Appendix A

Science Summary

THURSTON
CLIMATE
ADAPTATION
PLAN

Science Summary

Thurston Regional Planning Council

August 2016

FINAL

This page is left blank intentionally.

Contributors

Report Authors

Michael Burnham, Associate Planner, TRPC
Ben Silver, GIS Technician, TRPC

Science Advisory Committee

Lara Whitely Binder, Senior Strategist, University of Washington Climate Impacts Group
Carrie Parr (Pucko), Professor of Biology and Environmental Studies, The Evergreen State College
Chris Ellings, Salmon Recovery Program Manager, Nisqually Indian Tribe
Candace Penn, Climate Change Specialist, Squaxin Island Tribe
Morgan Greene, Program Coordinator, Nisqually River Council

Project Team

Michael Burnham, Associate Planner & Project Manager, TRPC
Allison Osterberg, Senior Planner, Thurston County
Veena Tabbutt, Interim Executive Director, TRPC
Paul Brewster, Senior Planner, TRPC
Scott Carte, GIS Coordinator
Michael Ambrogi, Senior GIS Analyst, TRPC
Ben Silver, GIS Technician
Katrina Van Every, Associate Planner, TRPC

Acknowledgments

The Thurston Regional Planning Council (TRPC) prepared this report — which provides an overview of observed and projected climate change impacts at the global, national and regional scales — as part of the Thurston Climate Adaptation Plan project. The ongoing effort is funded by a U.S. Environmental Protection Agency National Estuary Program grant (#: 15-63401-001), which is being administered by the Washington Department of Commerce. For more information, please visit www.trpc.org/climate.

This page is left blank intentionally.

Table of Contents

1: Planning Framework

The Thurston Regional Planning Council (TRPC) is using a U.S. EPA National Estuary Program (NEP) grant administered by the Washington Department of Commerce to draft a watershed-based climate adaptation plan (Thurston Climate Adaptation Plan). The Plan will recommend strategies for the Thurston County region (Thurston Region) to prepare for and cope with storms, floods, droughts, wildfires, and other hazards exacerbated by climate change in the decades ahead.

This *Science Summary* — the adaptation plan's first deliverable — provides an overview of observed and projected climate change impacts at the global, national and regional scales. The *Science Summary* also provides an overview of the emissions scenarios and models used by the United Nations Intergovernmental Panel on Climate Change (IPCC) and the University of Washington Climate Impacts Group (UW CIG). The UW CIG's 2015 *State of Knowledge* report (Mauger et al., 2015), which projects climate change impacts within Puget Sound's watersheds, is the main data source for the analysis, maps and tables in the Thurston Climate Adaptation Plan's second deliverable — a *Vulnerability Assessment*, which serves as the foundational document for assessing the region's climate change risks and developing adaptation strategies.

Regional Goals & Targets

The Sustainable Thurston plan that Thurston Regional Planning Council (TRPC) policymakers adopted in late 2013 and subsequently integrated into local comprehensive planning efforts envisions the Thurston Region as a model for sustainable development in the decades ahead. The plan — formally known as *Creating Places—Preserving Spaces: A Sustainable Development Plan for the Thurston Region* — has 12 priority goals,[1] including:

- Protect and improve water quality, including groundwater, streams, lakes, and Puget Sound;
- Ensure that the water supply sustains people in perpetuity while protecting the environment;
- Move toward a "carbon-neutral" community (i.e., zero-out the region's net greenhouse gas emissions that contribute to global climate change);
- Maintain compliance with state and federal air-quality standards; and,
- Preserve environmentally sensitive lands, including farms, wetlands, forests and prairies.

One of Sustainable Thurston's first action steps is to develop a comprehensive climate plan with mitigation and adaption strategies for the region's public and private sectors (TRPC, 2013). Sustainable Thurston's targets to reduce regional greenhouse gas emissions provide the mitigation framework:

- Achieve 25 percent reduction of 1990 levels by 2020;
- Achieve 45 percent reduction of 1990 levels by 2035; and,
- Achieve 80 percent reduction of 1990 levels by 2050.

The Thurston Region — which includes the municipalities, urban growth areas, unincorporated rural lands, tribal reservations, and usual and accustomed tribal harvest areas within Thurston County — has been growing about twice as fast as its carbon footprint. Even so, the region has much work ahead to hit its emissions-reduction targets.

[1] At its second meeting (July 2016), the project's Stakeholder Advisory Committee selected the 12 Sustainable Thurston goals as the goals for the *Thurston Climate Adaptation Plan*.

In 2012, the Thurston Region's direct greenhouse gas emissions totaled roughly 2.71 million metric tons of carbon dioxide equivalent — up about 30 percent from the 1990 total [2.09 million metric tons of CO_2 equivalent] (Thurston Climate Action Team, 2014); the region's population grew by about 59 percent over the same period (TRPC, 2016).

Figure 1. Night traffic on Interstate 5, as seen from the Boulevard Road overpass. Vehicles constitute Thurston County's second-largest source of greenhouse gas emissions, after buildings. ***Source:*** *TRPC*

Global Targets

A growing body of scientific research concludes that the United States and other industrialized nations must hit something close to the 2050 emissions target — which also has been adopted by California, King County, Portland, Ore., and many other state and local governments — in order to stabilize atmospheric concentrations of carbon dioxide and other heat-trapping gases at 450 parts per million. This stabilization target, expressed as 450 ppm CO_2eq, provides a medium chance of preventing the global average temperature from rising more than 2 °Celsius (3.6 °Fahrenheit) above pre-industrial levels (i.e., before the 1860s) (Luers, Mastrandrea, Hayhoe, & Frumhoff, 2007).

The United Nations Framework Convention on Climate Change's "Paris Agreement," which the United States and other nations brokered in late 2015, includes the 2°C target but also stresses the importance of pursuing a more aggressive 1.5°C (2.7°F) target so as to mitigate the most dangerous climate change risks (Figueres, 2015). Such risks include warming oceans, melting polar ice, and rising seas sufficient to displace millions of coastal residents around the world in the centuries ahead (Clark et al., 2016).

Climate change adaptation — that is, preparing for and adjusting to the effects of a warming world — is just as critical as mitigation. Indeed, adaptation is "necessary to address impacts resulting from the warming that is already unavoidable" due to past emissions, the IPCC — the United Nations' climate research arm — concluded in its Nobel Prize-winning 2007 climate assessment (Klein et al., 2007).

> **Climate change adaptation entails "efforts by society or ecosystems to prepare for or adjust to future climate change."**
>
> — U.S. Environmental Protection Agency

Even the most stringent efforts to reduce emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), tropospheric ozone (O_3) and other greenhouse gases "cannot avoid further impacts of climate change in the next few decades," the report explained. Fortunately, there's a lot we can do as a region today to remain resilient tomorrow.

Adaptation Plan Overview

The Thurston Climate Adaptation Plan's study area [*Figure 2*] includes the parts of three watersheds that overlay Thurston County and drain into Puget Sound; these watersheds — defined by the Washington Department of Ecology as Watershed Resource Inventory Areas (WRIAs) — include Nisqually (WRIA 11), Deschutes (WRIA 13), and Kennedy/Goldsborough (WRIA 14).

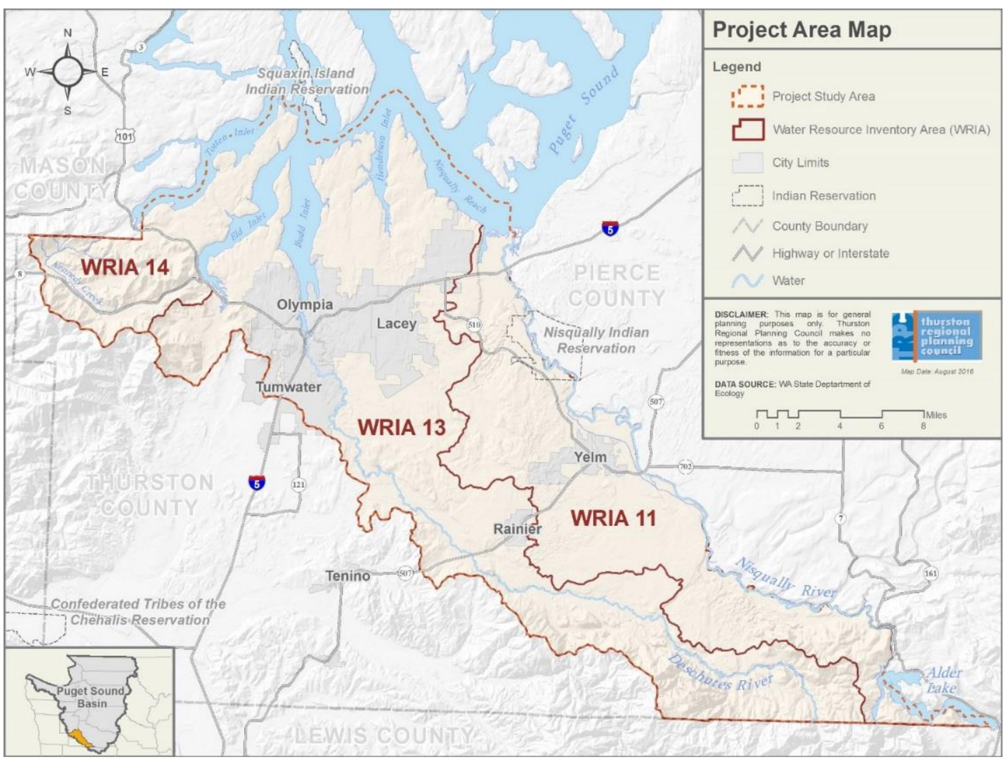

Figure 2: TRPC Climate Adaptation Plan study area. **Note:** The Nisqually and Squaxin tribes also have usual and accustomed harvest areas beyond the reservations noted within the study area. ***Source:*** *TRPC*

The planning scope of work includes: researching and analyzing global climate change projections; assessing regional climate change vulnerabilities and risks; developing adaptation strategies and conducting benefit-cost analyses; and, presenting TRPC policymakers a draft plan with adaptation recommendations for the region's public- and private-sector stakeholders.

2: Climate Change Impacts

> **"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased."**
>
> *— IPCC Synthesis Report, Summary for Policymakers, 2013*

Our individual actions affect our collective carbon footprint — whether we drive a car, charge a cellphone, or catch a plane. Emissions from burning all of those gallons of fuel and generating all of those kilowatts of electricity are adding up and changing the climate in significant ways.

Consider the science: The IPCC concluded in its 2013 global climate change synthesis report, it is "extremely likely" that human influence was the "dominant cause" of observed planetary warming between 1951 and 2010 (IPCC, 2013). Indeed, global climate models used in the report detect a human hand in warming of the atmosphere and the ocean, in changes in the global water cycle[2], in reductions in snow and ice, in global mean (average) sea-level rise, and in changes in some climate extremes.

There's no crystal ball that shows what the future holds, so scientists develop projections by running plausible scenarios of future greenhouse gas emissions through models that simulate global climate. These global scenarios can then be downscaled by researchers to produce climate change projections for temperature, precipitation, and other climate indicators at scales ranging from the Pacific Northwest to individual watersheds.

Science isn't static, of course. Climate scenarios reflect the scientific community's current understanding of complex and dynamic natural systems, coupled with informed assumptions about future human behaviors, economies, and technologies. Our understanding of these various components will continue to evolve over time, as will the climate projections developed on the basis of these components. Additionally, natural variability has and will continue to play a role in shaping Pacific Northwest climate.

The scientific research is clear, however: Our climate is changing in ways that could have significant implications for human and natural systems. Such research, summarized below,[3] provides the scientific foundation for the Thurston Climate Adaptation Plan.

2.1: The Planet

Shortly after calendars flipped to 2016, scientists reported that 2015 was the warmest year globally since modern record-keeping began in 1880. Last year's global average temperature was 58.62°F — about 1.62°F above the 20th century average (Borenstein, 2016). For the first time, the planet is now 1°C (1.8°F) warmer than it was in pre-industrial times (National Aeronautics and Space Administration, 2016). Just as noteworthy, 2015 marked the fourth time this century that a new record high for average

[2] The global water cycle includes precipitation over land, humidity, and ocean surface salinity as it relates to precipitation and evaporation.
[3] In several cases, this summary modifies text from the source documents (e.g., IPCC, 2013) only slightly so as to ensure technical accuracy. In-text citations are used to credit sources; footnotes are used to clarify terms, including those within quotation marks.

global temperature was set (National Oceanic and Atmospheric Administration, 2016). Taking a longer view, scientists conclude that each of the last three decades has been successively warmer at the planet's surface than any preceding decade since 1950. The rise in global temperatures is one of many lines of evidence, gathered through observations and instrumental data, that our climate is changing [*Figure 3*] (IPCC, 2013). For example, the 2013 IPCC report noted:

- **Atmosphere:** It is "virtually certain"[4] that the troposphere, the lowest layer of Earth's atmosphere where weather occurs, has warmed globally since the middle of the 20th century.
- **Ocean:** It is "virtually certain" that the upper ocean (roughly 0-1000 feet) warmed from 1971 to 2010, and it "likely" warmed between 1870s and 1971.
- **Cryosphere:** There is "high confidence" that, during the last two decades, the Greenland and Antarctic ice sheets lost mass, glaciers continued to shrink almost worldwide, and the extent of Arctic sea ice and Northern Hemisphere spring snow cover continued to decrease.
- **Sea Level:** There is "high confidence" that the rate of sea-level rise since the mid-19th century has been larger than the average rate during the previous two millennia.
- **Greenhouse Gases**: Atmospheric concentrations of carbon dioxide, methane, and nitrous oxide "substantially exceed" the highest concentrations recorded in ice cores spanning the past 800,000 years. The average rates of increase in concentrations over the past century are, with "very high confidence," unprecedented during the past 22,000 years.

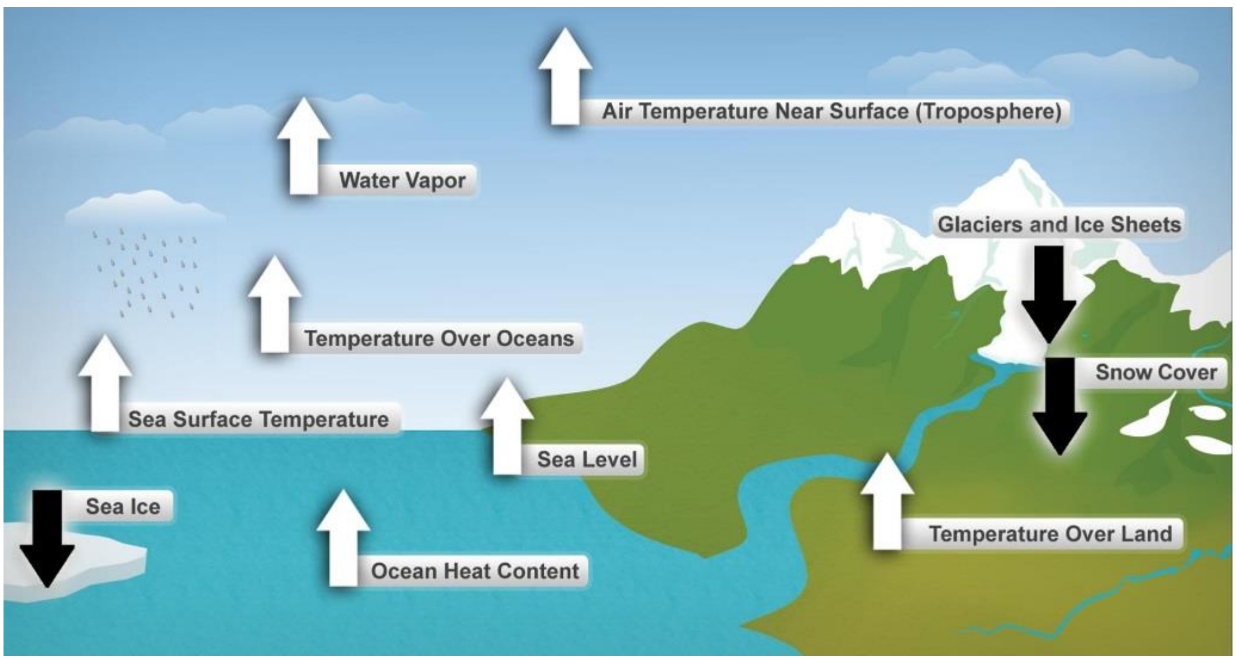

Figure 3: Key indicators of a changing climate (white arrows indicate increasing trends based on global observations; black arrows indicate decreasing trends)
Source: *U.S. Global Change Research Program, 2014: National Climate Assessment*

[4] The IPCC's 2013 *Summary for Policymakers* uses the following terms, which are based on the type, amount, quality, and consistency of evidence, to indicate the assessed likelihood of an outcome: "virtually certain," 99-100% probability; "very likely," 90-100% probability; "likely," 66-100% probability; "about as likely as not," 33-66% probability; "unlikely," 0-33% probability; "very unlikely," 0-10% probability. The report uses the following qualifiers to denote a level of confidence that is based on the degree of scientific agreement and available evidence: "very low," "low," "medium," "high," and "very high."

As noted previously, greenhouse gas scenarios — also known as Representative Concentration Pathways (RCPs) — are used in model simulations of the earth's future climate. These RCPs range from an "extremely low" scenario, involving aggressive emissions reductions, to a "high" (i.e., business-as-usual) scenario, involving continued substantial greenhouse gas emissions through 2100[5] [*Figure 4*]. Variations in the global climate model simulations reflect differences in how the models simulate major modes of natural variability (e.g., El Niño) and how the models respond to rising greenhouse gas emissions. The RCPs used by the University of Washington Climate Impacts Group in its latest synthesis of Puget Sound climate change impacts are noted with asterisk (*) in Figure 4.

Greenhouse gas scenarios (IPCC, 2013) [6]	**Scenario characteristics**	**Amount of carbon dioxide in the atmosphere, 2100[7]**	**Qualitative description, as used by UW CIG**
RCP 2.6	A very low emissions scenario that assumes ambitious greenhouse gas emissions reductions (*50% reduction in global emissions by 2050 relative to 1990 levels, and near or below zero net emissions in the final decades of the 21st century*)	400 parts per million (ppm)	"Very Low"
RCP 4.5*	A low scenario in which greenhouse gas emissions stabilize by mid-century and fall sharply thereafter	538 ppm	"Low"
RCP 6.0	A medium scenario in which greenhouse gas emissions increase gradually until stabilizing in the final decades of the 21st century	670 ppm	"Medium"
RCP 8.5*	A high scenario that assumes continued increases in greenhouse gas emissions until the end of the 21st century	936 ppm	"High"

Figure 4: Greenhouse gas emissions scenarios used in global and regional climate studies. The scenarios most commonly used in Pacific Northwest climate change studies are noted with an asterisk. Emission scenarios are typically updated every 5-10 years for use in Intergovernmental Panel on Climate Change (IPCC) global assessment reports, which are released every 5-7 years.
Source: *UW Climate Impacts Group*

[5] The IPCC and UW reports cited in this climate science summary make projections through 2100. However, a considerable fraction of the human-caused greenhouse gases that has been emitted or could be emitted during this century is expected to remain in the atmosphere for much longer and continue to impact sea levels and other climate indicators (Clark, et al., 2016).
[6] (IPCC) Intergovernmental Panel on Climate Change. 2013. *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.
[7] Atmospheric concentration values from Meinshausen, M., S.J Smith, K. Calvin, J.S. Daniel, M.L.T. Kainuma, J-F., Lamarque, K. Matsumoto, S.A. Montzka, S.C.B. Raper, K. Riahi, A. Thomson, G.J.M. Velders, and D.P. van Vuuren. 2011. The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic Change*, 109(1-2):213-241.

2.1A: Temperature

Global average temperature is projected to increase by 1.8°F to 6.7°F, on average, by the end of the century depending on the greenhouse gas scenario [*Figure 5*]. Further, it is "virtually certain" there will be more frequent hot and fewer cold temperature extremes across most land areas on daily and seasonal time scales as the global average temperature rises (IPCC, 2013). And while cold winter extremes will continue to occur, it is also "very likely" that summer heat waves will occur with a higher frequency and duration.

		2046-2065		2081-2100	
	Scenario	**Mean**	***Likely Range****	**Mean**	***Likely Range***
Global Mean Surface Temperature Change (°F)	RCP 2.6	1.8	0.7 to 2.9	1.8	0.5 to 3.1
	RCP 4.5	2.5	1.6 to 3.6	3.2	2.0 to 4.7
	RCP 6.0	2.3	1.4 to 3.2	4.0	2.5 to 5.6
	RCP 8.5	3.6	2.5 to 4.7	6.7	4.7 to 8.6
	Scenario	**Mean**	***Likely Range***	**Mean**	***Likely Range***
Global Mean Sea-Level Rise (inches)	RCP 2.6	9.5	6.7 to 12.6	15.7	10.2 to 21.7
	RCP 4.5	10.2	7.5 to 13.0	18.5	12.6 to 24.8
	RCP 6.0	9.8	7.1 to 12.6	18.9	13.0 to 24.8
	RCP 8.5	11.8	8.7 to 15.0	24.8	17.7 to 32.3

Figure 5: Projected change in global mean surface air temperature and global mean sea-level rise for the mid- and late-21st century relative to 1986-2005 [*Figures converted from Celsius to Fahrenheit and from meters to inches*].

Notes: * These figures are calculated from projections as 5-95% model ranges and then assessed to be "likely" ranges after accounting for additional uncertainties or different levels of confidence in models, the 2013 IPCC report explained. Confidence is "medium" for projections of global mean surface temperature change in 2046-2065; this is because the relative importance of natural internal variability, and uncertainty in non-greenhouse gas forcing and response, are larger than for 2081-2100. For projections of global mean sea-level rise, confidence is "medium" for both time periods. However, based on current understanding, only the collapse of marine-based portions of the Antarctic ice sheet could cause global average sea level to rise "substantially" above the likely range during the 21st century, the 2013 IPCC report underscored.

Source: *Adapted from Table SPM 2, IPCC 2013, Summary for Policy Makers*

2.1B: Precipitation

Changes in the global water cycle in response to warming will not be uniform. The contrast in precipitation between wet and dry regions and seasons will increase, although there may be regional exceptions (IPCC, 2013).

Indeed, it is "likely" that the equatorial Pacific Ocean and high latitudes will experience an increase in annual mean precipitation under RPC 8.5 (IPCC, 2013). In subtropical dry regions, precipitation will "likely" decrease by the end of the century; mean precipitation will "likely" increase in many mid-latitude regions (e.g., the Pacific Northwest) over the same period.

Extreme precipitation events over mid-latitude land masses and wet tropical regions will "very likely" become more intense and frequent as the global mean surface temperature rises (IPCC, 2013). As explained in greater detail in the following pages, projected changes in the timing, type, and intensity of precipitation will pose significant risks for the nation's and region's human and natural systems — everything from our stormwater and energy infrastructure to our streams and forests. This document's companion *Vulnerability Assessment* explores such risks throughout South Puget Sound and the project area.

2.1C: Oceans

Global ocean temperatures will continue to rise throughout the 21st century. The strongest ocean warming is projected, with "high confidence," for the surface in tropical and Northern Hemisphere subtropical regions; at greater depth, the strongest ocean warming will be throughout the southern extent of the world's oceans (IPCC, 2013). By the end of the century, warming in the oceans' top 100 meters (roughly 0-328 feet) will be about 1.1°F for RCP2.6 to 3.6°F for RCP8.5; at a depth of 1,000 meters (roughly 3,000 feet) warming will be about 0.6°F for RCP2.6 to 1.1°F for RCP8.5. The warmer temperatures will drive changes in ocean chemistry, depth, and ice coverage.

Global average sea-level rise for 2081-2100 relative to 1986-2005 will "likely" be in the ranges of 10.2 to 21.7 inches for RCP 2.6 and 17.7 to 32.3 inches for RCP 8.5 due to increased ocean warming and loss of mass from glaciers and ice sheets (IPCC, 2013).[8] Sea-level rise will not be uniform across the earth, however.

By the end of the 21st century, it is "very likely" that sea level will rise amid more than 95 percent of the global ocean area (IPCC, 2013), but coastal flood depths will vary depending on how land moves vertically.

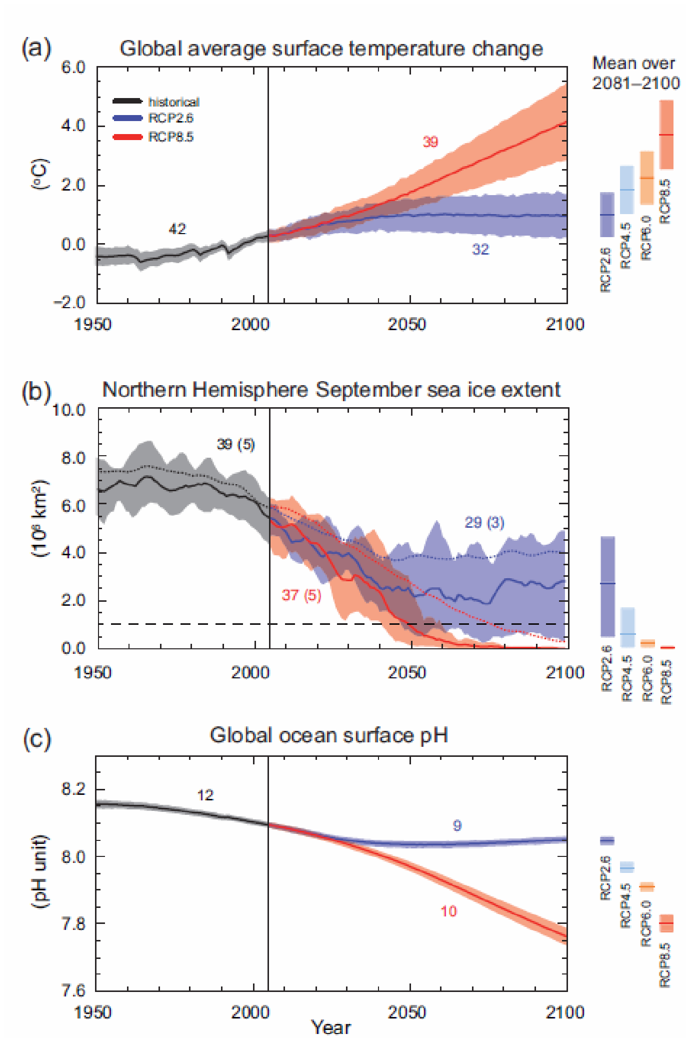

Figure 6: Ocean surface temperature, pH and sea ice extent, 1950-2100
Source: *IPCC, 2013: Summary for Policymakers*

The IPCC report stated with "high confidence" that the pH level of ocean surface water has decreased by 0.1 units since the beginning of the industrial era, increasing the acidity of the ocean [*Figure 6*]. Ocean acidification will, with "very high confidence," continue to increase throughout the 21st century in all scenarios due to the continued uptake of carbon emissions in the oceans (IPCC, 2013). This will likely

[8] Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet could cause global average sea level to rise "substantially" above the "likely" range during the 21st century, the 2013 IPCC report underscored.

have wide-ranging effects on marine ecosystems and inhibit the ability of some organisms to form shells (Nagelkerken & Connell, 2015).

2.1D: Air Quality

Changes in air quality are driven primarily by emissions as opposed to physical climate change. Modelling indicates that, with locally higher surface temperatures in polluted regions, regionally triggered feedbacks in chemistry and local emissions will, with "medium confidence," (IPCC, 2013) increase peak levels of ozone and PM2.5 (particulate matter smaller than 2.5 micrometers).[9]

PM2.5 poses a human health risk because such fine particles (about 1/30th the average width of a human hair) can be inhaled and lodge deeply in lungs (EPA, 2016). Combustion sources of PM2.5 include automobile engines and power plants. Surface ozone (tropospheric), a main ingredient of urban smog, is also harmful to breathe and damages vegetation (EPA, 2014).

2.2: The Nation

Climate change impacts will vary across the United States during the 21st century. Already, extreme weather events (e.g., prolonged periods of heat and drought, as well as severe storms and flooding) are becoming more prevalent, according to the U.S. Global Change Research Program's 2014 *National Climate Assessment* report, which utilized emissions scenarios published by the IPCC in 2000 (Melillo, Richmond, & Yohe, 2014).

Other climate change-exacerbated impacts are already being felt across large parts of the United States — notably, sea-level rise — in part, because of where and how we build: Almost 5 million residents, hundreds of billions of dollars of property, and many industrial hubs are located within 4 feet of the local high tide line (Melillo, Richmond, & Yohe, 2014). Below is a summary of projected impacts amid the nation's regions:

The Northeast — the nation's most densely populated region — is expected to experience more extreme summer heat waves, more extreme precipitation events, and coastal flooding due to sea-level rise and storm surges (Melillo, Richmond, & Yohe, 2014). Heading down the Atlantic Coast, population growth and land-use change will also exacerbate fresh water security.

The Southeast and Caribbean regions are expected to be hit by increasingly intense — and potentially more frequent — hurricanes (Melillo, Richmond, & Yohe, 2014). The Gulf Coast, which features a comparatively flat topography and stretches of degraded wetlands, is particularly susceptible to the impacts of sea-level rise and more intense storm surges. The area is economically and strategically important because it includes significant oil and gas infrastructure.

Increases in heavy precipitation are projected to occur in the Midwest and Great Plains — where recent heavy downpours have overwhelmed stormwater systems and levees — and cause large flooding events

[9] The Clean Air Act requires the U.S. EPA to set National Ambient Air Quality Standards for six criteria pollutants, including PM2.5. The federal law identifies two types of national ambient air quality standards: "Primary" standards protect the health of children, elderly and other sensitive populations; "secondary" standards protect against decreased visibility and damage to animals, vegetation and buildings (TRPC, 2013). The federal primary/secondary standards for PM2.5 are as follows: 12 micrograms per cubic meter of air (µg/m3), annual average; 35 µg/m3, 24-hour average.

and accelerate erosion (Melillo, Richmond, & Yohe, 2014). A projected increase in drought is expected to increase competition for water resources.

Such is already true for the Southwest, which is projected to experience potentially severe drought associated with stretches of warmer, drier weather in the decades ahead. Further, earlier snowmelt and reduced snowpack in the mountains are expected to have widespread impacts across ecosystems and economies that rely on snowmelt during dry months.

Alaska, the nation's only Arctic state, will continue to experience receding glaciers, thawing permafrost, and warming waters that will melt sea ice and change ocean chemistry (Melillo, Richmond, & Yohe, 2014). Such changes are expected to decrease the productivity of fisheries and increase the vulnerability of coastal communities to erosion. Further, melting summer sea ice in the Arctic and Alaska — a loss of ice cover roughly equal to half of the area of the continental U.S. — will reduce the reflectivity of the Earth's surface and create a positive feedback loop of heat absorption (Melillo, Richmond, & Yohe, 2014).

In Hawaii and the U.S. Pacific territories, lower frequency of large precipitation events and increased temperatures will likely lead to decreased water and food security (Melillo, Richmond, & Yohe, 2014). Sea-level rise will also be a major challenge for communities on low-lying islands.

2.3: The Pacific Northwest

As is true for the nation, climate change impacts this century will be varied and potentially significant across Washington and the broader Pacific Northwest.

The Pacific Northwest's average annual temperature is expected to rise 4.3°F (range: +2.0 to +6.7°F) for a "low" emissions scenario (RCP 4.5) or 5.8°F (range: +3.1 to +8.5°F) for a high emissions scenario (RCP 8.5) for the 2050s, relative to 1950-1999 (Snover et al., 2013).[10] The changing temperature will come with a changing hydrological cycle.

Summer precipitation is expected to decrease, while autumn, winter, and spring precipitation is likely to increase (Adelsman & Ekrem, 2012). More of that winter precipitation, however, will fall as rain rather than snow.

Warmer, wetter winters are expected to lead to less snow cover on Cascade and Olympic mountain peaks, as well as increased floods, scouring flows, and overwhelmed urban stormwater systems. Conversely, a future with warmer, drier summers increases the risk of wildfires, drought, and reservoirs and rivers with less water for fish, irrigation, recreation, hydropower production, and other competing needs.

Forest fire intensity is expected to increase throughout the region, due in part to higher temperatures, more frequent summer heat waves, decreased snowpack, earlier snowmelt, and decreased summer precipitation. For example, one set of fire models for the Pacific Northwest projected that total area

[10] Many characteristics of Washington's climate and vulnerabilities are similar to those of the broader Pacific Northwest, so projections for the state are generally expected to align with those for the region — with potential for some variation at any specific location (Snover et al., 2013).

burned by wildfire could increase from 0.5 million acres historically (1916-2006) to 1.1 million acres by the 2040s for a moderate greenhouse gas scenario (Littell et al., 2010). With this increase, the cost and risk of fighting fires will also rise.

Changes to the ocean have the potential to put additional stresses on coastal communities. Low-lying roads, bridges, buildings, industrial facilities, ferry docks, port facilities, and fisheries are among the coastal infrastructure threatened by rising sea levels.

Ocean acidification, compounded in developed areas by terrestrial pollution and other stressors, is already posing major challenges for salmon, shellfish, and other sea creatures with significant cultural, economic and environmental value (Suatoni, 2015). Studies indicate that as the acidity of seawater increases, shell calcification rates decline, harmful algae grow faster and more toxic, and salmon fry growth rates decrease (Klinger, 2016).

2.4: The Puget Sound region

The University of Washington Climate Impacts Group (CIG) has downscaled global climate models to project impacts in the Pacific Northwest and the Puget Sound region [*Figure 7*]. The following analysis draws heavily from the UW CIG's 2015 Puget Sound *State of Knowledge* report (Mauger et al., 2015).

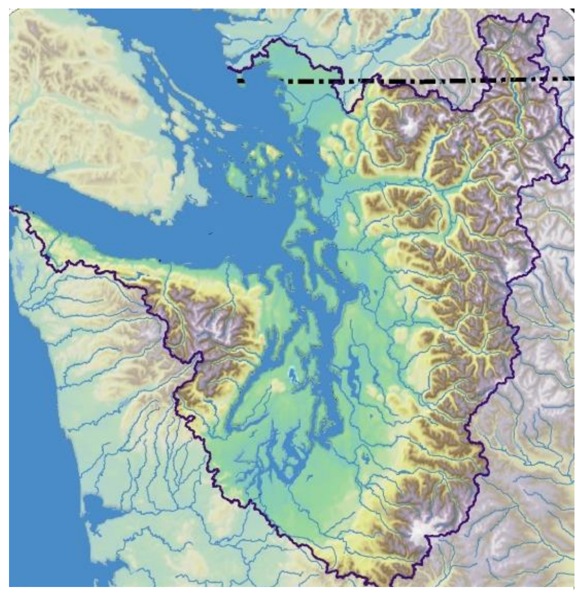

Figure 7: Puget Sound region as defined in the *State of Knowledge* report. The region includes all watersheds that drain into Puget Sound.
Source: *UW Climate Impacts Group, Robert Norheim*

2.4A: Temperature

Our region experienced a warming trend during the 20th century, and all but six of the years from 1980 to 2014 were above the century average (Mauger et al., 2015). Other observed changes include a longer frost-free season and warmer nighttime temperatures.

Additional warming is projected this century, with the change in average annual temperature projected to be at least double that experienced last century and possibly nearly 10 times as large (Mauger et al, 2015). The Puget Sound region's average annual temperature is expected to rise 4.2°F (range: +2.9 to +5.4°F) for the low emissions scenario or 5.9°F (range: +4.3 to +7.1°F) for the high emissions scenario for the 2050s, relative to 1970-1999 [*Figure 8*].

There is no scientific consensus regarding local projected changes in wind speeds and patterns. Observed trends in wind speed and pattern are ambiguous, with some studies finding increases, others finding decreases, and others concluding that there is no significant trend in winds for the Pacific Northwest region (Mauger et. al, 2015).

		2050s *(2040-2069, relative to 1970-1999)*		**2080s** *(2070-2099, relative to 1970-1999)*	
Indicator	**Scenario***	**Mean**	**Range**	**Mean**	**Range**
Average annual air temperature	Low (*RCP 4.5*)	+4.2°F	2.9°F to 5.4°F	+5.5°F	2.3°F to 11°F
	High (*RCP 8.5*)	+5.9°F	4.3°F to 7.1°F	+9.1°F	4.3°F to 17°F
Temperature of hottest days[11]	Average of RCP 4.5 and 8.5	+6.5°F	4.0°F to 10.2°F	+9.8°F	5.3°F to 15.3°F
Temperature of coolest nights[12]	Average of RCP 4.5 and 8.5	+5.4°F	1.3°F to 10.4°F	+8.3°F	3.7°F to 14.6°F

Figure 8. Projected changes in average annual temperature and extreme heat, cold events for the Puget Sound region for the 2050s and 2080s.

Notes: * Under the "low" greenhouse gas scenario (RCP 4.5), global emissions stabilize by mid-century and fall sharply thereafter. Under the "high" greenhouse gas scenario (RCP 8.5), emissions continue to increase through 2100 and beyond. RCP 8.5 is considered a "business-as-usual" scenario; global emissions are currently following this trajectory (footnote adapted from Raymond 2016)[13]

Source: *Mauger, et al., 2015*

2.4B: Precipitation

There is no discernable long-term trend in regional precipitation over the past few decades. Looking ahead, our seasonal precipitation totals — and to a lesser extent, our annual precipitation totals — are projected to change. Generally, future Puget Sound summers are expected to be warmer and drier, with more extreme heat events; winters are likely to be warmer and wetter, with more intense heavy rain events. Such changes during cold-weather months will continue to reduce snowpack, as well as the number and volume of glaciers on high peaks such as Mount Rainier (Mauger et al., 2015).

Summer precipitation is projected to decline 22 percent, on average, by the 2050s[14] under both the "low" and "high" emissions scenarios (Mauger et al., 2015). Less summer rainfall will mean streams with lower flows and higher temperatures — particularly in rain-dominant watersheds such as the Deschutes and Kennedy-Goldsborough, as well as in mixed rain-and-snow watersheds such as the Nisqually. Indeed, by the 2080s,[15] the number of Puget Sound region river miles with August stream temperatures in excess of thermal tolerances for adult salmon (64°F) and char (54°F) is projected to increase by 1,016 and 2,826 miles, respectively (Mauger et al., 2015).

A majority of climate scenarios project increases in fall, winter, and spring precipitation by the 2050s — ranging from +3 percent to +11 percent — on average, depending on the season and greenhouse gas scenario (Mauger et al. 2015). The largest changes are projected for winter (about 10 percent wetter on average by the 2050s for the low and high greenhouse gas scenarios, with a range of -1.6 to +21

[11] Projected change in the top 1% of daily maximum temperature. Projections are based on 10 global models and two greenhouse gas scenarios (RCP 4.5 and 8.5).

[12] Projected change in bottom 1% of daily minimum temperature for climate scenarios described in Footnote 8.

[13] Raymond, C. 2016. Seattle City Light Climate Change Vulnerability and Adaptation Assessment. Seattle City Light, Environmental Affairs and Real Estate Division.

[14] References to the 2050s refer to the 2040-2069 period, relative to 1970-1999.

[15] References to the 2080s refer to the 2070-2099 period, relative to 1970-1999.

percent). This precipitation could come in the form of more heavy rainfall events, increasing the risk of river and stormwater flooding.

The heaviest[16] 24-hour rain events in the region could intensify by +22 percent, on average, by the 2080s for a "high" greenhouse gas scenario (Mauger et al., 2015). Such high-intensity events [*Figure 9*] are also projected to occur more frequently — about seven days per year by the 2080s compared to two days per year historically.

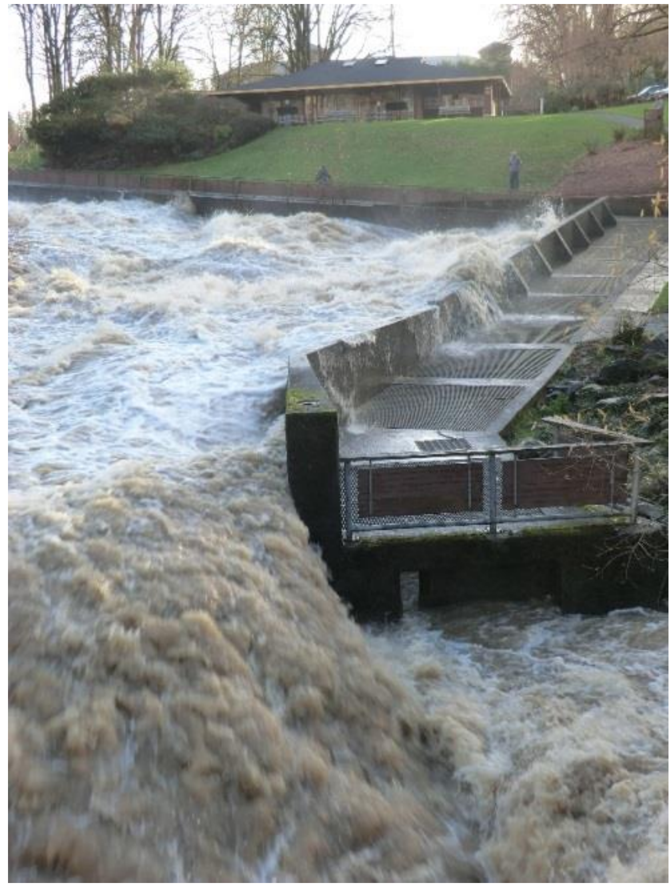

Figure 9: The Deschutes River surges over its banks at Tumwater Falls Park following a record-breaking rainstorm in December 2015. ***Source:*** *TRPC*

Heavy rain events can reduce the stability of slopes by quickly raising the water table and boosting drainage through the soil to lower layers (Mauger et al., 2015). This can cause flooding amid areas with high groundwater, as well as trigger landslides or significant sediment runoff amid steep slopes where vegetation has been removed. Such hazards can damage homes, roads and fish habitat in streams.

Hydrologic models project a dramatic shift to more rain-dominant conditions across the Pacific Northwest as a result of warming temperatures, resulting in higher streamflow during the autumn and winter months but lower streamflow during the late spring and summer months. Locally, the Nisqually Watershed is projected to shift from a mixed rain-and-snow watershed (i.e., watersheds that receive between 10 and 40 percent of precipitation as snow) to a rain-dominant watershed (i.e., watersheds where less than 10 percent precipitation is snow) by the 2080s (Mauger et al., 2015). The lower-elevation Deschutes and Kennedy-Goldsborough watersheds would remain rain-dominant.

[16] The term "heaviest" means the top 1 percent (99th percentile) in daily water vapor transport, the principal driver of large rain events in region. The UW researchers evaluated projected changes in storm intensity for latitudes ranging from 40N to 49N.

2.4C: Streamflow

Modeling for the Nisqually River and 11 other major Puget Sound watersheds shows important shifts in streamflow temperature, volume and timing [*Figure 10*]. In general, the highest "peak" river flows are projected to increase by 18-50 percent, on average, by the 2080s, for a "moderate" greenhouse gas scenario (Mauger et al., 2015).

Streamflow is a key indicator of a watershed's health. Major storm events can flood streams with sediment and fast-moving water that destroys critical habitat for fish and other organisms. Conversely, warmer and drier weather can leave streams with low flows and high temperatures that are also harmful to such organisms.

Nisqually River	
Indicator	**Change**
River miles with August stream temperatures in excess of thermal tolerances for fish	+24 miles (*adult salmon*) +179 miles (*char*)
Streamflow volume associated with 100-year (*1 percent annual probability*) flood event	+18% (*range: -7% to +58%*)
Summer minimum streamflow volume	-27% (*range: -35% to -17%*)
Peak streamflow timing (*days earlier*)	-34 days (*range: -45 to -25 days*)

Figure 10. Projected changes in the Nisqually River's streamflow temperature, volume and timing for the 2080s (moderate emissions scenario).
Source: *Adapted from Mauger et al., 2015*

2.4D: Sea-Level Rise

Throughout the 21st century, the Puget Sound region is expected to experience continued, and possibly accelerated, sea-level rise. This may result in permanent inundation of some low-lying areas, and increased frequency, depth, and duration of coastal flood events due to increased tidal and storm surge reach. Sea-level rise may also exacerbate river flooding by slowing the ability of floods to drain into the Puget Sound (Mauger et al., 2015).

Globally, average sea level rose about 8 inches — about the same level recorded at the Seattle tidal gauge — during the 20th century (Mauger et al., 2015). The Puget Sound region's sea level is projected to rise another 14 to 54 inches this century, relative to 2000. Local levels could be higher or lower than this range, however, depending upon the rate of vertical land motion.

Most Thurston County shorelines are stable. However, Olympia City Hall in downtown is subsiding by about 2.5 millimeters (0.9 inch) per decade (Pacific Northwest Geodetic Array, 2016). Thus, City of Olympia engineers estimate that sea-level rise could be 11 inches greater amid low-lying downtown — much of which is built atop fill — than the surrounding shoreline areas (Christensen, 2016).

2.4E: Farms & Forests

Higher air temperature, lower summer precipitation, increasingly varied winter precipitation, and more CO_2 fertilization are expected to lead to significant changes in many aspects of vegetation growth and distribution amid the Puget Sound region (Mauger et al., 2015). Below is a summary of projected impacts on farms, forests, prairies, and freshwater and marine ecosystems.

Agriculture

Puget Sound agriculture as a whole is expected to be relatively resilient to the impacts of climate change. Even so, changes in water availability, sea-level rise, saltwater intrusion into groundwater, and warmer temperatures are likely to lead to changes in the types of crops grown in Puget Sound. Among the agricultural crops that have been studied specifically, berries, tree fruit, and tubers could experience a decline in production due to climate change stresses (Mauger et al., 2015). Conversely, certain invasive species may benefit, potentially gaining a competitive advantage over native species and crops. Wine grapes could thrive under the projected climate changes amid the region.

Forests

As a whole, there will likely be a continued shift in the geographic distribution of Puget Sound species, changes in forest growth and productivity, an increased risk of forest fire, and changes in the prevalence and location of disease, insects and invasive species (Mauger et al., 2015).

The Nisqually River Council's *Nisqually Watershed Forest and Water Climate Adaptation Plan* notes that, by the 2080s, peak snowmelt is expected to occur 4 to 9 weeks earlier in the year in the South Puget Sound region (Greene & Thaler, 2014). This will allow tree growth to expand into subalpine and alpine meadows where snowpack has historically limited growing seasons.

At lower elevations, warmer summer temperatures will likely decrease the extent of suitable habitat for Douglas-fir trees. Indeed, the range of Douglas-fir trees may decline by as much as 32 percent by 2060, with most of the loss occurring in low-elevation forests, particularly in the South Puget Sound region (Greene & Thaler, 2014). Conversely, western hemlock, white bark pine, and western red cedar may expand their range across the entire Pacific Northwest.

Increased water stress and lower productivity may in turn lead to higher forest mortality, decreased fuel moisture, and more intense fires (Greene & Thaler, 2014). These disturbances may be compounded by a higher incidence of pest and disease outbreaks.

Prairies & Woodlands

Prairies that existed historically amid South Puget Sound lowlands are characterized as open, well-drained sites with native grasses and oak trees. Such prairies can range from open savanna-type landscapes to areas with scattered woodlands dominated by Garry oak, Douglas-fir, Oregon ash, bigleaf maple, and/or Pacific madrone trees (Washington Department of Fish and Wildlife, 2011). These ecosystems, which historically covered 10 percent of the landscape in the South Puget Sound lowlands, have been reduced by 90 percent during the past 150 years, due largely to settlement. Such ecosystems also have become increasingly fragmented by development and natural factors that limit their distribution to specific physical environments.

Climate change will exacerbate shifts in the composition of these ecosystems in the decades ahead. A recent study concluded that climate suitability for Garry oak is likely to improve throughout Washington, Oregon and British Columbia by the century's end; however, climate suitability in specific areas that now support the oak will decline in the near future and will not likely return to current conditions (Bodtker, 2009).

2.4F: Freshwater Ecosystems

Rising temperature is a major stressor for freshwater species. In the decades ahead, plants and animals will either adapt and shift to new habitats or potentially be eliminated from the ecosystem. Spring pool and freshwater lake species are likely to be more susceptible to stresses because their habitats could potentially dry up (Washington Department of Fish and Wildlife, 2011). Furthermore, fish and amphibian species will experience increased habitat temperatures that will ultimately affect their food supply and fitness. Warmer air and water conditions could lead to fewer nutrients in the water, higher competition for nutrients between native and invasive species, and higher instances of pathogens and associated diseases (Washington Department of Fish and Wildlife, 2011).

Warmer water, changes in snowmelt and peak stream flows, and changes in timing and type of precipitation all create a number of consequences for species that depend on very specific aquatic conditions. For example, lifecycles of many aquatic organisms depend on temperature, and warmer water could increase organism growth rates and ecosystem production. Warmer water also contains less dissolved oxygen, however, which could affect the ability of non-photosynthetic organisms to thrive. In lakes and ponds, higher water and air temperatures will likely support the growth of nuisance algae, and potentially eliminate cold, deep-water refuges for local species (Washington Department of Fish and Wildlife, 2011).

Temperatures also control the timing of biological events such as reproduction and development in many species, and even slight temperature changes may be detrimental to those biological processes (Washington Department of Fish and Wildlife, 2011). Additionally, as precipitation shifts to more high-volume rain events during winter, and snowmelt shifts to earlier in the year, species that have evolved around predictable springtime peak flows may experience negative impacts and potentially die-offs.

Higher air temperatures and less summer precipitation also could lead to less riparian recharge, ultimately stressing trees and other plant species living near streams, lakes and ponds (Washington Department of Fish and Wildlife, 2011). Lake levels may change directly as a result of climate change, and those areas that become drier will experience higher water stress, higher competition for nutrients and water resources, and lower water quality.

2.4G: Marine Ecosystems

The Nisqually Estuary and other coastal areas amid the region support diverse ecosystem services, including fisheries, flood protection, and wildlife habitat, which will be affected by climate change.

A 2010 National Wildlife Federation report identified six climate-driven effects that will alter Washington marine and coastal ecosystems: rising sea surface temperature, sea-level rise, altered hydrology, coastal erosion, coastal hypoxia, and ocean acidification. All of these effects may lead to significant changes in the structure and health of such ecosystems (Morgan & Siemann, 2010).

For example, increased sea surface temperature affects species' metabolism, growth patterns, and reproductive health. Thus, it is likely that warmer water will result in regional declines in abundance of some fish and seabird species, altered distribution of some fish species, higher susceptibility to disease, and physiological changes (Morgan & Siemann, 2010). Some cold-blooded marine organisms may actually experience an increase in growth rate due to warmer water; however, this could be offset by higher competition for food and/or lower concentration of dissolved oxygen in the water (hypoxia).

As noted previously, ocean acidification is also expected to impact coastal ecosystems. Higher acidity (lower pH) inhibits calcification and can interfere with normal development of shellfish, coral, plankton, and other organisms. Thus, in the decades ahead, our region could see a decline of these and other species that support biodiversity, fisheries, and the broader food web (Morgan & Siemann, 2010).

Sea-level rise will likely inundate coastal habitats such as marshes, beaches, and tidal flats if ecosystems cannot shift inland quickly enough, or if habitats are prevented from doing so because of development or coastal armoring (Morgan & Siemann, 2010). Erosion due to sea-level rise could increase the rate of loss amid these habitats. Coastal armoring (e.g., sea walls and levees) may hold off erosion in some places, yet such armoring may also accelerate erosion rates in other places and prevent redistribution of sand and other sediments important to adaptation (Morgan & Siemann, 2010).

A 2007 National Wildlife Federation analysis of sea-level rise and coastal habitats in the Pacific Northwest predicted major changes in marine and coastal ecosystems due to the compounding effect of sea-level rise and erosion over the next century (Glick et al., 2007):

- 65% loss of estuarine beaches do to erosion and inundation;
- 6% loss of ocean beaches;
- 61% loss of tidal swamps;
- 44% loss of tidal flats;
- 52% conversion of brackish marshes to tidal flats, transitional marsh, and saltmarsh; and,
- Expansion of traditional marshes.

3: Next Steps

This summary of climate change projections — which was reviewed by TRPC's ad hoc Science Advisory Committee — marks the first significant step toward developing a regional climate adaptation plan. In coming months, TRPC will work with its scientific advisors, as well as a group of community members (Stakeholder Advisory Committee), to assess climate change vulnerabilities and risks [*Figure 11*].

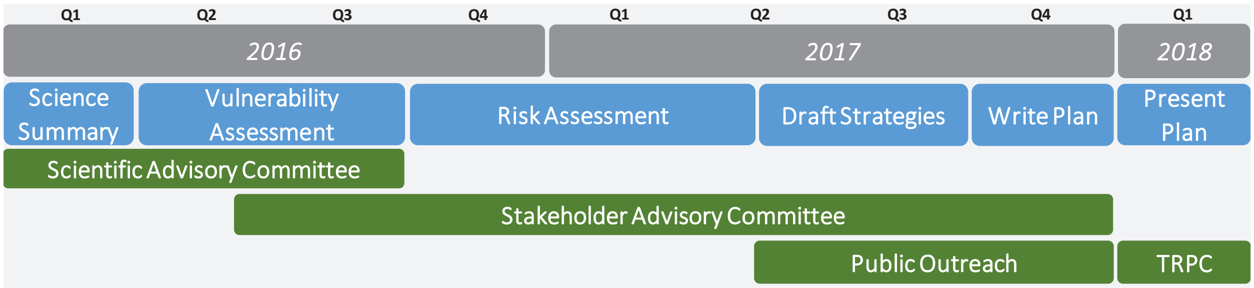

Figure 11: The process diagram above shows key Thurston Climate Adaptation Plan dates and components, including the vulnerability and risk assessments. ***Source:*** *TRPC*

TRPC will then work with community members to develop adaptation strategies for the region's human and natural systems (i.e., human health, as well as built and natural assets). The Tacoma-based firm Earth Economics will conduct a quantitative benefit-cost analysis for select strategies.

In early 2018, the project team will present TRPC policymakers a draft climate action plan with a menu of strategies that local governments could integrate into their comprehensive plans, development codes and other policies. Other strategies will be applicable to tribes and private-sector stakeholders.

In the meantime, TRPC and its partners will continue to take steps to mitigate the region's greenhouse gas emissions — the other half of the comprehensive climate strategy envisioned by Sustainable Thurston.

Sustainable Thurston's foundational principles and policies are now a part of the Countywide Planning Policies, the framework for coordinating local comprehensive plan updates. This is important in a regional context because Sustainable Thurston includes dozens of climate-related goals and actions — ranging from reigning in urban sprawl, to reducing vehicle miles traveled, to slashing waste production, to prioritizing weatherization funds for affordable housing. Going forward, TRPC will continue seeking out grant sources for mitigation planning, as well as continue working with regional public- and private-sector stakeholders to evaluate funding strategies for local clean-energy and energy-efficiency initiatives.

This multifaceted approach, comprised of climate change adaptation and mitigation strategies, is built on the premise that many actions — large and small — are needed to help the Thurston Region shrink its carbon footprint today and remain resilient tomorrow.

4: References

Adelsman, H., & Ekrem, J. (2012). *Preparing for a Changing Climate: Washington State's Integrated Climate Response Strategy.* Washington State Department of Ecology, Climate Policy Group, Olympia, WA.

Bodtker, e. a. (2009). *A bioclimatic model to assess the impact of climate change on ecosystems at risk and inform land management decisions: Report for the Climate Change Impacts and Adaptation Directorate, CCAF Project A718.* Vancouver, B.C.: Parks Canada Agency (Canadian government report).

Borenstein, S. (2016, January 20). "NOAA, NASA: 2015 was Earth's hottest by a wide margin". *The Associated Press*. Retrieved January 29, 2016

Christensen, E. (2016, February 9). Sea Level Rise Update 2016. *Presentation to Olympia City Council*. Olympia, Washington, United States: City of Olympia.

Clark, P., Shakun, J. D., Marcott, S. A., Mix , A. C., Eby, M., Kulp, S., . . . Plattner, G.-K. (2016). Consequences of twenty-first-century policy for multi-millenial climate and sea-level change. *Nature Climate Change*, DOI: 10.1038/NCLIMATE2923.

EPA. (2014, September). *Good Up High Bad Nearby -- What is Ozone*. Retrieved from Air Now (U.S. Environmental Protection Agency): http://cfpub.epa.gov/airnow/index.cfm?action=gooduphigh.index

EPA. (2016, February 25). *Overview of Greenhouse Gas Emissions: Methane*. Retrieved from U.S. Environmental Protection Agency: http://www3.epa.gov/climatechange/ghgemissions/gases/ch4.html

EPA. (2016, February 23). *U.S. Environmental Protection Agency*. Retrieved from Fine Particle (PM2.5) Designations: Frequent Questions: https://www3.epa.gov/pmdesignations/faq.htm

Figueres, C. (2015). Proceedings from the United Nations Framework Convention on Climate Change Conference: The Paris Agreement., *Article 2, Section 1.*

Glick et al. (2007). *Sea-level rise and coastal habitats in the Pacific Northwest: An analysis for Puget Sound, southwestern Washington, and northwestern Oregon.* National Wildlife Federation.

Greene, M., & Thaler, T. (2014). *Forest and Water Climate Adaptation: A Plan for the Nisqually Watershed.* Sagle, ID: Model Forest Policy Program in Association with the Nisqually River Foundation and the Cumberland River Compact.

IPCC. (2013). Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (T. Stocker, D. Qin, G. Plattner, M. Tignor, S. Allen, J. Boschung, . . . P. Midgley, Eds.) pp. 1-30. doi:10.1017/CBO9781107415324.004

Klein, R., Huq, S., Denton, F., Downing, T., Richels, R., Robinson, J., & Toth, F. (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (M. Parry, O. Cansiani, J. Palutikof, P. van der Linder, & C. Hanson, Eds.) (745-777).

Klinger, T. (2016, Janurary 13). "The Science of Ocean Acidification: A Quick Survey of Biological Impacts". *Current Research and Regional Impacts*. Olympia, WA: The Evergreen State College.

Littell, J., Oneil, E., MeKenzie, D., Hicke, J., Lutz, J., Norheim, R., & Elsner, M. (2010). *Forest ecosystems, disturbance, and climatic change in Washington State, USA.* Climatic Change 102(1-2): 129-158, doi: 10.2007/s10584-010-9858-x.

Luers, A. L., Mastrandrea, M. D., Hayhoe, K., & Frumhoff, P. C. (2007). *How to Avoid Dangerous Climate Change: A Target for U.S. Emissions.* Union of Concerned Scientists.

Mauger, G., Casola, J., Morgan, H., Strauch, R., Jones, B., Curry, B., . . . Snover, A. (2015). *State of Knowledge: Climate Change in Puget Sound.* Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Seattle, WA: Climate Impacts Group, University of Washington. doi:10.7915/CIG93777D

Melillo, J. M., Richmond, T., & Yohe, G. W. (2014). *Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program. doi:10.7930/J0Z31WJ2

Morgan, E., & Siemann, D. (2010). *Climate Change Effects on Marine and Coastal Habitats in Washington State.* National Wildlife Federation, Pacific Regional Center.

Nagelkerken, I., & Connell, S. D. (2015). Global alteration of ocean ecosystem functioning due to increasing human CO2 emissions. *Proceedings of the National Academies of Sciences*, 13272–13277.

National Aeronautics and Space Administration. (2016). "NASA, NOAA Analyses Reveal Record-Shattering Global Warm Temperatures in 2015". Retrieved February 4, 2016

National Oceanic and Atmospheric Administration. (2016). *State of the Climate: Global Analysis for December 2015.* National Oceanic and Atmospheric Administration, National Centers for Environmental Information. Washington, D.C.: NOAA. Retrieved February 4, 2016, from http://www.ncdc.noaa.gov/sotc/global/201512

Pacific Northwest Geodetic Array. (2016, March 9). *OLMP (PANGA) Olympia WA*. Retrieved from Pacific Northwest Geodetic Array -- Central Washington University: http://www.panga.org/sites/olmp/

Snover, A., Mauger, G., Whitely Binder, L., Krosby, M., & Tohver, I. (2013). *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers.* Seattle: State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington.

Suatoni, L. (2015). How Vulnerable are North America's Shellfisheries. *Environmental Law Symposium.* Seattle: University of Washington School of Law.

Thurston Climate Action Team. (2014). *Estimating Greenhouse Gas Emissions and Targets in Thurston County.* Olympia, WA: Thurston Climate Action Team.

Thurston Regional Planning Council. (2013). *Creating Places - Preserving Spaces: A Sustainable Development Plan for the Thurston Region.* Olympia, WA.

Thurston Regional Planning Council. (2016). *The Profile.* Olympia, WA: Thurston Regional Planning Council.

Washington Department of Fish and Wildlife. (2011). *Summary of Climate Change Effects on Major Habitat Types in Washington State; Forest, Alpine, Western Prairie Habitats.* Washington Department of Fish and Wildlife, and the National Wildlife Federation.

Washington Department of Fish and Wildlife. (2011). *Summary of Climate Change Effects on Major Habitat Types in Washington State; Freshwater Aquatic and Riparian Habitats.* Washington Department of Fish and Wildlife, and the National Wildlife Federation.

Washington State Department of Transportation. (2011). *Climate Impacts Vulnerability Assessment.* Olympia, WA: Washington State Department of Transportation. (M. Maurer, C. L. Roalkvam, & S. Salisbury, Eds.)