

*State of Knowledge Report*

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**Climate Change Impacts and Adaptation  
in Washington State:  
Technical Summaries for Decision Makers**

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*Executive Summary*

*Prepared by the*  
Climate Impacts Group  
University of Washington

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**COLLEGE OF THE ENVIRONMENT**  
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- Full report: <http://cses.washington.edu/db/pdf/snoveretalsok816.pdf>
- Executive summary: <http://cses.washington.edu/db/pdf/snoveretalsokexecsum819.pdf>

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**Eric Salathé**, University of Washington

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## Table of Contents

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<b>Executive Summary</b>	ES-1
<i>Observed Changes</i>	
SECTION 1 How Are <b>Global and National Climate</b> Changing?	1-1
SECTION 2 How Is <b>Pacific Northwest Climate</b> Changing?	2-1
<i>Projected Changes</i>	
SECTION 3 Making Sense of the New <b>Climate Change Scenarios</b>	3-1
SECTION 4 How Are <b>Global and National Climate</b> Projected to Change?	4-1
SECTION 5 How Is <b>Pacific Northwest Climate</b> Projected to Change?	5-1
SECTION 6 How Will Climate Change Affect <b>Water</b> in Washington?	6-1
SECTION 7 How Will Climate Change Affect <b>Forests</b> in Washington?	7-1
SECTION 8 How Will Climate Change Affect <b>Plants and Animals</b> in Washington?	8-1
SECTION 9 How Will Climate Change Affect the <b>Coast and Ocean</b> in Washington?	9-1
SECTION 10 How Will Climate Change Affect <b>Infrastructure</b> in Washington?	10-1
SECTION 11 How Will Climate Change Affect <b>Agriculture</b> in Washington?	11-1
SECTION 12 How Will Climate Change Affect <b>Human Health</b> in Washington?	12-1
<i>Appendix</i>	
Bibliography: <b>Key References</b> on Climate Change	A-1

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## EXECUTIVE SUMMARY

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This State of Knowledge Report, *Climate Change Impacts and Adaptation in Washington State*, summarizes existing knowledge about the likely effects of climate change on Washington State and the Pacific Northwest,<sup>[A]</sup> with an emphasis on research since 2007.<sup>[B]</sup> This report provides technical summaries detailing observed and projected changes for Washington’s climate, water resources, forests, species and ecosystems, coasts and ocean, infrastructure, agriculture, and human health in an easy-to-read summary format designed to complement the foundational literature from which it draws. This literature includes recent major international, United States, and Pacific Northwest assessment reports, especially two recent efforts associated with the Third U.S. National Climate Assessment,<sup>[C]</sup> scientific journal articles, and agency reports. This report also describes climate change adaptation activities underway across the state and data resources available to support local adaptation efforts.

**A rapidly growing body of research has strengthened and added local detail to previous knowledge about the causes and consequences of climate change.** (*Sections 1 and 2*) Human

activities have increased atmospheric levels of greenhouse gases (carbon dioxide, methane, and nitrous oxide) to levels unprecedented in at least the past 800,000 years. The Earth’s climate system is warming, global sea level is rising, snow and ice are declining, and ocean chemistry and climate extremes are changing. From the global scale to the scale of the western U.S., many of these changes can be attributed to human causes.

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*Human influence on the climate system is clear... Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. (IPCC 2013)*

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**Observed changes in regional climate, water resources, and coastal conditions are consistent with expected human-caused trends, despite large natural variations.** (*Section 2*) Washington and the Pacific Northwest have experienced long-

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<sup>A</sup> Whenever possible, this report focuses on information about observed and projected changes that are specific to Washington State. In cases where Washington-specific results were unavailable, information is provided relative to the Pacific Northwest as a whole. Because many characteristics of Washington’s climate and climate vulnerabilities are similar to those of the broader Pacific Northwest region, results for Washington State are expected to generally align with those provided for the Pacific Northwest, with potential for some variation at any specific location.

<sup>B</sup> Research since 2007 is emphasized in order to capture major contributions to global and regional climate science since release of the fourth global climate change assessment report by the Intergovernmental Panel on Climate Change (IPCC) in 2007. Findings from the IPCC’s fifth assessment report, released in September 2013, and from the U.S. National Climate Assessment are included where possible. These and other recent scientific assessment reports most salient to understanding the consequences of climate change for Washington State are described in Appendix 1.

term warming, a lengthening of the frost-free season, and more frequent nighttime heat waves. Sea level is rising along most of Washington's coast,<sup>[D]</sup> coastal ocean acidity has increased, glacial area and spring snowpack have declined, and peak streamflows in many rivers have shifted earlier. These long-term changes are consistent with those observed globally as a result of human-caused climate change. Still, natural climate variability will continue to result in short-term trends opposite those expected from climate change, as evidenced by recent regional cooling and increases in spring snowpack.

**Significant changes in the Earth's climate system and the climate of the Pacific Northwest are projected for the 21<sup>st</sup> century and beyond as a result of greenhouse gas emissions (Box ES-1, Figure ES-1).** (*Sections 3 through 5*) All scenarios indicate continued warming. Projected changes prior to mid-century are largely inevitable, driven by the warming that is already "in the pipeline" due to past emissions of greenhouse gases. In contrast, current and future choices about greenhouse gas emissions will have a significant effect on the amount of warming that occurs after about the 2050s. For example, global warming projected for the end of the century ranges from +1.8°F (range: +0.5°F to +3.1°F), if greenhouse gases are aggressively reduced, to +6.7°F (range: +4.7°F to +8.6°F) under a high "business as usual" emissions scenario.<sup>[E][1]</sup>

**Box ES-1.** Projected changes in key Pacific Northwest climate variables.

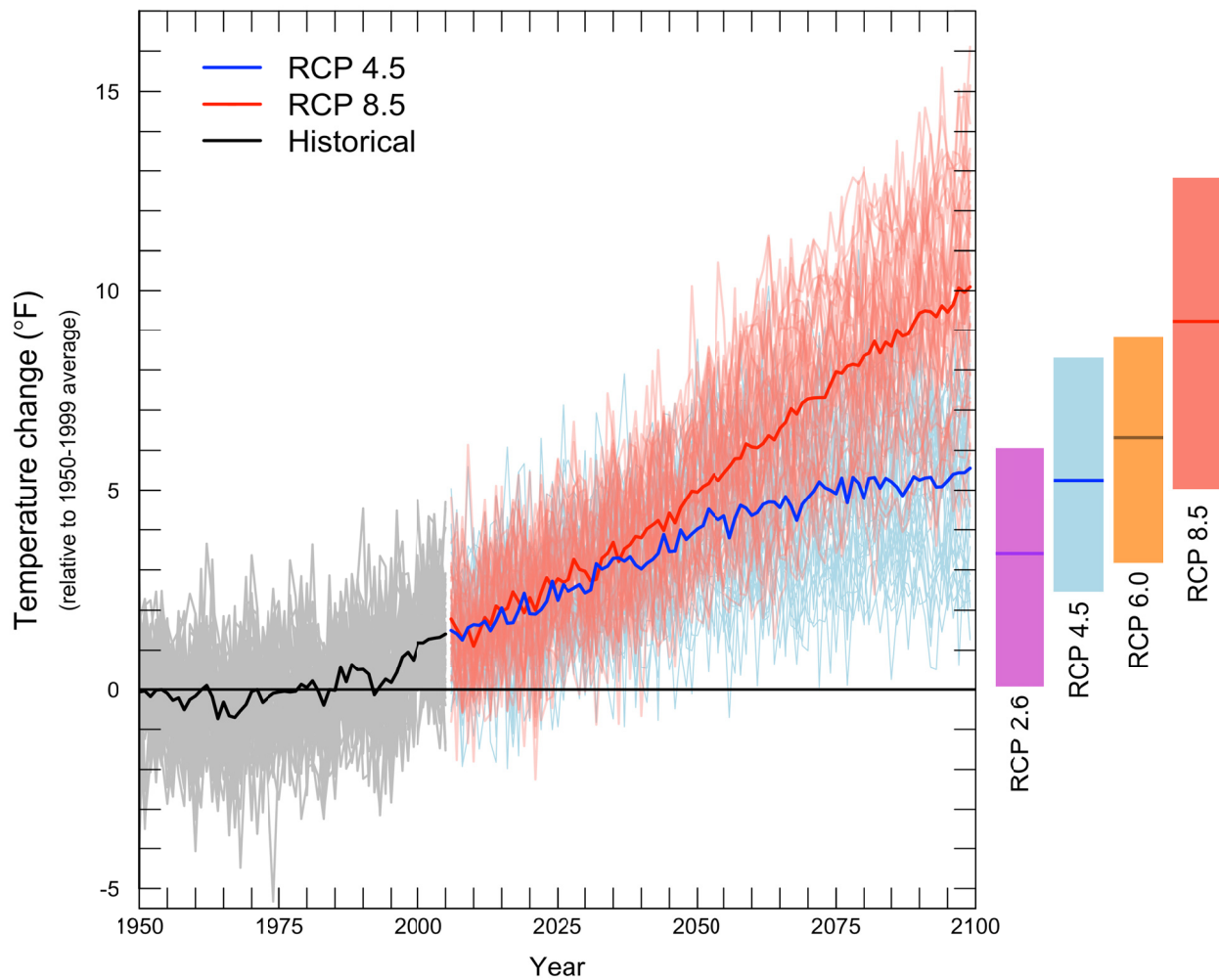
- *Average annual temperature, for 2050s:* +4.3°F (range: +2.0 to +6.7°F) for a low greenhouse gas scenario or +5.8°F (range: +3.1 to +8.5°F) for a high greenhouse gas scenario (both relative to 1950-1999).
- *Extreme precipitation, for 2050s:* number of days with more than one inch of rain increases +13% (±7%) for a high greenhouse gas scenario (relative to 1971-2000).
- *Average April 1 snowpack in Washington State, for 2040s:* -38 to -46% for a low and a medium greenhouse gas scenario (relative to 1916-2006).
- *Sea level in Washington State, for 2100:* +4 to +56 inches for low to high greenhouse gas scenarios (relative to 2000). Local amounts of sea level rise will vary.
- *Ocean acidity, for 2100:* +38 to +41% for a low greenhouse gas scenario and +100 to +109% for a high greenhouse gas scenario (relative to 1986-2005).

See Sections 3 and 6 for more detailed projections and additional time periods.

<sup>C</sup> The Northwest chapter of the U.S. National Climate Assessment (scheduled for release in spring 2014) and *Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities* (2013; edited by M.M. Dalton, P.W. Mote, and A.K. Snover, Washington, D.C.: Island Press, 271 pp.), a more detailed report developed to support the key findings presented in the Northwest chapter.

<sup>D</sup> Although *regional* sea level is rising in concert with global sea level rise, *local* sea level change also reflects variations in vertical land motion resulting from plate tectonics and other processes. As a result, sea level is currently falling in some Washington locations.

<sup>E</sup> These changes are for the period 2081-2100 relative to 1986-2005. The lower amount of warming is for the RCP 2.6 scenario, which requires that global emissions be reduced to about a 50% of 1990 levels by 2050 and for total



**Figure ES-1.** All scenarios project warming for the 21<sup>st</sup> century. The graph shows average yearly temperatures for the Pacific Northwest relative to the average for 1950-1999 (gray horizontal line). The black line shows the average simulated temperature for 1950–2011, while the grey lines show individual model results for the same time period. Thin colored lines show individual model projections for two emissions scenarios (low: RCP 4.5, and high: RCP 8.5 – see Section 3 for details), and thick colored lines show the average among models projections for each scenario. Bars to the right of the plot show the mean, minimum, and maximum change projected for each of the four emissions scenarios for 2081-2100, ranging from a very low (RCP 2.6) to a high (RCP 8.5) scenario. Note that the bars are lower than the endpoints from the graph, because they represent the average for the final two decades of the century, rather than the final value at 2100. *Figure source: Climate Impacts Group, based on climate projections used in the IPCC 2013 report.*<sup>[1]</sup>

net emissions to become near or below zero in the final decades of the 21<sup>st</sup> century. The higher amount of warming is for the RCP 8.5 scenario, which assumes continued increases in greenhouse gas emissions through the end of the 21<sup>st</sup> century. See Section 3 for more on greenhouse gas scenarios.

Projected regional warming and sea level rise are expected to bring new conditions to Washington State. By mid-century, Washington is likely to regularly experience average annual temperatures that exceed the warmest conditions observed in the 20<sup>th</sup> century. Washington is also expected to experience more heat waves and more severe heavy rainfall events, despite relatively small changes in annual and seasonal precipitation amounts.

**These and other local changes are expected to result in a wide range of impacts for Washington’s communities, economy, and natural systems.** (*Sections 6-12*) These include projected changes in water resources, forests, species and ecosystems, oceans and coasts, infrastructure, agriculture, and human health.

*Hydrology and Water Resources (Section 6).* Washington’s water resources will be affected by projected declines in snowpack, increasing stream temperatures, decreasing summer minimum streamflows, and widespread changes in streamflow timing and flood risk. These changes increase the potential for more frequent summer water shortages in some basins (e.g., the Yakima basin) and for some water uses (e.g., irrigated agriculture or instream flow management), particularly in fully allocated watersheds with little management flexibility. Changes in water management to alleviate impacts on one sector, such as hydropower production, irrigation or municipal supply, or instream flows for fish, could exacerbate impacts on other sectors.<sup>[2]</sup>

*Forests (Section 7).* Washington’s forests are likely to experience significant changes in the establishment, growth, and distribution of tree species as a result of increasing temperatures, declining snowpack, and changes in soil moisture. A rise in forest mortality is also expected due to increasing wildfire, insect outbreaks, and diseases.<sup>[3]</sup> The projected changes could affect both the spatial distribution and overall productivity of many ecologically and economically important Pacific Northwest tree species, including Douglas-fir, ponderosa pine, lodgepole pine, and whitebark pine.

*Species and Ecosystems (Section 8).* Areas of suitable climate for many plants and animals are projected to shift considerably by the end of the 21<sup>st</sup> century. Many species may be unable to move fast enough to keep up, resulting in local species losses<sup>[4]</sup> and changes in the composition of plant and animal communities. Challenges are expected for many federally-listed endangered and threatened species dependent on coldwater habitat, including salmon, trout, and steelhead. Projected impacts on other habitat types in Washington State, including wetlands, sagebrush-steppe, prairies, alpine tundra and subalpine habitats, would affect species dependent on those habitats.



*Coasts and Oceans (Section 9).* Sea level is projected to rise in most areas<sup>[F]</sup> of the state, increasing the likelihood for permanent inundation of low-lying areas, higher tidal and storm surge reach, flooding, erosion, and changes and loss of habitat. Sea level rise, rising coastal ocean temperatures, and ocean acidification will also affect the geographical range, abundance, and diversity of Pacific Coast marine species. These include key components of the marine food web (phytoplankton and zooplankton) as well as juvenile Chinook salmon and commercially important species such as Pacific mackerel, Pacific hake, oysters, mussels, English sole, and yellowtail rockfish.<sup>[5]</sup>

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*Climate change can make today's extreme events more common. For example, two feet of sea level rise in Olympia could turn today's 100-year flood into an annual event.*

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*Built Infrastructure (Section 10).* Climate change is expected to affect the longevity and performance of built infrastructure in Washington State. Most climate change impacts are likely to increase the potential for damage and service disruptions, although some risks (such as snow-related highway maintenance and closures) may decrease. Higher operating costs and reduced asset life are also expected. Sea level rise and increased river flooding are important causes of impacts on infrastructure located near the coast or current floodplains.

*Agriculture (Section 11).* Washington crops and livestock will be affected by climate change via increasing temperatures and water stress, declining availability of irrigation water, rising atmospheric carbon dioxide, and changing pressures from pests, weeds, and pathogens. Some impacts on agriculture may be beneficial while others may lead to losses – the consequences will be different for different cropping systems and locations. While impacts on some locations and subsectors may be significant, most agricultural systems are highly adaptable. As a result, the overall vulnerability of Washington's agricultural sector to climate change is expected to be low. However, given the combination of increasing water demands and decreasing supply in summer, water stress will continue to be a key vulnerability going forward.

*Human Health (Section 12).* Climate change is expected to affect both the physical and mental health of Washington's residents by altering the frequency, duration, or intensity of climate-related hazards to which individuals and communities are exposed. Health impacts include higher rates of heat-related illnesses (e.g., heat exhaustion and stroke); respiratory illnesses (e.g., allergies, asthma); vector-, water-, and food-borne diseases; and mental health stress (e.g., depression, anxiety). These impacts can lead to increased absences from schools and work, emergency room visits, hospitalizations, and deaths.

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<sup>F</sup> Recent research projects +4 to +56 inches of sea level rise by 2100 for Washington State, compared to 2000, which will be modulated by local vertical land movement. The potential for continued decline in local sea level for the Northwest Olympic Peninsula cannot be ruled out at this time. For more information, see Section 5.

**While climate change is expected to have important consequences for most sectors, key areas of risk have been identified.** According to analyses completed for the U.S. National Climate Assessment, priority issues of concern for the Pacific Northwest are:

- Changes in the natural timing of water availability, due to the impacts of warming on snow accumulation and melt, reducing water supply for many competing demands and causing far-reaching ecological and socioeconomic consequences;
- Coastal consequences of sea level rise, river flooding, coastal storms, erosion, inundation, and changes in the coastal ocean including increasing ocean acidity;
- Additional forest mortality and long-term transformation of forest landscapes, caused by the combined impacts of increasing wildfire, insect outbreaks, and tree diseases.<sup>[6]</sup>

These key risk areas, identified because of their likely significant consequences for the regional economy, infrastructure, natural systems, and human health, are also relevant to Washington State.

**Many Washington communities, government agencies, and organizations are preparing for the impacts of climate change.** Washington State—one of 15 U.S. states with a state adaptation plan<sup>[G]</sup>—has been identified as one of “the best states when it comes to planning for climate change.”<sup>[H]</sup> Innovative partnerships are linking science, management, and planning across jurisdictions, helping a growing number of communities and organizations in the public and private sector to begin adapting to climate change (Box ES-2).

**Box ES-2.** A sampling of Washington communities, government agencies, and organizations preparing for the local effects of a changing climate.

- *Washington State:* Departments of Ecology, Transportation, Natural Resources, Fish and Wildlife, Health, Agriculture, Office of the Insurance Commissioner.
- *Local governments:* King County, Seattle, Anacortes, Olympia, Sound Transit, Port of Bellingham, Port of Seattle.
- *Federal agencies:* U.S. Army Corps of Engineers, Bureau of Reclamation, Bonneville Power Administration, U.S. Forest Service, National Park Service.
- *Tribal governments:* Swinomish Indian Tribal Community, Jamestown S’Klallam Tribe.

<sup>G</sup> *Preparing for Climate Change: Washington State’s Integrated Climate Response Strategy* includes recommended adaptation actions for a range of sectors important to Washington State. These recommendations were developed through a year-long, multi-stakeholder collaboration among agencies, non-government organizations, and academic institutions. More information is available at: [www.ecy.wa.gov/climatechange/ipa\\_responsestrategy.htm](http://www.ecy.wa.gov/climatechange/ipa_responsestrategy.htm).

<sup>H</sup> <http://www.nrdc.org/water/readiness/>

The growth in adaptation efforts across the state has been stimulated by increasing awareness of the potential implications of climate change, the recognition that climate risks can be reduced by advance action, and the availability of locally-specific climate data, tools, and technical guidance to support adaptation planning. However, most efforts are still in the initial stages of assessing potential climate impacts and developing response plans; few have begun the challenging work of implementing adaptive responses. As more entities act to reduce their climate risks, new knowledge gaps and decision support needs will emerge. Building a climate resilient Washington will require effectively and efficiently meeting those needs.

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**The Climate Impacts Group**

*University of Washington*

<http://ces.washington.edu/cig/>

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