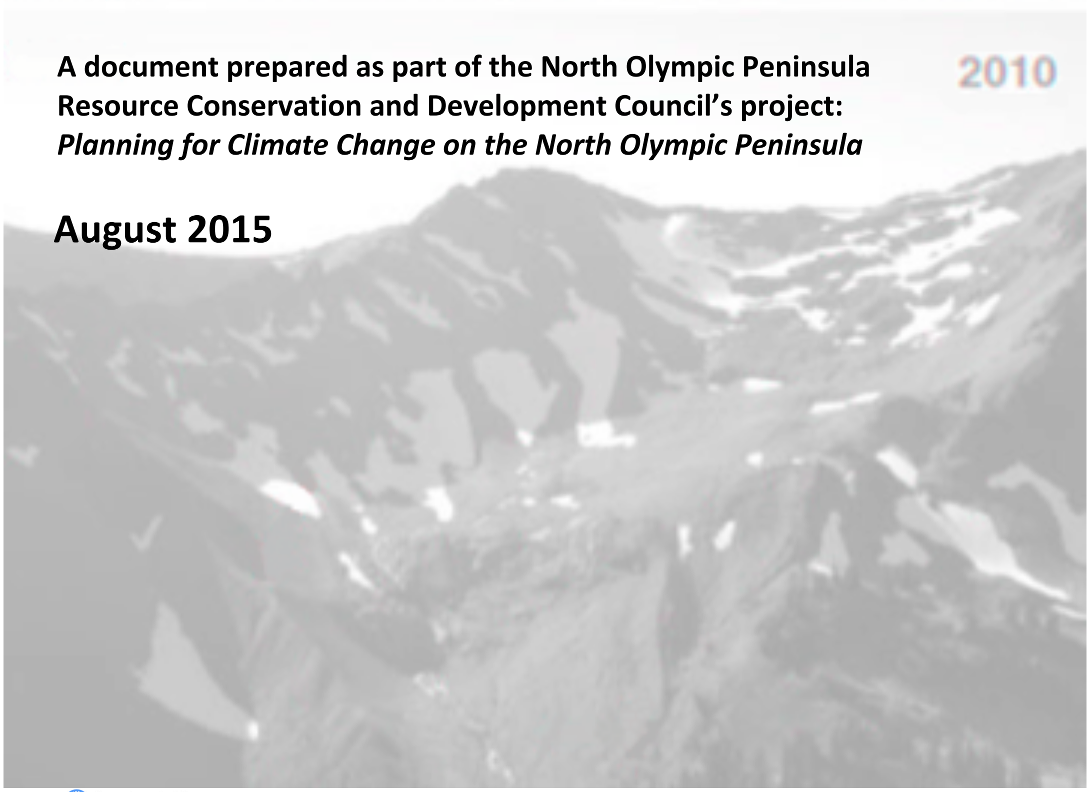
NORTH OLYMPIC PENINSULA RESOURCE CONSERVATION & DEVELOPMENT **NOP RC&D**

Climate Change Preparedness Plan for the North Olympic Peninsula



A document prepared as part of the North Olympic Peninsula Resource Conservation and Development Council's project: *Planning for Climate Change on the North Olympic Peninsula*

August 2015

Department of Commerce
Innovation is in our nature.

adaptation international

Sea Grant Washington

THIS PROJECT HAS BEEN FUNDED WHOLLY OR IN PART BY THE UNITED STATES ENVIRONMENTAL PROTECTION AGENCY UNDER PUGET SOUND ECOSYSTEM RESTORATION AND PROTECTION COOPERATIVE AGREEMENT GRANT PC-00J20101 WITH WASHINGTON DEPARTMENT OF ECOLOGY. THE CONTENTS OF THIS DOCUMENT DO NOT NECESSARILY REFLECT THE VIEWS AND POLICIES OF THE ENVIRONMENTAL PROTECTION AGENCY, NOR DOES MENTION OF TRADE NAMES OR COMMERCIAL PRODUCTS CONSTITUTE ENDORSEMENT OR RECOMMENDATION FOR USE.

Cover Photo: Comparison photographs illustrate that the Lillian Glacier in the Olympic Mountains disappeared completely between 1905 and 2010[1]

Recommended Citation of this Plan

Petersen, S., Bell, J., Miller, I., Jayne, C., Dean, K., Fougerat, M., 2015. *Climate Change Preparedness Plan for the North Olympic Peninsula*. A Project of the North Olympic Peninsula Resource Conservation & Development Council and the Washington Department of Commerce, funded by the Environmental Protection Agency. Available: www.noprcd.org

Acknowledgements

This project represents the collaborative effort of the more than 150 people who attended in-person workshops, participated in online webinars and conference calls, and reviewed written outputs of this project. Their participation is directly responsible for the success of this plan and will continue to be central to this ongoing effort to build climate change resilience for the North Olympic Peninsula.

Thank You Core Team!

The "Core Team" of local stakeholders helped refine and guide this project. They participated in every aspect of the project including monthly conference calls. Without their participation this project would not have been possible. Thank you to the following members of the Core Team, listed in alphabetical order:

Last Name	First Name	*Title*/Organization
Bell	Harry	*Director of Environmental Affairs*/ Green Crow Corporation
Cambalik	John	*Coordinator*/ Strait Ecosystem Recovery Network, Local Integrating Organization, Strait Action Area
Collins	Brad	*Council member*/ Port Angeles City Council
Doherty	Mike	*Retired*/ Clallam County Commissioner
Hals	Hansi	Environmental Planning Program Manager/ Jamestown S'Klallam Tribe
Hart	Lucas	*Citizen Representative*/ North Olympic Peninsula
McCoy	Randall	*GIS Analyst*/ Lower Elwha Klallam Tribe
McLean	Chrissy	*Marine Program Coordinator*/ Port Townsend Marine Science Center
Peters	Seraphina	*Project Coordinator*/ Makah Tribe
Sarff	Dana	*Environmental Division Manager*/ Makah Tribe
Stinson	Deborah	*Council Member*/ Port Townsend City Council
Surber	Judy	*Senior Planner*/ City of Port Townsend
Vreeland	Bob	Olympic Climate Action
Walat	Jean	*Special Project Lead*/ Port Townsend Marine Science Center

Primary Authors and Expertise

Sascha Petersen

Sascha has been working specifically on climate change for almost 10 years. He is the managing director of the American Society of Adaptation Professionals and was a Lead Author for the Great Plains Region of the National Climate Assessment (2014). He has worked with both climate scientists and municipal governments with a focus on bridging the gaps between climate chance science, policy, and action. Sascha has a Bachelor's degree in physics from Pomona College and a Master's degree focusing on climate change science and policy from the University of Washington.

Jacob Bell

Jake has been involved in the Climate Change field since 2007 with a focus primarily on the human health impacts of climate change. Along with coordinating previous Adaptation International projects, he provides project consulting on climate change public health research in Alaska Native Villages. Jake holds a degree in Psychology from Pomona College and a Master's degree in Global Health with a focus in environmental health from Trinity College, University of Dublin.

Ian Miller

Dr. Ian Miller is Washington Sea Grant's coastal hazards specialist on the Olympic Peninsula. He is based at Peninsula College in Port Angeles and also at the Olympic Natural Resources Center in Forks, WA. As a coastal hazards specialist Dr. Miller works with coastal communities on the Olympic Peninsula to increase their ability to plan for and manage coastal hazards, including tsunami, chronic erosion, coastal flooding and hazards associated with climate change. Ian received a bachelor's degree in marine ecology from Western Washington University's Huxley college of Environmental Studies and earned a doctoral degree in Ocean Sciences from the University of California, Santa Cruz.

Cindy Jayne

Cindy Jayne has managed projects for over fifteen years, for both for-profit and non-profit organizations. She has a strong personal interest and knowledge of sustainability issues, and is currently the chair of the Port Townsend/Jefferson County Climate Action Committee. Cindy holds an MBA from Seattle University as well as a Bachelor's of Science degree from Rensselaer Polytechnic Institute, Troy, NY and a Master's of Science degree from University of California, Berkeley, CA, both in Electrical Engineering.

Kate Dean

Kate Dean has worked on rural community and economic development projects in the Pacific Northwest for 20 years. She specializes in collaborative public processes that address challenging natural resource-based issues. She has worked in the public, private and non-profit sectors, bringing a diverse skill set and broad socio-economic lens to projects where common ground can be difficult to identify. Kate holds a BA in Sustainable Agriculture and received her Masters in Public Administration from the Evans School of Public Policy at the University of Washington.

Matt Fougerat

Matt is an environmental planner specializing in the conservation and sustainable use of natural resources. Since 2002, Matt has worked on numerous international projects aimed at balancing the development of local communities with the protection of native habitats and the preservation of productive landscapes. Matt holds a Bachelor's in Landscape Architecture from Texas A&M University, as well as a Master's in Community and Regional Planning and a Master's in Sustainable Design, both from the University of Texas at Austin.

Table of Contents

List of Tables

List of Figures

Executive Summary: Taking Action on Climate Change

Jeff Taylor

Randall McCoy

Marrowstone Marine Field Station

USFWS-Google creative commons

A. Climate Change on the North Olympic Peninsula

It is increasingly apparent that the global climate is rapidly changing and that these changes will affect the people, ecosystems, economy, and culture of the North Olympic Peninsula. The most noticeable impacts will likely include:

- A diminishing snowpack lowering the region's summer river flow and extending the summer drought season;
- Shifts in the timing and type of precipitation, creating rain on snow events and unseasonably high stream flows that scour river bottoms and flood low-land areas;
- Ongoing sea level rise driving coastal flooding, saltwater inundation, and enhanced shoreline erosion;
- Extended warm temperatures which result in increased river water temperatures, enhanced wildfire risk, decreased soil moisture, and stressed forests through disease and insect outbreaks; and
- Increasingly corrosive ocean waters (i.e. ocean acidification) from the ongoing absorption of human emissions of CO_2.

These changes will affect the natural resources and livelihoods of the people of the North Olympic Peninsula, as well as the entire regional economy. The general magnitude of these expected environmental changes are described below:

Climate Changes[2]	Observed Changes		Future Projections
Temperature Averages *(for Pacific Northwest)*	Warmed 1.3°F (1895-2011)		By 2050's – between 4.3°-5.8°F average increase in all seasons.
Temperature Extremes	Increase in nighttime heat events.		Slight increase in days over 90°F (+8 days) for the Pacific Northwest (PNW), with limited increase in days over 95°F on the Olympic Peninsula[3]. Longer frost-free season (+ 35 days) across PNW.
Precipitation Averages *(for Pacific Northwest)*	No significant change in amount; region wide decrease in snowpack and glaciers.		Little average annual change – with drier summers (-6% to -8% average decrease) Continued declining snowpack with a significant loss of snowpack in Olympics by 2080[4].
Precipitation Extremes	Ambiguous		More heavy rainfall events: 13% (± 7%) increase in days with > 1 inch of rain.
Future Sea Level Rise[5] *(probability that mean sea level will reach or exceed ___ ft at a given year)*	Neah Bay	50% chance of ≥ 0.3 feet (2050) and ≥ 1.3 feet (2100) 5% chance of ≥ 0.7 feet (2050) and ≥ 2.7 feet (2100)	
	Clallam Bay/Sekiu	50% chance of ≥ 0.3 feet (2050) and ≥ 1.3 feet (2100) 5% chance of ≥ 0.7 feet (2050) and ≥ 2.7 feet (2100)	
	Port Angeles	50% chance of ≥ 0.6 feet (2050) and ≥ 1.9 feet (2100) 5% chance of ≥ 0.9 feet (2050) and ≥ 3.3 feet (2100)	
	Port Townsend	50% chance of ≥ 0.9 feet (2050) and ≥ 2.4 feet (2100) 5% chance of ≥ 1.2 feet (2050) and ≥ 3.9 feet (2100)	
Future Annual Coastal Flood elevation[6] *(probability that mean sea level will reach or exceed ___ ft at a given year)*	Neah Bay	50% chance of ≥ 3.5 feet (2050) and ≥ 4.5 feet (2100) 5% chance of ≥ 4.4 feet (2050) and ≥ 6.2 feet (2100)	
	Clallam Bay/Sekiu	50% chance of ≥ 3.5 feet (2050) and ≥ 4.5 feet (2100) 5% chance of ≥ 4.4 feet (2050) and ≥ 6.2 feet (2100)	
	Port Angeles	50% chance of ≥ 2.6 feet (2050) and ≥ 3.9 feet (2100) 5% chance of ≥ 3.5 feet (2050) and ≥ 5.5 feet (2100)	
	Port Townsend	50% chance of ≥ 2.9 feet (2050) and ≥ 4.5 feet (2100) 5% chance of ≥ 3.8 feet (2050) and ≥ 6.1 feet (2100	

The Pacific Northwest is already experiencing drier summers, reductions in snowpack and glacial mass, higher spring and lower summer river flows, 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[7].

Climate change exerts its influence on human lives both directly (from extreme weather events) and indirectly (through ecosystem shifts and associated impacts to the natural and built environment). This Plan utilizes a regional planning perspective to understand and prepare for Climate Change's impact to Ecosystems, Water Supplies, and Critical Infrastructure on the North Olympic Peninsula.

B. Collaborative Process

Successfully planning for and adapting to the impacts of climate change requires collaboration among a broad range of stakeholders. ***This project synthesized the best available climate change projections with local stakeholder expertise of vulnerable sectors to ultimately develop climate change preparation strategies for the North Olympic Peninsula.*** The outputs of this effort are compiled in this Preparedness Plan and include a regional **Vulnerability Assessment** (Section I & II) and **Adaptation Plan** (Section II). "Adaptation" is a common term used in climate change preparation work to denote any "process of adjustment to actual or expected climate and its effects"[8]. With this project and other similar efforts, the region has a unique opportunity to promote collaboration on climate change adaptation between federal, state, local, and tribal governments, non-profit organizations, academic institutions, and private businesses.

Over the course of one-year, this project brought together more than 150 partners through virtual meetings and a series of in-person workshops to build a climate change stakeholder network, share the best available climate change science, identify and assess potential areas of concern, and select and evaluate adaptation strategies to be used across Jefferson and Clallam Counties. These partners represented cities, counties, tribes, public utility districts, ports, non-profit organizations, advocacy groups, private companies, natural resource managers, and concerned citizens of the region. In-person workshop and meetings took place across the North Olympic Peninsula, from Port Townsend to Neah Bay. The project made extensive use of conference calls and webinars to bring people together virtually when in-person meetings were not feasible. The completion and success of this Adaptation Plan was dependent on the combined expertise and participation of this network of over 150 individuals.

C. Prioritized Climate Change Adaptation Strategies

Climate change preparation can take many forms, from developing educational materials to implementing policies and updating ordinances and regulations. There is no "one size fits all" approach to adaptation, as the climate challenges faced by a region, county, or community, are quite unique to the place and people who reside there. The North Olympic Peninsula is a diverse region and the ideal adaptation strategy in the drier eastern part of the peninsula may not be effective in the wetter west end. Similarly, a soft shoreline armoring strategy used to protect agricultural land in the Dungeness Valley from sea level rise may not be sufficient protection for sewer pump stations in downtown Port Townsend.

The list of adaptation strategies below represents some of the most targeted and effective actions the region can use to prepare for the impacts of climate change. They were selected to be useful across the entire region and will likely need to be tailored to specific local community contexts. A summary of the "top-10" adaptation strategies is included here for each of the three project focus areas: **Critical Infrastructure, Ecosystems, Water Supplies**. **Section II** describes each of these strategies in more detail in the context of their associated focus area. Many additional relevant strategies were discussed during this project and are included in an appendix to this Plan (**Appendix A**), which also includes additional information on the strategies, such as the opportunities or concerns and Key Action Steps regarding its implementation.

TOP 10 **Strategies for Ecosystems**

STRATEGY	TYPE	LEAD GROUP(S)	TIMEFRAME
Enhance efforts to encourage breeding and planting of drought tolerant, resilient plant species	AWARENESS	Agriculture/Forestry Sectors, Educational Organizations	Near-term
Incorporate climate change more explicitly into comprehensive plans and Shoreline Master Programs (SMP)	PLANNING	County and City Governments	Near-term
Enhance promotion of agricultural best management practices to include future climate conditions	AWARENESS	Agriculture Sector, Educational Organizations	Immediate
Update municipal codes to account for enhanced fire risk at forest/ residential interface where needed	POLICY	Local Governments	Near-term
Increase regional capacity for water storage *(preferable with natural systems)*	PLANNING	Multi-Stakeholder	Long-term
Encourage FEMA to incorporate climate change in rate maps and guidance	PLANNING	State and County Government	Long-term
Develop graphic tool to illustrate climate impacts	PLANNING	Multi-Stakeholder	Near-term
Update financing policies for development in high risk areas	POLICY	Banks and Insurance Groups	Medium-term
Enhance efforts to incentive use of native plants landscaping in residential, commercial, industrial settings	AWARENESS	Local Governments and Private Sector	Near-term
Utilize low cost citizen science monitoring and analysis approaches and technologies	AWARENESS	Research Institutions, Non-profit Education Centers, Citizen Scientists	Near-term

TOP 10 **Strategies for Water Supplies**

STRATEGY	TYPE	LEAD GROUP(S)	TIMEFRAME
Enhance education on drought & water supplies issues for the peninsula	AWARENESS	Multi-Stakeholder	Immediate
Adopt new regulations requiring water-efficient appliances	POLICY	State Government	Medium-term
Promote and incentivize smart irrigation technologies for agriculture	AWARENESS	Agricultural Sector	Medium-term
Identify monitoring needs and enhance water supply monitoring	AWARENESS	Multi-Stakeholder	Near-term
Enhance efforts to educate home and business owners on the value of on-site water conservation, retention, and catchment	AWARENESS	Multi-Stakeholder	Immediate
Continue to study ways to enhance water storage and groundwater recharge	PLANNING	Water Utility & Local Governments	Near-term
Encourage forestry practices promoting water retention within the watershed	AWARENESS	Forestry Sector	Medium-term
Research or develop model to assess sea level rise and saltwater intrusion to groundwater	PLANNING	Local Governments, PUDS	Medium-term
Improve forecasting for future water supply and demand	PLANNING	Water Utility Managers	Medium-term
Map water retention values for ecosystems	PLANNING	Multi-Stakeholder	Near-term

TOP 10 **Strategies for Critical Infrastructure**

STRATEGY	TYPE	LEAD GROUP(S)	TIMEFRAME
Update Emergency management and response planning to include climate change where needed	PLANNING	Emergency Managers	Near-term
Reduce inflow and infiltration to wastewater systems	POLICY	Operations and Maintenance Departments	Immediate
Update planning documents for sea level rise and flooding where needed	PLANNING	Multi-Stakeholder	Near-term
Do outreach and education on climate adaptation to build community support	AWARENESS	Multi-Stakeholder	Immediate
Develop and utilize decision making tools related to climate change risks	PLANNING	Local Governments	Medium-term
Create critical area flood mapping beyond FEMA's historical flood data	PLANNING	Multi-Stakeholder	Near-term
Encourage soft defenses for shoreline infrastructure	POLICY	Local Governments and Private Sector	Near-term
Improve on-site stormwater management practices	POLICY	Multi-Stakeholder	Near-term
Participate in FEMA's Community Rating System (CRS)	PLANNING	Multi-Stakeholder	Medium-term
Enhance stormwater retention in upstream areas	POLICY	Multi-Stakeholder	Medium-term

---

In an effort to help move these strategies from planning to action, this project has developed a suite of supporting materials, which include:

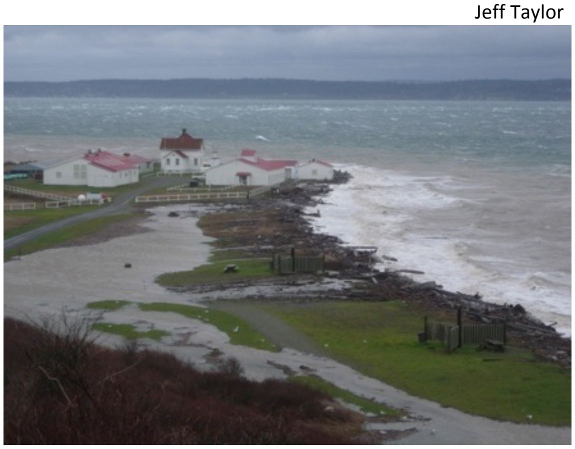
I. A full list of adaptation strategies developed by this project in a spreadsheet format (**Appendix B**);
II. A PowerPoint presentation summarizing the findings of this report, to be used for outreach and engagement on topics of regional climate preparedness (**Supplementary Information B); **and
III. A summary of how other communities are incorporating climate change into their comprehensive planning efforts and revising/creating climate change relevant ordinances (**Supplementary Information C).**

Preparing for the impacts of a changing climate and building resilience is a process and not an outcome. By participating in the development of this preparedness plan, appendices, and supplementary information all of the partners involved have initiated this resilience building process. This project has already borne rich cross-sectoral discussions and enhanced and strengthened professional networks and social connections. With continued collaboration, the recommended actions and processes of this project have the potential to ***build overall climate resilience on the North Olympic Peninsula and promote best possible future outcomes for the region's inhabitants and ecosystems.***

I. Introduction

Jeff Taylor

Randall McCoy



Marrowstone Marine Field Station

USFWS-Google creative commons

A. The North Olympic Peninsula Context

Climate change is occurring and is shifting regional climate and weather patterns. Despite the ongoing scientific consensus on the scope and scale of climate change impacts at the global and national level, projected regional effects have not received a comparable degree of research attention[9]. This report focuses on preparing for the impacts of climate change exclusively on the *North Olympic Peninsula* of Washington State, the region defined for the purposes of this project by the flow of water from the Olympic Mountains north to the Strait of Juan de Fuca and northeastward to Puget Sound and Hood Canal. Much of the climate of the Pacific Northwest is determined by the interface of the North Pacific Ocean and mountainous western North America. The climate of the Olympic Peninsula is, in many ways, the epitome of that interface, with wetter western coastlines, heavy precipitation in the coastal Olympic Mountains, more mild interior waterways and lowlands, and drier areas in the eastern rain shadow of the Olympic Mountains.

Figure 1: The North Olympic Peninsula is defined for the purposes of this project as the region whose terrestrial waters flow to the Strait of Juan de Fuca and Puget Sound.

The watershed areas represented in this project include those of Clallam County and Jefferson County that drain to Puget Sound and the Strait of Juan de Fuca, and exclude the western watersheds that drain to the Pacific Ocean. The *North Olympic Peninsula* is home to two counties, three population hubs, and numerous unincorporated areas. The three major centers of commerce from west to east in the region are Port Angeles (pop. 19,038), Sequim (pop. 6,606), and Port Townsend (pop. 9,113)[10]. However, these numbers do not reflect the full distribution of population in the rural and unincorporated areas around each of these hubs. Clallam County's population in 2014 was estimated at 72,715 persons, and Jefferson County's estimated at 30,228 persons[11].

Ecosystems on the Peninsula are rich and varied, and include but are not limited to alpine and sub alpine zones, coastal rainforest, river habitats spanning from the mountains to the sea, broad floodplain influenced lowlands suitable for agriculture, near-shore and ocean influenced marine habitat, estuaries, sand spits, and protected bays. Humans have impacted these ecosystems, with the region seeing intensive fishing, logging, dam and levee construction, and land conversion to agricultural, residential, and industrial purposes.

A number of climate change risks to the Pacific Northwest have been detailed by researchers, mostly centering around: changes in the timing of precipitation and stream flow; coastal impacts from ongoing sea level rise, erosion, and increasing ocean acidity; forest disease, insect outbreak and wildfire risk; and agricultural impacts[12]. Climate change exerts its influence on human lives both directly (from extreme weather events) and indirectly (through ecosystem shifts and associated impacts to the natural and built environment). This Plan utilizes a regional planning perspective to understand and prepare for Climate Change's impact to Ecosystems, Water Supplies, and Critical Infrastructure on the North Olympic Peninsula.

The North Olympic Peninsula has an opportunity to build climate resilience to current weather extremes and future climate changes through the use of this **Preparedness Plan** in the comprehensive and strategic planning processes of the cities, counties, tribes, public utility districts, and ports of the region. This Preparedness Plan includes:

- A "**Vulnerability Assessment"** comprised of:
  - Detailed local projections of climate change impacts based on the best available science and a comprehensive participatory process (**Section I**);
  - A collaborative prioritization of local resources and locations most vulnerable to climate change (**Section II**);
- An "**Adaptation Plan"** comprised of:
  - A collaborative prioritization of locally relevant adaptation strategies (**Section II**).

"Adaptation" is a common term used in climate change preparation work to denote any "process of adjustment to actual or expected climate and its effects"[13].

B. Climate Change on the North Olympic Peninsula

"Climate Change, once considered an issue for a distant future, has moved firmly into the present" – U.S. National Climate Assessment, 2014[14].

The Pacific Northwest is already experiencing drier summers, reductions in snowpack and glacial mass, higher spring and lower summer river flows, 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[15].

> *"Evidence for climate change abounds, from the top of the atmosphere to the depths of the oceans. Scientists and engineers from around the world have meticulously collected this evidence, using satellites and networks of weather balloons, thermometers, buoys, and other observing systems. Evidence of climate change is also visible in the observed and measured changes in location and behavior of species and functioning of ecosystems. Taken together, this evidence tells an unambiguous story: the planet is warming, and over the last half century, this warming has been driven primarily by human activity" (National Climate Assessment, 2014[16]).*

Global emissions of gasses like Carbon Dioxide (CO_2) have increased dramatically since the industrial revolution. This is due primarily to human activities such as the combustion of coal, oil, and natural gas.

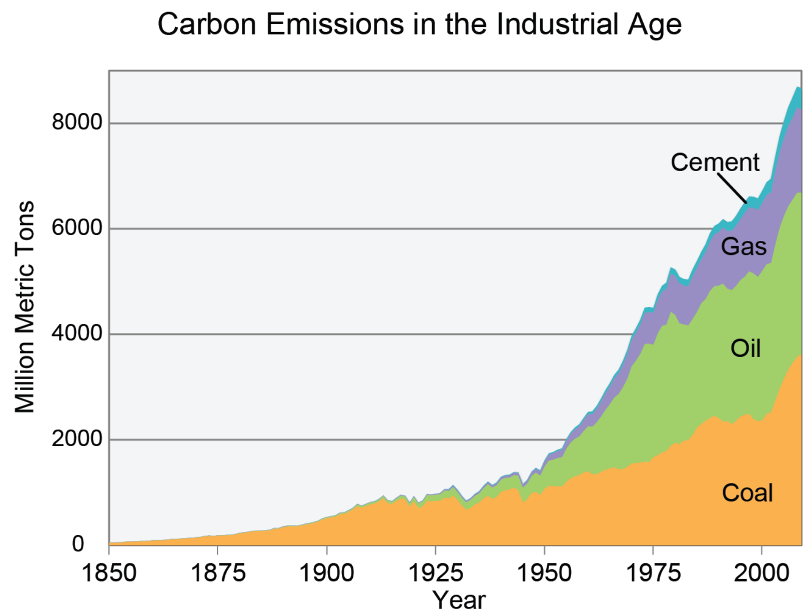


Figure 2: Global carbon emissions from burning coal, oil, natural gas, and cement production since the start of the industrial revolution[17].

The carbon dioxide in the atmosphere acts like a heat trapping blanket around the Earth, warming the atmosphere, land, and oceans. In addition to carbon dioxide there are other greenhouse gasses (GHGs), such as methane and nitrous oxide, which can be produced by human activity and also trap heat in the atmosphere. Based on the current concentrations of these gases in the atmosphere, a certain amount of atmospheric warming on the planet is inevitable. Alongside society's efforts to reduce ('mitigate') human emissions of GHGs that drive climate change, planning efforts have been initiated to respond ('adapt') to the observed and projected impacts of climate change. The reduction in GHG emissions will ultimately decide the success of adaptation efforts. ***This report recognizes the urgent need to reduce emission of GHGs at all scales of human society, from the local to the global, to minimize the costs and protect against the negative impacts of climate change.*** Local governments are beginning to set their own goals for reduction of GHGs, including a Port Townsend/Jefferson County joint resolution to reduce GHG emissions to 80% of 1990 levels by 2050[18]. Unfortunately, the current trajectory of global GHG emissions and the associated rate of atmospheric warming are likely to cause a widespread and disruptive suite of environmental impacts. As such, efforts to adapt and generally prepare for climate change are increasingly critical.

Climate change adaptation efforts are complex and require coordination among a broad range of stakeholders. ***This project synthesized the best available climate change projections with local stakeholder expertise of vulnerable sectors to ultimately develop adaptation strategies for the North Olympic Peninsula.*** The region has a unique opportunity to promote collaboration on climate change adaptation among federal, state, local, and tribal governments, non-profit organizations, academic institutions, and private businesses. Collaboratively defined and prioritized adaptation strategies help build overall climate resilience and promote best possible outcomes for the region's natural, economic, social, and cultural assets.

C. Existing Relevant Climate Change Reports

The Pacific Northwest and Washington State are fortunate in that they have a long history of observing and recording climate and weather data. There has been a substantial amount of effort to study how the observed changes in climate have affected the natural and human system in the region, and to project how those changes will affect those systems in the future. For example, the Climate Impacts Group (CIG) at the University of Washington was formed in 1995 and has been working since then on climate change issues across the State of Washington. There are also a number of state and federal agencies, communities, tribal nations, and non-profit and private sector organizations that have been working together to contribute to local and regional knowledge about the impacts of climate change.

The 2014 National Climate Assessment[19] chapters on the Pacific Northwest[20], coasts[21], and supporting technical documents[22,23], combine to provide a comprehensive look at the state of climate science and the key issues facing the region as a whole. There have also been a number of state specific reports, many developed by CIG, like the recent "*Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*[24]*.*" These documents highlight how changing stream flow patterns, sea level rise, ocean acidification, increased stress on forests, and challenges to agriculture will each substantially affect the region over the course of the coming decades.

Attention has also been paid to the potential impacts on the critical natural resources of the region and the Olympic Peninsula in particular. A compilation of literature on the *Climate Change Effects and Adaptation Approaches for Ecosystems, Habitats, and Species*[25] completed in 2013 for the North Pacific Landscape Cooperative analyzed more than 250 documents and conducted more than 100 interviews to assess how climate change is already affecting and is projected to affect the species and habitat of the region. A study by the Olympic National Park and the Olympic National Forest looked at how climate change will affect the natural resources in the lands they manage[26]. A report by the State of Washington's Blue Ribbon Panel on Ocean Acidification[27] provides a summary of the current state of knowledge on ocean acidification in the region, why it matters, how it will affect the marine species and economy of the state, and actions that can be taken to reduce those impacts and better monitor and prepare for future changes. The Olympic Coast National Marine Sanctuary completed a study last year considering how climate change will affect their specific geographic area and the species and habitats within the sanctuary[28].

The Washington Department of Transportation (WSDOT) has completed a climate change vulnerability assessment[29] for the state highway networks and ranked transportation corridors based on their perceived vulnerability to climate change risks. Recognizing that new transportation investments have an important opportunity to build climate resilient infrastructure, WSDOT's current strategic plan[30] outlines the need to assess the impacts of long term climate change and extreme weather for new projects.

Regarding the wildfire risk to the region, Clallam County completed a *Community Wildfire Protection Plan* in 2009[31], which includes a Wildfire Hazard and Risk Assessment, description of wildland-urban interface "at-risk" communities, mitigation strategies, monitoring and evaluation tools, and funding sources. The plan recognizes climate change projections of increased wildfire hazard across the Northwest, especially within the wildland-urban interface, and longer summer drought periods for eastern Clallam County specifically. Although the plan does not label its fire mitigation measures as climate change adaptation strategies, any action addressing an increased wildfire risk could be considered a climate change adaptation strategy.

A large uncertainty for stakeholders in the region revolves around the response of global and national societies to climate change impacts, and whether that includes migration to or from the Pacific Northwest (a population known as "environmental migrants"). One report has attempted to look at this issue for a specific location in the Pacific Northwest: *Environmental Migrants and the Future of the Willamette Valley*[32]. The report recognizes the full complexities of the issue, including a discussion of current trends in population dynamics and migration for the region, and analysis of various theories of climate change migration.

A number of local communities throughout the region have undertaken climate change vulnerability assessments to better understand the potential risk to their communities and started to develop adaptation plans in order to reduce those vulnerabilities and better prepare for those impacts. Some of those efforts include the work done by the Swinomish[33] and Jamestown S'Klallam[34] Tribes and the City of Seattle[35], and work done in local infrastructure sectors such as Sound Transit[36]. There are many other indirectly relevant reports, too numerous to list here. The References Section of this report provides citations and links to many of the climate change documents relevant to the North Olympic Peninsula.

The findings from this diverse body of work have been incorporated into this project's assessment, vulnerability ranking and prioritization, and development of adaptation strategies for vulnerable sectors, resources, and assets of the North Olympic Peninsula. This plan does not aim to recreate or summarize all of these existing climate change efforts; the references above are available for those desiring in-depth discussion of those topics. The process followed by this project was to prioritize the overall climate change vulnerabilities for the region, and identify the topic areas where this project could add the most benefit to the climate change adaptation effort. To accomplish this, the core team applied "Action Planning Criteria" (see pg. 11) to a broad list of vulnerability issues drawn up in a collaborative scoping process. By leveraging existing climate change research for the region and working collaboratively with a diverse group of stakeholders from across the North Olympic Peninsula, this project explored how climate change will impact the **ecosystems, water supplies, and critical infrastructure** of the region and in turn, which adaptation strategies will best minimize these impacts.

D. Collaborative Project Process

The Project Team for this project includes the North Olympic Peninsula Resource Conservation & Development Council (NOPRCD), Adaptation International, and Washington Sea Grant. All members of the NOPRCD council (within the project's geographic boundaries) are partners in this project, including: Jefferson County, Clallam County, the cities of Port Angeles, Sequim and Port Townsend, Clallam Economic Development Council, Team Jefferson Economic Development Council, Port of Port Townsend and Port of Port Angeles, Clallam Conservation District, the Clallam and Jefferson PUDs, Jamestown S'Klallam Tribe, Makah Tribe, and Lower Elwha Klallam Tribe, Peninsula College, Puget Sound Partnership's Strait of Juan de Fuca Ecosystem Recovery Network, and Washington State University. At the initiation of this project, these groups were invited to designate a representative to act as a member of the **Core Team**. The Core Team met periodically with the project team to discuss project progress and direct the project through scoping, outreach, and data review.

As described, this project sets out to develop an adaptation plan for the North Olympic Peninsula through *collaborative* synthesis of climate change projection and observation science with local stakeholder expertise of vulnerable sectors and relevant adaptation strategies. Any local stakeholder that became engaged in the processes of this project, whether in participatory workshops (described below) or through other outreach efforts became **Partners** who were invited to participate in workshops, and who helped review project materials prior to public distribution via email and project webinars.

<u>Project Kick Off</u>

Sascha Petersen

Sascha Petersen

The project kicked off with structured interviews between core team members and the project team to identify key climate change related concerns. The results of these interviews were organized into draft "Key Concerns" for the project, which included: Water Supplies, Critical Infrastructure, Agriculture and Forest Health, Economic Vitality, Shorelines, and Marine Species. These Key Concerns were presented alongside region-specific climate change projections to the core team during an in-person meeting on August 21st, 2014 in Sequim, WA. During this meeting, core team members evaluated how Key Concerns could either be condensed or expanded to develop central "focus areas" that best represented the experience of climate change on the North Olympic Peninsula, with attention to the regions' specific socio-economic structure, ecosystem, and culture. At the end of the meeting, the core team selected the most important Key Concerns for the objectives of this project. The result was four focus areas: Community Vitality, Water Resources, Natural and Managed Ecosystems, and Critical Infrastructure. These focus areas were reviewed and refined a second time with the core team and a wider group of project partners during a webinar on September 12th, 2014. The focus areas acted as the functional structure for the vulnerability assessment and adaptation planning processes.

Following agreement on the focus areas themselves, the core team, project team, and project partners began to compile tables detailing potential **vulnerabilities** under each focus area as they relate to the Human and Natural systems, as well as the drivers of climate change impacts between these systems[37]. "Vulnerability" is a broadly encompassing term, defined by the Intergovernmental Panel on Climate Change as: "*The propensity or predisposition to be adversely affected. 'Vulnerability' encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.*"[38]

Participatory Workshop 1: Climate Change Impacts and Vulnerabilities

Ian Miller

Ian Miller

The participatory scoping process described above set the stage for wider group engagement in the project. This wider input was used to identify specific geographic locations, systems, and ecosystems that are likely to be affected by climate change. This collaborative data gathering occurred through four Participatory Workshops held over the week of November 10th – 14th, one full-day workshop for each focus area: **Community Vitality, Water Resources, Natural and Managed Ecosystems, and Critical Infrastructure**. The core team identified stakeholders that had relevant subject matter expertise and these stakeholders were invited to attend the workshop(s) most appropriate to their areas of expertise. Representatives from the following organizations were invited to attend each workshop, with number of attendees in parenthesis:

Table 1: Participants invited to Workshop 1: climate change impacts and vulnerabilities (bolded had a representative attend)

Community Vitality Workshop-November 10th in Sequim, WA (20 attended)	
Adaptation International	Lower Elwha Klallam Tribe
Clallam Bay-Sekiu Chamber Commerce	**Makah Tribe**
Clallam County EDC	**North Olympic Timber Action**
Clallam County Environmental Health	**North Olympic Peninsula Resource Conservation &**
Clallam County Planning Department	**Development Council**
Clallam County Department of Community	**North Olympic Land Trust**
Development	**Olympic Medical Center**
Dungeness National Wildlife Refuge	**Olympic Climate Action**
EDC Team Jefferson	**City of Port Angeles Planning, CED, Parks**
Federal Emergency Management Agency	Port Angeles Regional Chamber
Feiro Marine Life Center	**Port Ludlow Village Council**
Fort Worden-State Parks	**City of Port Townsend**
Friends of Dungeness National Wildlife Refuge	Port Townsend Development Services
Jamestown S'Klallam Tribe	Port Townsend Marine Science Center
Jefferson County Chamber of Commerce	**City of Sequim**
Jefferson County Department of Community	**City of Sequim Community Development**
Development	**Sequim-Dungeness Chamber Commerce**
Jefferson County Environmental Health	**Strait Ecosystem Recovery Network**
Jefferson County Planning Department	Walk and Livable Communities Institute
Jefferson County PUD	**Washington State University Extension**
	Local 20/20 Climate Action
Water Resources Workshop-November 12th in Sequim, WA (32 attended)	
Adaptation International	**North Olympic Timber Action Committee**
Clallam County Public Works	**Olympic Climate Action**
Clallam County Public Utilities District	Olympic Environmental Council
Clallam Conservation District	City of Port Townsend Public Works
City of Port Angeles Public Works	Puget Sound Partnership
City of Port Townsend	**Port Angeles Business Association Natural**
City of Sequim Public Works	**Resources Committee**
Crescent Water Association	Port Gamble S'Klallam Tribe
Dungeness River Management Team	**Port Townsend Marine Science Center**
Dry Creek Water Association	**Protect the Peninsula's Future**
East Jefferson Watershed Council	**Puget Sound Partnership**
Jamestown S'Klallam Tribe	**Strait Ecosystem Recovery Network**
Jefferson Conservation District	**Streamkeepers**
Jefferson County Public Utilities District	**Washington Dept. of Ecology**
Local 20/20 Climate Action	WA Dept. of Fish and Wildlife
Lower Elwha Klallam Tribe	Water Resource Inventory Areas (WRIA) 17, 18, 19
Makah Tribe	**Washington Sea Grant**
North Olympic Salmon Coalition	**Washington Water Trust**
North Olympic Peninsula Resource Conservation &	WSU Extensions – Jefferson and Clallam Counties
Development Council	Jefferson County Public Works
North Olympic Land Trust	**Zoi Environment Network**

Natural and Managed Ecosystem Workshop-November 13th in Blyn, WA (26 attended)	
Adaptation International	**Makah Tribe**
Clallam County of Environmental Health	North Olympic Land Trust
Clallam County Planning	North Olympic Salmon Coalition
Clallam Conservation Districts	**North Olympic Timber Action Committee**
Cooperative Extension	**North Olympic Peninsula Resource Conservation & Development Council**
Icicle Seafoods	Olympic National Park
Jamestown S'Klallam Tribe	**Olympic Climate Action**
Jefferson Land Trust	**Olympic Environmental Council and Sierra Club**
Jefferson County Planning	**Olympic Peninsula Audubon Society**
Jefferson County Department of Community Development	Port Angeles Business Association
Jefferson County Environmental Health	**Port Gamble S'Klallam Tribe**
Jefferson County Water Quality	**Puget Sound Partnership**
Jefferson Conservation Districts	**Taylor Shellfish**
Lower Elwha Klallam Tribe	U.S. Forest Service
Local 20/20 Climate Action	**Washington State University Extension**
	Washington State Department of Ecology
	WA Department of Natural Resources
Critical Infrastructure Workshop- November 14th in Port Angeles, WA (28 attended)	
Adaptation International	Port of Neah Bay
Bonneville Power Administration	**Olympic Climate Action**
Clallam County Public Utility District	Olympic Environmental Council and Sierra Club
Clallam County Planning, Public Works	**Port of Port Townsend**
Clallam County Emergency Management	**Port of Port Angeles**
Clallam County Department of Community Development	Port Angeles Utilities
	City of Port Angeles Public Works
Dry Creek Water Association	City of Port Townsend Public Works
Hood Canal Coordinating Council	**City of Port Townsend**
Jamestown S'Klallam Tribe	**City of Port Angeles**
Jefferson County Planning, Public Works	Port Townsend Paper Company
Jefferson County Public Utility District	Port Townsend & Port Angeles Hospitals
Jefferson County Emergency Management	Regional Transportation Planning Organization
Jefferson PUD	City of Sequim Public Works
Lower Elwha Klallam Tribe	U.S. Coast Guard
Local 20/20 Climate Action	U.S. Navy
Makah Tribe	Washington State University extension
Nippon Paper Industries USA (Port Angeles Mill)	**WA Department of Transportation Olympic Region**
North Olympic Peninsula Resource Conservation & Development Council	**Washington Department of Ecology**
	WA Department of Natural Resources
Port Townsend Paper Company	**Washington Sea Grant**

The four workshops were all organized in the same way. The morning was devoted to a review of regional climate change projections most pertinent to the focus area, and the afternoon focused on identifying and ranking a broad suite of specific vulnerabilities based on their sensitivity and adaptive capacity to climate change. The use of "***sensitivity"*** (*how susceptible a potential vulnerability is to changing climate conditions*) and "***adaptive capacity"*** (*ability of a system or asset to respond to changing climate conditions*) is an internationally recognized means for assessing climate change related vulnerabilities[39]. Complete results of these workshop discussions are found in **Supplementary Information D**.

Participatory Workshop 2: Identifying & Prioritizing Adaptation Strategies

Sascha Petersen

Sascha Petersen

The results of Workshop 1 included a comprehensive set of 95 distinct climate change vulnerabilities across the four focus areas (see **Supplementary Information D**). Given the limited timeframe and resources of this project, it was not feasible to develop adaptation actions for all of these vulnerabilities. Instead, the Project Team and Core Team prioritized the vulnerabilities not only by their "sensitivity and adaptive capacity" rankings but also by a set of "Action-Planning Criteria" developed collaboratively by the project team and core team. This set of Action-planning criteria included consideration of a given vulnerability and its:

- R*esources available;*
- *Project capacity and data gaps;*
- *Relevance to both counties;*
- *Ability to inform decision-making; and*
- *Timing and magnitude of impacts*.

Filtering the initial set of 95 vulnerabilities by this method helped the team select 36 vulnerability issues to be considered for developing adaptation action in Workshop 2. This tightening of scope resulted in some very calculated decisions about how to approach important climate change issues for the region. For example, it drove the decisions to:

- focus on hatchery salmon operations and nearshore and riverine habitat for wild salmon instead of salmon fisheries management,
- focus on ecosystem level determinants of human health instead of public health interventions, and
- not explore new approaches to wildfire risk management and response, but to recognize the previous work and ongoing efforts of emergency managers [40].

The project team, core team, and partners finalized this sorting of vulnerabilities during a webinar on February 24th, 2015. At this time, the project team and core team also made a decision to merge the crosscutting "Community Vitality" focus area into the other three focus areas. This meant Workshop 2 consisted of three sessions instead of four. The list of vulnerabilities selected for Workshop 2, as well as the breakout session topics and results, are found in **Supplementary Information E**.

The workshop 2 sessions took place on April 15th, 16th, 17th, 2015 focusing on the Region's **Critical Infrastructure, Ecosystems, and Water Supplies** at three locations on the Peninsula. All partners from Workshop 1 (Table 1) were invited to Workshop 2, alongside other newly interested stakeholders. Representatives from the following organizations attended Workshop 2 sessions, with total number of attendees in parenthesis.

Table 2: Participants in Workshop 2: Identifying and prioritizing adaptation strategies

Critical Infrastructure Workshop-April 15th-Sequim, WA (38 attended)	
Adaptation International Baril Networks Clallam County Clallam Conservation District City of Port Townsend Crescent Water Association Feiro Marine Life Center Hood Canal Coordinating Council Jefferson Public Utility District Jefferson Marine Resource Council Jefferson County Jefferson Marine Resource Council Lower Elwha Klallam Tribe Local 2020 Climate Adaptation Group Makah Tribe Marine Surveys & Assessments	North Olympic Peninsula Resource Conservation & Development Council Olympic Climate Action Olympic Environmental Council City of Port Angeles Port Angeles Business Association Port of Port Angeles Port of Port Townsend Port Townsend City of Sequim Zoi Environment Network City of Sequim STARR (*FEMA Contractors)* Washington Dept. of Natural Resources Washington State University Extension WA Dept. of Transportation - Olympic Region WA Sea Grant 10,000 Years Institute
Ecosystems Workshop-April 16th-Blyn, WA (31 attended)	
Adaptation International Crescent Water Association Citizen Action Training Clallam County Feiro Marine Life Center Jefferson Land Trust Jefferson County Public Health Lower Elwha Klallam Tribe Local 2020 Climate Adaptation Group Makah Tribe Marine Surveys & Assessments Nash's Organic Produce	North Olympic Peninsula Resource Conservation & Development Council North Olympic Timber Action Committee Olympic Environmental Council and Sierra Club Olympic Peninsula Audubon and Stream keeper Olympic Climate Action Port Townsend Marine Science Center Port Townsend Puget Sound Partnership Sound Science WA Sea Grant WA State Dept. of Natural Resources

Water Supplies Workshop-April 17th-Port Angeles, WA (26 attended)	
Audubon Society	
Adaptation International	Local 2020 Climate Adaptation Group
Crescent Water Association	Makah Tribe
Clallam County	North Olympic Timber Action Committee
Clallam County Commissioner	Olympic Climate Action
Jefferson Public Utility District	Port Angeles Public Works
Jefferson County Public Health	PUD #1 of Clallam County
Jefferson County	PW&U, City of Port Angeles
City of Port Townsend	City of Sequim Public Works
North Olympic Peninsula Resource Conservation & Development Council	Washington State Department of Ecology Washington State University Extension

The structure of Workshop 2 followed a general outline of:

I. Review of findings of Workshop 1 - climate change science and vulnerabilities;
II. Large group brainstorming on appropriate adaptation strategies (drawing inspiration from promising practices being used across the country);
III. Targeted small group selection and evaluation of adaptation strategies; and
IV. Large group review of prioritized adaptation strategies.

Review of Preparedness Plan

The Project Team and Core Team worked to finalize first a Table of Contents and then a draft copy of this Preparedness Plan for review by the project partners. Ultimately, 175 project partners had the opportunity to review and recommend revisions to this plan for a one-month period during the summer of 2015. Their input, comments, and recommendations have been incorporated into this document.

E. Observed and Projected Climate Trends in the Pacific Northwest

Residents of Jefferson and Clallam Counties, including fishermen, farmers, natural resource managers, business owners, public health practitioners, utility managers, emergency responders, coastal residents, tribal citizens, and others, have already noticed changes in the weather and climate conditions on the North Olympic Peninsula. These changes are part of a larger suite of changes occurring at the regional, national, and global scale. This section provides an overview of the observed and projected changes in the region focusing on three categories: changing temperatures, changing precipitation, and changing ocean conditions.

Additional climate impacts or exposures specifically relevant to a given focus area are covered in **Section II**.

When considering projections for future climate change it is important to take into account the possibilities of future human activities. How quickly (or slowly) humans act to decrease greenhouse gas emissions will determine the ultimate amount of greenhouse gasses in the atmosphere and thus the degree of overall warming. In order to quantify different possible futures, climate researchers have developed *Emissions Scenarios*. Each scenario makes assumptions about economic, technological, demographic, policy, and institutional futures. The current set of scenarios is called the *Representative Concentration Pathways* (RCPs). The RCPs are named based on the amount of extra radiative forcing (in watts/m^2), that adds to the heat imbalance in the global system, associated with each scenario. For example, RCP4.5 specifies an additional 4.5 watts/m^2 of heat energy added to the global system by the year 2100.

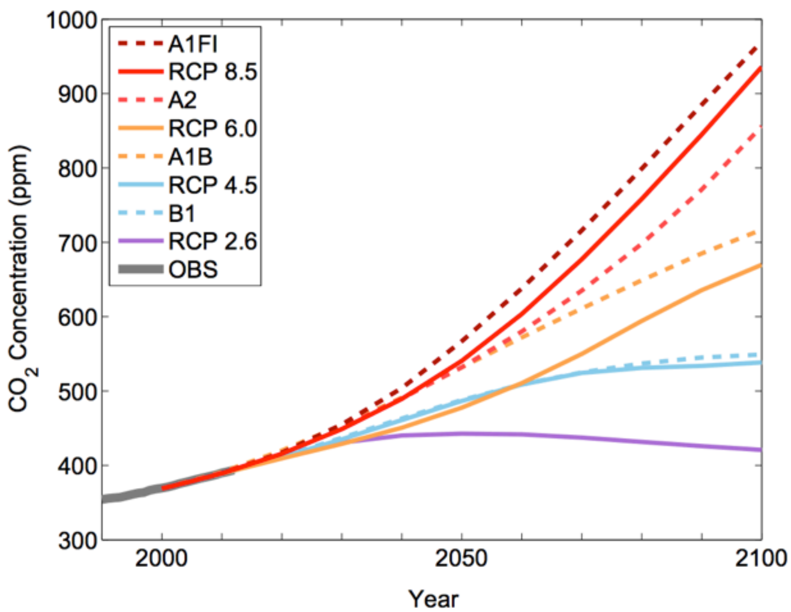


Figure 3: Carbon Dioxide (CO_2) concentrations in parts per million (ppm) for each of the emissions scenarios. Figure shows current Representative Concentration Pathways (RCPs) and the older A1FI, A2, A1B and B1 Scenarios, which are used in some of the research cited by this report[41].

In this project you will see specific reference to RCP 4.5 and RCP 8.5 scenarios. RCP 8.5 is frequently referred to as the "business as usual" scenario and can be considered the "higher" emissions scenario that the world is likely to follow if little action is taken to reduce greenhouse gas emissions. RCP 4.5 is considered a "lower scenario" where significant action is taken to stabilize emissions by the middle of the century. RCP 2.6 is now considered extremely unlikely, as it would require substantial cuts to greenhouse gas emissions in the immediate future. Recognizing this, the RCP 2.6 scenario is not utilized in the projections shared in this report.

Temperature: Trends and Extremes

Temperatures[42]	Observed Changes	Future Projections
Averages *(for Pacific Northwest)*	Warmed 1.3°F (1895-2011)	By 2050's – increases of 4.3°F (lower emissions), to 5.8°F (higher emissions)
Extremes	Increase in nighttime heat events.	Slight increase in days over 90°F (8 ± 7 days) for PNW with limited increase in days over 95°F on the Olympic Peninsula. Frost-free season increases + 35 days across PNW.

Historic Temperatures

Over the last century, average annual air temperature in the Pacific Northwest has increased by 1.3°Farenheit (F)[43]. The dark black line in Figure 4 below shows observed annual average temperature (relative to the 1901-1960 average) for the Pacific Northwest. Although temperature anomalies continue to fluctuate year to year, as a trend they have moved upward from the historical average, as can be seen by the dashed trend line. Additionally, seasonal warming has been observed across the Pacific Northwest along with a longer freeze-free season and increasing temperatures on the coldest nights[44]. The frost-free season has lengthened by 35 days relative to the historical period 1895-2011, and nighttime heat events have become more frequent in western Washington State[45].

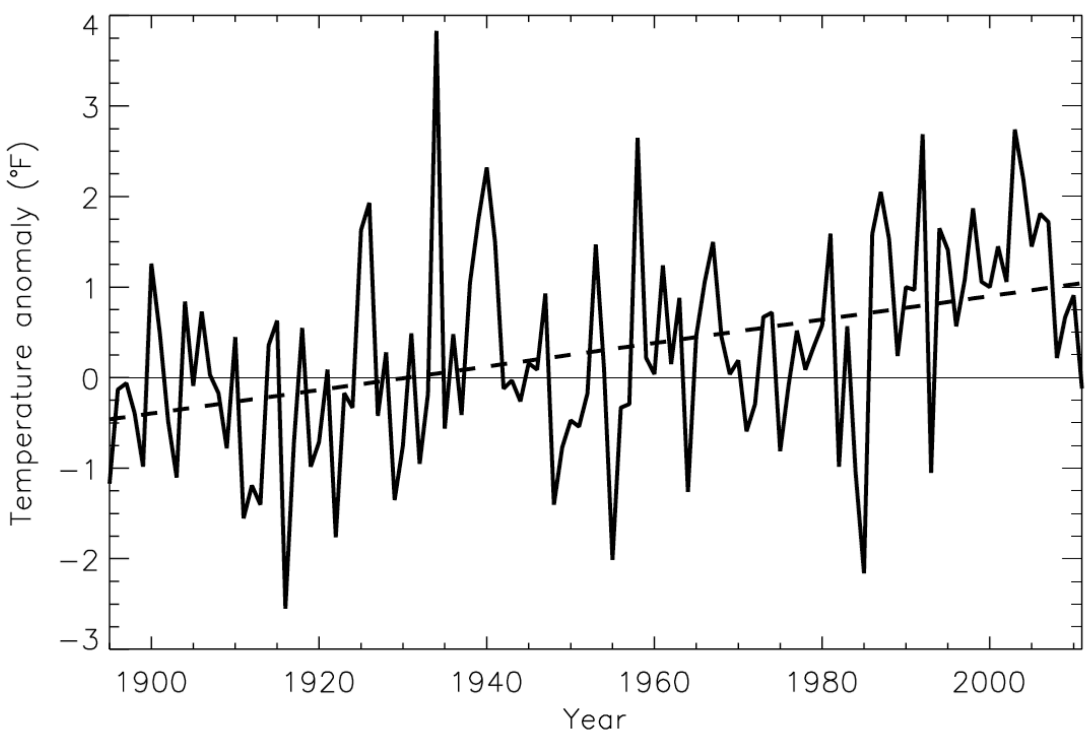


Figure 4: Average annual temperature anomaly (changes from the 1901-1960 average) in the Pacific Northwest[46].

Future Temperatures

Average annual temperature by the 2050's is projected to increase 4.5°F to 5.8°F (relative to 1950-1999) depending on future greenhouse gas emissions scenarios[47]. Annual average temperatures in Washington are projected to increase 5.8° Fahrenheit by the 2050s under a higher emissions scenario (RCP 8.5)[48].

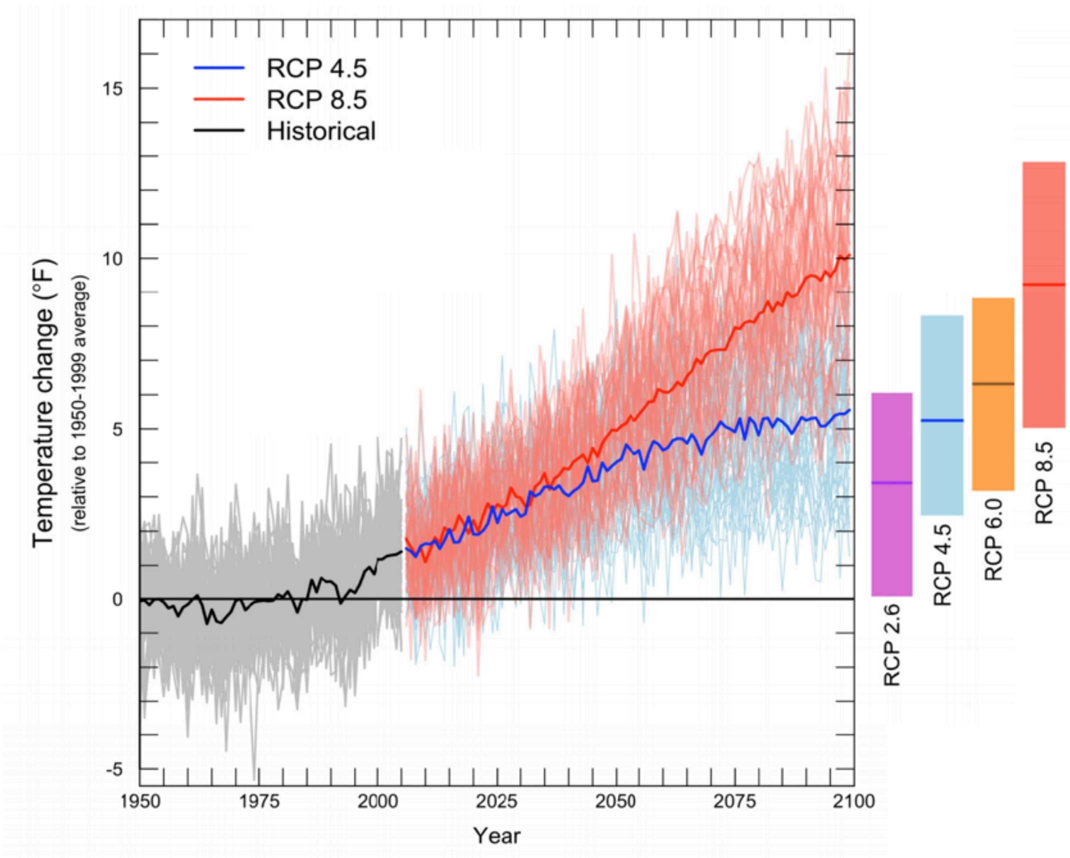


Figure 5: Observed and projected changes in temperature for the Pacific Northwest. Observed (1950-2011) regional mean annual temperature increases are shown in gray, and projected increases in blue and red (blue for a lower greenhouse gas emission scenario - RCP 4.5, and red for a higher greenhouse gas emissions scenario – RCP 8.5). Average annual temperature for the 2050s is projected to increase 4.5°F (RCP 4.5 - range 2.0°F to 6.7°F) to 5.8°F (RCP 8.5 -range 3.1°F to 8.5°F) relative to 1950-1999[49]

While tracking average annual temperatures are useful, seasonal changes and extreme weather events provide a more accurate representation of the potential for climate change impacts to the region. The figures below show monthly maximum and minimum air temperature (2 meters above the ground) averages for Clallam and Jefferson Counties for four time periods using the RCP 4.5 and RCP 8.5 emissions scenario simulations. The solid lines indicate the average of 30 climate models and the respective shaded envelopes indicate their standard deviations.

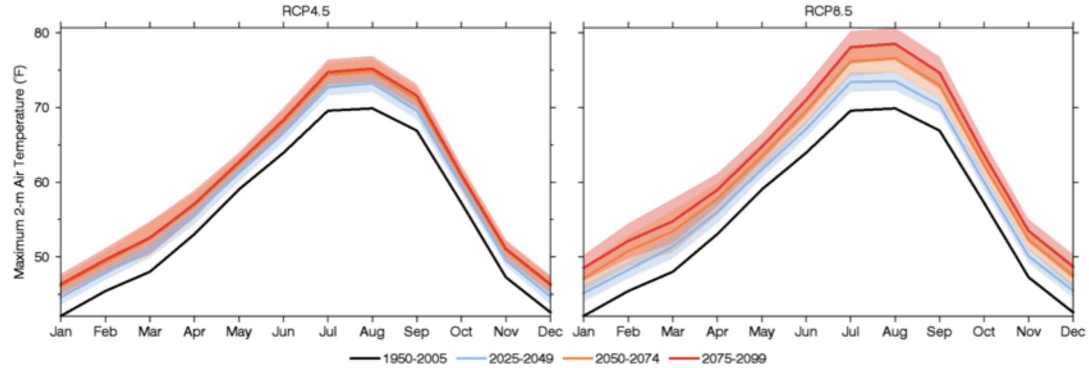


Figure 6: Projected changes to maximum temperatures in Clallam County[50].

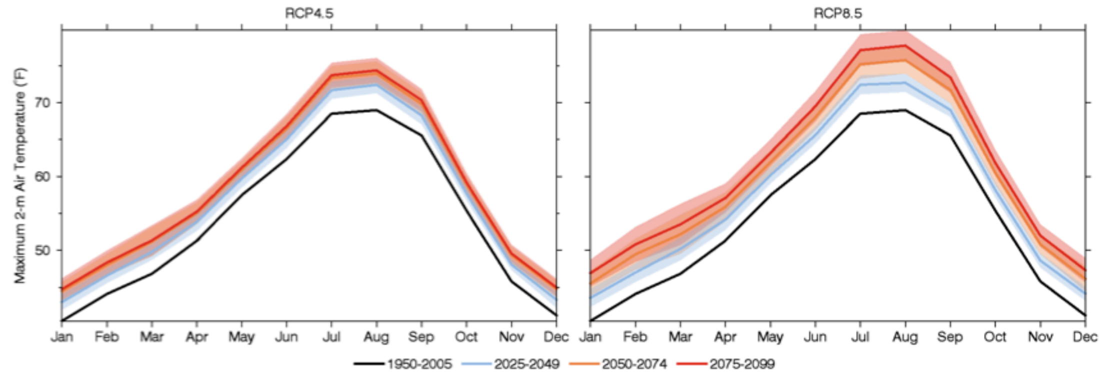


Figure 7: Projected changes to maximum temperatures in Jefferson County[51].

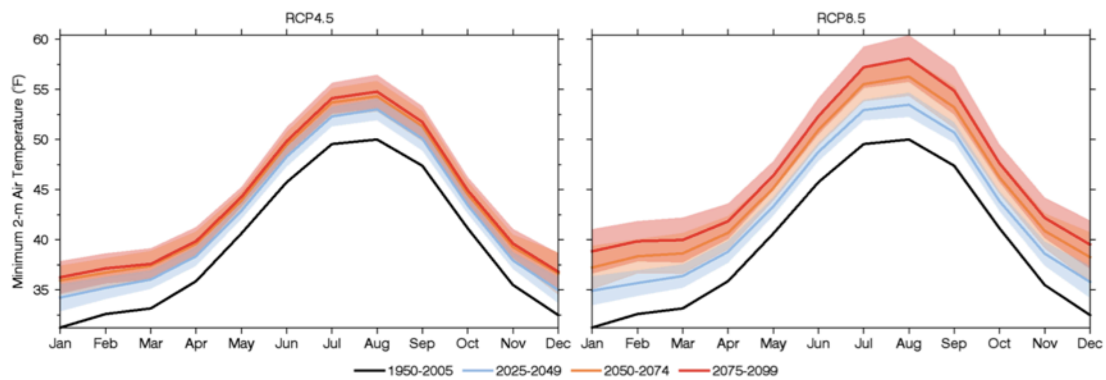


Figure 8: Projected changes to minimum temperatures in Clallam County[52].

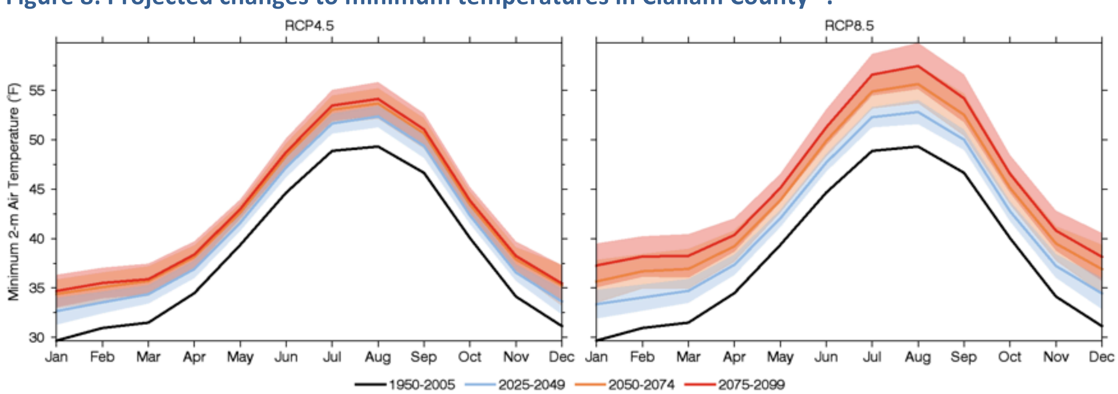


Figure 9: Projected changes to minimum temperatures in Jefferson County[53].

Extreme Temperatures

The North Olympic Peninsula may be generally protected from truly extreme temperatures over the next century due to its location in the Pacific Northwest and close proximity to the moderating influence of the Pacific Ocean. Summer high temperatures are projected to increase substantially in the region (5.8°F by the 2050's with the higher emission scenario[54]). For the Olympic Peninsula, extreme heat days (days > 95 degrees F) are projected to remain relatively few (< 5 per year) and not increase significantly by the middle of the century (2050s)[55]

Precipitations: Trends and Extremes

Precipitation[56]	Observed Changes	Future Projections
Averages (for Pacific Northwest)	No significant changes in average amount; Region-wide decrease in snowpack.	Little average annual change – with dryer summers (-6% to -8% average decrease). Continued declining snowpack with potential loss of snowpack in Olympics by 2080[57].
Extremes	Ambiguous	More heavy rainfall events: 13% (± 7%) increase in days with > 1 inch of rain.

Historic Precipitation

Year to year variability in precipitation (rain and snow) is historically quite large for the Pacific Northwest, with some wet years (or decades) and other dry years (or decades). There is no long-term observed trend to drier or wetter conditions annually across the Pacific Northwest[58]. The dashed line shown in Figure 10 below is a trend line, but the slight increase is not statistically significant.

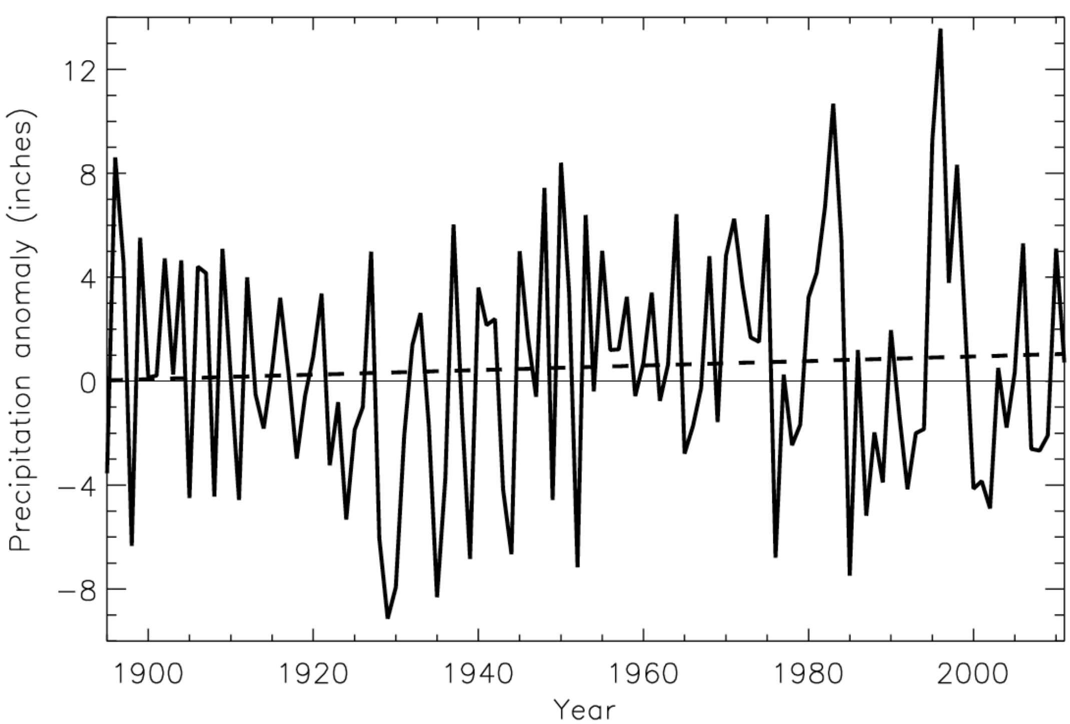


Figure 10: Average annual precipitation anomaly (changes from the 1901-1960 average) in the Pacific Northwest[59]. Trend line (dashed) is not statistically significant (i.e. not different than zero).

Longer growing seasons and higher temperatures have led to an increased potential for evapotranspiration. When combined with decreases in precipitation during summer and fall this has led to increased drought stress on soils and plants over the last forty years[60]. Changes in precipitation type in the Olympic Mountains have also been observed. The Anderson and Lillian glaciers in the Olympics (whose size are dependent on successive years of predominantly snowfall precipitation type) have experienced dramatic retreat and almost disappearance over the last century[61].

Future Precipitation

Most climate projections for the Pacific Northwest are in agreement regarding seasonal precipitation changes, projecting a decrease in summer precipitation and an increase in fall and winter precipitation (see Figure 11 & Figure 12 below)[62]. Changes in total annual precipitation are projected to be small for the 2050s (-4% to +14%)[63], with most models projecting drier summers for the Pacific Northwest[64] (-6% to -8% for the 2050s on average, with some models showing up to a -30% decrease in summer precipitation).

The following figures show monthly averages precipitation and run-off for Clallam and Jefferson Counties covering four time periods for the RCP4.5 future emission scenario (reduced future GHG emissions) and RCP8.5 scenario (continued current levels of GHG emissions) simulations. The solid lines indicate the average of 30 climate models and the respective shaded envelopes indicate their standard deviations. These averages are across the entire county, so precipitation in any specific location may be significantly higher or lower than these averages.

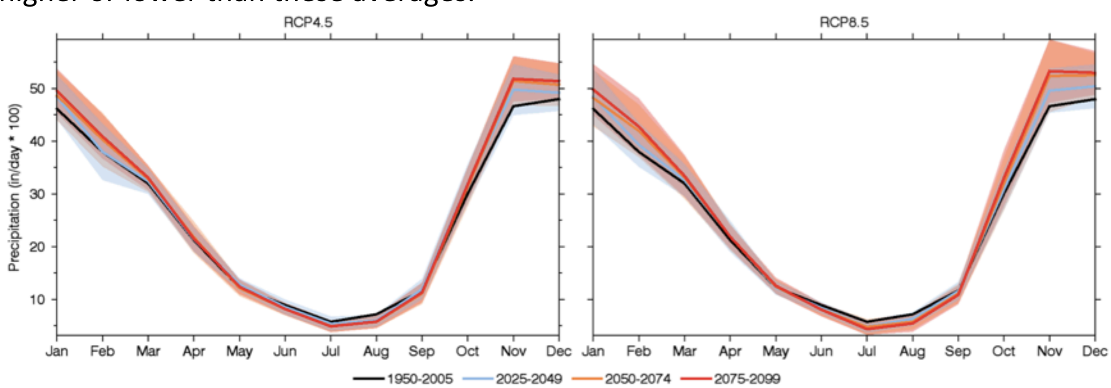


Figure 11: Monthly average precipitation in Clallam County[65].

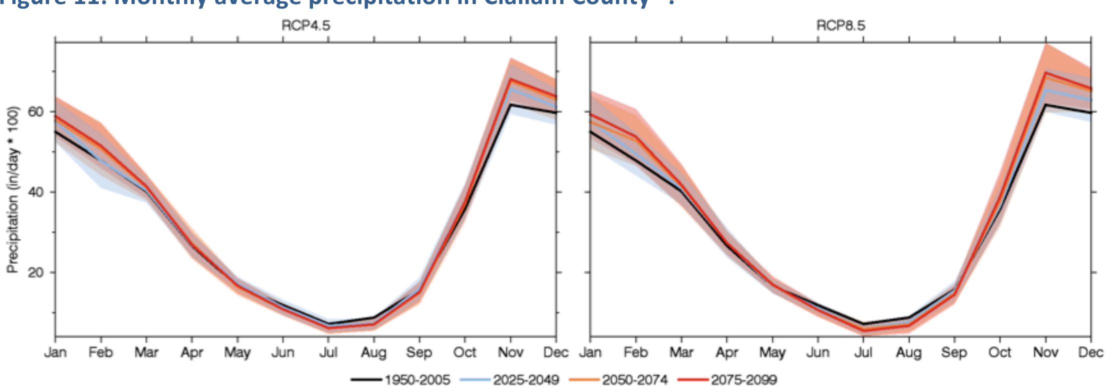


Figure 12: Monthly average precipitation in Jefferson County[66].

Changing precipitation patterns, coupled with air temperature changes, will result in increased winter and spring runoff for many of the region's rivers (see Figure 13 & Figure 14 below). The North Olympic Peninsula region holds both 'rain dominant' (generally lower elevation) and 'transient' watersheds, which can see precipitation as both rain and snow[67]. These transient watersheds experience high flows in mid-summer as their accumulated snowpack melts into their tributaries, while rain dominated watersheds experience peak flows during heavy rain events in the fall and winter. Projections for Clallam and Jefferson County suggest that mixed rain and snow ('transient') watersheds (historically those on the eastern half of the peninsula – see Figure 34) will be the most altered by climate change.

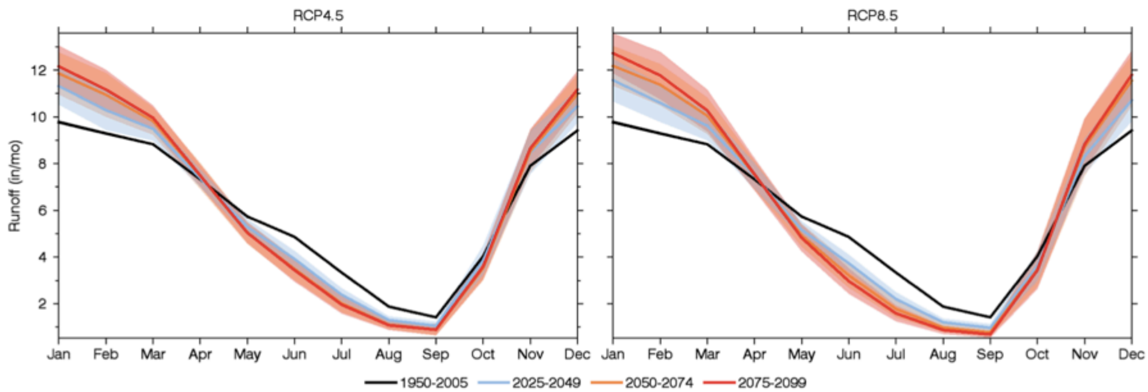


Figure 13: Monthly average runoff in Clallam County[68].

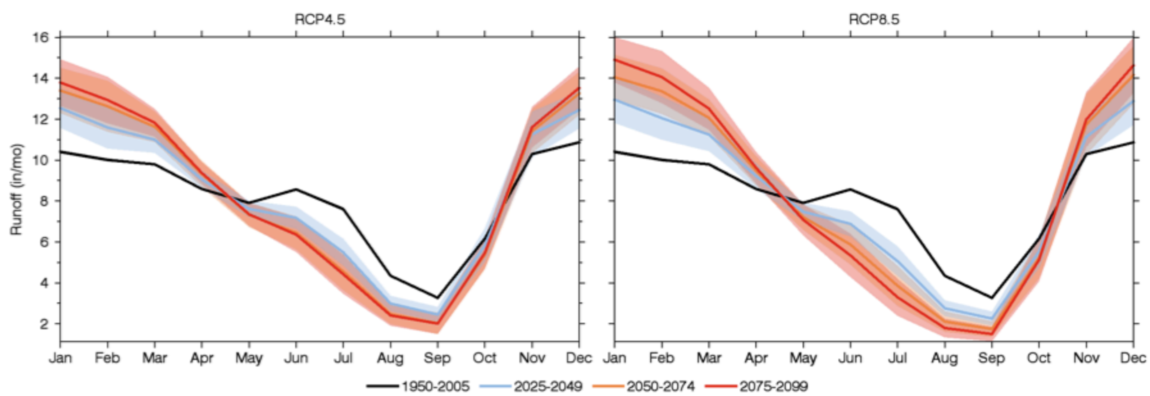


Figure 14: Monthly average runoff in Jefferson County[69].

Extreme Precipitation

Extreme precipitation and its associated river flooding is nothing new for the Pacific Northwest. Large winter storms often produce heavy rain events that can deliver large amounts of rainfall[70]. Runoff and streamflow will be directly impacted by projected changes in heavy precipitation, particularly for a continued higher emissions scenario. Specifically, events in Washington State with more than 1 inch of rain falling in 24 hours are projected to increase 13% by the 2050s[71]. On the other extreme, drought conditions such as those being experienced during the summer of 2015, can lead to an increased risk of wildfire[72] and reduce summer streamflow that salmon, agriculture, and industries all depend on.

The projected changes in precipitation patterns along with changes in temperatures for the region will likely have substantial impacts on:

- **Hydrology and water resources** (higher stream temperatures in the summer and lower summer stream flows);
- **Forests** (changes to forest complexes through shifting distribution of tree species and increased mortality due to more wildfire, insect outbreaks, and disease);
- **Species and ecosystems** (shifting composition of ecosystems as habitats and species adjust to temperatures and water availability);
- **Agriculture** (through too much or too little water and increasing heat stress on crops and livestock);
- **Infrastructure** (direct exposure to flooding and other impacts leading to service interruption and increased maintenance and operation costs); and
- **Human health** (through both direct exposure to flooding, extreme heat, and vector born disease and indirect impacts such as changes to diet and mental health)[73].

This range of more specific impacts will be discussed in detail as they relate to each of the focus areas of this project in **Section II**.

Oceans: Sea-level Rise Scenarios, Sea-surface Temperature, Acidification

Sea-Level Rise Scenarios

Mean sea level is rising globally[74] due primarily to two mechanisms: ocean warming, and the melting of land-grounded ice[75]. Oceans absorb about 90% of the heat trapped by increasing concentrations of carbon dioxide and greenhouse gasses in the Earth's atmosphere[76], and their volume expands as the oceans warm, raising sea level. Additionally, warmer air and water temperatures also drive the melting of land-grounded glaciers (like those in the Olympic Mountains) and ice sheets (like those resting atop Greenland and Antarctica), which adds new fresh water to the oceans and thus contributes to sea level rise. About 40% of current sea level rise is attributed to thermal expansion of the oceans and 60% is due to the freshwater additions to the oceans[77]. It is these two mechanisms that are also primarily responsible for projections of accelerating rates of global sea level rise in the coming decades.

Global sea level rise projections and mechanisms are important, but they don't fully explain observed and projected sea level rise in the Pacific Northwest. Global sea level patterns can be altered at the regional scale by factors like wind and atmospheric pressure patterns, and even by the distribution of water around the globe due to the gravitational influence of landmasses, glaciers, and ice sheets. Additional factors, like the vertical movements of the land due to tectonic forces, glacio-isostatic adjustment (land movement after the weight of a glacial mass is removed), or groundwater extraction, must also be factored in to understand relative sea level, or the level of the sea relative to the land, and vulnerabilities at the community scale. In Washington State in particular, vertical land movement due to tectonic forces and glacio-isostatic adjustment can vary dramatically over very short distances. If the land is subsiding, that increases the relative rate of sea level rise, and conversely if the land is rising, that lowers the relative rate of sea level rise.

This section describes an approach for projecting future sea levels for communities on the Strait of Juan de Fuca that combines probabilistic sea level rise projections for the Strait of Juan de Fuca with high-resolution estimates of vertical land movement and observed patterns of coastal flooding. These projections *are not predictions* to predict a specific water level at a given date, instead these projections display a range of probabilities of potential sea level rise and storm surge elevations, allowing a reader to choose which probability of occurrence they would like to plan for. We start by describing the “base” sea level rise projections (these are also known as “eustatic” projections, and describe the level of the ocean irrespective of movements of the land), then describe our approach for estimating vertical land movement on the Strait of Juan de Fuca, incorporate those vertical land movement estimates into the “base” sea level projections, and finally outline how we estimate and incorporate coastal flooding risk.

For more information on; using these sea level rise projections with the NOAA Sea Level Rise Viewer, comparison of these projections to other published sea level rise projections, description of observed eustatic sea level for the Strait of Juan de Fuca, the complexities of sea level rise and bluff erosion, and instructions on locating the Mean Higher High Water contour, see **Appendix D: Sea Level Rise Analysis Details.**

Base sea level rise projections

The “base” sea level projections for the Strait of Juan de Fuca used in this assessment were derived from Kopp and others (2014)[78], who developed a probabilistic approach for projecting sea level at sites around the world by combining full probability distributions of the primary constituents of global sea level rise (Figure 15) with local sea level data derived from tide gauges. The advantage of a probabilistic approach is that it better communicates the inherent uncertainties in sea level rise projections while also enhancing a community’s ability to be selective about risk tolerance for different applications. For example, when designing and siting a critical facility, such as a hospital or wastewater treatment plan, it likely makes sense to plan for a lower probability upper range sea level rise projection because the potential consequence of inundation would be costly. Additionally, probabilistic projections allow a user to potentially incorporate emerging research on sea level and effectively account for uncertainties in projections that are the result of an incomplete understanding of sea level processes. For example, recent publications[79] suggest that ice loss from Antarctica may be under-represented in current projections; a user could take this into account by using a lower probability sea level rise projection (i.e. 1% or 5% probability).

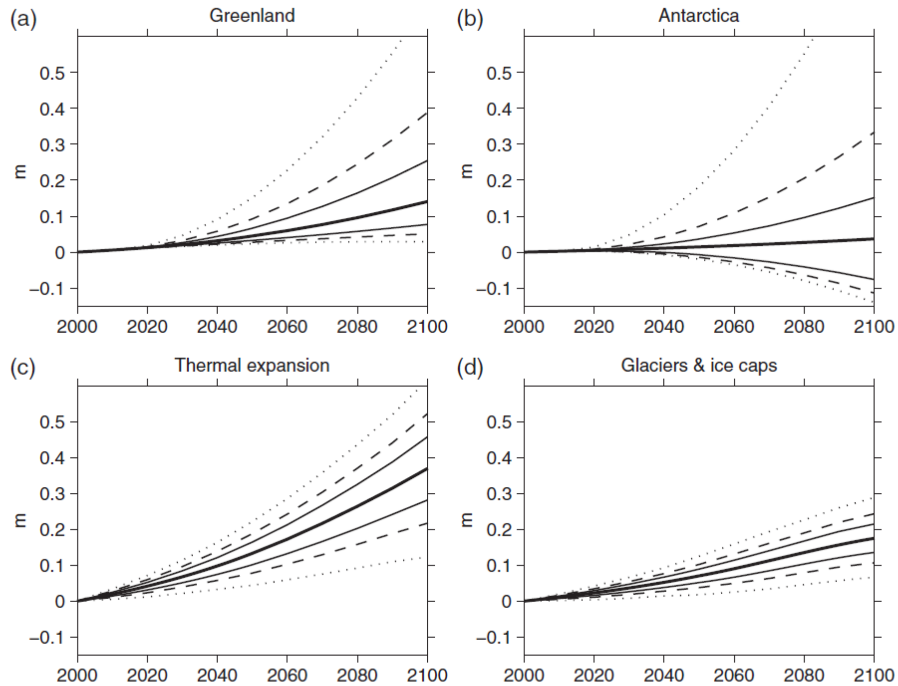


Figure 15: Projections of cumulative contribution of (a) the Greenland ice sheet, (b) the Antarctic ice sheet, (c) thermal expansion, and (d) glaciers to global sea-level rise under RCP 8.5[80]. Heavy line=median, light line = 67% range, dashed = 5th-95th percentile; dotted = 0.5th-99.5th percentiles. X-axis units are in Meters (M), and 0.1M = approximately 4".

The "base" sea level rise projections for the Strait of Juan de Fuca (**Figure 16**) were obtained from the "LocalizeSL" package[81] for the software Matlab provided as part of the supplementary material of Kopp and others (2014). These sea level rise projections take into account both the processes that drive global sea level, as well as the processes that can modify sea level patterns at a regional scale.

As has been described, RCP 8.5 represents a higher-emissions, "business as usual" scenario for the remainder of the 21st century and is similar to the A1FI scenario used in the IPCC's 4th Assessment report (Note: The A1F1 scenario was the upper-range scenario used in the National Academy of Science's 2012 report titled, "Sea-Level Rise for the Coasts of California, Oregon and Washington: Past Present and Future"). For this analysis, the RCP 8.5 scenario was selected as the most appropriate scenario for planning purposes, since global sea level rise as measured by satellite altimetry is currently most closely tracking sea level rise projections associated with upper-range emissions scenario[82].

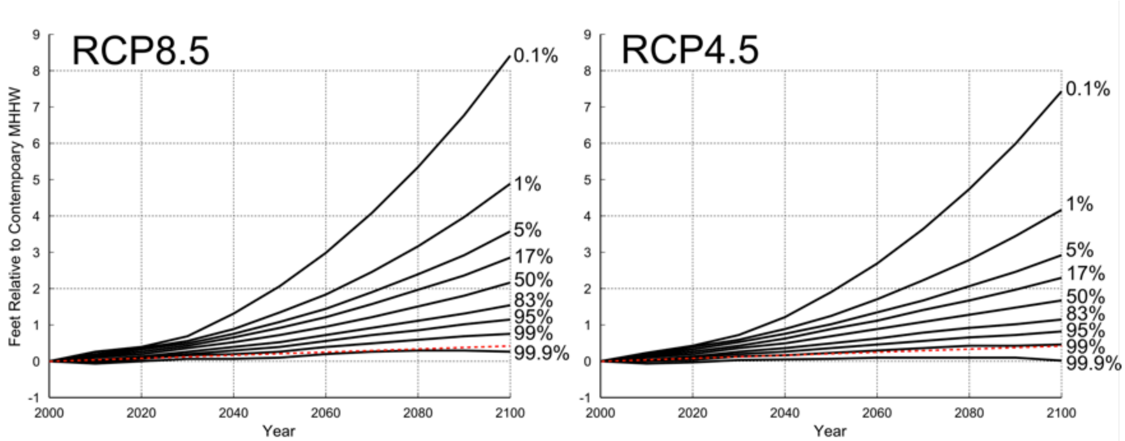


Figure 16: Probabilistic "base" (eustatic, or irrespective of the vertical movement of the land) sea level projections (in feet) through 2100 for RCP 4.5 and RCP 8.5 for the Strait of Juan de Fuca, Washington, based on Kopp and others (2014)[83]. These projections are expressed as the probability (in percent) that sea level will be at or above a particular elevation relative to the contemporary Mean Higher High Water (MHHW). As an example, there is a 50% chance sea levels will rise >2ft by 2100 under a "business as usual" emissions scenario (RCP8.5). For comparison, the *overall* estimate of the 20th century eustatic sea level trend in the Strait of Juan de Fuca (~4 inches per century) is shown as a dashed red line

Estimating vertical land movement

Vertical land movement along the Strait of Juan de Fuca was estimated by differencing monthly sea level data[84] from National Oceanic and Atmospheric Association (NOAA) water level monitoring stations in Neah Bay, Port Angeles, Port Townsend, and Seattle against water level measured at a nearby "reference" station in Friday Harbor, Washington.

The differencing technique subtracts monthly water level records from two tide-stations against each other, and attributes any resulting trend in the residual to different rates of vertical movement between the two stations. An example is shown in Figure 17 below. The monthly sea level from Friday Harbor is differenced against the record from Port Townsend (see map in Figure 18). The trend over time in the difference between the two stations can be attributed to differences in the rate of vertical movement between the two stations. In this example Port Townsend is "subsiding", or moving downward relative to Friday Harbor, at a rate of 0.67 millimeters/year (about 3 inches/century; Figure 17). Note, that this tells us nothing about how Friday Harbor is moving. Rather, differencing provides an accurate way to estimate the *relative movement* of tide stations against each other.

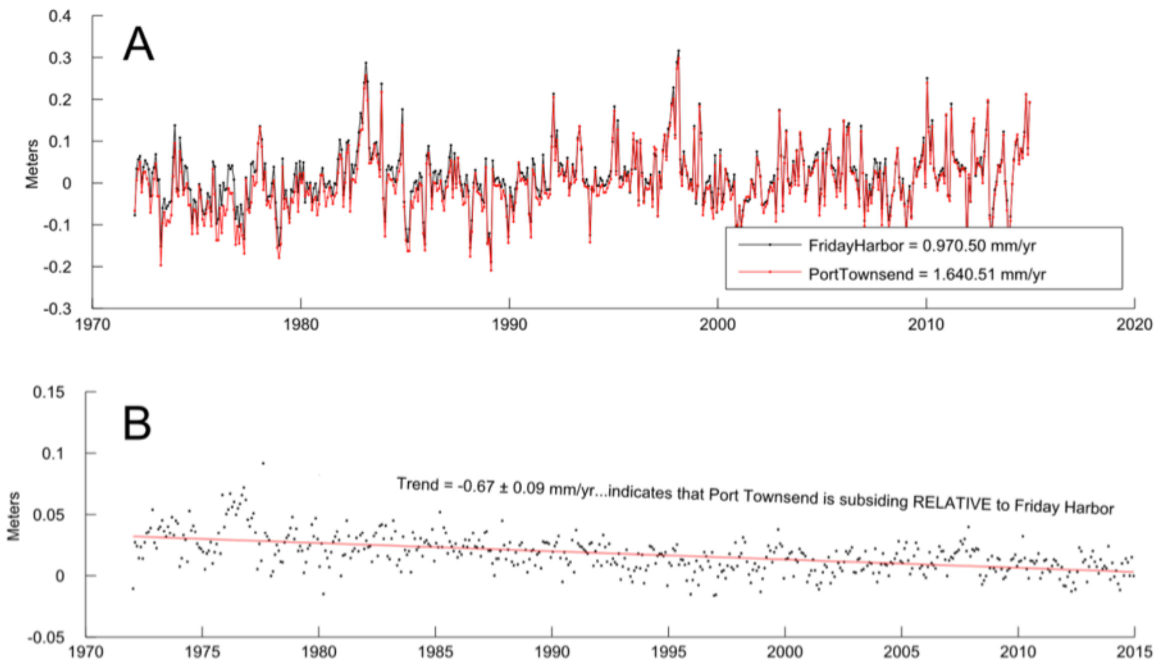


Figure 17: A differencing example, using water level records from Friday Harbor and Port Townsend, Washington (Panel A, at top). The trend in the difference between the two (Panel B, at bottom) can be used as an estimate of the relative vertical movement of one station against another. X-axis units are in Meters (M), and 0.1M = approximately 4".

To tie these relative vertical land movement estimates into an "absolute", or geocentric, reference frame, we used a continuous global positioning system (GPS) station located less than 1 km from the tide gauge in Friday Harbor[85]. Continuous GPS stations are fixed in place, and continuously collect location data that over years to decades, can provide estimates of the long-term average rate of movement of the Earth's crust. The vertical land movement estimate from the station (#SC02) in Friday Harbor, WA (-0.13 ± 0.19 mm/yr) is applied to the relative estimate between the stations to estimate the vertical land movement, in an absolute reference frame, at each station (Table 3).

Table 3: Relative vertical land movement estimates for tide stations (along with confidence limits at the 95% level) along or near the Strait of Juan de Fuca derived from differencing monthly water level estimates. The relative estimates are tied to an absolute reference frame using a continuous GPS station (SCO2) near the tide station in Friday Harbor, WA and units are millimeters (mm) per year (yr). 25mm = approximately 1 inch.

Station	**Relative Vertical Land Movement** (in millimeters per year **with** ± confidence limits)	**Absolute Vertical Land Movement** (in millimeters per year **with** ± confidence limits)
Friday Harbor	NA	-0.13 ± 0.19 mm/yr
Seattle	-1.04 ± 0.04 mm/yr	-1.17 ± 0.16 mm/yr
Port Townsend	-0.67 ± 0.09 mm/yr	-0.80 ± 0.18 mm/yr
Port Angeles	1.06 ± 0.13 mm/yr	0.93 ± 0.20 mm/yr
Neah Bay	2.76 ± 0.07 mm/yr	2.63 ± 0.17 mm/yr

The absolute vertical land movement estimates for each tide gauge are shown in Figure 18 below, along with vertical velocity estimates for a series of continuous GPS stations scattered throughout the region of interest[86].

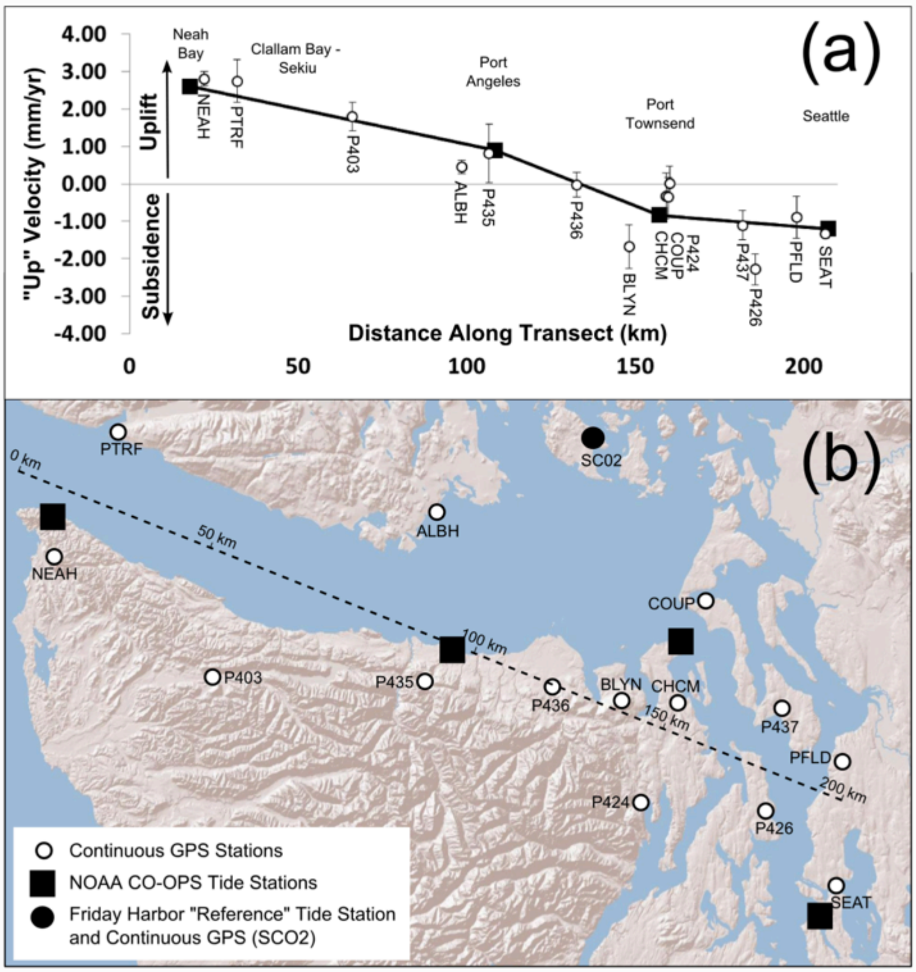


Figure 18: Vertical land movement estimates, in millimeters per year, for both tide gauges (black boxes) and continuous GPS stations (open circles) are expressed along an east-west transect through the Strait of Juan de Fuca (panel a). The same stations locations are shown graphically in the map (panel b). The relative reference station at Friday Harbor is shown as a filled circle. 25mm = approximately 1 inch.

Incorporating an Estimate of Storm Impacts

The visualization of a changing mean sea level across the landscape due to sea level rise is a useful tool for estimating the possible systematic and long-term impacts of sea-level rise, and also for estimating shoreline areas that may be particularly susceptible to erosion. However, similar to changing temperature and precipitation patterns, it is not necessarily the changes in the average condition that will first impact communities, ecosystems, and resources. Rather, it is changes in the frequency or magnitude of extreme events. For sea level, it is important to take into consideration annual flood events, in which water levels rise above the "average" high water line (here we use the contemporary MHHW elevation) resulting in intermittent flooding in the coastal zone. MHHW stands for Mean Higher High Water, which is a historical measurement of the average height of the highest tide at a given location. In coastal Washington, these events are typically associated with low atmospheric pressure, and sometimes wind-driven waves or water “pile-up”, happening concurrently with a high tide. Annual storms bring with them water levels that can be greater than three feet higher than the predicted tidal water level (this is often referred to as “storm surge”). Therefore, there is value in coupling sea level rise projections with estimates of the probability that storm surge will intermittently impact infrastructure or resources.

For this assessment the entire water level record from the tide gauge placed in Neah Bay (1934-2014), Port Angeles (1975-2014) and Port Townsend (1972-2014) was analyzed to identify the highest water level in each year on record relative to the local MHHW level. The relatively short water level records available from each community present a problem. They make it difficult to be sure that *measured* water levels over the available record represent the full range of possible water levels. To address this problem, the distribution of the annual high water level was fit with a Generalized Extreme Value distribution model, which has been shown to be the best distribution for extreme water level distributions[87], and is also used by NOAA for estimating extreme water level probabilities. An example, from Neah Bay, is shown in Figure 19.

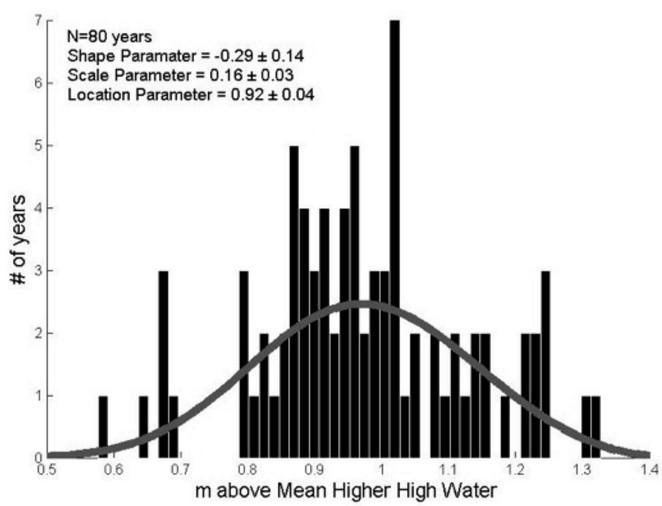


Figure 19: The annual extreme high water distribution for the 80-year water level record from Neah Bay, Washington (in meters above contemporary MHHW). The General Extreme Value distribution model is shown, with the model parameters. X-axis units are in Meters (M), and 0.1M = 4”.

Due to their short water level records (< 45 years in both cases), the extreme annual water levels for Port Angeles and Port Townsend could not be reliably used to estimate the general extreme value distribution. Therefore, we examined water level data from nearby stations with a longer water level record (Friday Harbor and Seattle) to determine if either displayed similar annual extreme water level patterns. Based on this analysis, the water level record from Friday Harbor was used to create an extreme annual water level model for Port Angeles and Port Townsend.

The extreme annual water level model developed for each community, which represents an estimated probability that water level will reach a certain elevation above

MHHW at least once in a year, allowed us to directly combine the probabilistic sea level rise projections with the extreme water level probabilities. The output (Table 4 right column) is useful, since it represents the probability, combining the uncertainties associated with both sea level rise projections and the variability in the annual flood risk, that water will reach a particular elevation above the contemporary MHHW between 2000 and 2100. Data from Climate Central's Surging Sea's database[88] suggests that the combination of sea level rise and annual coastal flooding will result in increased impacts to valuable property in Clallam and Jefferson Counties in the coming decades (see Figure 20).

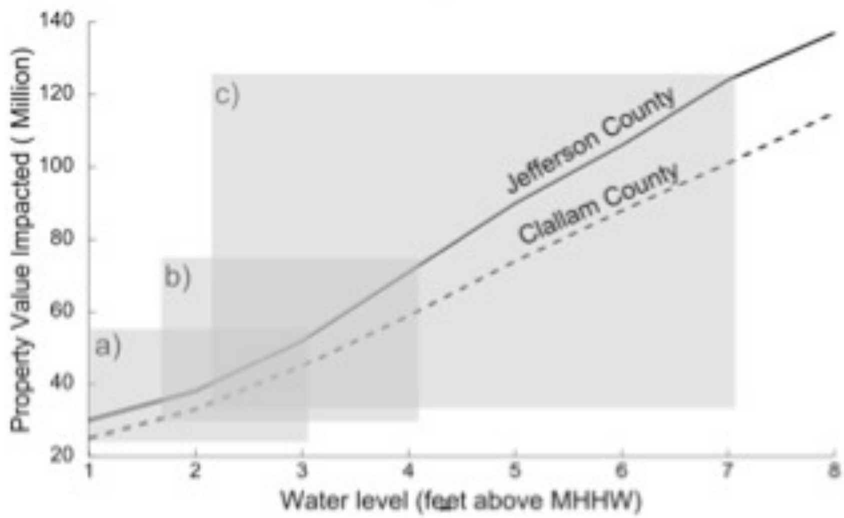


Figure 20: Property value (in millions of dollars) exposed to combined sea level rise and coastal flooding a) currently, b) in 2050 and c) in 2100 in Clallam and Jefferson counties[89].

"Localized" relative sea level projections

Relative sea level rise projections were derived for each community in the study area by applying their absolute rate of vertical land movement (Figure 18) to the "base" sea level projections for RCP 8.5 (Figure 16). For this assessment, we selected a range of probability levels, and provide the resulting sea level rise projections, relative to the current (1983-2001 epoch) Mean Higher High Water (MHHW) tidal datum for Neah Bay, Port Angeles and Port Townsend in Table 4 below. A set of maps using these probabilities are shown in Figures 21, 22, 23, 24, & 25 with the full set of maps created for this project available in **Appendix C.**

Table 4: Relative sea level (third column) and annual extreme coastal flood projections (right column, which includes sea level rise) for the coastal communities of the Strait of Juan de Fuca relative to the contemporary Mean Higher High Water (MHHW) tidal datum. The third column of the table provides the probability (in percent) that mean sea level will be at or above a certain elevation (in feet) above contemporary MHHW by 2030, 2050 or 2100. The right column of the table provides the probability in a given year that the largest single coastal flooding event will reach a given elevation (in feet) above the contemporary MHHW. This column reflects how storm surge amounts vary at locations across the peninsula.

Location	Probability	…that mean sea level will reach or exceed ___ ft relative to current MHHW…			…and that the annual extreme coastal flood will reach ____ ft relative to current MHHW			
		2030	*2050*	*2100*	*Current*	*2030*	*2050*	*2100*
Neah Bay and Clallam Bay-Sekiu	99%	-0.1	-0.2	-0.1	2.0	2.1	2.2	2.6
	95%	-0.1	-0.0	0.3	2.4	2.4	2.6	3.1
	83%	0.0	0.1	0.7	2.7	2.9	3.0	3.7
	75%	0.0	0.2	0.9	2.8	2.9	3.1	3.9
	50%	0.1	0.3	1.3	3.2	3.3	3.5	4.5
	25%	0.1	0.5	1.8	3.6	3.6	3.9	5.1
	17%	0.2	0.5	2.0	3.7	3.8	4.0	5.4
	5%	0.2	0.7	2.7	4.1	4.1	4.4	6.2
	1%	0.3	0.9	4.0	4.3	4.4	4.8	7.5
Port Angeles	99%	0.1	0.1	0.5	1.1	1.4	1.6	2.2
	95%	0.1	0.2	0.9	1.4	1.6	1.9	2.7
	83%	0.2	0.4	1.2	1.6	1.9	2.2	3.2
	75%	0.2	0.4	1.4	1.8	2.0	2.3	3.4
	50%	0.3	0.6	1.9	2.1	2.3	2.6	3.9
	25%	0.3	0.7	2.3	2.4	2.6	3.0	4.5
	17%	0.3	0.8	2.6	2.5	2.8	3.2	4.8
	5%	0.4	0.9	3.3	2.8	3.1	3.5	5.5
	1%	0.5	1.2	4.6	3.1	3.4	3.9	6.8
Port Townsend	99%	0.2	0.4	1.0	1.1	1.5	1.9	2.8
	95%	0.3	0.5	1.4	1.3	1.8	2.2	3.3
	83%	0.3	0.7	1.8	1.6	2.1	2.5	3.8
	75%	0.4	0.7	2.0	1.8	2.2	2.6	4.0
	50%	0.4	0.9	2.4	2.1	2.5	2.9	4.5
	25%	0.5	1.0	2.9	2.4	2.8	3.3	5.1
	17%	0.5	1.1	3.1	2.5	2.9	3.5	5.3
	5%	0.6	1.2	3.9	2.8	3.3	3.8	6.1
	1%	0.6	1.5	5.2	3.1	3.6	4.1	7.3

The figures below show examples of the probabilistic sea level rise and coastal flood risk maps created for five locations: Port Townsend, Port Angeles, Clallam Bay/Sekiu, Neah Bay, and the Dungeness River Delta, using 2050 as the example time horizon. The full set of maps and additional details on how they were created are included in **Appendix C & D.**

Figure 21: Probabilistic sea level rise/coastal flood risk map for Port Townsend, WA for 2050.

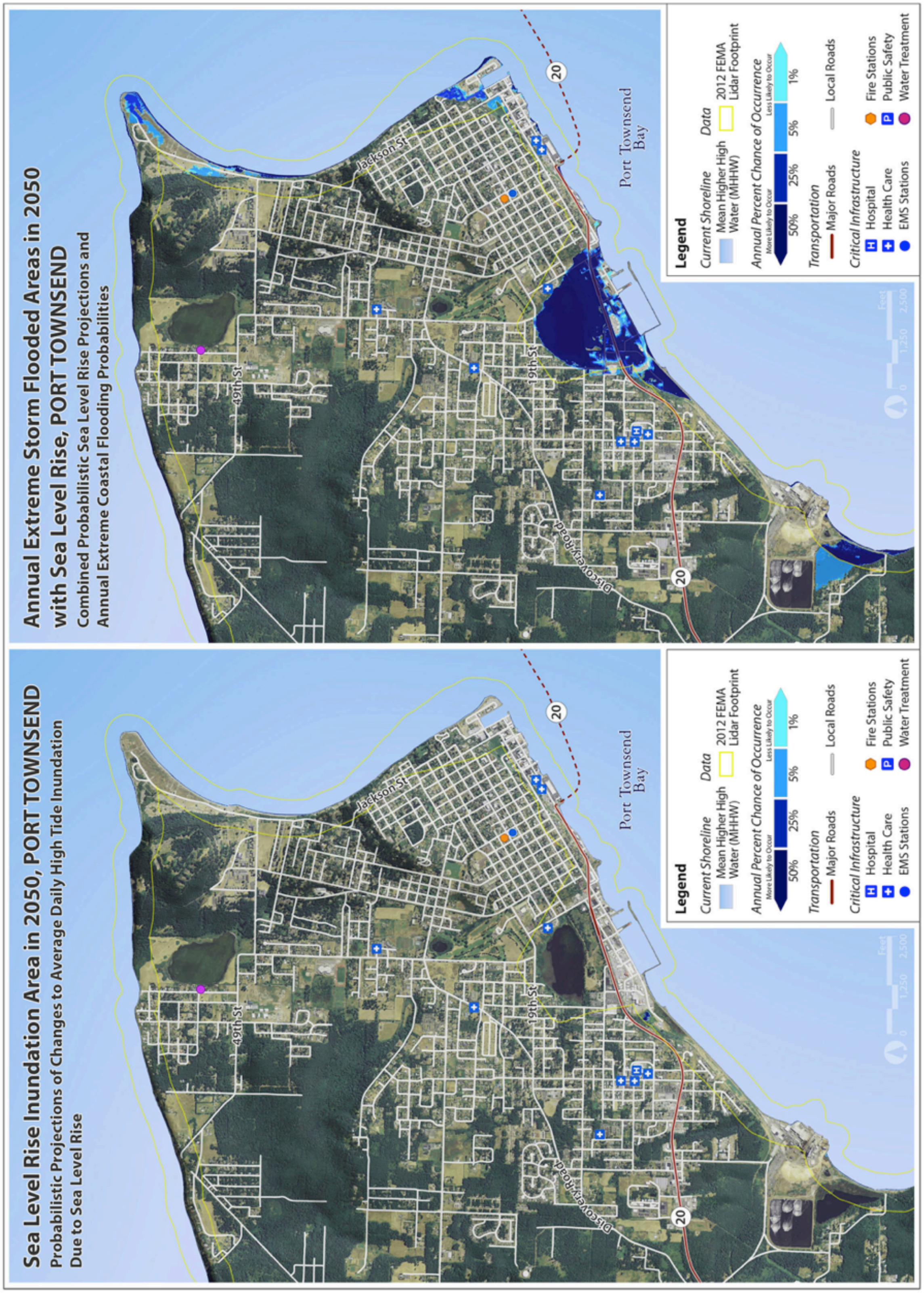


Figure 22: Probabilistic sea level rise/coastal flood risk map for Port Angeles, WA for 2050.

Figure 23: Probabilistic sea level rise/coastal flood risk map for Neah Bay, WA for 2050

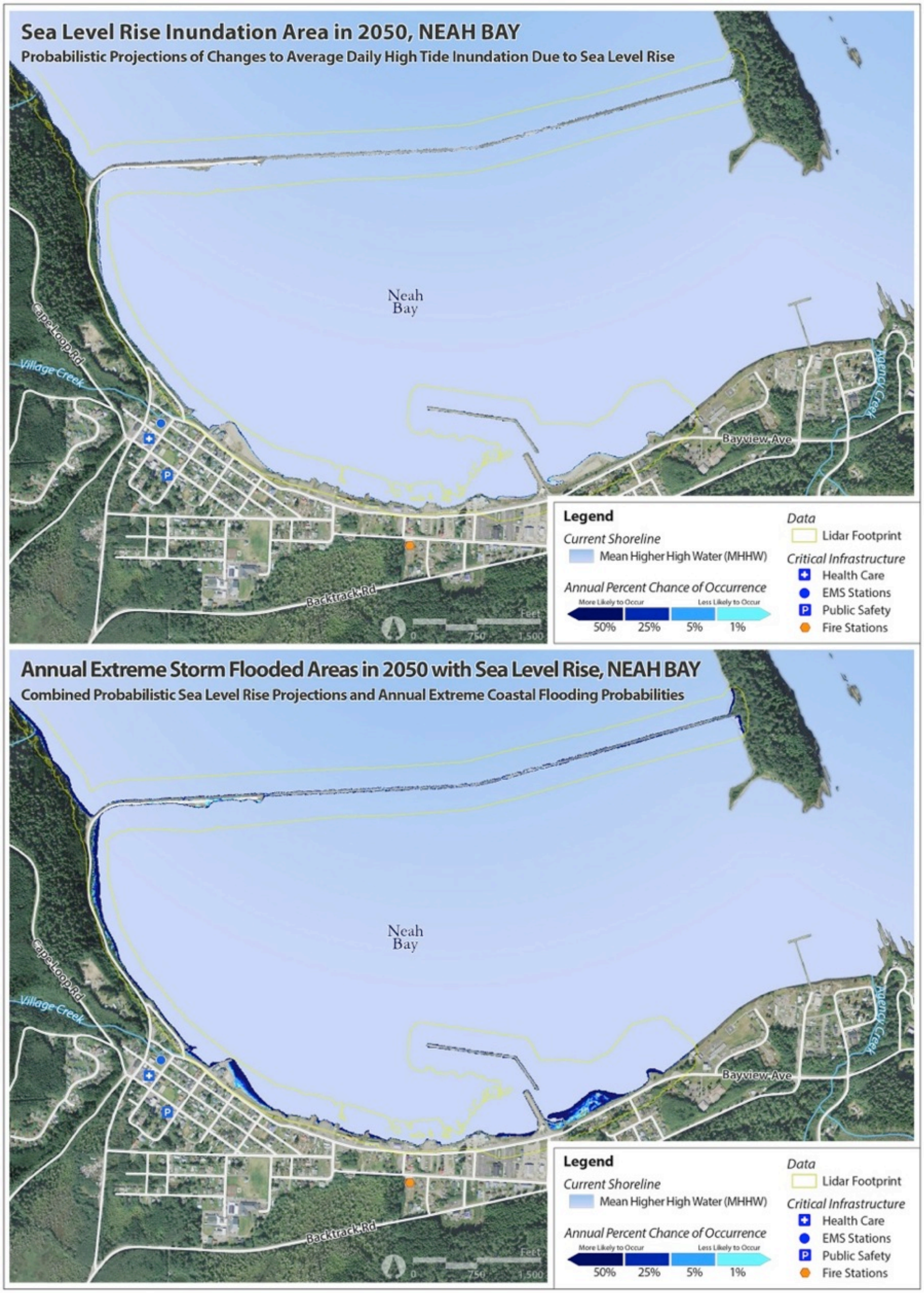


Figure 24: Probabilistic sea level rise/coastal flood risk map for Clallam Bay and Sekiu, WA for 2050

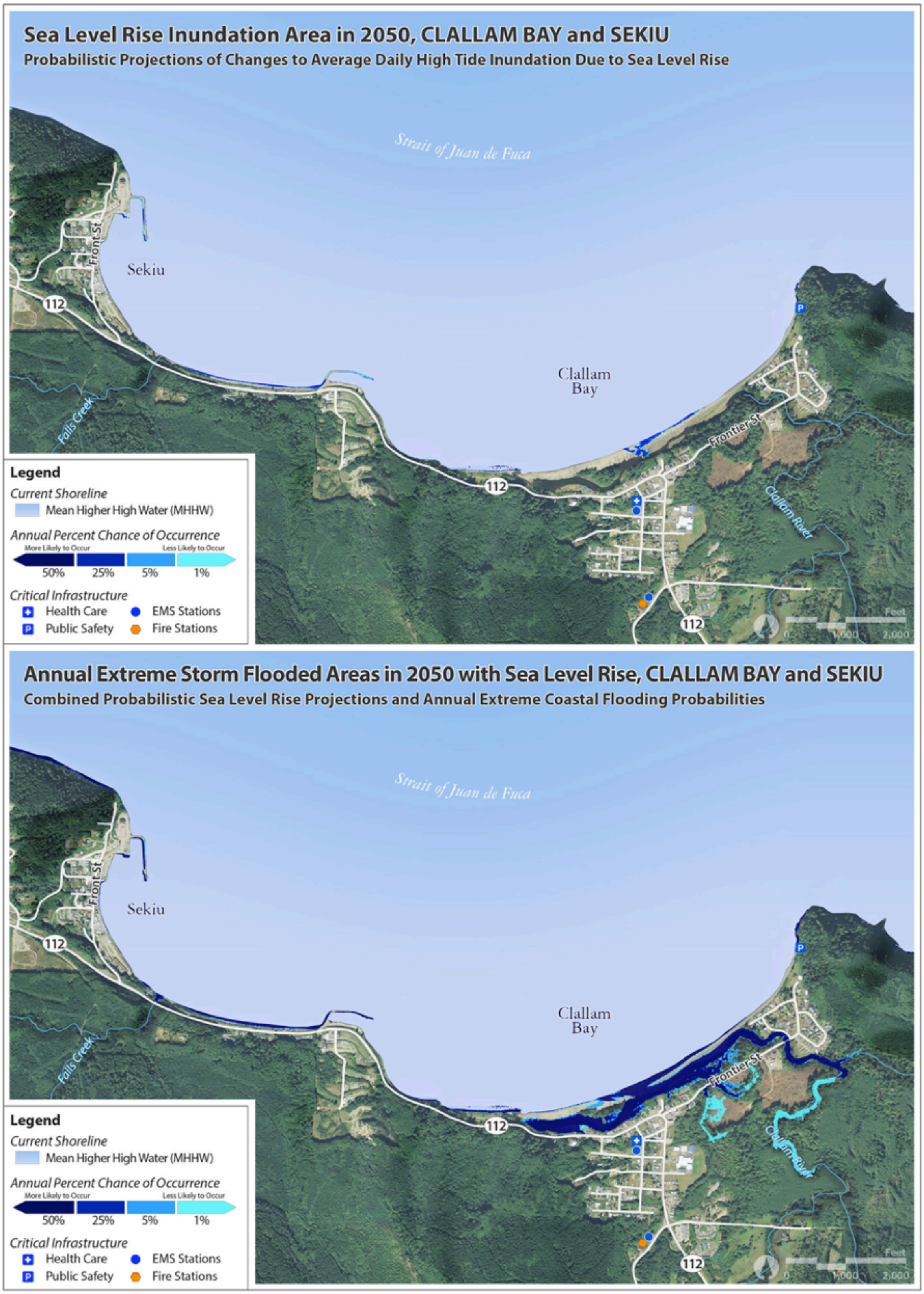
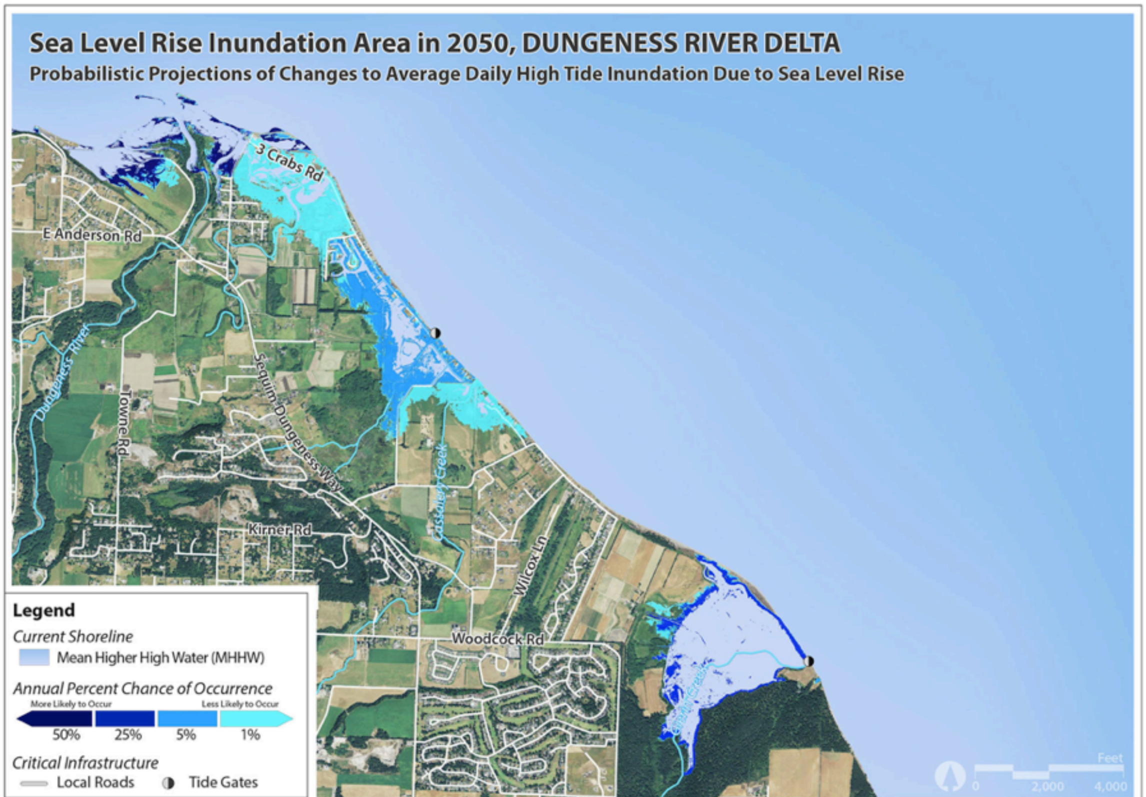
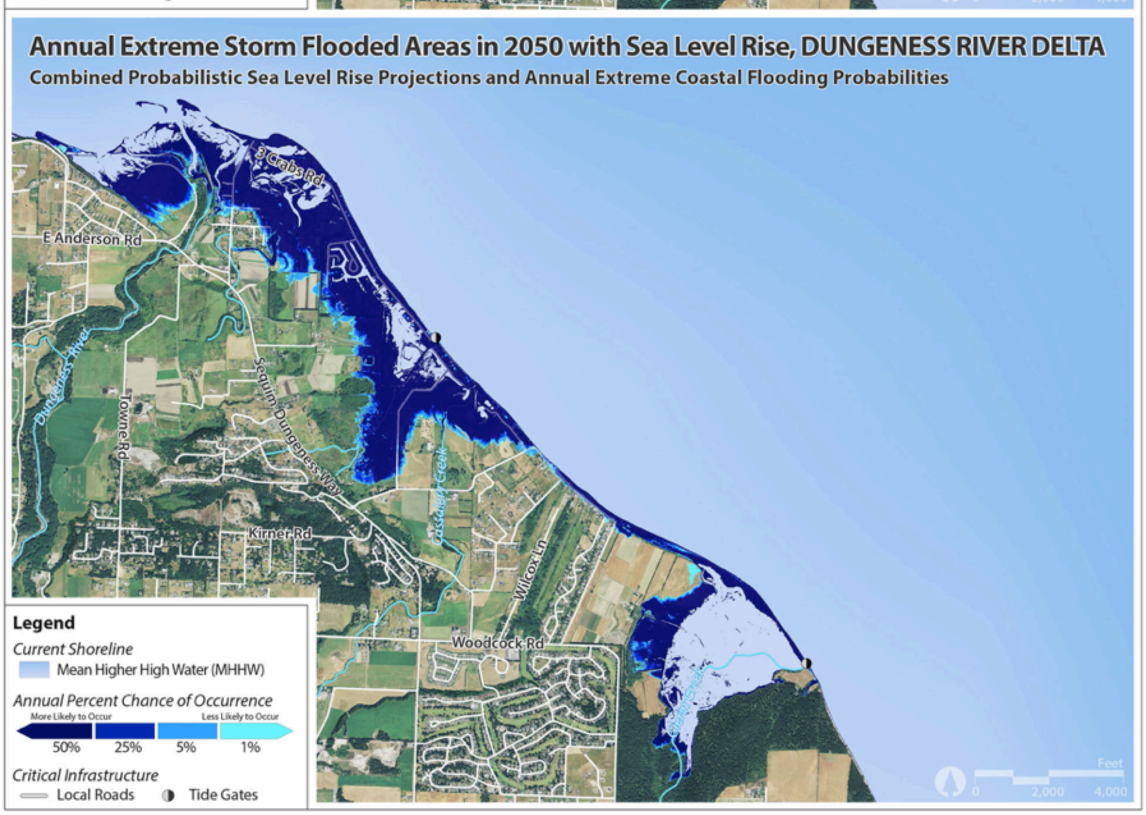


Figure 25: Probabilistic sea level rise/coastal flood risk map for Dungeness River Delta, WA for 2050





The maps above are just one representative timeframe of the three timeframe maps (2030, 2050, 2100) developed for the project. The full set of maps for all time periods and for the five key geographic focus areas of the project area are available in **Appendix C**.

Limitations of this sea level rise projection approach

There are a few important limitations to the sea level rise and coastal flooding approach used in this assessment. First, our method does not take into account any changes to the shoreline (i.e. erosion or accretion) that might be brought about by sea level change[90]. Also, this method doesn't take into account that local storm impacts, particularly wind-driven water pile-up or waves, may act to drive water higher on the shoreline than is projected here, or directly impact infrastructure

Next, we assume that the contemporary annual extreme water level patterns used in this study to incorporate the annual maximum flood risk will remain unchanged over the next century. Climate change, however, may alter patterns of storminess in the North Pacific Ocean that could lead to changes in the probabilities associated with the annual maximum coastal water level.

Additionally, seismic activity, which could dramatically change the observed patterns of vertical land movement instantaneously, is not taken into account here. Some earthquake models suggest, for example, that Neah Bay may subside dramatically during a large Cascadia Subduction zone earthquake, which would negate the contemporary uplift occurring there.

Finally, the approach used here to map both sea level rise and coastal flooding is an elevation-based "bath-tub" approach, and does not take into account either the momentum in storm surges that can change flooding patterns relative to what is shown in the maps provided here, or structures on shorelines (i.e. tide-gates, seawalls, soft armoring) that can modify flooding in low-lying areas. As a result, the projections and maps provided here should be carefully considered in light of local knowledge of the shoreline. Despite these limitations, these projections should provide a useful tool for identifying vulnerable areas. Since the projections provided here are probabilistic, they inherently provide an estimate of the uncertainty associated with future sea level, and allow a community or end-user to select a level of risk appropriate for a particular activity or development near the coast.

Sea Surface Temperature Increases

Ocean water temperature is also expected to increase due to climate change. Ocean water temperature in the Pacific Northwest, especially at the ocean's surface, is highly variable, making it difficult to detect a long-term warming trend in historical ocean temperature in the Pacific Northwest. Some warming has been detected for the Strait of Georgia and off the coast of Vancouver Island, but no long-term warming trend has been detected along the Pacific Coast of North America[91]. However, ocean models suggest that sea surface temperature in the Pacific Northwest could rise by 2.2° F by the middle of the century (Figure 26).

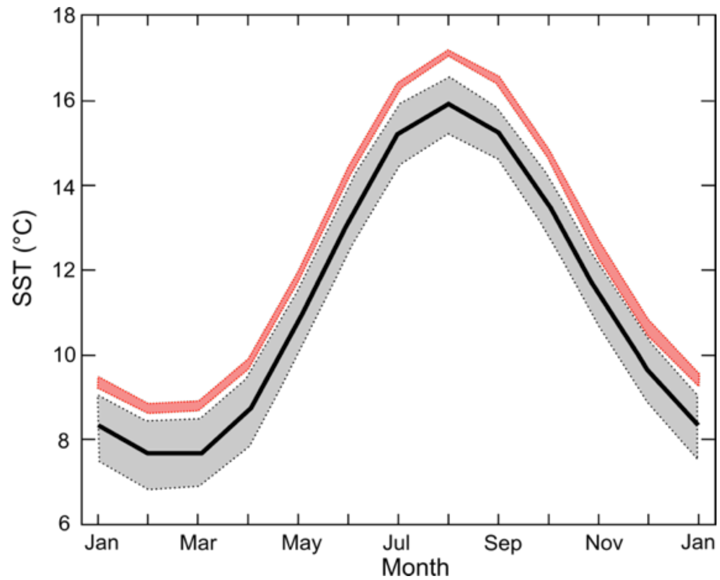


Figure 26: Current and projected sea surface temperature. This figure depicts the annual cycle of sea surface temperature for the coastal waters of the Pacific Northwest for 1970-1999 (black line is the average and gray shading is the range). The months are shown along the horizontal axis (x-axis) and the average sea surface temperature is shown along the vertical axis (y-axis in °C). The projected 2.2°F (1.2°C) increase in sea surface temperature by the middle of the century (2030-2059) is shown by the red line[92]. This projection is a combined reflection of three emissions scenarios: A2, A1B, B1. See Figure 3 for comparison with other models.

The approximately 2.2°F increase in sea surface temperatures in Pacific Northwest coastal waters projected by mid-century is expected to directly and indirectly impact the growth and survival of many marine and anadromous species. Persistent warm sea surface temperatures (2°F to 7°F above normal) in the Northeast pacific have been observed over the last two years in a mass of water 1,000 miles wide and 300 feet deep, labeled "the blob". The blob has been identified as a culprit behind Washington's mild 2014 winter and hot 2015 summer, and influenced fish sightings in unusual locations and disruptions to the marine food web by warm, diminished-nutrient waters[93].

Ocean Acidification

An observed climate change impact to the marine and coastal waters of the North Olympic Peninsula is the increasing acidity of ocean waters. Oceans have absorbed about one quarter of human-produced CO_2 emissions in the last two centuries[94], a process that drives ocean acidification. There is a direct correlation between increasing atmospheric CO_2 since 1958 and decreasing pH (increasing acidity) of ocean waters[95]. This acidification has a variety of chemical consequences that lead ultimately to a reduced availability of carbonate ions (CO_3^-) in seawater, one of the structural building blocks for organisms that utilize calcium carbonate ($CaCO_3$) to build and maintain their shells.

There has been some work done looking specifically at the pH of ocean water and the impacts in the Strait of Juan de Fuca. The corrosiveness of ocean waters are not only dependent on the pH (or acidity) of the ocean, but also on the aragonite saturation, which determines how easy or hard it is for the marine organisms to access the calcium carbonate in the ocean water.

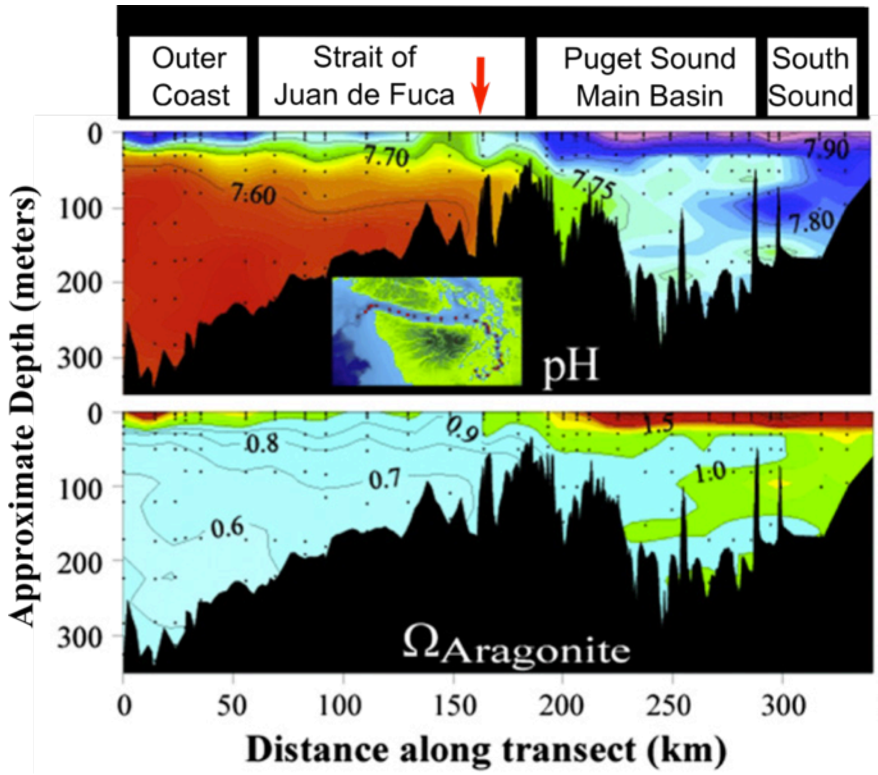


Figure 27: Measurements of pH and aragonite saturation along the coast of Washington. A scientific cruise measured pH and Ω aragonite of seawater from the outer coast to south Puget Sound. The route of the cruise is shown in the inset box (upper panel). Red arrow marks the location of the sampling site near to the Sequim Bay area. Red areas in upper panel represent low pH and higher acidity waters. Ω aragonite (lower panel) is a measure of the availability of calcium carbonate to many marine organisms. In general, levels below 1 (light blue bottom panel) are corrosive and may make it difficult for some marine organisms to build shells[96]. X-axis units are in Meters (M), and 0.1M = approximately 4".

The small marine species that are most likely to be affected by ocean acidification form the foundation of many food webs of salmon and other marine species important to the life, culture, and economy of the North Olympic Peninsula. Looking into the regional ocean acidification risk in 2012[97], NOAA and University of Washington Scientists found that invertebrates exhibiting negative responses to acidification conditions include several of economic and cultural importance to the region, such as oysters, clams, and mussels; these are most susceptible during their larval stage of development. Other species such as fish and phytoplankton show their own unique negative response to acidification, bringing to light the impact ocean acidification has on the entire food web. The scientists also found that higher seawater temperatures exacerbated the negative effects of acidification.

Changes to Wind Patterns and Intensity

The direction and intensity of wind is a potentially important aspect of changing ocean conditions. Wind direction and magnitude directly influence wave direction and height, and can also "pile" water against the coastline. Both processes exacerbate coastal erosion and increasing inundation during storm events[98].

Determining and projecting changes to wind patterns is complicated and not something that climate models can currently incorporate effectively. The recent study by the Olympic Coast Natural Marine Sanctuary concluded that model results: *"…tentatively suggest that the magnitude and frequency of storms in the north east Pacific may increase by 2100*[99]*."* And, that debate remains around a tentative finding that *"observational evidence generally suggests increasing mean wind speed and wave height"* along the outer coast over the past 50 years.

The Climate Change in the Pacific Northwest report found that: *"…climate change driven shifts in storms or ENSO [El Niño decadal patterns] characteristics in the Northwest is not yet discernible in the observational record or in model projections*[100]*."* There has been some work looking at climate change impacts on wind patterns in conjunction with coastal upwelling. There are high amounts of variability in the timing and intensity of upwelling winds, and significant correlations with decadal-scale variability (like the Pacific Decadal Oscillation). Wind time series used to detect historical changes in alongshore winds (the ones that cause upwelling) are generally too short to be reliable[101]. Thus, at this point, there is too much natural variability in wind speeds and storm events to be able to make specific projections of future changes to the direction, intensity, or patterns of winds in the region.

II. Vulnerabilities and Adaptation Strategies for the North Olympic Peninsula

As described in Section I, this project directed a collaborative process to explore North Olympic Peninsula climate change vulnerabilities and relevant adaptation strategies in three key focus areas: **Ecosystems, Water Supplies, and Critical Infrastructure**. The result of that process for each of the focus areas is described in detail in the following sections.

A. Ecosystems

Jeff Taylor

Port Townsend Marine Science Center

Egan Snow-Google creative commons

Mark Smith-Google creative commons

<u>Ecosystem's Exposure to Climate Change</u>

The Ecosystems focus area concentrated on the topics of: **nearshore environment and watersheds; agriculture and forestry; and emerging risks.** In addition to the general trends in temperature, precipitation, and ocean conditions described earlier in this report, climate change impacts to ecosystems include increases in air and river water temperature and changing water availability in soils.

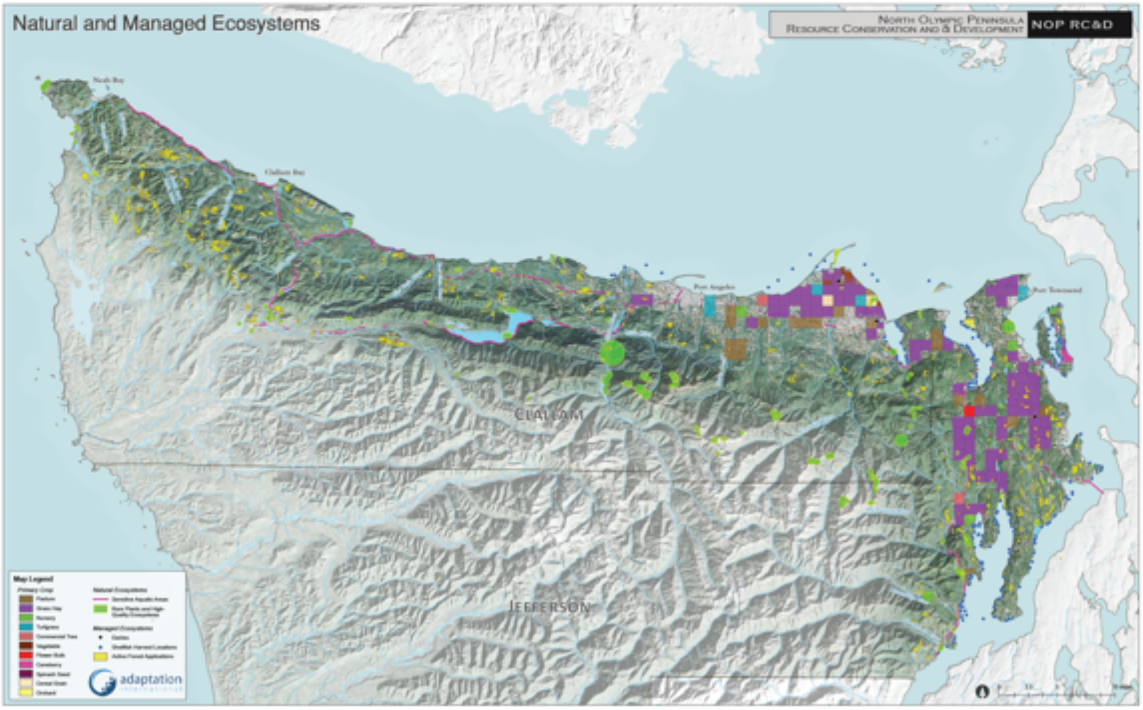


Figure 28: An overview of Ecosystems on the North Olympic Peninsula. Data layers include primary crop, shellfish harvest sites, sensitive aquatic sites, and rare plant locations. A larger version of this map is available in Appendix F

General increases in air temperatures will affect terrestrial species, shift habitats, and increase sea surface and river temperatures. Ecosystems and their species have developed to thrive and tolerate certain historical temperature and precipitation thresholds. Climate change conditions will likely alter or exceed these thresholds at a pace that restricts opportunity for effective natural adaptation. An inability to adapt will likely lead to similar outcomes as have been seen for sockeye salmon returning to the Columbia River in the summer of 2015, where a quarter million of the returning fish perished due to lethally high river water temperatures. Biologists linked the high river temperatures to low river flows (tied to a diminished snowpack) and extended high summer temperatures[102]. Figure 29 below shows projected changes to air and river temperatures and their relevance to the overall vitality of salmon species.

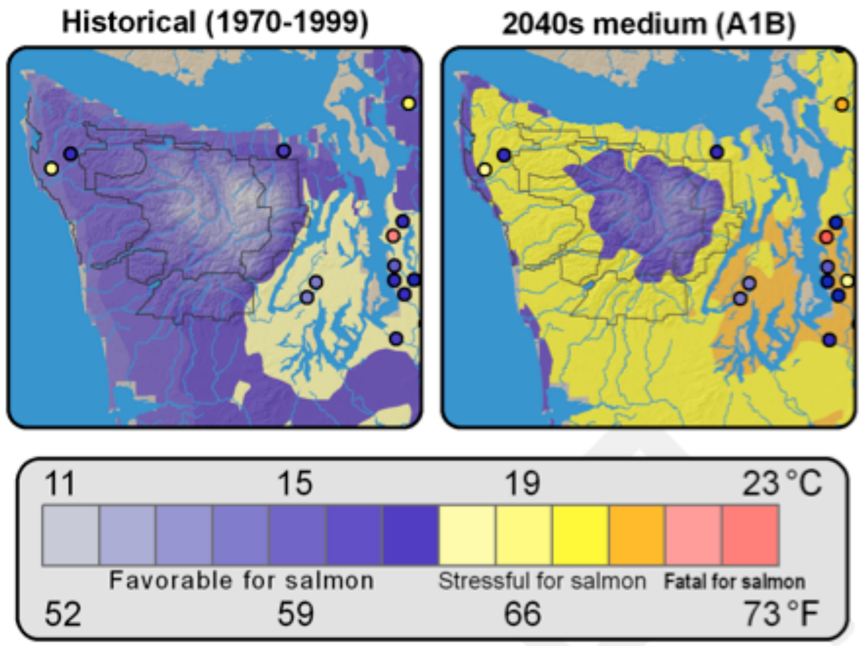


Figure 29: Current and projected air and river water temperatures[103]. Average weekly August air temp (shading) and river water temperatures (dots) for historic conditions, 1970-1999 (left panel) and future projections, 2040s (high emissions scenario – right panel). The Dungeness River (upper right quadrant) will likely remain cool (see blue dot in right panel) into mid-century, even as land temperatures increase, owing to steep gradient and snowmelt that supplies water to the river over the summer.

The shifts in timing and amounts of precipitation in the fall-winter months and the reduction in summer precipitation and river flows, coupled with higher summer temperatures, will reduce the amount of water stored in soils and therefore made available to forests, agriculture, and wildlife. Figure 30 and Figure 31 (below) show changes in projected soil water storage from now until the end of the century for Clallam County and Jefferson County. Both figures show the monthly average soil water storage for four time periods for the RCP 4.5 future emission scenario (reduced future GHG emissions) and RCP 8.5 scenario (continued levels of current GHG emissions) simulations. The average of 30 climate models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.

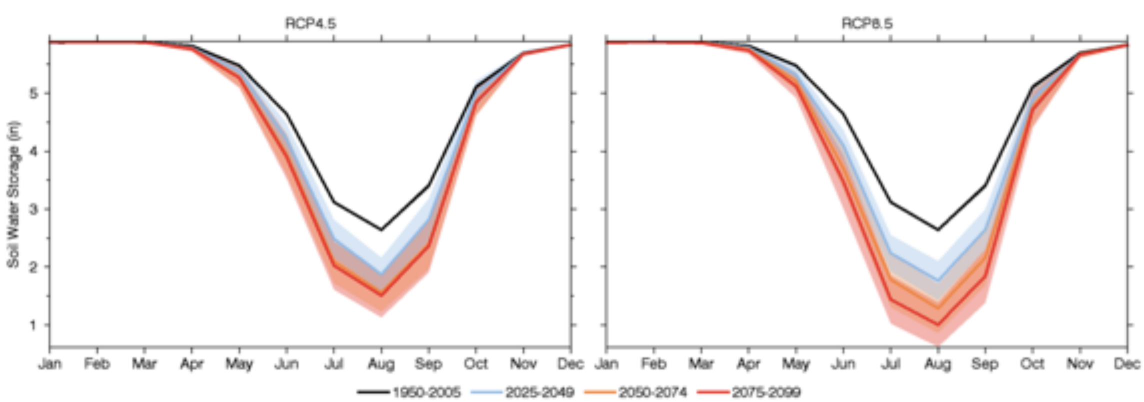


Figure 30: Projected changes to soil water storage in Clallam County[104]. Monthly averages of soil water storage for four time periods for the RCP4.5 and RCP 8.5 future emission scenarios.

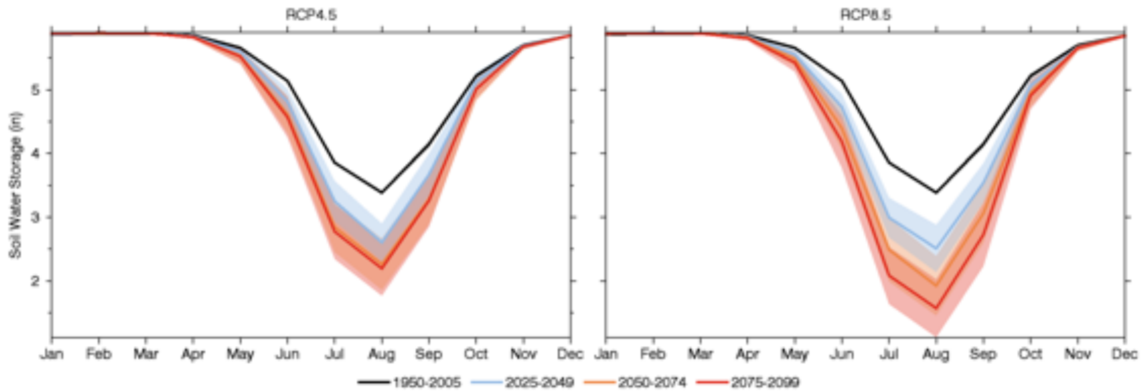


Figure 31: Projected changes to soil water storage in Jefferson County[105]. Monthly averages of soil water storage for four time periods for the RCP4.5 and RCP 8.5 future emission scenario.

Climate change impacts to agriculture in the region will vary greatly by type of agricultural commodity and the ultimate severity of climate change. The overarching relevant impacts of concern include: increases in mean summer temperatures, increases in mean cool-season temperatures, increases in length of growing season, increases in mean evapotranspiration, decreases in summer soil moisture, decreases in mean summer precipitation, reductions in summer/fall water availability due to decreases in snowpack, and increases in mean winter precipitation[106]. Figure 32 illustrates the connection between these impacts and particular portions of the agricultural sector for the Pacific Northwest.

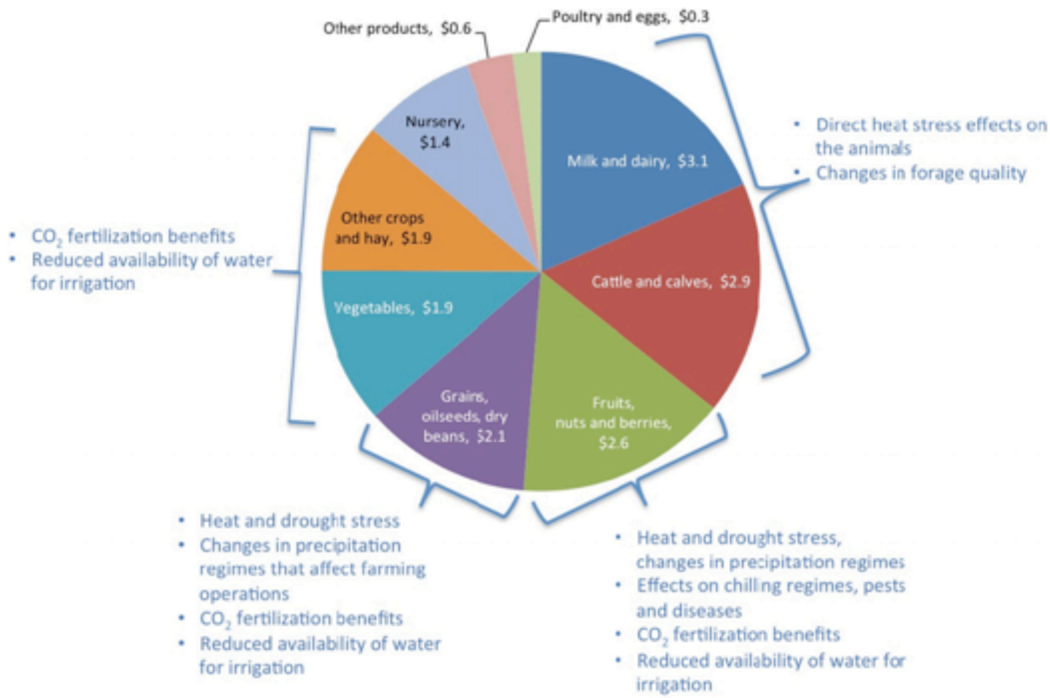


Figure 32: Pacific Northwest portions of the agricultural sector by market value ($billion) in 2007, alongside their sector specific potential climate change impacts[107].

Much like the plants and animals that make up the agricultural sector, natural and managed forest ecosystems will be vulnerable to the same suite of climate change impacts. These impacts are expected to substantially affect Pacific Northwest forest's "distribution, growth, and functioning"[108]. Generally, impacts include limited future sub-alpine forests, decreased water availability, changing growth patterns, increasing annual and extreme temperatures, altered carbon cycling, changing windows of opportunity for pine bark beetles and defoliating insects, and altered wildfire regimes[109].

While direct impacts on tree species and forests are important, the increasing risk of wildfire will likely be a bigger driver of change for Washington's forests[110]. The Olympic Mountains are generally wetter than other parts of the state and have been less prone to wildfires. However, it is expected that warmer summer temperatures, higher evaporation rates, and declines in soil moisture will increase wildfire risk on the Peninsula[111]. The fire season will also lengthen due primarily to earlier snowmelt. One set of projections expects a 150% - 1,000% increase in annual area burned in forests west of the Cascades by the end of the century[112]. When it comes to wildfire, the risk to property and people is determined primarily by the amount of development along the wildland/urban interface. In both Jefferson and Clallam County 24% of that interface is developed[113] and this includes 14,686 homes in Clallam County and 10,475 homes in Jefferson County (in 2013).

Current and Projected Impacts on Ecosystems

During the workshops there was rich discussion about the many ways that changing climate conditions will affect *Nearshore environment and watersheds; Agriculture and Forestry; and Emerging Risks* across the North Olympic Peninsula. A summary of the discussion for each area of concern evaluated during the workshop is available in **Supplementary Information D**. This section highlights some of the key information and themes from those discussions. **The information detailed in this section is the result of the collaborative workshops and reflects the knowledge of those who participated.**

Near-Shore Environments and Wetlands

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 (pg. 2).[114]"*

For this project, the nearshore environment includes all shorelines on the North Olympic Peninsula along the Strait of Juan de Fuca and along Hood canal to the Jefferson County line. **High Feeder Bluffs** along many sections of the nearshore are a complex and fundamental sediment source for the beaches, offshore substrate, and sandspits of the region, which provide ecologically important habitat[115]. 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[116].

Juvenile salmon have a critical 2-3 month survival period in the near-shore habitat, which can be impacted by temperatures, hypoxia, low oxygen and competition from other species. Areas adjacent to urban/residential/industrial development are subject to runoff from non-point source pollution, armoring for shoreline defense, and loss of riparian habitat. When it comes to **non-point source pollution,** material accumulates during the drier summer period and fall rains create large run-offs of contaminants. More intense fall storms may be large enough to liberate contaminants that previously were too heavy for transport (e.g. metals on roads).

Agriculture and Forestry

The agricultural sector in the region is valued for a number of reasons including: the desire to grow foods locally, the importance to the region historically, economic value, tourism opportunities, and the recreational landscapes it provides. An increase in atmospheric CO_2 levels, warmer temperatures, and longer growing seasons could be beneficial to **crops** and allow greater flexibility in crop selection. However, not all changes will be positive. Heat waves, intense rainfall or drought, and emerging pests and diseases may affect production. For instance, intense rainfall events can alter planting schedules and potentially increase root rot. Warmer temperatures lead to reduced winter pest kills and northern migration of pest species, as well as alteration in plant pathogen incidence and range. Livestock are also susceptible to heat stress and potential altered disease patterns under climate change.

The **Chimacum Valley** is Jefferson County's most productive farmland and highly valued for the community benefits it provides. The valley currently has very little water available for agriculture during the growing season, making it sensitive to drought and heat stress under climate change. Striking a balance between adequate water supply for both farmers and fish has been an ongoing challenge in the region.

The **Dungeness Valley** region has some of the finest agricultural soils in the region and water rights that support vibrant agriculture. These conditions also make the area attractive to development. The potential for increased development pressure and land conversion puts agriculture lands in the Dungeness at risk.

Water availability is a continuing source of tension in areas with water rights restrictions, where lower availability leads to increased competition between users. Water rights for commercial agriculture on the North Olympic peninsula rarely include groundwater use, leading the sector to other water sources for irrigation. Permit exempt wells can be used for stock watering but are limited to 5,000 gallons per day, which is too small for most other commercial agricultural uses. Factors such as drier summers and decreasing snowpack have the potential to alter river levels and recharge rates for underground aquifers, and affect agricultural water availability from both wells and irrigation sources.

The region already experiences erosion and higher turbidity during extreme events on Johnson Creek, as well as erosion at Matriotti Creek (a conveyance from the Dungeness to agricultural irrigation systems)[117]. The expected increase in winter rainfall amounts and intensity under climate change will likely lead to increased upland runoff, causing sheet, rill and gully erosion that carries sediment, nutrients, pathogens, and pesticides into waterways. Agricultural nonpoint source pollution is a contributor to water quality impacts on rivers, lakes, and wetlands, as well as a contributor to contamination of estuaries and ground water.

Forests on the North Olympic Peninsula are dominated by three species regimes: western hemlock, Sitka spruce, and Pacific silver fir. The western hemlock regime is located in the low to middle elevations of the Peninsula, and includes Douglas-fir as another common species. The Sitka spruce regime is located in the lowlands of the western edge of the Peninsula, with western hemlock and red cedar represented as well. The Pacific silver fir regime is located in the mid to upper slope forests of the Peninsula, often sharing space with Douglas-fir and western hemlock[118].

Hotter and drier summers under climate change will likely introduce drought conditions to species unaccustomed to the stress, leading to greater success of drought-tolerant species. Sitka spruce and Western hemlock could decline and be **replaced** by Douglas fir, western red cedar, lodgepole pine, and western white pine[119]. In higher elevation areas, hotter temperatures and a longer growing season will likely alleviate historical growth-limiting factors and result in increased growth and productivity in these forests. Pacific silver fir may move higher in elevation and western hemlock could become more prevalent in current Pacific silver fir zones[120]. The **Forestry sector** has already been affected by pine bark beetle infestations, and could see climate conditions that increase forest pests in the future. Logging practices in steep terrain hold the potential to compound erosion and landslide risk associated with increased extreme precipitation events under climate change.

Emerging Risks

Emerging risks of climate change to the region's ecosystems include increases in **Harmful algal blooms** (and their resulting illness in humans through Paralytic or Diarrhetic Shellfish Poisoning), macro algae blooms(, **acidic ocean waters** threatening major local shellfish industries, and shifting biodiversity patterns. **Leland Lake and Lake Sutherland** have experienced invasive freshwater plants. Climate change could expand invasive species' opportunities to gain footholds and proliferate in a given ecosystem.

In wild and hatchery seeded oyster beds there has been a lack of recruitment for pacific oyster (a non-native species). Native hood canal oysters (which have evolved to deal with anoxic, freshwater conditions) and Geoducks have been more resilient to recent changes to marine conditions. Olympia oysters in estuaries may have historically seen lower pH water conditions, which would increase their overall resilience to ocean acidification, but they have a narrow preference for habitat and pacific oysters (non-native) are already highly dominant. **Taylor Shellfish** in Dabob Bay is seeing a decrease in Pacific oysters due to the impact of ocean acidification on oyster larvae. The current practices in seeded shellfish beds also include the use of spraying herbicides and pesticides[121], which add additional stress to the ecosystems upon which the shellfish depend. Across the Pacific Northwest, hatcheries closest to the Pacific Ocean and its associated upwelling of acidic ocean waters have been the hardest hit by water quality changes. Hatcheries are already reporting continuous treatment of water inputs and outputs at their plants.

Salmon hatcheries (tribal, state, federal, and private) have also been dealing with changing environmental conditions that affect the success of juvenile salmon rearing. These conditions, such as; low average river flow, high water temperatures, and more intense flooding events with diminished water quality, have forced some hatcheries to alter their operating procedures such as increasing treatment of water inputs and releasing juvenile fish early. Hatchery salmon must also compete with invasive salmon species, including escaped aquaculture (Atlantic) salmon. Higher water temperatures in streams and the ocean hold potential to alter disease and parasite proliferation among both hatchery and aquaculture salmon. Stemming from these concerns, Jefferson County has prohibited aquaculture in some areas. Port Angeles already has salmon aquaculture in its harbor, and Clallam County's new Shoreline Master Program allows it with conditions, such as requiring large circulation and flushing conditions.

Ecosystems-Prioritized Adaptation Strategies

Adaptation strategies were developed collaboratively with input and review by over 175 project partners and based on inspiration from promising practices in adaptation from across the country. This group of strategies was developed to specifically address and reduce climate change vulnerabilities of ecosystems.

Strategies were evaluated and prioritized during the workshop using the following set of criteria. Each strategy was ranked on a scale of 1-4 for each criterion and then those scores were summed to create a total score for the strategy.

Table 5: Criteria used for evaluation and scoring of potential adaptation strategies along with descriptions. A complete table of all scores is available in Supplementary Information E.

CRITERIA	DESCRIPTION
Timeframe for Implementation	The ideal timeframe for initiating implementation of the proposed action in order to be most effective. Actions requiring immediate action received higher scores.
Adaptive/Flexible	The proposed strategy allows for responding to uncertain outcomes or timing of climate change impacts.
Technical Feasibility	Current technology can be used and physically implemented to solve the problem it is meant to address.
Political & Social Feasibility	Action has political and social community support or, at a minimum, does not have political or community opposition. This also considers the "fundability" of an action.
Alignment with other Community Goals	The action has co-benefits for other community goals, plans, or actions, leads to increase in social resilience, if relevant; action is socially equitable.

The workshop attendees also considered the following additional criteria. They were not used directly in the scoring of the strategy but to explore the potential cost effectiveness of a strategy (the ratio of the cost avoided to cost of action) and whether the action was environmentally sound.

- Cost of the Action - *Direct financial cost or economic costs of the project.*
- Avoided Cost - *Perceived cost of inaction (financial or economic) ranked on same scale as "Cost of Action".*
- Environmentally Sound - *Action increases resilience of natural environment in the face of a range of climate change impacts; action decreases the emission of GHGs (has mitigation co-benefits); action complies with environmental regulations; there will be no immediate or cumulative negative environmental consequences from the action.*

A listing of ALL of the adaptation strategies considered for Ecosystems on the North Olympic Peninsula, and their overall scoring on the evaluation criteria above are found in Appendix A.

As an output from this ranking exercise, the table below outlines the "Top 10" adaptation strategies for building ecosystem resilience on the North Olympic Peninsula.

Table 6: "Top-10" strategies for building ecosystem resilience on the north Olympic Peninsula by addressing the key vulnerabilities developed over the course of the project. "Top-10" status determined based on overall strategy score on a set of evaluation criteria (previous page). Included are "Key Action Steps" which speak to the details of implementing each strategy. A complete list of all strategies considered for this focus area are available in Appendix A

E-1: Enhance efforts to encourage breeding and planting of drought tolerant, resilient plant species					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
20	Aware-ness	Near-term	Agricultural/ Forestry Sectors, Educational Organizations	*Highly adaptive, feasible, in line with political and social goals*	*Water Supplies*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Identify most drought tolerant, resilient plant species for the region.
- Work with partners to develop and distribute education materials to homeowners, renters, and businesses.

E-2: Incorporate climate change more explicitly into comprehensive plans and Shoreline Master Programs (SMP)					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
19	Planning	Near-term	County and City Governments	*N/A*	*Critical Infrastructure*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Research sample language from other regional and national efforts. One example is the San Juan Islands- http://www.sanjuans.org/documents/Loring_2014_sea_level_rise_regulatory_review.pdf.
- Use best available climate change projections and share relevant information with County and City governments in region.
- See **Supplementary Information C** for more details.
- Other relevant and critical plans that would benefit from climate change planning include: functional plans, strategic plans (especially those of Ports, PUDs, and non-profits), and comprehensive schemes.

E-3: Enhance promotion of agricultural best management practices to include future climate conditions					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Sectors of Co-benefit
19	Aware-ness	Immediate	Agricultural Sector, Educational Organizations	*Highly adaptive, feasible, in line with political and social goals*	*Water Supplies*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Collaborate with Clallam Conservation District, Jefferson County Conservation District and Washington State University to identify priority BMPs, and lessons learned from implementation efforts.
- Identify practices most relevant to climate change impacts such as sustaining soil moisture and health, erosion control, conservation irrigation, diversity of crop species, incorporation of efficient water use technologies.
- Develop educational material about best practices and share with those in agricultural sector.

E-4: Update municipal codes to account for enhanced fire risk at forest/residential interface where needed					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
19	Policy	Near-term	Local Governments	*Highly adaptive, feasible, in line with political and social goals*	*Critical Infrastructure*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Use education, incentives, and building codes to minimize fire risk, particularly in forest/residential interface.
- Enforce set-backs on building permits in forested areas.
- Update existing hazard analyses that incorporate historical climate variables (such as the Clallam County Community Wildfire Protection Program, 2009) with temperature and precipitation projections for a chosen climate change scenario.
- Review existing hazard analyses (such as the Clallam County Community Wildfire Protection Program, 2009) for strategies to mitigate the wildfire risk, and assess their continued viability with increased wildfire risk.

E-5: Increase regional capacity for water storage (preferably with natural systems)					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
18	Planning	Long-term	Multi-stakeholder	*High need for additional storage but facing numerous political barriers*	*Water Supplies*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Create water storage and usage options at all scales (recharge, mitigation, irrigation).
- Leverage natural systems where possible (wetlands, rainwater collection).
- Explore innovative technologies for water storage (e.g., bladders, engineered wetlands).

E-6: Encourage FEMA to incorporate climate change in rate maps and guidance					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
18	Planning	Long-term	State and County Governments	*A way to incentivize adaptive measures taken by homeowners in the face of climate change, though FEMA's processes for updates are lengthy and slow.*	*Critical Infrastructure*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Update scope of flood maps to reflect changing risk associated with climate change (e.g. revisions to frequency of 100 year flood events).
- Update rate maps to reflect areas of continued or emerging risk to flooding under climate change.
- Hold workshop or training to educate residents and businesses on changes.

E-7: Develop graphical tool to illustrate climate impacts					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
17.5	Planning	Near-term	Multi-stakeholder	*Complexity will depend on the approach and type of impact modeled*	*Water Supplies Critical Infrastructure*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Work with key stakeholders to understand their needs and desires for a graphical tool. Consider applying existing graphical models (e.g. sea level rise) to areas of interest. Alternatively, could devise new combinations of models to graphically demonstrate climate impacts.
- Secure funding, if needed, to create tool.

E-8: Update financing policies for development in high risk areas					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
17	Policy	Medium-term	Banks and Insurance Groups	*This action would remedy an inappropriate incentive to build in high-risk areas, though political support would be difficult.*	*Critical Infrastructure*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Work with banks to remove mortgage subsidies (e.g. loans) for areas with high climate change impact risk.
- Work with insurance industry to realistically incorporate risk into future policies and remove subsidies.
- Educate homeowners about the changes.

E-9: Enhance efforts to incentivize use of native plants landscaping in residential, commercial, industrial settings					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
17	Aware-ness, Policy	Near-term	Local Governments and Private Sector	*Very feasible, low cost*	*Water Supplies*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Develop financial, regulatory, or other incentive program to promote greater use of native plants at homes and at industrial / commercial sites.
- Integrate regulations requiring the use of native plant use into building codes.
- Provide incentives for removing lawns and invasive species and replacing them with native plans.
- Collaborate with Clallam Conservation District, Jefferson County Conservation District and local native plant societies on their efforts to sell affordable native plants.

E-10: Utilize low cost citizen science monitoring and analysis approaches and technologies					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
17	Awareness	Near-term	Research Institutions, Non-profit Education Centers, Citizen Scientists	*Highly adaptive, feasible, and in line with political and social goals.*	

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Host trainings for interested individuals. Including detail about monitoring and analysis specific to emerging climate change impacts on the peninsula, such as: the presence of invasive/migrating fish species, monitored through trace DNA molecular analysis of seawater collected by citizen scientists.

In addition to the "top-10" strategies listed above, there are other strategies that ranked lower on the evaluation criteria not because they would be ineffective, but because they faced some political, social, technical, or other implementation challenge. For example: ***supporting and enhancing watershed and nearshore habitat restoration***, ***decreasing non-climate ecosystem stressors****, and* ***Re-energize efforts to reduce stressors to salmon stream habitats*** are important approaches to building resilient ecosystems that can respond to and accommodate climate changes. However, these strategies scored only medium for "political/social feasibility" and "alignment with community goals" due to the complex environmental variables driving these "stressors" and the differing perspectives surrounding actions that may enhance ecosystems but are costly for industry, agriculture, or municipal sectors. Shorelines identified as priority areas for conserving intact nearshore ecosystems include the majority of central and western North Olympic Peninsula with an emphasis on Dungeness Bluffs, Elwha bluffs, Freshwater Bay, and Crescent Bay. Some opportunities for ecosystem adaptation to climate change could come from leveraging existing work, such as the strategy: **Monitor and analyze climate change impacts at salmon stream restoration sites,** which would potentially guide habitat restoration techniques as environmental conditions change.

When discussing nearshore ecosystems and options for protecting shorelines and infrastructure from rising sea levels and coastal flood risk, approaches may differ greatly by circumstance. The three general categories of responses to sea level rise are referred to as ***protection, accommodation, or retreat***. For the continued viability of ecosystem services and habitat protection under sea level rise, it can be valuable to move hard infrastructure away from the shoreline to allow for natural upland migration. The use of soft shoreline protection can provide similar coastal defense to infrastructure as hard shoreline armoring does, but without the associated negative impacts on the nearshore ecosystem from wave deflection and scouring of the nearshore habitat. However, the feasibility of soft shoreline protection must be assessed on a case-by-case basis. Particularly, for critical infrastructure such as wastewater treatment plans or hospitals, it may be extremely costly or impossible to relocate those facilities, thereby necessitating hard shoreline protection efforts to guarantee the facilities remain operational during extreme weather events.

B. Water Supplies

David Deffenbaugh

David Deffenbaugh

Ann Soule

Barney Burke

Water Supplies' Exposure to Climate Change

The Water Supplies focus area included the topics of: **surface water supplies; groundwater supplies; and water quantity and availability.** In addition to the general trends in temperature, precipitation, and ocean conditions described earlier in this report, there are other climate change impacts specifically relevant to water supplies, including shifting hydrologic basin types and timing of seasonal stream flows.

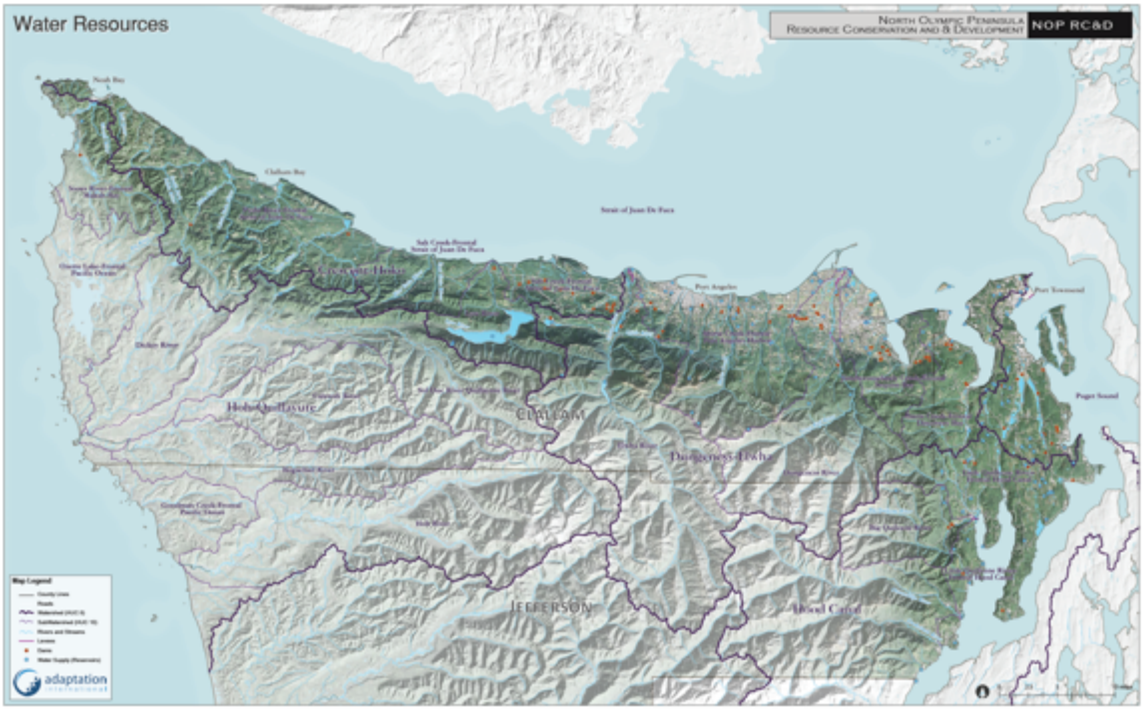


Figure 33: Overview of the Water Resources focus area with key rivers and watershed boundaries as well as other water infrastructure. A larger version of this map is available in Appendix F

As warmer overall temperatures shift precipitation away from snow and towards rain throughout the fall, winter, and spring seasons, changes in precipitation type will be particularly pronounced in those high elevation zones such as the Olympic Mountains where snowfall has historically maintained glaciers and influenced entire ecosystems as a rain-snow “transient” hydrologic basin. Figure 34 shows the projected shifts in hydrologic basin types for the Pacific Northwest region over this century.

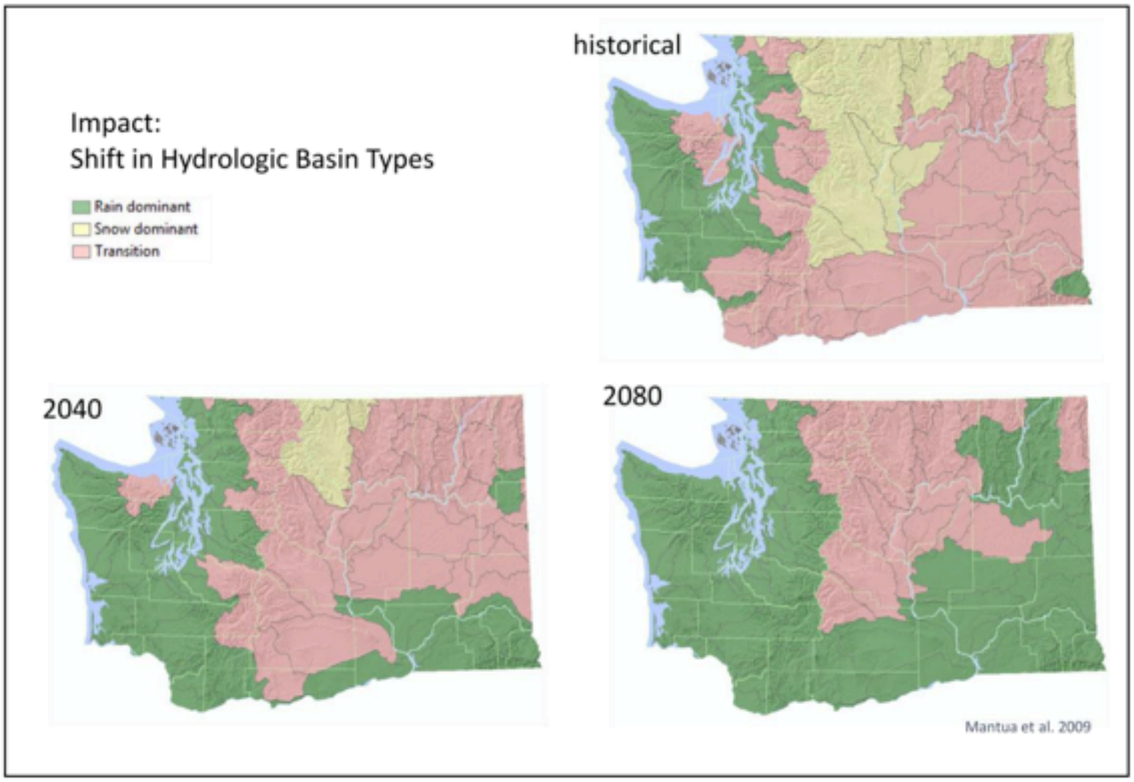


Figure 34: Shifting hydrologic basin types in the PNW under climate change[122]. This projection shows the shifting of hydrologic basins on the North Olympic Peninsula away from a transient (rain & snow) watershed to rain dominant by the end of the century under climate change. With global temperature rise showing few signs of future abatement, this future may vary in timing but not in ultimate outcome.

Shifts in precipitation and hydrologic basin types directly influence the timing of water release and flow from high elevation to downstream lowlands. The general projection of increased fall and winter precipitation and decreased summer precipitation in the region, paired with the shift towards a more rain dominant watershed, suggests long-term changes to watersheds on the North Olympic Peninsula. Figure 35 shows the projected hydrographs for both the Elwha and Dungeness Rivers for a variety of future time periods and two different emissions scenarios.

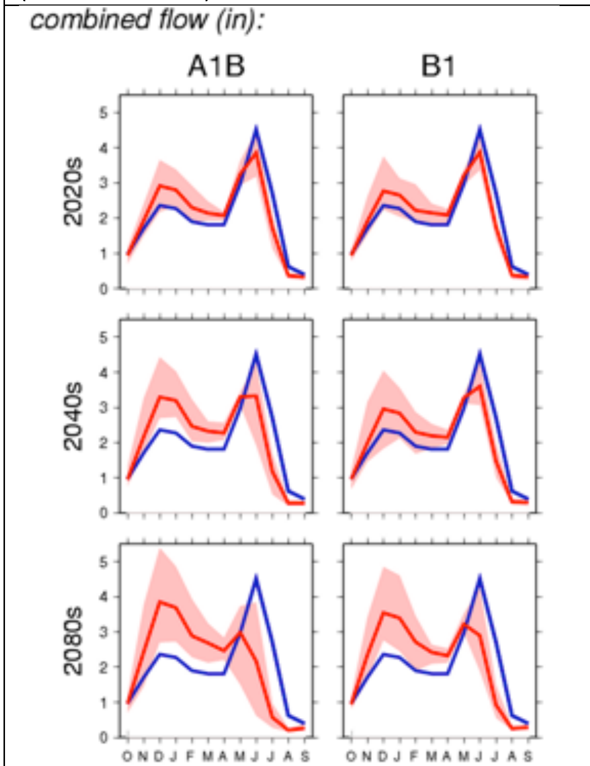
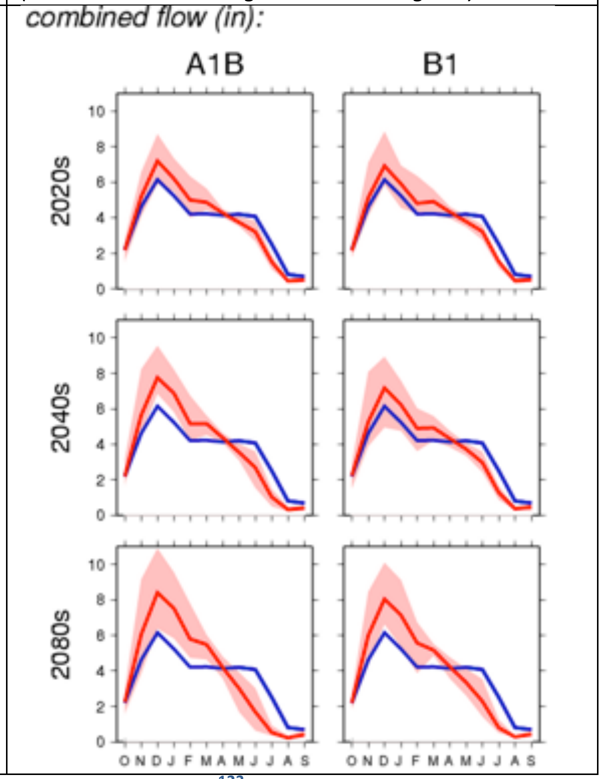
Dungeness River Hydrograph (near river outlet)	**Elwha River Hydrograph** *(near McDonald bridge near Port Angeles)*
	

Figure 35: Hydrograph projections for the Dungeness and Elwha rivers[123]. The blue line is the historical flow, while the red line is the projected average flow with the red shading showing variability. Flow amount is shown with monthly values, starting in October and ending in September. The A1B scenario is similar to the RCP 8.5 scenarios represents the "business as usual" scenario where little attempt is made at greenhouse gas (GHGs) emissions reductions, the B1 scenario is similar to the RCP 4.5 scenario and represents a future where reductions in current amounts of GHGs are undertaken. A detailed illustration of the GHG assumptions between scenarios is available in Figure 3.

In Figure 35, it can be seen that a shift away from a transient (rain and snow) hydrologic basin towards more rain dominant for the Dungeness River means increased winter flows and reduced summer flows. For the Elwha, which in comparison was historically a more rain dominant watershed, there is less of a shift in timing of flow, but instead a projected increase in amount of winter flow and reduction in summer flow.

The **historically low snowpack and the drought of 2015 on the North Olympic Peninsula** exhibits many environmental characteristics that scientists expect to see increase with climate change. For the 2014-2015 winter the Olympic Mountains received at or near their average annual precipitation[124], but the temperatures were warmer than average and much of that precipitation fell as rain rather than snow (see Figure 36), so by early spring the snowpack was at historic lows[125]. Without the snowpack to feed the rivers in the region, the summer river flows across the region are the lowest ever recorded[126].

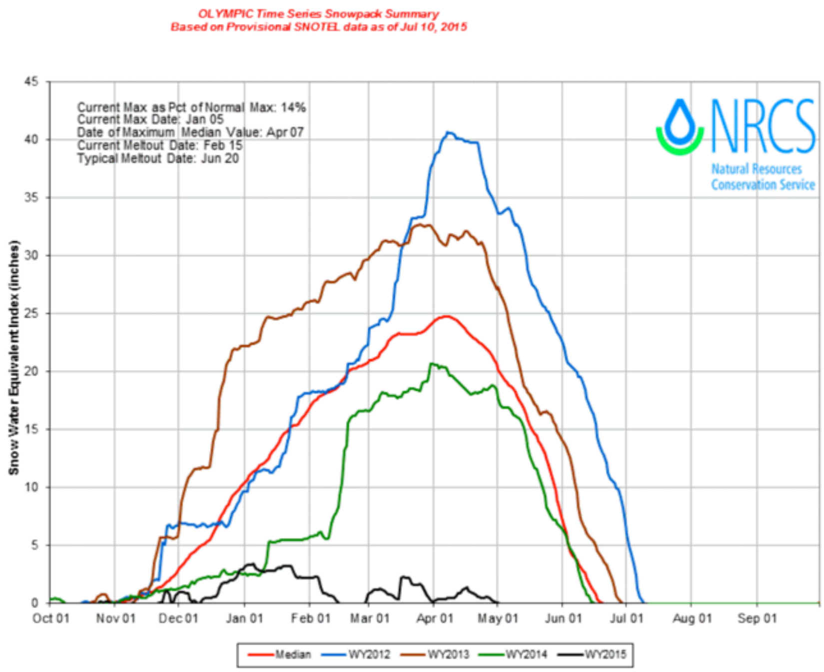


Figure 36: Snow Water Equivalent for the Olympic Peninsula. Smooth red line shows average, blue line is 2012, brown line is 2013, green line is 2014 and black line is 2015. Graph from the Washington State Department of Ecology presentation at the Jefferson County Drought Forum July 14th, 2015[127].

At the same time a heat wave in late June and early July (2015) increased evaporation and evapotranspiration in the region led to extremely low soil moisture and total moisture levels (less than 2% of the historic average) across the Olympic Peninsula[128]. This can be seen clearly in Figure 37 showing observations vs. historical averages and ranges for those parameters for the Dungeness-Elwha sub-basin.

Stream flows in many of the region's rivers are at all time lows for July, the Big Quilcene River (where Port Townsend gets most of its municipal water supply) is at historically low levels (see Figure 38).

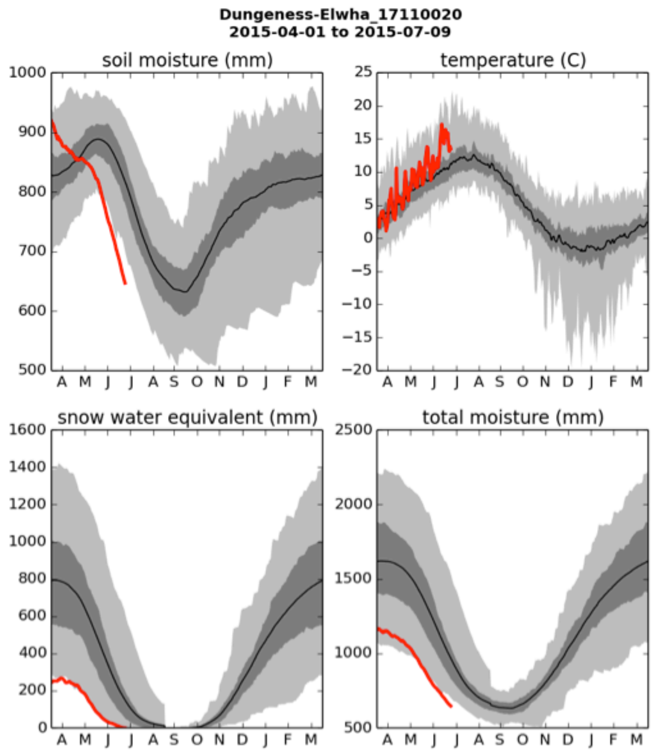


Figure 37: Soil moisture, temperature, snow water equivalent, and total moisture. Black line is the historical (1920-2010) average; dark gray shaded area represents the 25%-75% range; light gray represents the 0%-100% range; for the historical period by river sub-basin, July 9th, 2015[129]. Red line is measured or calculated data for that sub-basin. Note total moisture level at the lowest level ever observed for this time of year.

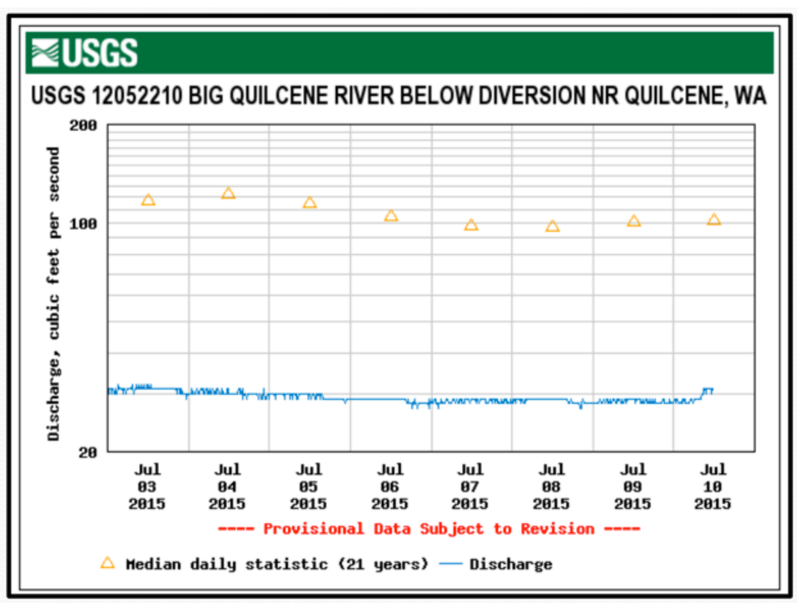


Figure 38: Measured flow rates in the Big Quilcene River for early July, 2015. Historic average flow rates from the past 21 years shown by the yellow triangles (y-axis is non-linear), observed flow rates shown in blue[130]. 27cfs is the level of in-stream flows reserved for fish species, leaving other water users without a legal right to tap the Big Quilcene when it is below these levels.

Current and Projected Impacts on Water Supplies

During the workshops there was rich discussion about the ways that changing climate conditions will affect *surface water supplies; ground water supplies; and water quantity and availability* across the North Olympic Peninsula. A summary of the discussion for each area of concern evaluated during the workshop is available in **Supplementary Information D**. This section highlights some of the key information and themes from those discussions. **The information detailed in this section is the result of collaborative workshops and reflects the knowledge of those who participated.**

Surface Water Supplies

Surface water supplies across the region will be affected by climate change through: seasonal changes to river flows and recharge rates, lower stream flows for extended periods especially during the summer and fall (which may result in more restriction of stream diversions to meet in-stream flow goals), more intense and frequent extreme precipitation events (increasing turbidity and hampering water treatment), increased water demand due to higher temperatures and increased evapotranspiration and potentially increased fire suppression efforts, and extended growing seasons potentially increasing annual demand for irrigation water.

Surface water supplies in the region have already experienced some of these impacts; **Port Townsend** has seen low snowpack years that have led to water shortages as well as warm temperatures driving algal blooms that lower water quality. **Clallam Public Utility** District has seen low streamflows due to a low snowpack and timing of rains; the **Makah Tribe** has experienced drought conditions paired with extreme precipitation events which make water treatment and storage a challenge; and **Beaver Creek** and **Lake Pleasant** have had water availability issues. The climate change projections of a continued reduction in snowpack in the North Olympic Peninsula and shift from transient to rain dominant watersheds along some of the region's main rivers (with the exception of the west end of the Peninsula which is currently rain-dominant) may hinder the efficient refilling of reservoirs and require new approaches to water management

Groundwater Supplies

Groundwater supplies will see: altered precipitation intensity and timing along with decreases in snow pack that may decrease recharge rates; increased water demand due to increased evapotranspiration and potentially increased fire suppression efforts; extended growing seasons potentially increasing annual demand for irrigation water; and sea level rise that could drive salinization of **coastal groundwater** tables.

Groundwater supplies have already experienced some of these impacts. **Jefferson Public Utility District** has experienced drought followed by rain, where the overall recharge rate was much less than expected, perhaps because of the increased water uptake by dry soils and drought stressed plants. In the past, drought events in the region correlated with drops in the static water levels directly tied to the timing and quantity of precipitation. The **Clallam Bay/Sekiu** groundwater supply currently is not snowpack influenced, therefore, it may see smaller impacts to groundwater recharge, though extended drought periods and extreme precipitation events could still alter the groundwater table.

Water Quantity and Availability

Changing snowpack, frequent drought periods, and lower summer precipitation may decrease water supply and increase competition for water resources between in-stream flows and ecosystem needs, water access for vulnerable populations, industrial access, and agricultural use. For instance, the Big and Little Quilcene Rivers supply the **City of Port Townsend**'s water system and the **Port Townsend Paper Company** mill. Several local leaders have expressed concern about how even a marginal reduction in water supply could affect the mill, which is the largest private employer in the county. The mill has significantly reduced its water use in recent years through the implementation of efficiency measures[131], which has reduced the risk of this impact.

Agriculture, as a major water user on the Peninsula, will likely be affected by changes in water availability. The **Chimacum Valley** is Jefferson County's most productive farmland and highly valued for the community benefits it provides. The valley currently has very little water available for agriculture during the growing season, making it sensitive to drought and heat stress under climate change. There are adaptive measures that could mitigate some of this risk, but, currently, water rights restrictions limit the amount of new water that can be used in the basin. The **Dungeness Valley** region has some of the finest agricultural soils on the peninsula and supports a vibrant agriculture sector. Striking a balance between adequate water supply for both farmers and fish has been an ongoing challenge for both areas.

Water Supplies-Prioritized Adaptation Strategies

Adaptation strategies were developed collaboratively with input and review by over 175 project partners and based on inspiration from emerging promising practices in adaptation from across the country. This group of strategies was developed to specifically address and reduce climate change vulnerabilities of Water Supplies.

Strategies were evaluated and prioritized during the workshop on the following set of criteria. Each strategy was ranked on a scale of 1-4 for each criterion and then those scores were summed to create a total score for the strategy.

Table 7: Criteria used for evaluation and scoring of potential adaptation strategies along with descriptions. A complete table of all scores is available in Supplementary information E.

CRITERIA	DESCRIPTION
Timeframe for Implementation	The ideal timeframe for initiating implementation of the proposed action in order to be most effective. Actions requiring immediate action received higher scores.
Adaptive/Flexible	The proposed strategy allows for responding to uncertain outcomes or timing of climate change impacts.
Technical Feasibility	Current technology can be used and physically implemented to solve the problem it is meant to address.
Political & Social Feasibility	Action has political and social community support or, at a minimum, does not have political or community opposition. This also considers the "fundability" of an action.
Alignment with other Community Goals	The action has co-benefits for other community goals, plans, or actions, leads to increase in social resilience, if relevant; action is socially equitable.

The workshop attendees also considered the following additional criteria. They were not used directly in the scoring of the strategy but to look at the potential cost effectiveness of a strategy (the ratio of the cost avoided to cost of action) and whether the action was environmentally sound.

- Cost of the Action - *Direct financial cost or economic costs of the project.*
- Avoided Cost - *Perceived cost of inaction (financial or economic) ranked on same scale as "Cost of Action".*
- Environmentally Sound - *Action increases resilience of natural environment in the face of a range of climate change impacts; action decreases the emission of GHGs (has mitigation co-benefits); action complies with environmental regulations; there will be no immediate or cumulative negative environmental consequences from the action.*

A listing of ALL of the adaptation strategies considered for Water Supplies on the North Olympic Peninsula and their overall scoring on the evaluation criteria above are found in Appendix A

As an output from this ranking effort, the table below outlines the "Top 10" adaptation strategies for building Water Supplies resilience on the North Olympic Peninsula.

Table 8: "Top-10" strategies for building water supply resilience on the North Olympic Peninsula by addressing the key vulnerabilities developed over the course of the project. "Top-10" status determined based on overall strategy score on a set of evaluation criteria (previous page). Included are "Key Action Steps" which speak to the details of implementing each strategy. A complete list of all strategies considered for this focus area are available in Appendix A

WS-1: Enhance education on drought and water supplies issues for the peninsula					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
20	Awareness	Immediate	Multi-stakeholder	*Highly adaptive, feasible, in line with political and social goals, low cost*	*Ecosystems*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Identify and implement appropriate educational activities. Options could include: tour of existing facilities/locations, targeted messaging around conservation, workshops and peer exchange, enhanced research partnerships.

WS-2: Adopt new regulations requiring water-efficient appliances					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
20	Policy	Medium-term	State Governments	*Technically and politically feasible, but potentially limited ability to influence state regulations*	*Ecosystems*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Work with state legislators to revise regulations.

WS-3: Promote and incentivize smart irrigation technologies for agriculture					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
20	Aware-ness	Medium-term	Agriculture Sector	*High cost, technical and political feasibility*	

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Promote benefits of decreasing "consumptive use" of water.
- Utilize Washington State University's "CropSyst" software which, among other things, models cultivar water needs amount and timing (http://modeling.bsyse.wsu.edu/CS_Suite_4/CropSyst/index.html)
- Conduct assessment of existing irrigation issues: http://drought.wsu.edu/tools-resources/irrigation/
- Develop and distribute educational materials about smart irrigation technologies.
- Consider working with agricultural sector to host education workshop or meetings related to water conservation.

WS-4: Identify monitoring needs and enhance water supply monitoring					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
19	Aware-ness	Near-term	Multi-stakeholder	*Highly adaptive, feasible, in line with political and social goals, low cost*	*Ecosystems*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Create a data clearinghouse for water information from universities, cities, non-profits, others, and include both information resources and information needs (potential home is the NOPRCD).
- When and where it is needed, install additional flow and snowpack sensors.
- The data from all of these could be used to identify water storage sites, establish baseline of use and availability, and to enhance system management.

WS-5: Enhance efforts to educate home and business owners on the value of on-site water conservation, retention, and catchment					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
18	Aware-ness	Immediate	Multi-stakeholder	*Highly adaptive, feasible, in line with community goals, low cost*	*Critical Infrastructure*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Create outreach materials to explain to home and business owners the value of on-site storm-water retention, rainwater catchment, Low Impact Development (LID) techniques, and vegeta-tion management to reduce water usage, including the availability of incentives, and value to the community and ecosystems.
- Educate on the broader issue of the need for water conservation, retention, and catchment.
- Decommission “forgotten” wells on properties served by public water.

WS-6: Continue to study ways to enhance water storage and groundwater recharge					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
18	Planning	Near-term	Water Utilities and Local Governments	*Highly adaptive, feasible, in line with political and social goals, low cost*	

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Consider enlarging existing storage and identify locations for new structures.
- Identify off stream storage including conveyance, groundwater infiltration rates, and potential for active recharge of groundwater resources such as infiltration wells.
- Consider potential for “banking” water during high flow events for use in low flow times (Port Angeles and Peninsula College have data on this).
- Note that WRIA 18 has recently researched (2014) storage and recharge opportunities in the Dungeness River area, contact Washington Water Trust for details.

WS-7: Encourage forestry practices promoting water retention within the watershed					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
18	Aware-ness	Medium-term	Forestry Sector	*N/A*	*Ecosystems*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Identify forestry practices that promote upstream water retention and educate individuals about the practices.
- Consider integrating water retention into forestry practices permits.

WS-8: Research or develop model to assess sea level rise and saltwater intrusion to groundwater					
Score	Type of Strategy	Timeframe for plementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
18	Planning	Medium-term	Local Government, PUDs	*N/A*	

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Enhance seasonal ground water level monitoring.
- Research what other communities are doing to assess sea level rise and salt water intrusion into groundwater.

WS-9: Improve forecasting for future water supply and demand					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
18	Planning	Medium-term	Water Utility Managers	*Politically feasible but technically difficult*	

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Improve forecasting tools for matching expected demand (including expected growth) with models of water availability including climate change.

WS-10: Map water retention values for ecosystems					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
18	Planning	Near-term	Multi-stakeholder	*Technically and politically feasible*	*Ecosystems*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Develop methodology and implement a valuation of the water retention services a landscape provides (as opposed to engineering storage systems).
- Recognize the economic benefits of assessing a "triple-bottom line" and communicate this to stakeholders.
- Look at what others have done to monetize environmental services and apply that technique to those services available in the region. Examples include the Earth Economics report: "Nature's value in Clallam County" http://wdfw.wa.gov/grants/ps_marine_nearshore/files/ee_clallam_county_report_2013.pdf
- Create a mechanism for compensating landowners for the environmental services maintained on their property.

In addition to the “top-10” strategies listed above, there are other strategies that ranked lower not because they would be ineffective, but because they faced political, social, technical or other implementation challenges. For example: ***enhancing residential water conservation through incentives and outreach*** and ***developing an inverted block rate structure for water and sewer billing*** would incentivize conservation, and additional water system capacity could serve as a buffer for drought periods. However, this strategy ranked low due to the fact that it is politically difficult to raise utility rates or fund incentives. ***Developing municipal water reuse infrastructure*** and ***encourage the use of gray water on-site*** were also both discussed but scored lower due to a high perceived cost of implementation and the political difficulty of changing state policy on gray water use.

Adaptation strategies which target enhancement of natural groundwater processes were also discussed, including: **Explore opportunities for artificial recharge of groundwater aquifers**, and **Manage/ enhance upstream watersheds**. Strategies for artificial recharge such as infiltration basins, injection wells, and engineered lakes/ ponds were thought to hold some challenges in the long lead time, costs, disruption of the landscape, and political barriers to move from studying the options to implementation. Opportunities to support upstream watersheds included slowing water flow, the use of buffers, committing to Low impact development (LID), and engineered wetlands. These actions may be very viable approaches, but were not fully evaluated during the workshop due to time constraints.

C. Critical Infrastructure

Hugh Shipman, WA Ecology

Brewbooks- Google creative commons

Port Townsend Marine Science Center

Ann Soule

Critical Infrastructure's Exposure to Climate Change

The critical infrastructure focus area included discussions of: **downtowns, ports, and coastlines; floodplains and stormwater; sewer and septic systems**. In addition to the general trends in temperature, precipitation, and ocean conditions described earlier in this report, there are additional climate change impacts specifically relevant to critical infrastructure, including sea level rise and the long-term viability of transportation corridors.

Figure 39: Overview for Critical Infrastructure Focus Area including slope stability, transportation corridors, and critical infrastructure buildings such as hospitals, EMS, and Fire stations. A larger version of this map is available in Appendix F

This project involved the creation of probability based regionally specific sea level rise projections. As described earlier in this report, these projections take into account global and regional changes to sea levels as well as local vertical land movement from tectonic forces to determine coastal flood risks. More information on these projections is available in **Section I.E.** and **Appendix D**. The full set of sea level rise maps created for this project are located in **Appendix C**.

The North Olympic Peninsula is connected to the population centers of Seattle and Tacoma by a small network of highways and the marine ferry system. The Washington Department of Transportation has completed a climate change vulnerability assessment[132] for these networks and ranked state transportation corridors based on their perceived vulnerability to climate change risks. Figure 40, below, displays Olympic Peninsula transportation vulnerabilities to sea level rise and extreme events.

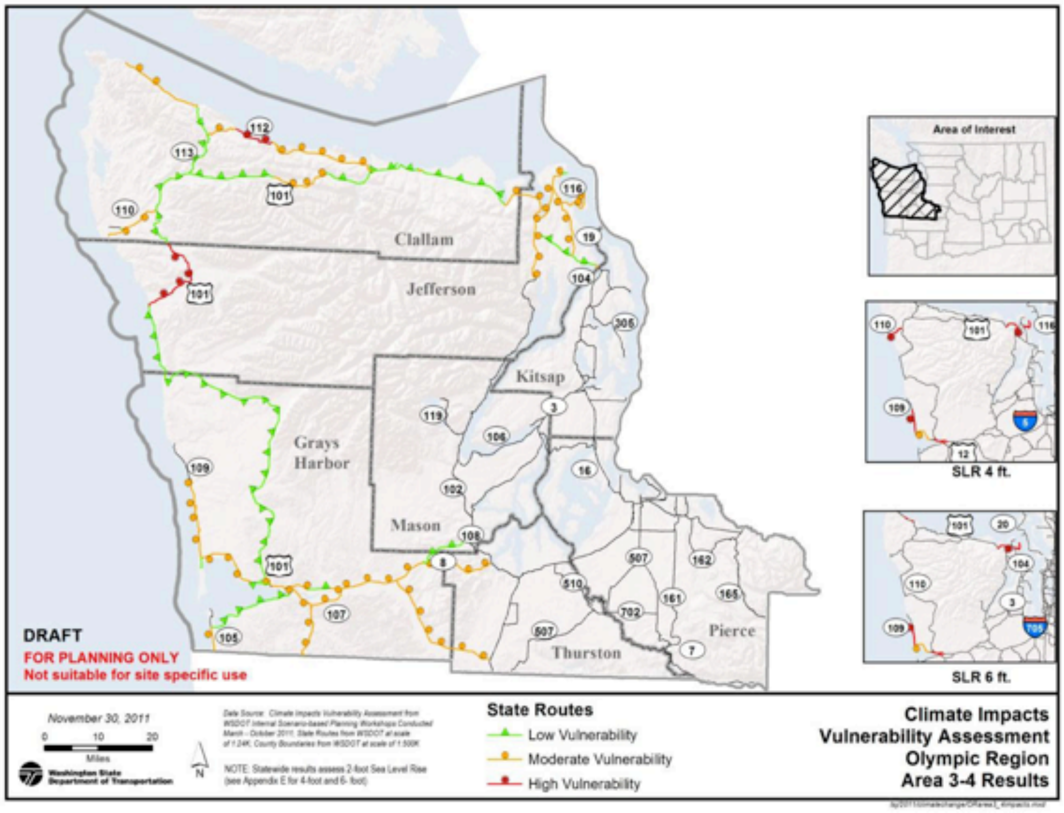


Figure 40: Olympic Peninsula climate change transportation vulnerabilities identified by WA DOT[133]. Red corridors are high vulnerability, yellow are moderate vulnerability, and green are considered low vulnerability.

Vulnerability findings from Figure 40 above include:

> *"SR [State Route] 101 between mileposts 165 and 185 is subjected to impacts from creeks and rivers that are aggrading due to increased sedimentation. This is likely to increase as the glaciers and snowfields melt in the mountains. This area is also likely to experience more extreme weather events. SR 101 near Discovery Bay is susceptible to impacts from higher sea levels at 4 and 6 feet. SR 105 would be affected by a 4- and 6-foot sea level rise and flood the road. SR 112 between mileposts 29 and 40 is affected by unstable soils. This would be made worse by more extreme precipitation events that would saturate the soils. SR 116 currently has only a few feet of freeboard. The road is an earthen causeway with culverts at the susceptible points, and sea level increases will flood the road. Flooding the road could lead to roadway instability in addition to closure during high tide events."*[134]

WSDOT has committed to using their findings from the vulnerability assessment in new transportation planning efforts. The design of proposed improvements will consider current and future climate conditions, including sea level rise, changes in stormwater flow, and extreme heat and cold[135]. WSDOT also recognizes that secondary roads (city and county roads), which were not assessed in their report, could be extremely critical to the viability of the North Olympic Peninsula's transportation system under climate change. In Workshop 1, the Project Partners identified secondary roads vulnerable to climate change impacts including: 3 Crabs Road, logging and forest service roads (especially accessing communication towers), roads in Clallam Bay, streets of downtown Port Townsend, Quilcene/Brinnon/Center Rd. Valley, Morse Creek and Hot Springs Road, and the Hoko/Ozette road.

Current and Projected Impacts on Critical Infrastructure

During the workshops there was rich discussion about the ways changing climate conditions will affect *Downtowns, Ports, Coastlines; Floodplains and Stormwater; Sewer and Septic Systems* across the North Olympic Peninsula. A summary of the discussion for each area of concern evaluated during the workshop is available in **Supplementary Information D**. This section highlights some of the key information and themes from those discussions. **The information detailed in this section is the result of collaborative workshops and reflects the knowledge of those who participated.**

Downtowns, Ports, Coastlines

Many pieces of critical infrastructure on the North Olympic Peninsula are found on low-bank oceanfront sites or within floodplains. This infrastructure includes buildings supporting: health and safety, utility services, maritime industries, tourism, banking, government, residential, and retail. These are vulnerable to the projected climate change impacts of sea level rise, storm surge, and coastal flooding. This presents a risk to both long-term economic sustainability and essential services in the region.

Downtown Port Townsend was developed in the mid to late 1800s and is just above sea level, with many historic structures that form the heart of the National Register Historic District. In the past, flooding has affected some basements, closed building and roads, degraded road surfaces, and a high water table has undermined structures on both sides of Water Street (basement sump pumps are common). Existing businesses in this area face a range of practical and financial challenges, from access to credit and flood insurance, to navigating procedural and regulatory hurdles. Building owners may not have money to invest in needed building retrofits. The downtown drives a strong tourism economy and has both community support and iconic value. In recent years, the Port has invested in the two marinas at each end of downtown in anticipation of rising sea levels with higher pilings and walkway access.

The old Coast Guard station buildings at **Point Hudson** are aging and there is currently nuisance flooding during large rainfall events. This area is particularly exposed to the wind and wave action of Admiralty Inlet and Port Townsend Bay. The jetty is old and failing and obtaining the funding for its replacement is both challenging and uncertain. The stormwater outfall for the **Boat Haven** is near the maximum water level during storm events that occur during high tide. Failure of the tide gate on the end of the outfall pipes could take the stormwater system off-line, affecting operations at the boatyard (the yard directly and indirectly supports over 500 jobs). The **Kai Tai Lagoon** is primarily an undeveloped park on the remnants of a tidal lagoon just inland from the Boat Haven. The restored wetlands within its boundaries are currently subject to flooding during storm events, and that flooding is expected to become more frequent with sea level rise. The **Port Townsend Paper Company** is a major employer in the county and does not expect a problem with sea level rise at its facilities since it has an excessive amount of freeboard at its dock, and its settlement ponds reside above the projected annual flood risk zone.

The downtown area of the **City of Port Angeles** was built on pilings and fill and although it remains above the annual coastal flood risk zone even with sea level rise, the area may be subject to erosion or the impact of wind driven waves not shown in the sea level rise maps. The industrial waterfront, including **Ediz Hook** and the **Nippon Paper Industries** site will likely be affected by coastal flooding though not significantly until the latter half of the century. The **landfill** is currently being affected by bluff erosion and this erosion is likely to be exacerbated by sea level rise. There are existing remediation efforts taking place at the eroding site but the new seawall may continue to be vulnerable to sea level rise and storm surge.

Floodplains & Stormwater

Many of the developed areas on the peninsula are located within floodplains, especially close to the Dungeness, Elwha, Duckabush, and Dosewallips rivers. Heavy rainfall events could bring increased erosion, scouring, entrainment of more rocks and sediments, loss of uplands sediment sources, expanded flood zones, changes in side channel habitat, increased property damage, and increased “flashiness” of floods. Levees, bridges, diversions, upland land use practices, and storm water management all influence floodplains. The **Lower Elwha Klallam Tribe** depends on a set-back levee flood pump station and it is unknown whether that pump will be able to handle climate changes to flooding patterns. The **Makah Tribe** sees flooding in portions of Neah Bay when heavy rainfall events raise river levels and coincide with an extreme high tide, backing up water along the river corridors.

The successful (or unsuccessful) management of stormwater in the region will ultimately determine the overall impacts in the region. Stormwater systems have diversified inputs and outputs, and are usually not treated before being released through the outfall infrastructure. There is existing flooding of streets when rainstorms coincide with high tides. In Port Angeles, the **Hill Street/Marine Drive system** serving west Port Angeles is currently inundated at high water. Historically, **stormwater pipe outfalls** were not below high tide line but that will likely change with sea level rise, causing pushback up the pipe. Currently, the stormwater pump stations in Port Townsend are at flooding risk, as they are only 1 to 2 feet above current sea level. There is a general lack of funds available for wastewater infrastructure upgrades, which are often dependent on the local tax stream.

Sewer and Septic Systems

The **Clallam Bay/Sekiu sewage treatment plant** is particularly susceptible to the impacts of sea level rise and riverine flooding. Around 1,000-1,200 people are served by this system and currently nuisance flooding occurs near the facility at the outflow pipe during high river flow events. The system is aging with many maintenance needs; existing leaky pipes allow inputs from groundwater, which max out treatment capacity. Sekiu has a middle point pump station that is low-lying and has been previously overloaded (serves approximately 100 people). **Downtown Port Townsend** has a sewer pump station near Kah Tai Lagoon, which is currently below ground level, dependent on electricity, and close to the shoreline. Given the area's exposure to sea level rise and storm surge, there is a likelihood this component of the sewer system could be compromised.

The Elwha lowlands area utilizes a **vacuum sewer system** that may be vulnerable to alterations to the groundwater table. Currently, there are some uncertain projections about the future of the water table as the Elwha dam was removed and the floodplain adjusts. There is a risk of inundation of low-lying vacuum chambers/pump stations.

Septic systems vulnerabilities include groundwater table alterations, shifting precipitation patterns, changes in evaporation rates (for mound systems), and sea level rise inundation of coastal septic fields. It can also be difficult to motivate or enforce changes to septic systems as most are on private property and highly distributed across the region. Permanently high water tables close to beaches have impeded successful use of septic tanks at the Brinnon-Quilcene and Golden Sands communities. There has been some collective action, for example the community of Beckett Point installed a neighborhood septic system to grind and pump waste up to a community drain field.

Critical Infrastructure-Prioritized Adaptation Strategies

Adaptation strategies were developed collaboratively with input and review by over 175 project partners and based on inspiration from promising practices in adaptation from across the country. This group of strategies was developed to specifically address and reduce climate change vulnerabilities of Critical Infrastructure.

Strategies were evaluated and prioritized during the workshop on the following set of criteria. Each strategy was ranked on a scale of 1-4 for each criterion and then those scores were summed to create a total score for the strategy.

Table 9: Criteria used for evaluation and scoring of potential adaptation strategies along with descriptions. A complete table of all scores is available in Supplementary Information E.

CRITERIA	DESCRIPTION
Timeframe for Implementation	The ideal timeframe for initiating implementation of the proposed action in order to be most effective. Actions requiring immediate action received higher scores.
Adaptive/Flexible	The proposed strategy allows for responding to uncertain outcomes or timing of climate change impacts.
Technical Feasibility	Current technology can be used and physically implemented to solve the problem it is meant to address.
Political & Social Feasibility	Action has political and social community support or, at a minimum, does not have political or community opposition. This also considers the "fundability" of an action.
Alignment with other Community Goals	The action has co-benefits for other community goals, plans, or actions, leads to increase in social resilience, if relevant; action is socially equitable.

The workshop attendees also considered the following additional criteria. They were not used directly in the scoring of the strategy, but to explore the potential cost effectiveness of a strategy (the ratio of the cost avoided to cost of action) and whether the action was environmentally sound.

- Cost of the Action - *Direct financial cost or economic costs of the project.*
- Avoided Cost - *Perceived cost of inaction (financial or economic) ranked on same scale as "Cost of Action".*
- Environmentally Sound - *Action increases resilience of natural environment in the face of a range of climate change impacts; action decreases the emission of GHGs (has mitigation co-benefits); action complies with environmental regulations; there will be no immediate or cumulative negative environmental consequences from the action.*

A listing of ALL of the adaptation strategies considered for Critical Infrastructure on the North Olympic Peninsula, and their overall scoring on the evaluation criteria above are found in Appendix A.

As an output from this ranking exercise, the table below outlines the "Top 10" adaptation strategies for building Critical Infrastructure resilience on the North Olympic Peninsula.

Table 10: "Top-10" strategies for building critical infrastructure resilience on the North Olympic Peninsula by addressing the key vulnerabilities developed over the course of the project. "Top-10" status determined based on overall strategy score on a set of evaluation criteria (previous page). Included are "Key Action Steps" which speak to the details of implementing each strategy. A complete list of all strategies considered for this focus area are available in Appendix A.

CI-1: Update emergency management and response planning to include climate change where needed					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
20	Planning	Near Term	Emergency Managers	*Highly adaptive with very good political support for this strategy*	

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Prior to a hazard event, identify lead contacts serving vulnerable populations and coordinate actions to maximize safety and information sharing. Leads can assist and provide support during hazard events.
- Establish a network of "block captains" that can be activated to go door to door to check on the health of high-risk neighbors.
- Work with residents to create a home emergency kit that ensures that all residents have the resources they need to survive during an event. This kit should include back-up medications, rations of food, and secondary communication technologies.
- Help individual households to take their own steps to reduce flooding, such as installing rain barrels and back-up power for sump pumps.
- Expand training and education of health and social services systems/providers to identify and treat mental health problems after extreme climate events.

CI-2: Reduce inflow and infiltration to wastewater systems					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
19.5	Policy	Immediate	Operations and Maintenance Dept.	*Existing issue with high levels of political/social support but also higher costs associated with strategy*	*Ecosystems*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Identify current inflow and infiltration to wastewater system.
- Draft revised inflow and infiltration standards and meet with stakeholders to review standards.
- Formalize standards and conduct education with key stakeholders to make them aware of key changes and new requirements.
- Enhance funding to accelerate repairs and replacement of critical areas.

CI-3: Update planning documents for sea level rise and flooding where needed					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
19	Planning	Near Term	Multi-Stakeholder	*Medium and long-term issue where planning now can help reduce future costs*	*Ecosystems*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Create a sea level risk district for inclusion in Comprehensive Plan and promulgate new codes and code changes associated with managing for sea level risk.
- Incorporate climate change and coastal hazard considerations into building codes by increasing freeboard requirements to two feet (three feet for critical projects) above the current 100-yr flood plain as buildings are redeveloped, developed, or renovated.
- See **Supplementary Information C** for more details.

CI-4: Do outreach and education on climate adaptation to build community support					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
19	Awareness	Immediate	Multi-Stakeholder	*Low cost but only moderate political support*	*Ecosystems Water Supplies*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Conduct outreach and education on climate issues and adaptation solutions to multi-stakeholder groups of residents, businesses, and politicians. Examples include: Public outreach for opportunities in existing relevant stormwater programs (e.g. rain gardens, cisterns).
- Consider real estate disclosures of climate change risk for residential property owners.
- Establish Community Design Centers to assist property owners in designing and retrofitting infrastructure.

CI-5: Develop and utilize decision making tools related to climate change risks					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
18	Planning	Medium-term	Local Governments	*Highly adaptable until tools are developed then hard to change. These tools receive moderate/low political support*	*Ecosystems Water Supplies*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Work with key stakeholders to identify the types of resources, tools, and information they need to make climate-appropriate decisions. For instance, a cost analysis tool that could help the Port guide investment decisions in the face of sea level rise may be a valuable tool to develop.
- As an example, WSDOT has committed to consulting the results of its vulnerability assessment (2011) when designing future transportation improvements.
- The WA state departments of transportation, commerce, ecology and health are developing joint webpages and data resources to help create resilient, transportation efficient communities. This effort is carried out under Governor's Exec Order 1404. Staff at WSDOT and Commerce are available to coach community planners interested in conducting their own qualitative climate change vulnerability assessments (using WSDOT and Federal Highway's framework)[136].

CI-6: Create critical area flood mapping beyond FEMA's historical flood data					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
17	Planning	Near-term	Multi-Stakeholder	*Low cost with moderate political feasibility*	

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Cities and Counties should establish a climate change flood overlay as part of the critical area designations specific to their future flood concerns and use it to in addition to the FEMA flood maps which are constrained by only using historical data.
- Conduct education to community and developers about the change.

CI-7: Encourage soft defenses for shoreline infrastructure					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
16	Policy	Near-term	Local Governments and Private Sector	*High cost with moderate political support. Rated highly for environmental benefits.*	*Ecosystems*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Protect and restore natural systems along the shoreline to enhance buffer between coastal storms and development.
- Develop protective green infrastructure in front of the facilities to create a natural buffer to storm surge and flooding.
- Remove hard protection or other barriers to shoreline retreat where feasible.
- Adopt soft defense strategies, such as establishing aquatic vegetation beds, using natural or artificial breakwaters and beach nourishment, where appropriate (e.g., sensitive habitats).

CI-8: Improve on-site stormwater management practices					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
16	Policy	Near-term	Multi-stakeholder	*Adaptable, high cost, and moderate political and social feasibility*	*Ecosystems Water Supplies*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Create monetary & non-monetary incentives for Stormwater Management or re-use, including within Low Impact Development (LID) projects. Applies to residential, industry, agriculture, and forestry sectors.
- Create pilot projects to demonstrate the value of on-site stormwater management. Examples include green roofs, rain gardens, cisterns, and bioswales.
- Effective on-site stormwater management can assist in preventing roads from washing out.

CI-9: Participate in FEMA's Community Rating System (CRS)					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
16	Planning	Medium-term	Multi-stakeholder	*Less adaptable, low cost, and with moderate political support*	

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Dedicate a staff person to learn more about what is involved in participation in the FEMA Community Rating System (CRS – http://www.fema.gov/national-flood-insurance-program-community-rating-system).
- Explore and if needed, develop more stringent regulations for homeowners in flood zones, so that the community is eligible for a reduction in insurance rates.
- Implement relevant actions under the CRS to become an official CRS community.

CI-10: Enhance stormwater retention in upstream areas					
Score	Type of Strategy	Timeframe for Implementation*	Lead Group (s)	Opportunities or Concerns	Focus Area Co-benefits
16	Policy	Medium-term	Multi-stakeholder	*Marginally adaptable, high cost, and marginally politically feasible*	*Ecosystems Water Supplies*

*Near-term (0-3 years), Medium-term (3-10 years), Long-term (>10 years)

Key Action Steps:

- Review other community policies aimed at stormwater retention.
- Draft and pass policy that uses conservation of natural ecosystems, enhance riparian buffers and land management to increase stormwater retention.
- Effective stormwater retention in upstream areas can assist in preventing roads from washing out.

In addition to the "top-10" strategies listed above, there are other strategies that ranked lower not because they would be ineffective, but because they faced some political, social, technical or other implementation challenges. For example: ***developing an inverted block rate structure for water and sewer billing*** would incentivize conservation and additional system capacity could serve as a buffer for drought periods. However, this strategy ranked low due to the fact that it is politically difficult to raise utility rates.

A strategy that was raised but not evaluated due to time constraints was **adopting new flood risk management standards and guidelines.** This potential strategy mirrors recently passed guidance from the White House to federal agencies on how to incorporate flood risk into federal projects. The guidance specifies using one of three approaches when designing new projects:

- Informed Science Approach: Use the best available climate science data to determine future flood conditions, and elevate structures above that future flood level
- Freeboard Value Approach: Elevate structures and facilities two feet for standard projects and three feet for critical projects above the 100-year flood level;

- 500-Year Elevation Approach: Elevate structures to the 500-year flood level (a flood with a 0.2 percent chance of occurring in any given year)

When discussing options for protecting shorelines and infrastructure from rising sea levels and coastal flood risk, approaches may differ greatly by circumstance. The three general categories of responses to sea level rise are referred to as ***protection, accommodation, or retreat***. For "Protection" efforts, the use of soft shoreline armoring can provide similar coastal defense for infrastructure as hard shoreline armoring does, but without the associated negative impacts on the nearshore ecosystem from wave deflection and scouring of the nearshore habitat. However, the feasibility of soft shoreline protection must be assessed on a case-by-case basis. Particularly, for critical infrastructure such as wastewater treatment plans or hospitals, it may be extremely costly or impossible to relocate those facilities, thereby necessitating hard shoreline protection efforts to guarantee the facilities remain operational during extreme weather events.

Another strategy of particular relevance to this project is the development of **Climate Action Plans.** There is an increasing recognition that climate change action should include both greenhouse gas emission reductions and adaptation planning, and that climate actions plans can be a useful approach to integrating those two sets of strategies. Developing strategies to reduce greenhouse gas emissions may increase the likelihood of state funding for capital improvement projects[137]. An example of a useful approach involves the City of Baltimore who chose to embed both their greenhouse gas emissions and climate adaptation actions into their all hazards mitigation plan[138]. On the North Olympic Peninsula, community volunteers initially took the lead on developing the Climate Action Plan for Port Townsend and Jefferson County. In the realm of critical infrastructure specifically, the WA State Departments of Transportation, Commerce, Ecology and Health are developing joint webpages and data resources to help create resilient, transportation efficient communities. This effort is carried out under the Governor's Exec Order 1404. Staff at WSDOT and Commerce are available to coach community planners interested in conducting their own qualitative climate change vulnerability assessments (using WSDOT and Federal Highway's framework)[139]. There are many ongoing opportunities across entities and sectors in the region to initiate these important climate-planning processes.

D. Concluding Remarks

Preparing for the impacts of a changing climate and building resilience is a process and not an outcome. By participating in the development of this preparedness plan, appendices, and supplementary information all of the partners involved have initiated this resilience building process. This project has already borne rich cross-sectoral discussions and enhanced and strengthened professional networks and social connections. With continued collaboration, the recommended actions and processes of this project have the potential to ***not only build overall climate resilience on the North Olympic Peninsula, but promote best possible future outcomes for the region's inhabitants and ecosystems.***

III. List of Appendices

Appendices are available to the Public from the North Olympic Peninsula Resource Conservation and Development Council on their website (www.noprcd.org), or please contact the council: info@noprcd.org ; (360) 301-1750 ; P.O. Box 894 Port Townsend, WA 98368

Appendix A: Comprehensive List of Adaptation Strategies

Appendix B: Adaptation Strategy Matrix

Appendix C: Sea Level Rise Probability Maps

Appendix D: Sea Level Rise Analysis Details

Appendix E: Monitoring Plan

Appendix F: Focus Area Overview Maps

IV. List of Supplementary Information

Appendices are available to the Public from the North Olympic Peninsula Resource Conservation and Development Council on their website (www.noprcd.org), or please contact the council: info@noprcd.org ; (360) 301-1750 ; P.O. Box 894 Port Townsend, WA 98368

Supplementary Information A: List of Project Partners

Supplementary Information B: Climate Preparedness Outreach PowerPoint

Supplementary Information C: Planning Language Examples for Climate Resiliency

Supplementary Information D: Workshop 1 Results

Supplementary Information E: Workshop 2 Results

Supplementary Information F: GIS Map Development

V. References

[1] Olympic National Park. "*Glaciers and Climate Change*". Webpage. Available: http://www.nps.gov/olym/learn/nature/glaciers.htm

[2] Unless otherwise noted, climate observations and projections in this table are from; University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[3] Kunkel, K., Stevens, L., Stevens, S., Liquiang, S., Janssen, E., Wuebbles, D., Redmond, R., Dobson, J.G., 2013 Regional Climate Trends and Scenarios for the U.S. national Climate Assessment, NOAA Technical Report NESDIS142-6.

[4] Mantua, N., Tohver, I., Hamlet, A., 2009. *The Washington Climate Change Impacts Assessment: Impacts of Climate Change on Key Aspects of Freshwater Salmon Habitat in Washington State*. In The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, Washington. Available: http://cses.washington.edu/db/pdf/wacciach6salmon649.pdf

[5] See section I.E. of this report, and Appendix C & D, for more information on this Sea Level Rise modeling methodology and outcomes.

[6] Ibid.

[7] U.S. Global Change Research Program. National Climate Assessment, 2014. http://nca2014.globalchange.gov/

[8] Intergovernmental Panel on Climate Change, 2014. United Nations. Fifth Assessment Report (AR5). Working Group II: Impacts, Adaptation, and Vulnerability. ANNEX II: GLOSSARY. Available: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-AnnexII_FINAL.pdf

[9] Hewitson, B., A.C. Janetos, T.R. Carter, F. Giorgi, R.G. Jones,W.-T. Kwon, L.O. Mearns, E.L.F. Schipper, and M. van Aalst, 2014: Regional context. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi,Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)].Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1133-1197.

[10] U.S. Bureau of the Census, Population Estimates Program (PEP). Updated annually. http://www.census.gov/popest/index.html. Census Bureau, 2010 Census of Population, Public Law 94-171 Redistricting Data File. Updated every 10 years. http://factfinder2.census.gov.

[11] Ibid.

[12] Mote, P., A. K. Snover, S. Capalbo, S. D. Eigenbrode, P. Glick, J. Littell, R. Raymondi, and S. Reeder, 2014: Ch. 21: North- west. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Rich- mond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 487-513.

[13] Intergovernmental Panel on Climate Change, 2014. United Nations. Fifth Assessment Report (AR5). Working Group II: Impacts, Adaptation, and Vulnerability. ANNEX II: GLOSSARY. Available: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-AnnexII_FINAL.pdf

[14] U.S. Global Change Research Program. National Climate Assessment 2014. Highlights. Available; http://nca2014.globalchange.gov/highlights/overview/overview

[15] Ibid.

[16] Ibid.

[17] Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014: Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT.

[18] Jeff County. Resolution. 44-07/ City of Port Townsend Resolution 07-022

[19] U.S. Global Change Research Program. National Climate Assessment, 2014. http://nca2014.globalchange.gov/

[20] U.S. Global Change Research Program. National Climate Assessment, 2014. *Northwest Region.* http://nca2014.globalchange.gov/report/regions/northwest

[21] U.S. Global Change Research Program. National Climate Assessment, 2014. *Northwest Region. Coasts.* http://nca2014.globalchange.gov/report/regions/coasts

[22] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[23] 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.

[24] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[25] Tillmann, P., D. Siemann, & P. Glick. *Executive Summaries for Marine & Coastal, Freshwater, and Terrestrial Ecosystems.* Climate Change Effects & Adaptation Approaches in Ecosystems, Habitats, and Species: A Compilation of Scientific Literature for the North Pacific Landscape Conservation Cooperative Region. 2013. http://www.nwf.org/~/media/PDFs/Global-Warming/2014/Executive-Summaries-of-all-three-NPLCC-reports.pdf

[26] Olympic National Forest and Olympic National Park. Gen. Tech. Rep. PNW-GTR-844. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 130 p. http://www.fs.fed.us/pnw/pubs/pnw_gtr844.pdf

[27] Washington State Blue Ribbon Panel on Ocean Acidification. *Ocean Acidification; From Knowledge to Action, Washington's Strategic Response, 2012.* https://fortress.wa.gov/ecy/publications/publications/1201015.pdf

[28] Miller, I.M, Shishido, C., Antrim, L., Bowlby, C.E. (Eds.), 2013. *Climate Change and the Olympic Coast National Marine Sanctuary: Interpreting Potential Futures.* U.S. Department of Commerce. http://sanctuaries.noaa.gov/science/conservation/cc_ocnms.html

[29] Washington State Department of Transportation (WSDOT), 2011. *Climate Impacts Vulnerability Assessment*. http://www.wsdot.wa.gov/NR/rdonlyres/B290651B-24FD-40EC-BEC3-EE5097ED0618/0/WSDOTClimateImpactsVulnerabilityAssessmentforFHWAFinal.pdf

[30] Washington State Department of Transportation, 2014. *Results WSDOT: Our Strategic Plan.* See Goal 3 Environmental Stewardship. Available: http://www.wsdot.wa.gov/Secretary/ResultsWSDOT.htm & Personal communication with *Carol Lee Roalkvam-WSDOT, 8-19-15.*

[31] Clallam County, 2009. *Clallam County Community Wildfire Protection Program.* Available: http://wa-dnr.s3.amazonaws.com/publications/rp_burn_cwpp_clallamco.pdf

[32] Portland State University, College of Urban and Public Affairs, 2011. *Environment Migrants and the Future of the Willamette Valley.* http://www.pdx.edu/usp/sites/www.pdx.edu.usp/files/Environmental_Migrants.pdf

[33] Swinomish Indian Tribe, 2009 & 2010. *Impact Assessment Technical Report* & *Climate Adaptation Action Plan*. http://www.swinomish.org/climate_change/project/reports.html

[34] Jamestown S'Klallam Tribe, 2013. *Climate Change Adaptation Report.* http://www.jamestowntribe.org/programs/nrs/nrs_climchg.htm

[35] City of Seattle Climate Action Plan, 2013. Seattle Office of Sustainability and Environment. Available: http://www.seattle.gov/Documents/Departments/OSE/2013_CAP_20130612.pdf

[36] Whitley-Binder, L., Snover, A., Shatzkin, A., Roalkvam, C., 2014. Sound Transit Climate Risk Reduction Project – 2014, project summary finding presented at the Pacific Northwest Climate Science Conference in 2014 http://pnwclimateconference.org/Seattle2014/2014presentations/Whitely-Binder.pdf

[37] Cramer,W., G.W. Yohe, M. Auffhammer, C. Huggel, U. Molau, M.A.F. da Silva Dias, A. Solow, D.A. Stone, and L. Tibig, 2014: Detection and attribution of observed impacts. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II

to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 979-1037. Available; http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap18_FINAL.pdf *pg. 985*

[38] Intergovernmental Panel on Climate Change, 2014. United Nations. Fifth Assessment Report (AR5). Working Group II: Impacts, Adaptation, and Vulnerability. ANNEX II: GLOSSARY. Available: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-AnnexII_FINAL.pdf

[39] Intergovernmental Panel on Climate Change, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change, edited by Christopher B. Field, Vicente Barros, Thomas F. Stocker, Qin Dahe, David Jon Dokken, Gian-Kasper Plattner, Kristie L. Ebi, Simon K. Allen, Michael D. Mastrandrea, Melinda Tignor, Katharine J. Mach, and Pauline M. Midgley. Cambridge, UK and New York: Cambridge University Press.

[40] Clallam County, 2009. *Clallam County Community Wildfire Protection Program.* Available: http://wa-dnr.s3.amazonaws.com/publications/rp_burn_cwpp_clallamco.pdf

[41] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. Page 3-4. http://cses.washington.edu/cig/reports.shtml

[42] Ibid.

[43] Dalton, M., Mote, P., Snover, A. 2013. *Climate Change in the Northwest: Implications for our Landscapes, Waters and Communities*. Island Press. http://www.cakex.org/sites/default/files/documents/ClimateChangeInTheNorthwest.pdf

[44] Abatzoglou, J., Rupp, D., Mote, P., 2014. Seasonal Climate Variability and Change in the Pacific Northwest of the United States. American Meteorological Society.

[45] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[46] Kunkel, K., Stevens, L., Stevens, S., Liquiang, S., Janssen, E., Wuebbles, D., Redmond, R., Dobson, J.G., 2013 Regional Climate Trends and Scenarios for the U.S. national Climate Assessment, NOAA Technical Report NESDIS142-6.

[47] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[48] Ibid.

[49] Ibid.

[50] National Climate Change Viewer (NCCV), U.S. Geological Survey http://www.usgs.gov/climate_landuse/clu_rd/nex-dcp30.asp

[51] Ibid.

[52] Ibid.

[53] Ibid.

[54] Kunkel, K., Stevens, L., Stevens, S., Liquiang, S., Janssen, E., Wuebbles, D., Redmond, R., Dobson, J.G., 2013 Regional Climate Trends and Scenarios for the U.S. national Climate Assessment, NOAA Technical Report NESDIS142-6.

[55] Kunkel, K., Stevens, L., Stevens, S., Liquiang, S., Janssen, E., Wuebbles, D., Redmond, R., Dobson, J.G., 2013 Regional Climate Trends and Scenarios for the U.S. national Climate Assessment, NOAA Technical Report NESDIS142-6.

[56] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[57] Washington State Department of Transportation (WSDOT), 2011. *Climate Impacts Vulnerability Assessment*. PAGE 8 http://www.wsdot.wa.gov/NR/rdonlyres/B290651B-24FD-40EC-BEC3-EE5097ED0618/0/WSDOTClimateImpactsVulnerabilityAssessmentforFHWAFinal.pdf

[58] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[59] Kunkel, K., Stevens, L., Stevens, S., Liquiang, S., Janssen, E., Wuebbles, D., Redmond, R., Dobson, J.G., 2013 Regional Climate Trends and Scenarios for the U.S. national Climate Assessment, NOAA Technical Report NESDIS142-6.

[60] Abatzoglou, J., Rupp, D., Mote, P., 2014. Seasonal Climate Variability and Change in the Pacific Northwest of the United States. American Meteorological Society. DOI: 10.1175/JCLI-D-13-00218.1

[61] Olympic National Park. "*Glaciers and Climate Change*". Webpage. Available: http://www.nps.gov/olym/learn/nature/glaciers.htm

[62] National Climate Change Viewer (NCCV), U.S. Geological Survey http://www.usgs.gov/climate_landuse/clu_rd/nex-dcp30.asp

[63] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[64] Ibid.

[65] National Climate Change Viewer (NCCV), U.S. Geological Survey http://www.usgs.gov/climate_landuse/clu_rd/nex-dcp30.asp

[66] Ibid.

[67] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[68] National Climate Change Viewer (NCCV), U.S. Geological Survey http://www.usgs.gov/climate_landuse/clu_rd/nex-dcp30.asp

[69] Ibid.

[70] Kunkel, K., Stevens, L., Stevens, S., Liquiang, S., Janssen, E., Wuebbles, D., Redmond, R., Dobson, J.G., 2013 Regional Climate Trends and Scenarios for the U.S. national Climate Assessment, NOAA Technical Report NESDIS142-6.

[71] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[72] Kunkel, K., Stevens, L., Stevens, S., Liquiang, S., Janssen, E., Wuebbles, D., Redmond, R., Dobson, J.G., 2013 Regional Climate Trends and Scenarios for the U.S. national Climate Assessment, NOAA Technical Report NESDIS142-6.

[73] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[74] University of Colorado, CU Sea Level Research Group. "Global Mean Sea Level". Available: sealevel.colorado.edu

[75] Kopp, R. E., Horton, R. M., Little, C. M., Mitrovica, J. X., Oppenheimer, M., Rasmussen, D. J., Strauss, B. H. and Tebaldi, C. (2014), Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future, 2: 383–406.

[76] Church, J. A., N. J. White, L. F. Konikow, C. M. Domingues, J. G. Cogley, E. Rignot, J. M. Gregory, M. R. van den Broeke, A. J. Monaghan, and I. Velicogna (2011), *Revisiting the Earth's sea-level and energy budgets from 1961 to 2008,* Geophys. Res. Lett., 38, L18601

[77] U.S. Global Change Research Program. National Climate Assessment, 2014. http://nca2014.globalchange.gov/

[78] Kopp, R. E., Horton, R. M., Little, C. M., Mitrovica, J. X., Oppenheimer, M., Rasmussen, D. J., Strauss, B. H. and Tebaldi, C. (2014), Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future, 2: 383–406.

[79] eg. Harig, C. & Simons, F.J., 2015. Accelerated West Antarctic ice mass loss continues to outpace East Antarctic gains. Earth and Planetary Science Letters 415 (2015) 134–141

[80] Kopp, R. E., Horton, R. M., Little, C. M., Mitrovica, J. X., Oppenheimer, M., Rasmussen, D. J., Strauss, B. H. and Tebaldi, C. (2014), Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future, 2: 383–406.

[81] Kopp, R.E., 2015. LocalizeSL: Offline sea-level localization code for Kopp et al. (2014). Available: https://zenodo.org/record/15507 - .VR7YnZNLUlA

[82] Rahmstorf, S, Foster, G., Cazenave, A. (2012): Comparing climate projections to observations up to 2011. Environmental Research Letters 7 044035.

[83] Kopp, R. E., Horton, R. M., Little, C. M., Mitrovica, J. X., Oppenheimer, M., Rasmussen, D. J., Strauss, B. H. and Tebaldi, C. (2014), Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future, 2: 383–406.

[84] Santamaria-Gomez, A., Gravelle, M., and Woppelmann, G. 2013. Long-term vertical land motion from double-differenced tide gauge and satellite altimetry data. Journal of Geodesy, 88(3): 207-222.

[85] NASA. Time Series for Station SC02. Available: http://sideshow.jpl.nasa.gov/post/links/SC02.html

[86] NASA. GPS Time Series. Available: http://sideshow.jpl.nasa.gov/post/series.html

[87] Zervas, C. 2005. Response of extreme storm tides levels to long-term sea level change. NOAA National Ocean Service. Available at http://tidesandcurrents.noaa.gov/est/050415-53.pdf

[88] Climate Central. Surging Seas: Sea level rise analysis, Risk Finder: Washington. Available: http://sealevel.climatecentral.org/ssrf/washington

[89] Ibid.

[90] Committee on Sea Level Rise in California, Oregon and Washington. 2012. Chapter 6: Responses of the natural shoreline to sea-level rise. In: Sea-level rise for the coasts of California, Oregon and Washington. The National Academies Press.

[91] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[92] Mote, P.W., & Salathé, E.P., 2010. Future climate in the Pacific Northwest. *Climatic Change*, 102(1-2): 29-50.

[93] Bond, N. A., M. F. Cronin, H. Freeland, and N. Mantua (2015), Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophys. Res. Lett., 42, 3414–3420.

[94] Feely, R.A., Klinger, T., Newton, J.A., Chadsey, M., 2012. Scientific Summary of Ocean Acidification in Washington State Marine Waters. Washington State Blue Ribbon Panel on Ocean Acidification. Technical summary available at: https://fortress.wa.gov/ecy/publications/SummaryPages/1201016.html

[95] U.S. Global Change Research Program. National Climate Assessment, 2014. http://nca2014.globalchange.gov/

[96] Feely, R.A., Alin, S.R., Newton, J., Sabine, C.L., Warner, M., Devol, A., Krembs, C., Maloy, C., 2010.The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Estuarine Coastal and Shelf Science 88, 442-449.

[97] Washington State Blue Ribbon Panel on Ocean Acidification, 2012. Scientific Summary of Ocean Acidification in Washington State Marine Waters. Available: http://www.pmel.noaa.gov/pubs/PDF/feel3934/feel3934.pdf

[98] Miller, I.M, Shishido, C., Antrim, L., Bowlby, C.E. (Eds.), 2013. *Climate Change and the Olympic Coast National Marine Sanctuary: Interpreting Potential Futures.* U.S. Department of Commerce. http://sanctuaries.noaa.gov/science/conservation/cc_ocnms.html

[99] Ibid.

[100] Dalton, M., Mote, P., Snover, A. 2013. *Climate Change in the Northwest: Implications for our Landscapes, Waters and Communities*. Island Press.

[101] Bylhouwer, B., D. Ianson, and K. Kohfeld (2013), Changes in the onset and intensity of wind-driven upwelling and downwelling along the North American Pacific coast, J. Geophys. Res. Oceans, 118, 2565–2580, doi:10.1002/jgrc.20194.

[102] Northwest Power and Conservation Council & Harrison, J., 2015. "*Warm Water Blamed for Huge Columbia River Sockeye Die-off* ". Available: https://www.nwcouncil.org/news/blog/sockeye-die-ff-july-2015/

[103] Halofsky, Jessica E.; Peterson, David L.; O'Halloran, Kathy A.; Hawkins Hoffman, Catherine, eds. 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. Gen. Tech. Rep. PNW-GTR-844. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 130 p. http://www.fs.fed.us/pnw/pubs/pnw_gtr844.pdf

[104] National Climate Change Viewer (NCCV), U.S. Geological Survey http://www.usgs.gov/climate_landuse/clu_rd/nex-dcp30.asp

[105] Ibid.

[106] Dalton, M., Mote, P., Snover, A. 2013. *Climate Change in the Northwest: Implications for our Landscapes, Waters and Communities*. Island Press. http://www.cakex.org/sites/default/files/documents/ClimateChangeInTheNorthwest.pdf

[107] Ibid.

[108] Ibid.

[109] Ibid.

[110] University of Washington, Climate Impacts Group, 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers*. http://cses.washington.edu/cig/reports.shtml

[111] Ibid.

[112] Ibid.

[113] Headwaters Economics, 2013. As Wildland Urban Interface (WUI) Develops, Firefighting Costs Will Soar. Available: http://headwaterseconomics.org/dataviz/wui-development-and-wildfire-costs

[114] Flores, L., Harrison-Cox, J., Wilson, S., Batker, D. 2013. Nature's Value in Clallam County: The Economic Benefits of Feeder Bluffs and 12 Other Ecosystems. Earth Economics: Tacoma, Washington.

[115] Coastal Watershed Institute, 2015. *"High Feeder Bluffs: What they mean to you, and how to understand natural processes to inform a community 'Living on the Edge'"*. Available: http://www.coastalwatershedinstitute.org/blog/?p=169

[116] Flores, L., Harrison-Cox, J., Wilson, S., Batker, D. 2013. Nature's Value in Clallam County: The Economic Benefits of Feeder Bluffs and 12 Other Ecosystems. Earth Economics: Tacoma, Washington.

[117] WA State Department of Ecology & Sargeant, D., 2000. Quality Assurance Project Plan for Dungeness River/Matriotti Creek Fecal Coliform Bacteria Total Maximum Daily Load Study. Available: https://fortress.wa.gov/ecy/publications/publications/0003080.pdf

[118] Halofsky, Jessica E.; Peterson, David L.; O'Halloran, Kathy A.; Hawkins Hoffman, Catherine, eds. 2011. Adapting to climate change at Olympic National Forest and Olympic National Park. Gen. Tech. Rep. PNW-GTR-844. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 130 p. http://www.fs.fed.us/pnw/pubs/pnw_gtr844.pdf

[119] Ibid.

[120] Ibid.

[121] Cliff Mass Weather Blog, 2015. *"Oysters and Pesticides: The Washington State Department of Ecology Stumbles.*" Available: http://cliffmass.blogspot.com/2015/04/oysters-and-pesticides-washington-state.html?spref=fb

[122] Washington State Department of Transportation (WSDOT), 2011. *Climate Impacts Vulnerability Assessment*. http://www.wsdot.wa.gov/NR/rdonlyres/B290651B-24FD-40EC-BEC3-EE5097ED0618/0/WSDOTClimateImpactsVulnerabilityAssessmentforFHWAFinal.pdf

[123] Climate Impacts Group, University of Washington, 2010. Pacific Northwest (PNW) Hydroclimate Scenarios Project. http://warm.atmos.washington.edu/2860/

[124] USDA-Natural Resources Conservation Service. SNOTEL Update Report. Available: http://www.wcc.nrcs.usda.gov/reports/SelectUpdateReport.html

[125] Ibid.

[126] USGS Realtime stream flow compared to historical average for day of the year, http://waterwatch.usgs.gov/, accessed July 11th, 2015.

[127] Graphic from the Jefferson County Drought Forum presentation on July 14th, 2015 by Jeff Marti, Washington State Department of Ecology. Presentation available at: http://l2020.org/wp-content/uploads/2015/07/Drought-Forum-JeffCo-July14-2015small.pdf

[128] University of Washington Drought Monitoring System for the Pacific Northwest http://www.hydro.washington.edu/forecast/monitor_west/ accessed July 11th, 2010.

[129] Ibid.

[130] Graphic from the Jefferson County Drought Forum presentation on July 14th, 2015 by Ian Jablonski, City of Port Townsend. Data from the USGS. Presentation available at: http://l2020.org/wp-content/uploads/2015/07/Drought-Forum-JeffCo-July14-2015small.pdf

[131] Information from the Jefferson County Drought Forum presentation on July 14th, 2015. Presentation available at: http://l2020.org/wp-content/uploads/2015/07/Drought-Forum-JeffCo-July14-2015small.pdf

[132] Washington State Department of Transportation (WSDOT), 2011. *Climate Impacts Vulnerability Assessment*. http://www.wsdot.wa.gov/NR/rdonlyres/B290651B-24FD-40EC-BEC3-EE5097ED0618/0/WSDOTClimateImpactsVulnerabilityAssessmentforFHWAFinal.pdf

[133] Ibid

[134] Ibid.

[135] Personal communication with *Carol Lee Roalkvam-WSDOT, 8-19-15.*

[136] State of Washington Department of Commerce, 2015. "*Climate Change Adaptation*" Available: http://www.commerce.wa.gov/Services/localgovernment/GrowthManagement/Growth-Management-Planning-Topics/Climate-Change-and-Energy/Pages/Climate-Change-Adaptation.aspx

[137] Revised Code of Washington. RCW – 70.235.070: *Distribution of funds for infrastructure and capital development projects — Prerequisites*. Available: http://rcw.tswartz.com/70.235.070

[138] City of Baltimore, 2013. *Disaster preparedness and planning project report*. Available: http://www.baltimoresustainability.org/sites/baltimoresustainability.org/files/Baltimore_DP3_DRAFTPlan_9.19.13_v2.pdf

[139] WA Department of Commerce. *"Climate Change Adaptation"*. Available: http://www.commerce.wa.gov/Services/localgovernment/GrowthManagement/Growth-Management-Planning-Topics/Climate-Change-and-Energy/Pages/Climate-Change-Adaptation.aspx