource, or agriculture livelihood.

Cultural and Tribal Impacts

The Port Gamble S'Klallam Tribe is currently developing a comprehensive vulnerability assessment for resources important to the tribe. The draft document identifies the main findings of concern for Hood Canal tribes:

A Port Gamble S'Klallam Tribe canoe team departs from Old Man House Park. Photo courtesy of Flickr user sarahruthvg

1. Impacts on salmon from warmer temperatures, lower oxygen levels, increased marine hypoxic events, increases in disease and pathogens, ability to enter and or navigate in natal streams and rivers, as well as more intense winter and spring flooding events.
2. Ocean acidification impacts to vulnerable shellfish species as well as finfish dependent on impacted larval shellfish prey.
3. Sea level rise is likely to become a significant concern over the next few decades both for nominal continuous rise and short term, abrupt events.
4. Marine algal blooms are already increasing at accelerating rates with toxic algae that can kill fish and shellfish, trigger shellfish closures or sometimes cause larger scale ecosystem impacts.
5. Shellfish impacts are already occurring with ocean acidification but are also likely to start escalating due to increasing temperatures, sea level rise, ocean acidification, and increasing bluff erosion from sea level rise, shoreline sedimentation from floods, etc.

Other findings specific to the Port Gamble S'Klallam Tribe that may also be of concern for other tribes in Hood Canal such as the Skokomish Tribe, include:

- Significant areas of the Tribe's Reservation beaches and adjacent uplands are potentially at risk of inundation and erosion from increasing sea level rise and more intense winter storm events, including the Tribe's primary economic development lands, and sensitive shoreline areas.
- The Tribe's residential structures are at risk of inundation from sea level rise and/or tidal surge.
- The Tribe's fish hatchery is potentially at risk of inundation from sea level rise and/or tidal surge.

- There is an increased risk of potential wildfire especially in Usual and Accustomed forest lands based on projected temperature increases.
- Vital transportation links and access routes to traditional beaches and shorelines are at risk of inundation.
- Beach seining, set net sites, and shellfish beds along Reservation beaches and other traditional harvesting areas are at significant risk of permanent inundation, erosion and potential loss.
- Important "keystone" species such as shellfish, herring, and salmon are at risk of higher levels of contamination from algal blooms and other diseases that may be exacerbated by increased temperature and other changes.
- The Reservation population as a whole, particularly those who are ill or elderly, are potentially at risk of a variety of heat-related illnesses during isolated or extended high heat episodes as average temperatures increase; and tribal members in particular may be at risk of increased incidence of respiratory ailments such as asthma from potential increase in synergistic impacts of pollutants.
- Sensitive cultural sites within low-lying areas may face permanent inundation, and traditional native species may be lost as they are forced to migrate or adapt to hotter, drier climatic conditions.

Skokomish Tribe canoe princess.
. Photo courtesy of Flickr user Washington DNR

Conclusion

Signs of the changing climate are all around us, with major changes projected for the future. Hood Canal will experience changes in air and water temperature, precipitation, and ocean conditions. While many communities or sectors are beginning to assess how these changes will impact operations, the economy, natural resources and our daily lives, it is important that we begin planning now, to prepare for this change across all of Hood Canal. By expanding existing efforts, launching climate preparation-specific actions, and continuing to develop new strategies, the Hood Canal community can build resistance and resilience to climate change while ensuring that the region continues to thrive.

Citations

Bottom, D. L., C. A. Simenstad, J. Burke, A. M. Baptista, D. A. Jay, K. K. Jones, E. Casillas, and M. H. Schiewe. 2005. "Salmon at River's End: The role of the Estuary in the Decline and Recovery of Columbia River Salmon." US Department of Commerce, NOAA Tech. Memo.

Caldeira, K., and M.E. Wickett. 2003. "Anthropogenic carbon and ocean pH." Nature, 425(6956), 365–365, doi: http://dx.doi.org/10.1038/425365a.

Climate Impacts Group. 2009. "Washington Climate Change Impacts Assessment." http://cses.washington.edu/cig/files/waccia/wacciafullreport.pdf

Climate Impacts Group. 2012. "Responses to climate change integration challenges in the PNW." White paper. University of Washington, Seattle.

Climate Impacts Group. 2014. http://cses.washington.edu/cig/data/index.shtml#anchor1

Climate Impacts Group. http://cses.washington.edu/cig/data/index.shtml#anchor1 February 2015.

Dalton, M.M., P.W. Mote, and A.K. Snover [Eds.]. 2013. "Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities." Washington, DC: Island Press.

DeVries, P. E. 1997. "Riverine Salmonids Egg Burial Depths: Review of Published Data and Implications for Scour Studies." Canadian Journal of Fisheries and Aquatic Sciences 54:1685-1698.

Feely, R.A, T. Klinger, J. Newton and M. Chadsey (eds). 2012. "Washington Shellfish Initiative Blue Ribbon Panel on Ocean Acidificiation." Scientific Summary of Ocean Acidification in Washington State Marine Waters. NOAA/OAR Report Special Report.

Feely, R.A., S.R. Alin, J. Newton, C.L. Sabine, M. Warner, A. Devol, C. Krembs, and C.Maloy. 2010. "The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary." Estuary. Coast. Shelf Sci., 88(4), 442–449, doi: http://dx.doi.org/10.1016/j.ecss.2010.05.004.

Feely, R.A., C.L. Sabine, K. Lee, W. Berelson,J. Kleypas, V.J. Fabry, and F.J. Millero. 2004. "Impact of anthropogenic CO2 on the CaCO3 system in the oceans." Science, 305(5682),362–366, doi:

Independent Science Advisory Board. 2007. "Climate Change Impacts on Columbia River Basin Fish and Wildlife." ISAB Climate Change Report ISAB 2007-2. Portland, OR: Northwest Power and Conservation Council. 136 pp.

IPCC, 2007. "Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." Cambridge University Press.

Mantua, N., I. Tohver, and A. Hamlet. 2010. "Climate Change Impacts on Streamflow Extremes and Summertime Stream Temperature and Their Possible Consequences for Freshwater Salmon Habitat in Washington State." Climatic Change 102 (1): 187-223. doi: 10.1007/

NASA Goddall Institute for Space Studies. GISS Surface Temperature Analysis. November 2010.

National Climate Change Viewer, USGS. http://www.usgs.gov/climate_landuse/clu_rd/apps/nccv_viewer.asp. February 2015.

Orr, J. C., et al 2005. "Anthropogenic Ocean Acidification over the Twenty-First Century and its Impact on Calcifying Organisms". Nature 437: 681-686. doi: 10.1038/nature04095.

Pearcy, W. G. 1992. "Ocean Ecology of North Pacific Salmonids." Seattle, WA: University of Washington Press.

Randall, D.A., R.A. Wood, S Bony, et al, 2007. "Climate Models and Their Evaluation." In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, et al., Eds. Cambridge University Press.

Ward, E.J. et al, 2015. "Increasing hydrologic variability threatens depleted anadromous fish populations." Global Change Biology. doi: 10.1111/gcb.12847

Washington State Department of Transportation. 2011."Climate Impacts Vulnerability Assessment." http://www.wsdot.wa.gov/NR/rdonlyres/B290651B-24FD-40EC-BEC3-EE5097ED0618/0/WSDOTClimateImpactsVulnerabilityAssessmentforFHWAFinal.pdf

Wootton, J.T., C.A. Pfister, and J.D. Forester. 2008. "Dynamic patterns and ecological impacts of declining ocean pH in a high resolution multi-year dataset." Proc. Nat. Acad. Sci., 105(48), 18848-18853, doi: http://dx.doi.org/10.1073/pnas.0810079105.