The Washington Climate Change Impacts Assessment

Evaluating Washington's Future in a Changing Climate

Executive Summary

A report by

The Climate Impacts Group
University of Washington

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June 2009 addendum *Minor edits to the average temperature and precipitation projections summarized on pages 1, 6, and 7 were made in June 2009 to reflect updates made to the analysis after the March release of the Executive Summary. Additionally, the reference period in the caption for Figure 5 was corrected to provide the correct reference period (1916-2006) for changes in April 1 snowpack.*

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The Pacific Northwest is cloud-free in this SeaWiFS image. Multihued phytoplankton blooms are visible off of Washington's Olympic coast. Also visible in this image are: Fraser River outflow, snowcapped peaks of Mt. Olympus, Mt. Rainier, Mt. Adams, Mt. Hood, Mt. Jefferson, the Three Sisters, the North Cascades, and the Columbia and Snake River watersheds.

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Executive Summary

Temperature records indicate that Pacific Northwest temperatures increased 1.5°F since 1920. Climate models used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report simulate the same historical warming by including both human and natural causes, and point to much greater warming for the next century. **These models project[1] increases in annual temperature of, on average, 2.0°F by the 2020s, 3.2°F by the 2040s, and 5.3°F by the 2080s (compared to 1970 to 1999[2]), averaged across all climate models[3].** Projected changes in annual precipitation, averaged over all models, are small (+1 to +2%), but some models project an enhanced seasonal precipitation cycle with changes toward wetter autumns and winters and drier summers. Increases in extreme high precipitation in western Washington and reductions in Cascades snowpack are key projections that are consistent among different projections of a high-resolution regional climate model.

Probable impacts associated with projected 21st century changes in Northwest climate include the following:

- **April 1 snowpack is projected to decrease by 28% across the state by the 2020s, 40% by the 2040s, and 59% by the 2080s compared with the 1916 - 2006 historical average.** As a result, seasonal streamflow timing will likely shift significantly in sensitive watersheds.
- **The Yakima basin reservoir system will likely be less able (compared to 1970 to 2005) to supply water to all users, especially those with junior water rights.** Historically (1916-2006), detrimental water shortages in the Yakima basin occurred in 14% of years. Without adaptation, shortages would likely occur more frequently: 32% of years in the 2020s, 36% of years in the 2040s, and 77% of years in the 2080s. Due to lack of irrigation water and more frequent and severe prorating, the average production of apples and cherries could decline by approximately $23 million (about 5%) in the 2020s and by $70 million (about 16%) in the 2080s.
- **Rising stream temperatures will likely reduce the quality and extent of freshwater salmon habitat.** The duration of periods that cause thermal stress and migration barriers to salmon is projected to at least double (low emissions scenario, B1) and perhaps quadruple (medium emissions scenario, A1B) by the 2080s for most analyzed streams and lakes. The greatest increases in thermal stress would occur in the Interior Columbia River Basin and the Lake Washington Ship Canal.

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[1] All changes are benchmarked to 1970 to 1999 unless otherwise stated.

[2] 20 different global climate models for greenhouse gas emissions under a "medium" emissions scenario (A1B) and 19 models for a "low" scenario (B1) - see Box 3 for more information. All statements in this document are for the "medium" scenario (A1B) unless otherwise stated.

[3] We use the term "projections" throughout to minimize confusion with "forecasts" and "predictions", both of which convey levels of certainty inappropriate for future climate. We use "likely" to convey relatively high certainty and "possibly" to convey less certainty.

- **Due to increased summer temperature and decreased summer precipitation, the area burned by fire regionally is projected to double by the 2040s and triple by the 2080s[4].** The probability that more than two million acres will burn in a given year is projected to increase from 5% (observed) to 33% by the 2080s. Primarily east of the Cascades, mountain pine beetles will likely reach higher elevations and pine trees will likely be more vulnerable to attack by beetles.
- **Although few statistically significant changes in extreme precipitation have been observed to date in the Puget Sound, the Spokane area, or Vancouver/ Portland, regional climate model simulations generally predict increases in extreme high precipitation over the next half-century, particularly around Puget Sound.** In that region, existing drainage infrastructure designed using mid-20th century rainfall records may be subject to rainfall regimes that differ from current design standards.
- **Climate change in Washington will likely lead to significantly more heat- and air pollution-related deaths throughout this century.** Projected warming would likely result in 101 additional deaths among persons aged 45 and above during heat events in 2025 and 156 additional deaths in 2045 in the greater Seattle area alone[5]. By mid-century, King County will likely experience 132 additional deaths between May and September annually due to worsened air quality caused by climate change.

The significance of these regional consequences of climate change underscore the fact that historical resource management strategies will not be sufficient to meet the challenges of future changes in climate. Rather, these changes demand new strategies. Options for adapting to climate change vary between sectors (e.g., between water resources and forest ecosystems) and even within sectors (e.g., between watersheds) depending on the unique characteristics of the systems being considered. This assessment highlights some of the likely impacts of future changes in climate in Washington. There is more work yet to be done, however, including (1) continuing work to identify and quantify impacts in these and other sectors, and (2) analyzing the adaptation options appropriate to specific impacts, specific locations, management goals, and jurisdictions. Additionally, the range of projected climates from different global climate models (or regional climate models) could be explored more fully in future work to develop a range of impacts scenarios useful for making decisions under different levels of risk tolerance. Integration between the sectors is also very important because the nature of some impacts is synergistic within and between sectors.

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[4] Relative to 1916 - 2006.

[5] Relative to 1980 - 2006.

Box 1: Climate Change, Climate Variability, and Weather

In this assessment, it is necessary to distinguish between climate change (the long term trend), climate variability (year-to-year or decade-to-decade variations), and weather (the daily to seasonal changes with which we are all familiar). Pacific Northwest events – storms, floods, winters that seem colder and summers that seem hotter - need to be put in an appropriate context and time frame. Such events can be associated with climate, but only over many years – a single flood, back-to-back snowy winters, or an extended drought don't necessarily signal a change in climate over longer time frames. Some common questions and their answers help distinguish these sometimes confusing terms.

Q. The last two winters have been cool in the Pacific Northwest. Has global warming stopped?

A. No. Rising greenhouse gases (carbon dioxide, methane, and others) continue to produce increasingly warmer temperatures. Additional upward or downward detours come from other important sources of climate variability. For example, an extremely strong tropical El Niño event helped make 1998 a record warm year, not to be matched until 2005, a year with a mild El Niño event. The 2008 La Niña event produced temporary global cooling, but even so, the National Climatic Data Center still ranked 2008 as the 8th warmest year globally on record. Local cold weather, or heat waves, tell us nothing about global factors in climate like the effects of rising greenhouse gases.

Q. Isn't the climate record dominated by natural variability?

A. Yes, but natural causes and natural variability cannot explain the rapid increase in global temperatures in the last 50 years. Scientists have searched for other explanations – heat from the ocean, solar variability, cosmic rays, instrumental error – and have used sophisticated statistical techniques, and nearly every study concludes that the rising temperature is a result of rising greenhouse gases. Laboratory tests, ground-based instruments, and satellite instruments show that adding greenhouse gases to the atmosphere warms the surface – a simple physical fact.

1. Introduction

The 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that 20th century warming of our climate is unequivocal and that human activities have contributed to increasing atmospheric greenhouse gas concentrations and therefore warming of the atmosphere and oceans. The IPCC expects global climate to continue warming in the 21st century, with the rate of warming somewhat dependent on the rate of human greenhouse gas emissions.

What are the consequences of a warming climate for the regional systems we rely upon for our livelihood? Certainly, we may no longer rely solely on past events, measurements, and management approaches to understand our natural and human resources. To help answer this question, the Washington State legislature passed House Bill 1303, which mandated the preparation of a comprehensive assessment of the impacts of climate change on the State of Washington. Passed in April 2007, HB 1303 specifically requested that the Departments of Community, Trade, and Economic Development and Ecology work with the University of Washington Climate Impacts Group (in collaboration with Washington State University and Pacific Northwest National Laboratory) to produce this comprehensive assessment.

To assess the future impacts of climate change, we integrate climate model projections into our understanding of the physical, biological, and human responses to climate that will shape Washington's future. This assessment presents the most complete and up to date look yet at the future climate of the Pacific Northwest (PNW) and the potential impacts of projected climate change on important ecological and economic sectors in Washington State, and provides Washington State decision makers and resource managers with information critical to planning for climate change.

This executive summary describes the key findings and conclusions of the Climate Impacts Group's Washington Climate Change Impacts Assessment. The Assessment addresses the impacts of global climate change over the next 50 years or more on eight sectors: Hydrology and Water Resources, Energy, Agriculture, Salmon, Forests, Coasts, Urban Stormwater Infrastructure, and Human Health (Box 2). In addition, the Washington Assessment addresses the need for adaptive planning and adaptation options within each sector. Full technical details are provided in a series of papers that together comprise the Washington Assessment.

Figure 1. Washington State and surrounding Pacific Northwest region. This assessment is focused on impacts of climate change on resources in the state of Washington, but the region as a whole has been considered because the climatic and hydrologic impacts require regional analyses. For example, Columbia River flow is related to conditions across an area much greater than Washington alone, the purple line outlines the Columbia River Basin.

Box 2: Impacts Assessment Sectors Covered in this Summary and Their Main Areas of Focus

- **Climate Scenarios:** changes in future temperature and precipitation for the Pacific Northwest and assessment of sub-regional climate change using regional climate models
- **Hydrology and Water Resources:** changes in the hydrology (streamflow, snowpack, soil moisture) and the water resources (water storage, irrigated agriculture) of Washington
- **Energy:** changes in the demand for and production of hydropower in Washington
- **Agriculture:** changes in the expected production of high-value crops in Washington
- **Salmon:** changes in the quality and quantity of salmon freshwater habitat in Washington
- **Forests:** changes in the productivity, distribution and disturbance of forest ecosystems in Washington
- **Coasts:** impacts in coastal areas of Washington
- **Urban Stormwater Infrastructure:** changes in storms and demands on urban stormwater infrastructure in Washington
- **Human Health:** impacts of heat waves and climate-related air pollution on health in Washington
- **Adaptation:** fundamental concepts for planning for climate change and options for adapting to the impacts identified in the above sectors

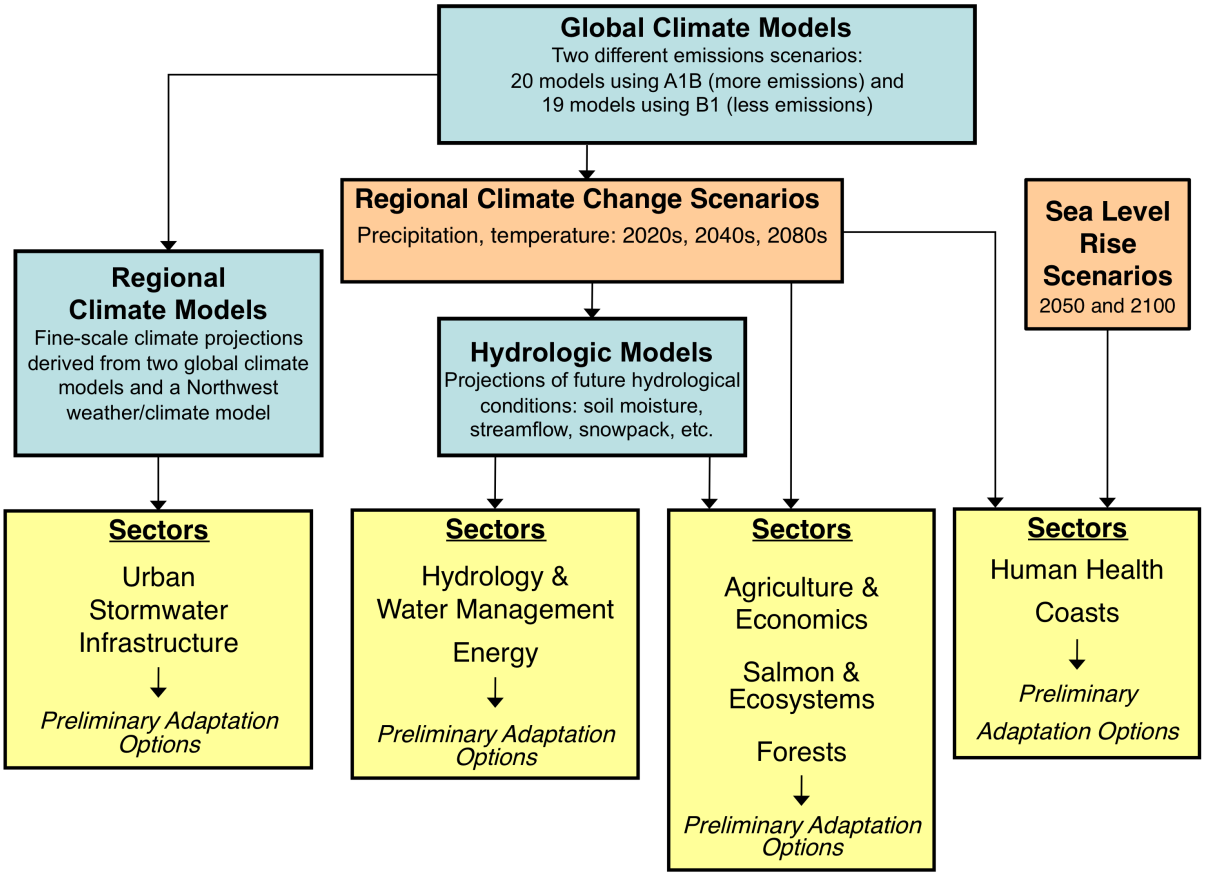

Figure 2. Summary of overall assessment approach. Sectors use one or more pathways in the flowchart above. Global and regional climate change information is related to sector impacts using hydrologic and regional climate models. This allows quantification of impacts at scales more useful for decision making. Adaptation options are developed based on the downscaled impacts.

1.1 Assessment Approach

The climate of the 21st century in Washington State will very likely be quite different from the climate we have witnessed in the past. The changes will in many cases be large, and the ultimate consequences will depend on how well we plan for and manage these changes. Effective planning requires sectorally and geographically specific information on which to base decisions. This assessment provides that information by using global climate model projections from the IPCC Fourth Assessment to develop regionally-specific climate change scenarios and then assessing some of the consequences for eight important sectors (Box 2) in Washington (Figure 1). Figure 2 illustrates the overall approach taken in this study. The sections that follow present the main conclusions for each sector. The Washington Assessment focuses on three 30-year windows in the 21st century, that is, the thirty years centered on the 2020s (2010 to 2039), 2040s (2030 to 2059), and 2080s (2070 to 2099)[6]. Projections for the 2080s are least certain of those presented here[7], because climate, human population growth, and energy use patterns are more difficult to estimate farther into the future.

1.2 Modeling Approach

Translating from projections of global climate change to impacts in Washington State requires making the climate projections more regionally specific and, in many cases, using those climate projections to develop other important information such as hydrologic projections (Figure 2). The process begins with 20 climate models from research groups around the world (models that were used in the 2007 IPCC Fourth Assessment). For each of these global climate models, two IPCC greenhouse gas emissions scenarios were used to represent different assumptions about future global development (see Box 3 for description of the emissions scenarios).

Box 3: Future Emissions Scenarios: Low (B1) and Medium (A1B)

Greenhouse gasses are the main cause of 21st century climate change, and they stem from human choices in many arenas. They are by no means the only influence on climate, nor are they the only forcings considered by the IPCC. This assessment uses two future scenarios that differ in their assumptions about future greenhouse gas emissions and other factors influencing climate. The two scenarios are called "B1" and "A1B" – these letters refer to emissions scenario "families" developed for the IPCC, and described fully in the IPCC Special Report on Emissions Scenarios (SRES). A1B refers to a future where global population peaks mid-century and there is very rapid economic growth and a balanced portfolio of energy technologies including both fossil fuels and high efficiency technology that is adopted rapidly. B1 refers to a future where population is the same as A1B, but there are rapid economic shifts toward a service/information economy, the introduction of clean and resource-efficient technologies and emphasis on global solutions to economic, social, and environmental sustainability. A1B results in warmer future climates by the end of the century and can be considered a "medium" scenario in terms of warming, (it is not the warmest of all the IPCC scenarios). B1 has less warming (see section 2, Future scenarios), and could be considered the "low" warming scenario. The emissions scenarios were used by the IPCC as input into global climate models to project climate changes for 20 (scenario A1B) or 19 (scenario B1) climate models (Figure 2).

Six average climate change scenarios (called "composites") were created for the Pacific Northwest by averaging the model output for the region for each of the model runs during each time period of interest, i.e., 2020s medium emissions scenario (A1B), 2020s low emissions scenario (B1), 2040s medium emissions scenario (A1B), 2040s low emissions scenario (B1), and so on for the 2080s. In order to make the composite climate scenarios suitable for locally-specific climate impacts analysis, they were "downscaled" to create higher resolution climate projections in the Pacific Northwest. Each downscaled climate change scenario was used as input into a hydrologic model (Hydrology chapter) that uses climate and other information to develop projections of future hydrologic conditions, soil moisture and streamflow. In addition, a regional

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[6] The overlap between the 2020s and 2040s is due to the focus on time frames most useful for decision-making (first half of the 21st century) and also the need to have sufficient numbers of years (~30) for projection purposes.

[7] Uncertainty about future projections is dealt with in several ways in the climate modeling and impacts sectors. Uncertainty about future climate is addressed by using many (20) climate models, two emissions scenarios, and two approaches for "downscaling" climate projections specifically for the Pacific Northwest. This allows a range of possible futures, i.e., different climates, different rates of change, and different levels of detail to be considered in the impacts assessments. The models are also "weighted" by their ability to track observed changes, with better models receiving higher importance when calculating the average changes ("composite delta") projected by the climate models. Uncertainty about future impacts is addressed in the individual chapters when necessary.

climate model (Regional Climate chapter) was used to better understand the influence of sub-regional geographic variability (such as mountains) on future climate. Both downscaling and regional climate models provide increased resolution for future projections by accounting for the influence of smaller features than can be resolved in a global climate model. Detailed descriptions of how the future climate scenarios were used to generate sector-specific results are available in each sector chapter (Box 2).

This assessment is the first to combine such a diverse set of climate models, fine spatial resolution, and hydrologic modeling into an integrated climate impacts assessment. It is also the first to examine impacts on human health, agriculture, and urban stormwater infrastructure in the Northwest. In each of the following sections, the most important projections of future impacts are presented for each sector. Further details are in the sector chapters that follow this summary.

2. Future Climate Scenarios

Using 20 different climate models (see Scenarios chapter) to explore the consequences of two different greenhouse gas emissions scenarios results in a wide range of possible future climates for the Pacific Northwest. All of the models indicate that this future climate will be warmer than the past and together, they suggest that Pacific Northwest **warming rates will be greater in the 21st century than those observed in the 20th century**. All changes below are relative to the period 1970-1999 unless noted, and all are regionally averaged changes that apply to the Pacific Northwest including the state of Washington.

- **Climate models project increases in annual average temperature** of 2.0°F (range of projections from all models: +1.1°F to +3.3°F) by the 2020s; 3.2°F (range: +1.5°F to +5.2°F) by the 2040s; and 5.3°F (range: +2.8°F to +9.7°F) by the 2080s (Table 1).
- Climate models are able to match the observed 20th century warming (+1.5°F since 1920, or +0.2°F per decade for 1920 to 2000) in the Northwest, and foresee a warming rate of roughly +0.5°F per decade of warming in the 21st century (Figure 3).
- **Projected changes in annual precipitation vary considerably between models, but averaged over all models are small (+1 to +2%).** Changes early in the 21st century may not be noticeable given the large natural variations between wetter and drier years. Some models show large seasonal changes, especially toward wetter autumns and winters and drier summers. Regional modeling additionally points out areas and seasons that get drier even as the region gets wetter (Figure 4).
- **Warming is expected to occur during all seasons** with most models projecting the largest temperature increases in summer. The models with the most warming also produce the most summer drying.
- **Medium projections of sea level rise for 2100 are 2 inches to 13 inches (depending on location) in Washington State.** Substantial variability within the region exists due to coastal winds and vertical land movement[8]. The small possibility of substantial sea level rise from the melting of the Greenland ice cap lead to projections as high as 35 inches to 50 inches for 2100 (depending on location).
- **Regional climate models project some changes that are similar across global models, namely increases in extreme high precipitation in western Washinton and reductions in Cascade snowpack.** Regional climate models project a larger increase in extreme daily heat and precipitation events in some locations than the global climate models suggest.
- **Regional climate models suggest that some local changes in temperature and precipitation may be quite different than average regional changes projected by the global models.** For example, the two global models examined suggest winter precipitation will increase in many parts of the Pacific Northwest, but potentially decrease in the Cascades. Future research is required to understand if this is a trend consistent across many global models.

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[8] Sea level rise projections for specific coastal areas can be found in: Mote et al. 2008. Sea-level rise in the coastal waters of Washington: A report by the Climate Impacts Group, University of Washington, and the Washington Department of Ecology.

	Temperature Change (F°)	Precipitation Change (%)
2020s	+2.0 (+1.1 to +3.3)	+1.3 (-9 to +12)
2040s	+3.2 (+1.5 to +5.2)	+2.3 (-11 to +12)
2080s	+5.3 (+2.8 to +9.7)	+3.8 (-10 to +20)

Table 1. Average and range of projected changes in temperature and precipitation for the Pacific Northwest. Reported averages are changes relative to 1970-1999, for both medium (A1B) and low (B1) scenarios and all models (39 combinations averaged for each cell in the table). The ranges for the lowest to highest projected change are in parentheses.

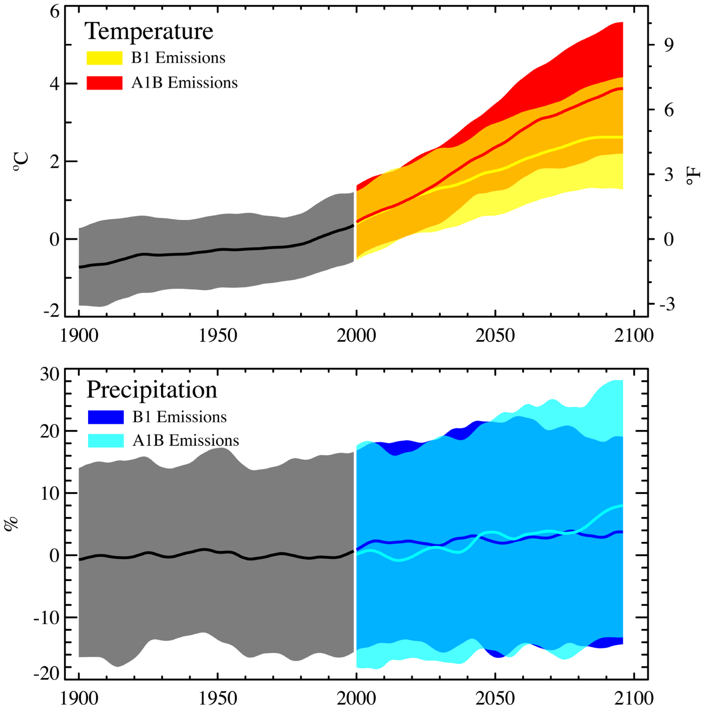

Figure 3. Simulated temperature change (top panel) and percent precipitation change (bottom panel) for the 20th and 21st century global climate model simulations. The black curve for each panel is the weighted average[9] of all models during the 20th century. The colored curves are the weighted average of all models in that emissions scenario ("low" or B1, and "medium" or A1B) for the 21st century. The colored areas indicate the range (5th to 95th percentile) for each year in the 21st century. All changes are relative to 1970-1999 averages.

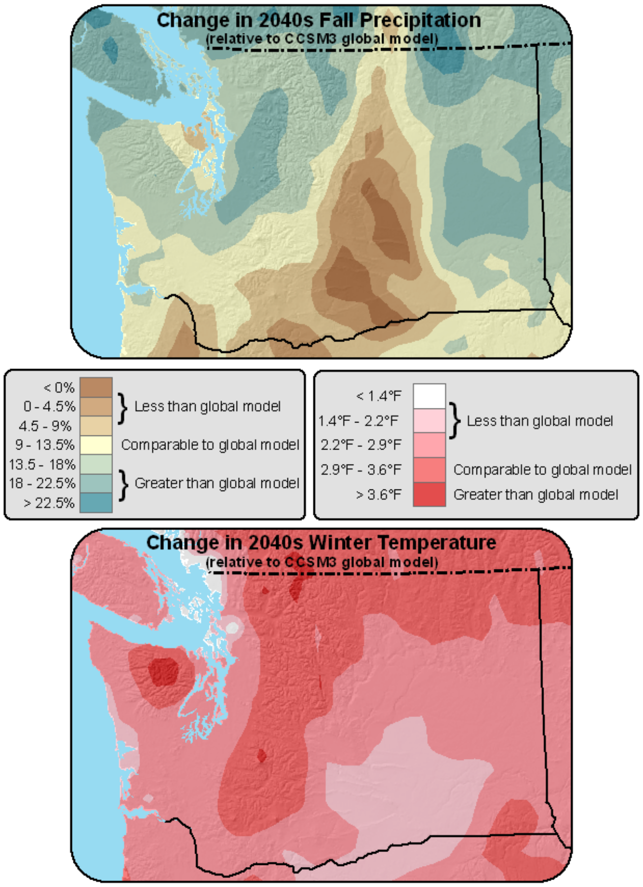

Figure 4. Differences between a regional climate model (WRF) and a global climate model (CCSM3) for projected changes in fall precipitation (September to November top) and winter temperature (December to February, bottom) for the 2040s. The global model produces a regionally averaged 11.7% increase in precipitation, but the regional model provides more detail (top), projecting some areas of increase (green) and some of decrease (brown) compared to the global model. Note that large increases are seen on windward (west and southwest) slopes and smaller increases on leeward (east and northeast) slopes. The global model produces a 3.6°F statewide averaged increase in winter temperature, while the regional model produces a statewide average 2.6°F warming. There are greater increases (darker red) at higher elevations and windward slopes, particularly the Olympic Mountains, North Cascades, and central Cascades. These differences illustrate the value of regional climate models for identifying sub-regional patterns and differences. The patterns of climate change differ depending on the global model being downscaled (we present only one here); nevertheless, the local terrain has a consistent influence on the results.

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[9] The global climate models used by the IPCC were weighted by their ability to model observed regional Pacific Northwest data, with better performing models weighted more highly than those that had significant bias for the last half of the 20th century. See Scenarios chapter for more detail.

3. Hydrology and Water Resources

Projected hydrologic changes across the state are closely linked with future projections of precipitation and temperature. This assessment evaluated the hydrologic implications of climate change over the State of Washington as a whole, and in addition focused on several watersheds that are of particular importance from a water resources management standpoint. Impacts of climate change on Washington's water resources are herein divided into three parts: regional hydrology (snowpack, soil moisture, streamflow); water management in the Yakima River basin; and water management in the Puget Sound region.

Washington snowpacks are among the most sensitive to warming in the West because of their relatively low elevation. The impact of warming temperature on snowpack will differ with the type of river basin. There are three important types: *rain dominant* (precipitation falls primarily as rain, usually in low elevations, such as the Chehalis River), *snowmelt dominant* (precipitation falls primarily as snow and is released as snowmelt, usually in higher elevation basins or large river systems with mountainous headwaters like the Columbia River, and *transient* (mixed rain and snowmelt dominant, usually in mid elevations, such as the Yakima River). Especially in transient basins, a relatively small increase in temperature can significantly increase the fraction of winter precipitation falling as rain and decrease the amount of water stored in snowpack.

3.1 Regional Hydrologic Impacts

- **April 1[10] snow water equivalent (snow water content) is projected to decrease** by an average of 28% to 29% across the state by the 2020s, 37% to 44% by the 2040s and 53% to 65% by the 2080s compared with the 1916 – 2006 historical mean (Figure 5).

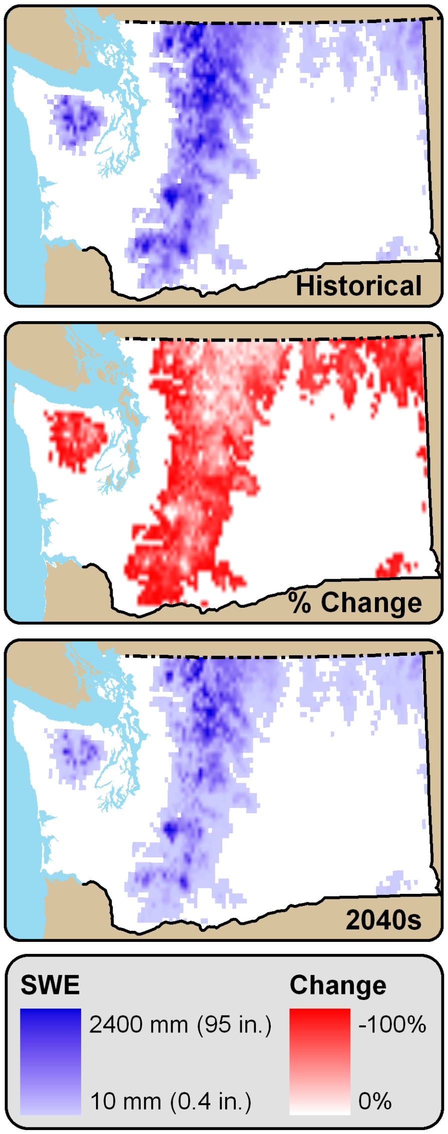

Figure 5. Summary of projected April 1 snow pack (measured as snow water equivalent, or SWE) and changes in April 1 snow pack for the 2040s, medium emissions scenario (A1B). Projected statewide decline relative to 1916-2006 is 37% to 44%. Snow water equivalent is simply the amount of water the snowpack would yield if it were melted.

- **By the 2080s, seasonal streamflow timing in snowmelt-dominated and transient rain-snow watersheds would shift significantly due to the decrease in snowpack and earlier melt (Figure 6).** Snowmelt-dominated watersheds will likely become transient, resulting in reduced peak spring streamflow, increased winter streamflow and reduced late summer flow. Transient basins will likely experience significant shifts, becoming rain dominant as winter precipitation falls more as rain and less as snow. Watersheds that are rain dominated will likely experience higher winter streamflow because of increases in average winter precipitation, but overall will experience relatively little change with respect to streamflow timing. These changes are important because they determine when water is available and how it must be stored.

- **For Washington State as a whole, projected changes in runoff depend strongly on season.**

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[10] In watersheds that accumulate significant snowpack, SWE on April 1 is a common indicator of summer water supply.

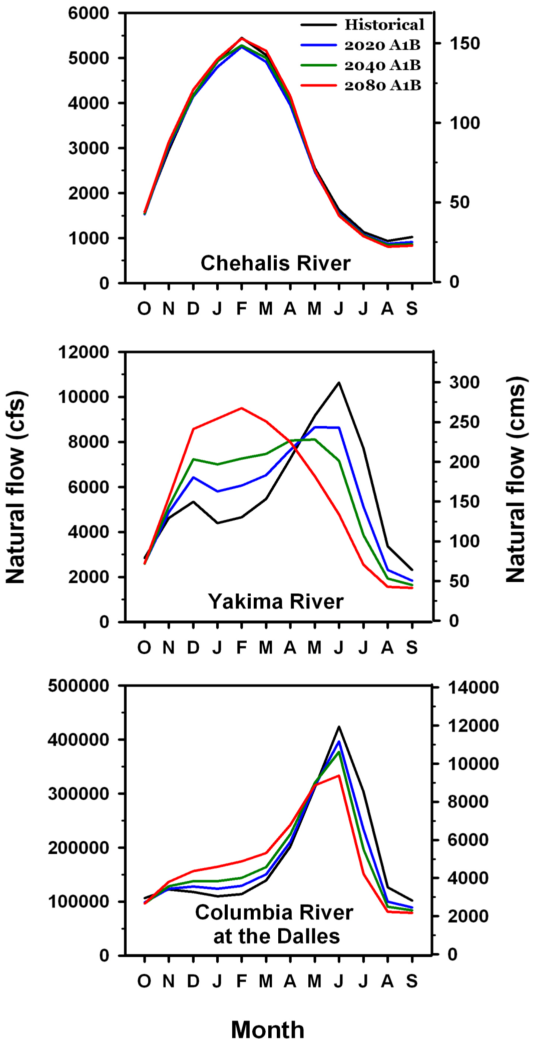

Figure 6. Historical and projected future hydrographs for three rivers under the medium emissions scenario (A1B). The Chehalis River represents a rain-dominated watershed, the Yakima River represents a transient watershed (mixed rain and snow), and the Columbia River represents a snowmelt-dominated watershed. Projected climate changes will influence the timing of peak streamflow differently in different types of hydrologic basins. The timing of peak streamflow does not change in rain-dominated basins because most of the precipitation falls as rain, both currently and in the future, and is therefore available for runoff as it falls. Timing of peak flow shifts earlier as climate warms in the transient and snowmelt-dominated basins because precipitation that historically fell as snow later falls as rain – snowpack melting ceases to dominate the timing of peak flow as the snowpack declines.

- Average cool season (October to March) runoff is projected to increase 10% to 13% by the 2020s, 16% to 21% by the 2040s, and 26% to 35% by the 2080s, corresponding with reduced snowpack and increased precipitation falling as rain.
- Average warm season (April to September) runoff is projected to decrease 16% to 19% by the 2020s, 22% to 28% by the 2040s, and 34% to 43% by the 2080s, although warm season runoff is historically about half of cool season runoff so the magnitude of these changes is smaller.
- Annual runoff (water into streams) across the state is projected to increase 0% to 2% by the 2020s, 2% to 3% by the 2040s, and 4% to 6% by the 2080s. These changes are mainly driven by projected increases in winter precipitation.

3.2 Water Management - Puget Sound

According to the 2000 census, the Puget Sound region contains almost 70% of Washington State's population. The water supply that is required to sustain the regional environment and more than 4 million people depends heavily on both natural and artificial means of storage. Puget Sound watersheds, like other basins that receive both rain and snow, are highly sensitive to changes in climate. Key findings on the implications of climate change for water management in the Puget Sound include the following:

- **The primary impact of climate change on Puget Sound natural water supply will be a shift in the timing of peak river flow from late spring (driven by snowmelt) to winter (driven by precipitation).** Puget Sound water supply systems will generally be able to accommodate changes through the 2020s in the absence of any significant demand increases. Projected changes in system reliability are small for the Everett, Seattle, and Tacoma systems in the 2020s. Even with future increases in demand, only the Tacoma system is projected to experience substantial reductions in reliability by the 2040s, primarily because water allocations within that system are closer to current system capacity.
- **Other aspects of system performance, such as reduced levels of summer and fall storage, occur as early as the 2020s.** Seasonal patterns of reservoir storage will be affected to varying degrees in all three systems. The amount of water stored in reservoirs will be lower from late spring through early fall, affecting water supply for municipal use and other

operating objectives such as hydropower production and the ability of the systems to augment seasonal low flows for fish protection. For example, in the Seattle system, October storage levels below 50% active capacity occurred historically 34% of the time, but are projected to increase to 58% in the 2020s, 67% in the 2040s, and 71% in the 2080s (scenario A1B).

3.3 Water Management and Irrigated Agriculture – Yakima

Crops in the Yakima Valley, most of which are irrigated, represent about a quarter of the value of all crops grown in Washington. The watershed's reservoirs hold 30% of streamflow annually and rely heavily on additional water storage in winter snowpack to meet water demand for agriculture. As in other watersheds across Washington, climate change is projected to cause decreases in snowpack and changes in streamflow patterns, making active management of water supply critical for minimizing negative impacts. Agricultural production increases caused by warming temperatures will likely be undermined by lack of water for irrigation.

- **The Yakima basin reservoir system will be less able (compared to 1970-2005) to supply water to all users, especially those with junior water rights.** Historically (1916-2006)[11], the Yakima basin has been significantly water short[12] 14% of the time. Without adaptations, current projections of the medium (A1B) emissions scenario estimate this value will increase to 32% (15% to 54% range) in the 2020s and will increase further to 36% in the 2040s and 77% in the 2080s.
- **Due to increases in temperature and changes in the timing and quantity of snowmelt and runoff, the irrigation season will likely be shorter, the growing season will likely be earlier by about two weeks, and crop maturity will likely be earlier by two to four weeks by the 2080s.**
- **Under the medium (A1B) emissions scenario, average apple and cherry yields are likely to decline by 20% to 25% (2020s) and by 40% to 50% (2080s) for junior water rights holders.** These declines are due to lack of irrigation water and more frequent and severe prorating, even though the direct effect of warming and CO_2 (carbon dioxide) would be to increase production (see Agriculture chapter).
- **The value of apple and cherry production in the Yakima basin is likely to decline by approximately $23 million (about 5%) in the 2020s and by $70 million (about 16%) in the 2080s.** These declines are buffered by senior irrigators and by price responses to smaller production. Overall, the risk of net operating losses for junior irrigators is likely to increase substantially.

4. Energy Supply and Demand

Hydropower accounts for roughly 70% of the electrical energy production in the Pacific Northwest and is strongly affected by climate-related changes in annual streamflow amounts and seasonal streamflow timing. Heating and cooling energy demand in Washington will be affected by both population growth and warming temperatures. Other factors influence energy supply and demand, but this assessment focuses on (1) the effects of projected warming and precipitation change on regional hydropower production, and (2) the effects of warming on energy demand, expressed in terms of heating energy demand (population times heating degree days, or the demand for energy for heating structures) and residential cooling energy demand (population times cooling degree days times the amount of air conditioning use, or the demand for energy for cooling structures).

- **Annual hydropower production (assuming constant installed capacity) is projected to decline by a few percent due to small changes in annual stream flow, but seasonal changes will be *substantial* (Figure 7).** Winter hydropower production is projected to increase by about 0.5% to 4.0% by the 2020s, 4.0% to 4.2% by the 2040s, and 7% to 10% by the 2080s (compared to water year 1917-2006) under the medium (A1B) emissions scenario. The largest and most likely changes in hydropower production are projected to occur from June to September, during the peak air conditioning season. Summer (JJA) energy production is projected to decline by 9% to11% by the 2020s, 13% to 16% by the 2040s, and 18% to 21% by the 2080s
- **Despite decreasing heating degree days with projected warming, annual heating energy demand**

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[11] Simulation models for the historical period 1916-2006 were used to determine the frequency of water short years – see chapter 3, Hydrology and Water Resources, for details. Prorating began on the Yakima system in 1970.

[12] "Water short" is defined as 75% prorating (effectively, a legal loss of 25% of water rights during drought) for junior water rights holders.

is projected to increase due to population growth[13] **(Figure 8).** In the absence of warming, population growth would increase heating energy demand in WA by 38% by the 2020s, 68% by the 2040s, and 129% by the 2080s. For fixed 2000 population, projected warming would reduce heating energy demand by 11% to 12% for the 2020s, 15-19% for the 2040s, and 24% to 32% for the 2080s due to decreased heating degree days. Combining the effects of warming with population growth, heating energy demand for WA is projected to increase by 22% to 23% for the 2020s, 35% to 42% for the 2040s, and 56% to 74% for the 2080s. Increases in annual heating energy demand will affect both fossil fuel use for heating and demand for electrical power.

- **Residential cooling energy demand is projected to increase rapidly due to increasing population, increasing cooling degree days, and increasing use of air conditioning (Figure 8).** In the absence of warming, population growth would increase cooling energy demand in WA by 38% by the 2020s, 69% by the 2040s, and 131% by the 2080s. For fixed 2000 population, warming would increase cooling energy demand by 92% to 118% for the 2020s, 174-289% for the 2040s, and 371% to 749% by the 2080s due to the combined effects of increased cooling degree days, and increased use of air conditioning. Combining the effects of warming with population growth, cooling energy demand would increase by 165% to 201% (a factor of 2.6-3.0) for the 2020s, 363-555% (a factor of 4.6-6.5) for the 2040s, and 981-1845% (a factor of 10.8-19.5) by the 2080s. Increases in cooling energy demand are expected to translate directly to higher average and peak electrical demands in summer.

- **Taken together the changes in energy demand and regional hydropower production suggest that adaptation to climate change in cool season will be easier than in warm season.** Increases in hydropower production in winter will at least partially offset projected increases in heating energy demand due to population growth. Adapting to projected increases in cooling energy demand (which would result in increased electrical energy demand) will be more difficult because of reductions in hydropower production in the peak air conditioning season. These effects in summer will put additional pressure on other sources of energy.

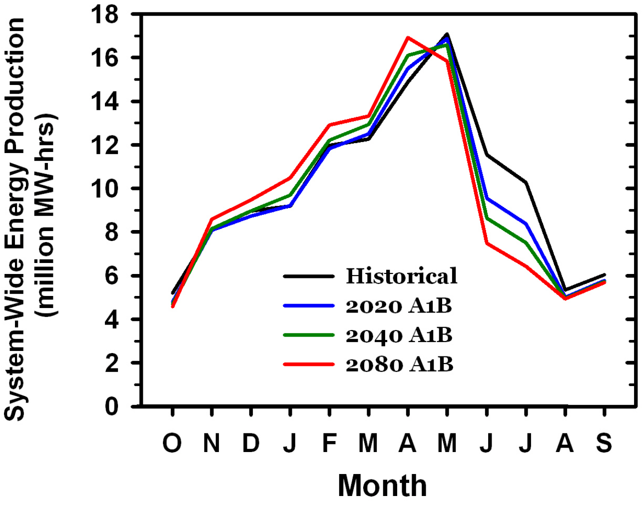

Figure 7. Long-term average system-wide energy production from the Columbia River hydro system for historical 20th century climate (1917-2006) by month, compared to future scenarios for the 2020s, 2040s, and 2080s for the medium (A1B) emissions scenario.

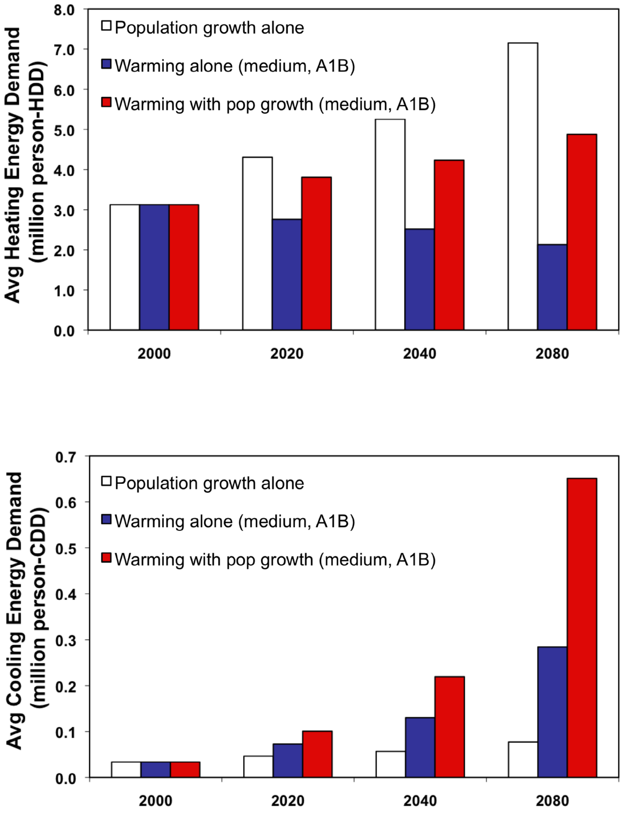

Figure 8. Heating energy demand (top) and cooling energy demand (bottom) for projected population growth and regional warming averaged over Washington. Units: million person-heating degree days (HDD) or million person-cooling degree days (CDD).

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[13] Population estimates in this study used information from both the Washington Growth Management Act estimates and global estimates. See Energy chapter for details.

5. Agriculture

The impact of climate change on agriculture in eastern Washington State is assessed in this study by focusing on the major commodities in terms of output value: apples, potatoes, and wheat. Agricultural impacts depend on the direct effects of climate, but they also depend on increasing atmospheric carbon dioxide (CO_2) independent of CO_2's influence on climate. Increased CO_2 in the atmosphere can increase crop yields for some plants and also increase water use efficiency, which in turn may provide additional benefits in dryland crop yields. Projections presented assume that plants have adequate supply of nutrients and are well protected from pests and weeds, and for irrigated crops they assume adequate availability of water for irrigation (see section 3.2, Water Management and Irrigated Agriculture). Crop response to climate change[14] is assessed based on changes for 2020, 2040, and 2080 scenarios with respect to a baseline climate (1975-2005).

- **The impact of climate change on these crops in eastern Washington is projected to be mild in the short term (i.e., next two decades), but increasingly detrimental with time, with potential yield losses reaching 25% for some crops by the end of the century**. However, increased atmospheric CO_2 will likely offset some of the direct effects of climate and result in important yield gains for some crops. There is some debate about whether the CO_2 effect on plants will be temporary (perennial plants may adapt to new conditions or growth of plants in natural environments may be limited by other factors), but mounting experimental evidence involving agricultural crops show a definite beneficial effect of "CO_2 fertilization" on growth and yield of many crops, even for perennial crops such as fruit trees that are expected to be in production for many years.
- **Yields of dryland winter wheat are projected to increase (2% to 8%) for the 2020s and remain unchanged or increase slightly for the 2040s because earlier maturity in response to warming will allow plants to avoid some water stress.** However, yield reductions (4% to 7%) are projected for the 2080s in the higher precipitation region. When CO_2 increase is added, yields are projected to increase by 13% to 15% (2020s), 13% to 24% (2040s), and 23% to 35% (2080s), with the larger gains in drier sites. No change in spring wheat yields is projected for the 2020s, but declines of 10% to 15% for the 2040s, and 20% to 26% for the 2080s are projected due to climate change. Increased CO_2 will compensate for decreased yields, leading to increases of 7% and 2% for the 2020s and 2040s at Pullman, but a 7% increase (2020s) followed by a 7% reduction (2040s) at Saint John. Earlier planting combined with CO_2 elevation is projected to increase yields by 16% for the 2020s.
- **Yields of fully irrigated potatoes are projected to decline by 9%, 15%, and 22% for the 2020s, 2040s, and 2080s, respectively, with smaller losses of only 2% to 3% for all scenarios when the effect of CO_2 is included.** The development of varieties with a longer duration of green leaf area, combined with elevated CO_2, could potentially result in yield gains of ~15%. However, tuber quality is a concern due to tuber growth limitations under warmer conditions.
- **Without the effect of elevated CO_2, future climate change is projected to decrease fully irrigated apple production by 1%, 3%, and 4% for the 2020s, 2040s, and 2080s, respectively.** When the effect of CO_2 is added, yields are projected to increase by 6% (2020s), 9% (2040s), and 16% (2080s). Realizing potential yield gains and maintaining fruit quality standards at higher yields will require management adaptations.

Caveats of the projection of impacts on agriculture presented in this study are: a) possible changes in the frequency and persistence of extreme temperature events (both frosts and heat waves) are not well represented in current climate projections, which could adversely affect crop yields, b) the extent to which the potential benefits of elevated CO_2 will be realized is moderately uncertain, c) changes in impacts by pests, weeds, and invasive species could affect agriculture in ways not described here, and d) although water supply was assumed to be sufficient for irrigated crops, other studies (see Water Resources - Irrigated Agriculture) indicate that it may decrease in many locations as a result of climate change, adding additional stress.

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[14] Climate change scenarios in the Agriculture sector used future scenarios from four global climate models with contrasting future conditions, rather than the average of many scenarios. These models were PCM1 (a model that projects less warming and more precipitation for the Pacific Northwest), CCSM3 (a model that projects more warming and less precipitation for the Pacific Northwest), and ECHAM5 and CGCM3 (models that project intermediate changes compared to the first two). All modeling used medium (A1B) CO_2 emission scenarios.

6. Salmon Production and Distribution

Climate plays a crucial role in salmon ecology at every stage of their life cycle. Key limiting factors for freshwater salmon reproductive success depend on species, their life history, watershed characteristics, and stock-specific adaptations to local environmental factors. The overarching questions addressed here are: (1) How will climate change alter the reproductive success of salmon and steelhead in freshwaters of Washington State? and (2) Where and under what conditions will salmon habitat be most vulnerable to climate change (increasing water temperatures and changes in the timing and amount of streamflow)?

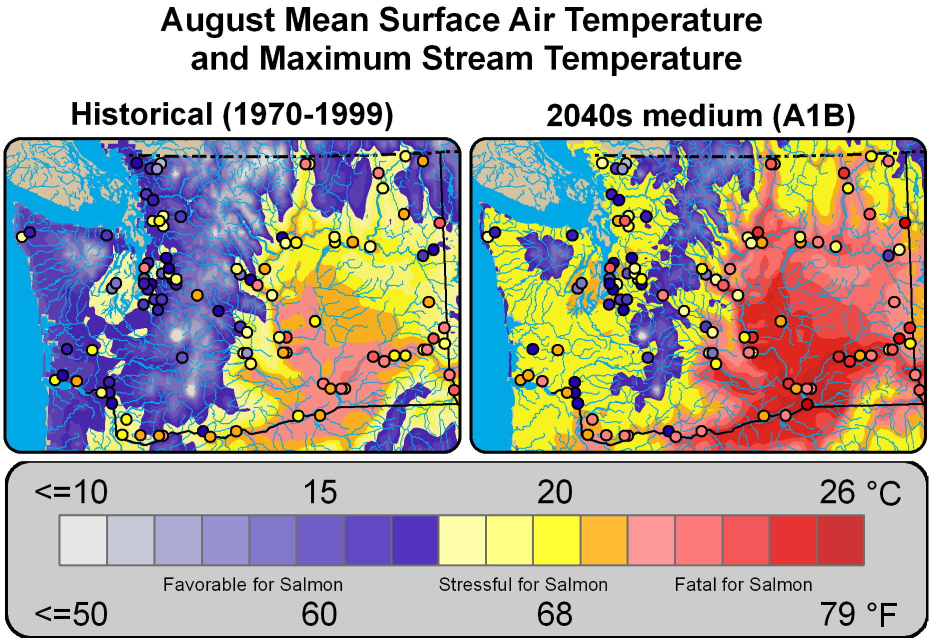

Figure 9. August mean surface air temperature (colored patches) and maximum stream temperature (dots) for 1970-1999 (left) and the 2040s (right, medium emissions scenario, (A1B)). The area of favorable thermal habitat for salmon declines by the 2040s in western Washington, and in eastern Washington many areas transition from stressful to fatal for salmon. Circles represent selected stream temperature monitoring stations used for modeling stream temperatures.

- **Rising stream temperature will reduce the quality and quantity of freshwater salmon habitat substantially.** Since the 1980s the majority of waters with stream temperature monitoring stations in the interior Columbia Basin have been classified as stressful for salmon (where annual maximum weekly water temperatures exceed 60°F). Water temperatures at these stations are projected to become increasingly hostile for salmon under both medium (A1B) and low (B1) emissions scenarios. The duration of temperatures[15] causing migration barriers and thermal stress in the interior Columbia Basin are projected to quadruple by the 2080s. Water temperatures for western Washington stations are generally cooler, and projected increases in thermal stress are significant but less severe - the duration of temperatures greater than 70°F will increase but such temperatures are still projected to be relatively rare for all but the warmest water bodies in Washington (Figure 9).

- **In the major river systems of Puget Sound and lower elevation basins in the interior Columbia Basin, flood risk will likely increase, which in turn increases the risk of streambed scouring of spawning habitat.** In snowmelt-dominated watersheds that prevail in the higher altitude catchments and in much of the interior Columbia Basin, flood risk will likely decrease. Summer low flows will decrease in most rivers under most scenarios (Figure 10), leading to reduced habitat capacities for rearing juveniles that must spend at least one summer in freshwater.

- **Consequences of these changes will vary with different populations and with where they spend the different parts of their life cycles.** Salmon populations that typically inhabit freshwater during summer and early fall for either spawning migrations, spawning, or rearing will experience significant thermal stress. For spawning migrations, effects of warming are projected to be most severe for adult summer steelhead, sockeye, and summer Chinook populations in the Columbia Basin, sockeye and Chinook in the Lake Washington system, and summer chum in Hood Canal. For rearing habitat, impacts of warming will likely be greatest for coho and steelhead (summer and winter run) throughout western Washington. Reductions in summer and

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[15] Thermal stress for salmon in streams can be of several types. Salmon suffer physical stress when stream temperatures are too warm, but warm waters also present thermal barriers to migration because the water is too warm for salmon to pass through. Where weekly water temperatures exceed 70°F, both physical stress and thermal barriers to migration are very likely.

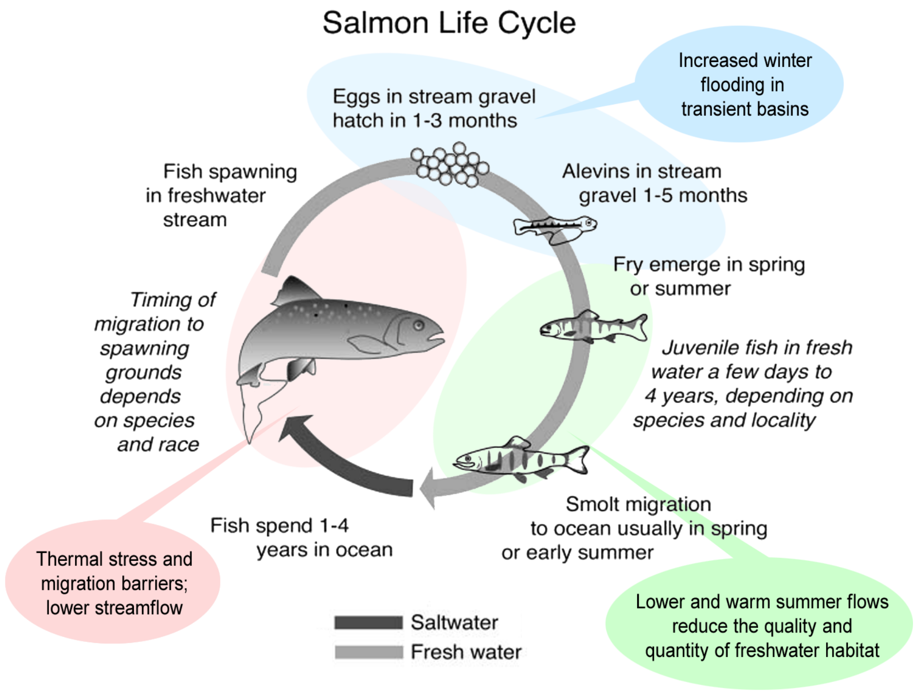


Figure 10. Life cycle assessment and impacts mechanisms for salmon and steelhead in Washington.

fall flows will likely negatively impact the rearing capacities and for coho, steelhead, and stream type Chinook because they all have a life history pattern that requires at least one year of juvenile rearing in freshwater.

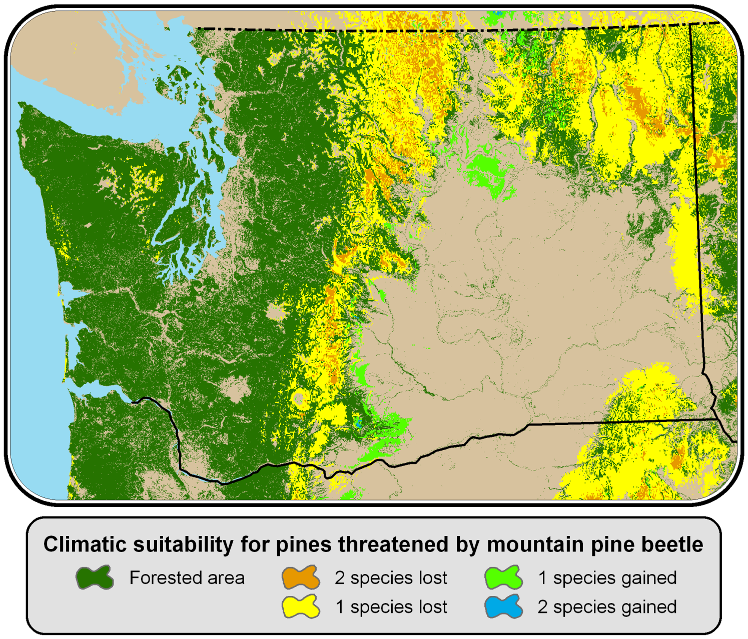
7. Forests

Climate influences nearly all aspects of forest ecosystems. Forest fires, insect outbreaks, tree species' ranges and forest productivity are closely tied to climate. Profound changes in forest ecosystems are possible given the magnitude of projected climate changes. The combined climate change impacts on tree growth, regeneration, fire, and insects will fundamentally change the nature of forests, particularly in ecosystems where water deficits are greatest. Many impacts will likely occur first in forests east of the Cascade crest, but forests west of the Cascades will likely experience significant changes in disturbance regime and species distribution before the end of the 21st century.

- **Due to changes in summer precipitation and temperature, the area burned by fire regionally (in the U.S. Columbia Basin) is projected to double or triple (medium scenario, (A1B)), from about 425,000 acres annually (1916-2006) to 0.8 million acres in the 2020s, 1.1 million acres in the 2040s, and 2.0 million acres in the 2080s.** The probability that more than two million acres will burn in a given year is projected to increase from 5% (1916-2006) to 33% by the 2080s. Fire regimes in different ecosystems in the Pacific Northwest have different sensitivities to climate, but most ecosystems will likely experience an increase in area burned by the 2040s. Year-to-year variation will increase in some ecosystems.
- **Due to climatic stress on host trees, mountain pine beetle outbreaks are projected to increase in frequency and cause increased tree mortality.** Mountain pine beetles will reach higher elevations due to a shift to favorable temperature conditions in these locations as the region warms. Conversely, the mountain pine beetle will possibly become less of a threat at middle and lower elevations because temperatures will be unfavorable for epidemics. Other species of insects (such as spruce beetle,

Douglas-fir bark beetle, fir engraver beetle, and western spruce budworm) will possibly also emerge in areas that are no longer suitable for the mountain pine beetle.

- **The amount of habitat with climate ranges required for pine species[16] susceptible to mountain pine beetle will likely decline substantially by mid 21st century (Figure 11).** Much of the currently climatically suitable habitat is in places unlikely to have future climatic conditions suitable for pine species establishment and regeneration, and established trees will be under substantial climatic stress. The regeneration of pine species after disturbance will likely be slowed, if the species can establish at all.
- **The area of severely water-limited forests[17] will increase a minimum of 32% in the 2020s, and an additional 12% in both the 2040s and 2080s (Figure 11, medium scenario, (A1B)).** Douglas-fir productivity varies with climate across the region and will potentially increase in wetter parts of the state during the first half of the 21st century but decrease in the driest parts of its range. Geographic patterns of productivity will likely change; statewide productivity will possibly initially increase due to warmer temperatures but will then decrease due to increased drought stress. It is important to note that changes in species mortality or regeneration failures will possibly occur before the point of severe water limitation (as it is defined here) is reached.



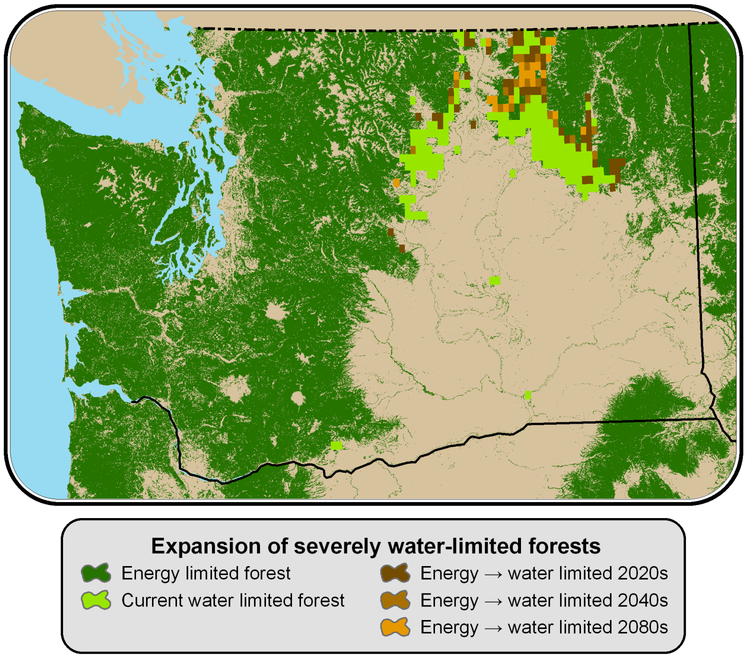


Figure 11. Changes in areas of potential pine species' ranges for 2060 (top panel) and severely water limited forest (bottom panel) in Washington. Areas of orange and yellow in the top panel indicate areas where one or more species of pines will possibly have difficulty re-establishing after disturbance (fire, insect attack, etc.) because the climate is beyond the ranges to which they are adapted (Data: Rehfeldt et al. 2006, multiple IPCC emissions scenarios[18]). Hydrologic modeling suggests that many forested areas on the northern edge of the Columbia basin will become severely water limited (bottom, scenario A1B), defined conservatively as those forests where summer environmental water demand exceeds annual precipitation. The area of water limited forests would increase substantially if the definition is expanded to a more general definition where forests are water limited if annual water demand exceeds annual precipitation (not shown).

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[16] Ponderosa pine, lodgepole pine, and whitebark pine were considered in this study.

[17] Severely water limited forests occur where the annual supply of water does not meet the summer environmental demand for water. Specifically, when summer potential evapotranspiration exceeds annual precipitation, there is severe water limitation.

[18] The data (from Rehfeldt et al. 2006) used for this analysis were developed by researchers using similar emissions scenarios in an older generation of global climate models to model tree species' ranges in western North America. The ranges of projected future climate changes used in Rehfeldt are comparable to those developed for this assessment.

8. Coasts

Washington State's approximately 3000 miles of coastline (Figure 12) are diverse, ranging from the sandy beaches and shallow waters of Willapa Bay to the steep rocky shores in the San Juan Islands, to the heavily populated but relatively unstable bluffs of the Puget Sound region. While global climate change will drive the same basic physical changes throughout the region, each shore area, and the human activities in those areas, will respond in specific ways depending upon substrate (sand versus bedrock), slope (shallow versus steep cliffs), and the surrounding conditions (exposed versus sheltered from storms). Because Washington's coasts are heavily utilized for ports, home sites, public recreation, wildlife habitat, and shellfish aquaculture, these physical effects of climate change will pose significant challenges. The summary of coastal impacts, and related threats posed to homes, infrastructure, and commerce, are derived from examination of several specific sites and physical threats. Some of the specific sites examined include Willapa Bay, Bainbridge Island, Whidbey Island, the San Juan Islands, and the Ports of Seattle and Tacoma. This assessment does not examine impacts on wildlife habitat, which climate change could possibly affect through sea level rise, bluff erosion, water temperature, and other impacts.

Overall, this brief survey of climate impacts on the coasts of Washington State has identified possible routes by which climate can interfere with typical human uses of the coast and has raised many questions requiring additional research.

- **Sea level rise will shift coastal beaches inland and increase erosion of unstable bluffs, endangering houses and other structures built near the shore or near the bluff edges (see Scenarios section for sea level rise information).** On Whidbey Island, future possible impacts include increased bluff erosion and landslides and inundation. On Bainbrige Island, inundation and, to a lesser extent, bluff erosion are possible. Willapa Bay would see possible increases in shoreline erosion.
- **Shellfish will possibly be negatively impacted by increasing ocean temperatures and acidity, shifts in disease and growth patterns, and more frequent harmful algal blooms.** Further, inter-tidal habitat for shellfish aquaculture will likely be slowly shifting shoreward as sea level rises. Health risks due to harmful algal blooms will possibly be a increasing concern, leading to more frequent closures of both recreational and commercial shellfishing.

Figure 12. Washington State coastal areas.

- **The major ports of Seattle and Tacoma are only slightly above existing sea level, and both have some plans to raise the height of piers, docks and terminals in response to sea level rise.** Both ports also rely on access to highway and railroad transportation to move freight, but key railroad tracks and much of the container yards will possibly be subject to flooding without more extensive construction of dikes or land filling. Protecting the port lands and transportation networks will be a challenge for these and other ports throughout the state.
- **These conclusions extend to other coastal structures and facilities in the Puget Sound region which must accommodate to sea level rise or retreat to higher ground.**

Adapting to these effects will possibly involve both innovative property boundary laws to accommodate the shifting high tide lines and genetic research to select more resilient sub-species of shellfish. Further research will be a necessary element of any longer-term, adaptive strategy for climate change in the region.

9. Urban Stormwater Infrastructure

Washington's urban infrastructure elements are not equally vulnerable to weather and climate. This assessment focuses on stormwater management facilities in urban areas because the relationship to potential climate change (particularly precipitation extremes on which much of their design is based) is obvious, the consequences of inadequate facilities are severe, and the economic impact of increasing the capacity of stormwater facilities (or more severe flooding) would be substantial. Three specific areas – the central Puget Sound, Spokane, and Portland-Vancouver – were chosen for detailed analyses because they are the most populous in the state.

- **Few statistically significant changes in extreme precipitation have been observed to date in the state's three major metropolitan areas.** Nonetheless, drainage infrastructure designed using mid-20th century rainfall records may be subject to a future rainfall regime that differs from current design standards.
- **Projections from two regional climate model (RCM) simulations generally indicate increases in extreme rainfall magnitudes throughout the state over the next half-century, but their projections vary substantially by both model and region (see Figure 13).**
- **Hydrologic modeling of two urban creeks in central Puget Sound suggest overall increases in peak annual discharge over the next half-century, but only those projections resulting from one of the two RCM simulations are statistically significant.** Magnitudes of projected changes vary widely, depending on the particular basin under consideration and the choice of the underlying global climate model.

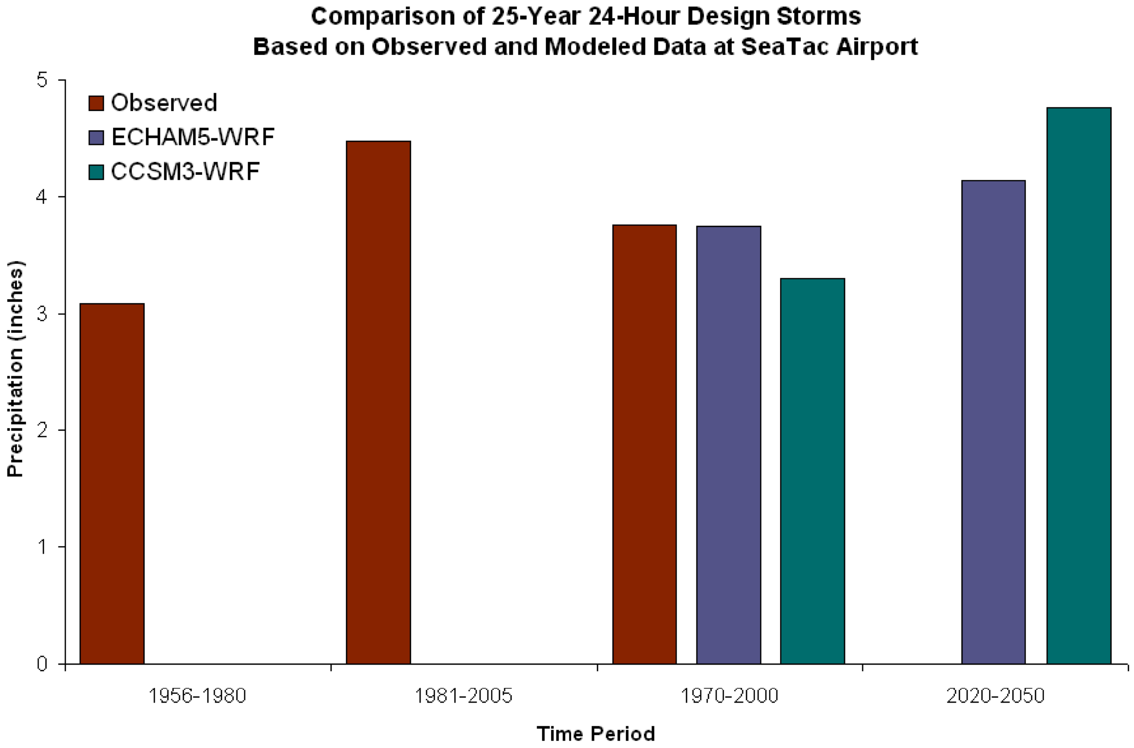

Figure 13. Comparison of 25-year, 24-hour design storms[18] based on observed and modeled (regional climate model) data at SeaTac airport. Projected changes under one climate model[19] are greater than those under another climate model, although both project increases. The historical range is similar to the range of projected changes. Note that the two time periods at left (1956 to 1980 and 1981 to 2005) overlap the third time period (1970 to 2000).

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[18] 25-year, 24-hour design storm is a typical design standard for storm sewer capacity. The 25-year 24-hour design storm is the amount of precipitation falling over a 24 hour period that has a 1 out of 25 (4%) chance of being exceeded in any given year.

[19] ECHAM5 and CCSM3 are global climate models, and in this assessment, these global models were the two used to provide input conditions to a much more detailed regional climate model (WRF) – see Scenarios chapter for details.

10. Human Health

Illness and mortality related to heat and worsening air quality are core public health concerns associated with climate change projections. First, the historical relationship between mortality rates and heat events in the greater Seattle area (King, Pierce and Snohomish counties), Spokane County, the Tri-Cities (Benton and Franklin counties) and Yakima County from 1980 through 2006 are examined for different ages of people and causes of mortality. Second, increased mortality from projected heat events is estimated for 2025, 2045, and 2085. Third, increased mortality due to ozone pollution caused by climate change is estimated for mid century (2045-2054) in King and Spokane Counties. We focused on these impacts because they are among the more direct effects of climate on human health. It is possible that impacts related to communicable diseases, changes in disease vector habits, extreme weather events, and other factors would also become problematic in the future, but these were not addressed in this study.

- **Washington State residents were more likely to die during heat waves than during more temperate periods (baseline 1980-2006).** Risks increased during heat waves lasting two or more days, and were greatest for older adults. Among residents of the greater Seattle area (King, Pierce and Snohomish Counties) aged 65 and above, heat waves of two to four days' duration were associated with a 14% to 33% increase in the risk of death from non-traumatic causes. Greater Seattle residents aged 85 and above were 31% to 48% more likely to die during heat waves of two to four days (Figure 14).
- **Climate change in Washington State will likely lead to larger numbers of heat-related deaths. The greater Seattle area in particular can expect substantial mortality during future heat events due to the combination of hotter summers and population growth.** Considering just the effects of climate, a medium (A1B) climate change scenario projects 101 additional deaths among persons aged 45 and above during heat events in 2025. By 2045, approximately a 50% increase in additional deaths could be attributed directly to climate change; even more excess deaths could be expected if population continued to grow beyond 2025 projections. Nearly half of these are expected to occur among persons 85 years of age and older.
- **Although better control of air pollution has led to improvements in air quality, warmer temperatures threaten some of the sizeable gains that have been made in recent years.** The estimated number of summer deaths due to ozone pollution in 1997-2006 is 69 in King County and 37 in Spokane County. Ground-level ozone concentrations are projected to increase in both counties. Using projections of the future population size[20] and ozone concentrations, this would increase to 132 deaths in King County and 74 deaths in Spokane County by the 2040s.

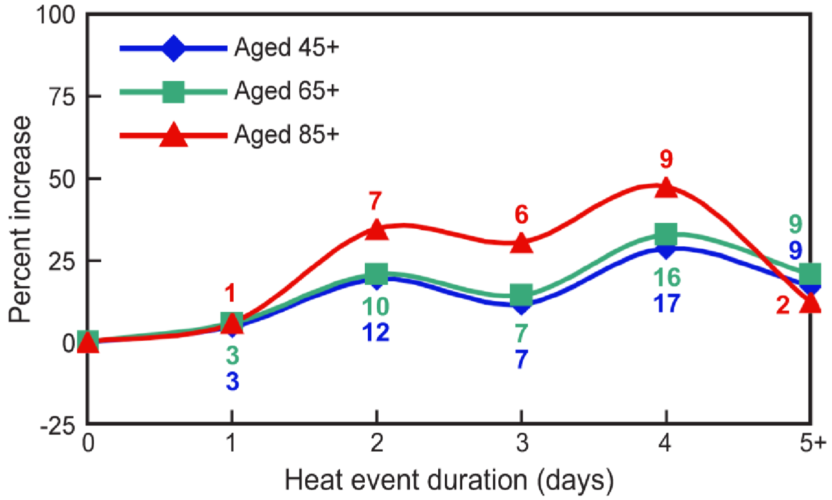

Figure 14. Percent increase in risk of death, and number of deaths each day for all non-traumatic causes by heat event duration, greater Seattle area, 1980-2006. Given 2006 population levels, residents of the greater Seattle area aged 65 and above could be expected to experience, on average, 3 additional deaths on day 1 of a heat event, 10 additional deaths on day 2, and so forth; over a 5 day heat event this age group would incur a total of 45 additional deaths, and during an average heat event of 2.2 days' duration, they would experience an additional 14 deaths. Persons aged 85 and above could be expected to experience 25 additional deaths during a 5 day heat event and 9 additional deaths during a typical heat event.

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[20] Population estimates from Washington State's Office of Financial Management.

11. Adaptation

Climate change will affect many aspects of Washington's natural, institutional, economic, cultural, and legal landscape. Furthermore, because of lags in the global climate system and the long lifetime for key greenhouse gasses in the atmosphere, climate change impacts over the next few decades are virtually certain. Impacts in the second half of the 21st century are also certain, but the magnitude of those changes will be greatly influenced by the success or failure of efforts to reduce greenhouse gas concentrations both in the near-term and over time.

Preparing for (or adapting to) the impacts of climate change is necessary to minimize the negative consequences of climate change in Washington State, including an increased risk for drought, forest fires, habitat loss, and heat stress. Adapting to climate change also creates opportunities to maximize the benefits of climate change, such as a longer growing season and increased winter hydropower production. Additional reasons for preparing for climate change at the state and local level are provided in Box 4.

Box 4. Why Preparing for Climate Change Is Required at the State and Local Level

1. Significant regional-scale climate change impacts are projected.
2. State and local governments, businesses, and residents are on the "front line" for dealing with climate change impacts.
3. Decisions with long-term impacts are being made every day, and today's choices will shape tomorrow's vulnerabilities.
4. Significant time is required to develop adaptive capacity and implement changes.
5. Preparing for climate change may reduce the future costs of climate impacts and responses.
6. Planning for climate change can benefit the present as well as the future.

Navigating Washington's changing future will require regulatory, legal, institutional, and cultural changes to reduce the barriers that limit building a more climate resilient Washington. Washington's commitment to adapting to climate change was formalized on February 7, 2007, when Governor Christine Gregoire signed the Washington Climate Change Challenge (Executive Order 07-02). In addition to establishing greenhouse gas reduction goals for the state, Executive Order 07-02 committed the state to determining what steps the State could take to prepare for the impacts of climate change in five key sectors: public health, agriculture, coasts and infrastructure, forestry, and water supply. Adaptation recommendations from the Preparation/Adaptation Working Groups (PAWGs) were presented to the Governor in February 2008.

The Washington Climate Change Impacts Assessment complements the State's effort with the PAWGs by providing updated and expanded details on the potential impacts of climate change in Washington. It is important to note that the adaptation discussion in the Washington Assessment should be viewed as starting point for initiating a more systematic look at the adaptation needs identified by the PAWGs in addition to other potential options. This could be done with continued involvement from the PAWGs and/or through a combination of intra- and inter-agency working groups (and public input) convened to evaluate what adaptation options are needed and how they can be implemented.

As Washington's state and local governments begin considering how to address climate change impacts, three fundamental principles must be recognized. **First, there is no "one size fits all" solution for adapting to climate change.** Options for adapting to climate change vary among sectors (e.g., between water resources and forest ecosystems) and even within sectors (e.g., between watersheds) depending on the unique characteristics of the systems being considered. Adapting to climate change will require multiple actions implemented over varying time frames based on projected impacts, resources, and risks.

Second, adapting to climate change is not a one-time activity. Climate will continue to change as will Washington's communities, economies, social preferences, and policies and regulations. The assumptions that shape adaptive planning must be revisited periodically and adjusted to reflect these changes. Thus, adapting to climate change must be seen as a continuous series of decisions and activities undertaken by individuals, groups, and governments rather than a one-time activity.

Third, effective adaptation will require more regulatory flexibility and systematic integration of governance levels, science, regulation, policy, and economics. Increased flexibility and integration is needed to accommodate uncertainties of climate change as well as the uncertainties in non-climatic stresses, such as population growth, changing resource demands, and economic trends. More general options for increasing flexibility in Washington State policy-making include, but are not limited to, building social capital (increasing knowledge and engagement); broader use of market mechanisms, conditional permitting, adaptive management, and the precautionary principle; and increasing legislative flexibility in the courts. Implementing no-regrets, low-regrets, and win-win (co-benefit) strategies are also effective ways of moving forward with adaptation in the face of uncertainty. Without more integration and flexibility, the institutions, laws, and policies used to govern human and natural systems could become increasingly constrained in their ability to effectively manage climate change impacts.

Implementing the PAWG recommendations and adaptation options identified in this report will require a concerted effort on the part of state and local decision makers, working in partnership with federal agencies, tribal governments, and the private sector, to make needed changes in how human and natural systems are governed in Washington. Washington State faces unprecedented economic challenges, however. A significant budget deficit looms and deep cuts will be required to balance the state budget.

Despite these challenges, preparing for climate change can continue from its important beginnings in the 2007 PAWG process. Many of the actions recommended by the PAWG process as well as others provided within this report require nominal fiscal resources. Furthermore, many adaptive actions may create cost savings through damage avoidance or delayed infrastructure upgrades, for example. Finally, many of the changes required to develop a more climate-resilient Washington will take time to implement. Waiting for climate change to "arrive" will be too late in some cases and could be significantly more costly in other cases.

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12. Conclusion

Climate plays a strong role in many of the resources and the quality of human life in Washington State. Projected increases in temperature and accompanying variability in precipitation point to a very different future for Washington's people and resources than that of the recent past. All sectors examined in this study project quantifiable impacts of climate change on important resources, and the projections of future climate indicate that these impacts are very likely to grow increasingly strong with time.

- **Adaptation to the changes in climate and their impacts on human, hydrological and ecological systems is necessary because the projected impacts of climate change are large.** There is enough current scientific information to plan and develop strategies for future projected climate changes and impacts even though information is not always complete. For example, "no regrets" strategies that provide benefits now and potential flexibility later are a good place to start. However, adaptation could be costly in some cases where the rate of change is very fast or where severe impacts are spread over large areas. Finally, significant impacts are projected in some sectors as early as the 2020s and certainly by the 2040s – these are not "far in the future" impacts.
- **To the extent that it can be identified, quantified, and mitigated, uncertainty is a component of planning, not a reason to avoid planning.** Many sectors report different impacts in different systems (e.g., snowpack response in low vs. high elevations, fire response in the western Cascades vs. Blue Mountains, different salmon populations and different crops etc.), but the **natural complexity (variability in geographic space and in time, such as decadal climate variability) of these systems is a key part of planning for the future.** Better climate information, better monitoring, and better awareness of complexity are all required to anticipate future impacts and to develop adaptation strategies that are likely to be successful.
- While there is compelling evidence that climate in the next century will differ markedly from that of the past, the exact nature of those differences are impossible to predict with precision. Our sensitivity to the inherent uncertainty of future climate change can be evaluated through an examination of multiple future climate scenarios and their associated impacts. **By understanding the likely direction and magnitude of future climate changes and impacts, we can manage risks and exploit opportunities in an informed and systematic way.**

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