3. Observed Trends and Future Projections



3. Observed Trends and Future Projections

Climate change is pushing temperature and many climate-influenced conditions and events beyond their historical ranges. In Washington State, we are already experiencing trends that are consistent with a warming climate, from warmer temperatures to rising sea levels to melting snow and ice to more drought and extreme rainfall. (See Appendix D for a summary of Pacific Northwest climate change impacts.) Scientists project that these trends will continue and in some cases accelerate, posing significant risks to human health, our forests, agriculture, freshwater supplies, coastlines, and other natural resources that are vital for our economy and the environment.

Nine key indicators and projections of climate change affecting Washington State are discussed in more detail below:

- Increasing carbon dioxide levels.
- Warmer air temperatures.
- Drier summers and reduced snowfall.
- More frequent and severe extreme weather events.
- Rising sea levels.
- More acidic marine waters.
- Warmer water temperatures.
- Increasing frequency and severity of wildfires.
- Increasing frequency and severity of flooding.

Scientific projections of future climate in the Pacific Northwest

The Washington Climate Change Impacts Assessment reported scientific projections of future climate for the Pacific Northwest and assessed the potential consequences for eight key ecological and economic sectors. The assessment projects future climate for the Pacific Northwest using two scenarios of future greenhouse gas (GHG) emissions.

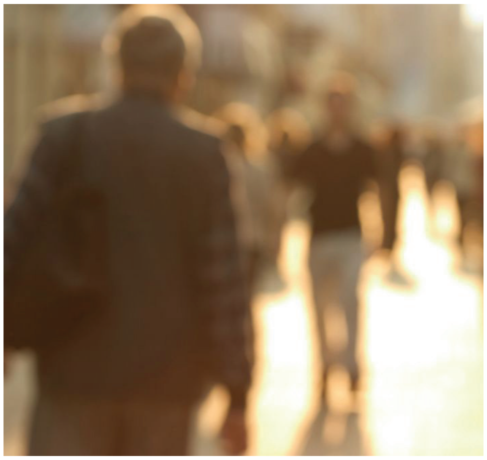
The scenarios provide plausible examples of what might happen given different assumptions about future technology, population growth, economic development, and other factors affecting greenhouse gas emissions. Scenarios can help us understand the likely range of future impacts and our vulnerability to climate change.

The **"A1B"** scenario represents a moderate GHG emissions scenario where global GHG emissions rise sharply until mid-century and slowly decline to the end of the century.

The **"B1"** scenario reflects a low emissions scenario where global GHG emissions rise slowly until mid-century and more rapidly decline to the end of the century.

GHG emissions are currently rising faster than what is projected in the A1B or B1 scenarios. This suggests that if current trends continue, climate impacts could be more severe than what is projected for the two scenarios.

http://cses.washington.edu/cig/res/ia/waccia.shtml#report



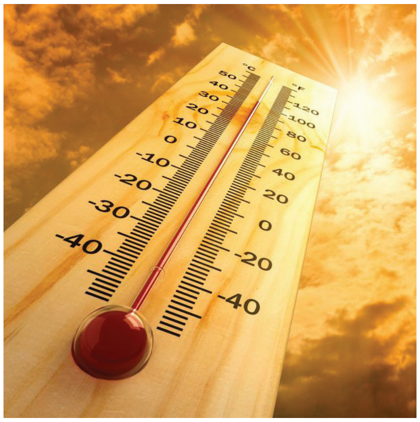
1 Increasing carbon dioxide levels

Climate change is caused by increasing levels of carbon dioxide and other greenhouse gases such as methane and nitrous oxide in the earth's atmosphere.

Observed trends: In 2010, atmospheric carbon dioxide levels were 392 parts per million (ppm), an increase of 41 percent over pre-industrial levels of 278 ppm and higher than any level in the past 650,000 years.[13]

Future projections: If current trends continue, carbon dioxide levels are projected to reach 600 to 1,000 parts per million by the year 2100.[14] Increasing levels of carbon dioxide and other greenhouse gases are causing global temperatures to rise and making the world's oceans become more acidic.

2 Warmer air temperatures



The *Washington Climate Change Impacts Assessment* projects potentially significant increases in average annual and seasonal temperatures in the Pacific Northwest.[15] Even at the low end of the projections, the changes in average annual temperature will be substantially higher than average conditions observed in the 20th century. Warming is expected in all seasons, with the greatest warming occurring during the summer months.

Observed trends: In the Pacific Northwest, average annual temperature rose 1.5°F between 1920 and 2003. The warming has been fairly uniform and widespread, with little difference between warming rates at urban and rural weather monitoring stations. Although the warmest single year on record was 1934, according to NASA the 2000s were the warmest decade since reliable modern records have been kept, going back to 1880.[16]

[13] NOAA/ESRL, http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html; IPCC (2007b).
[14] IPCC (2007a).
[15] Climate Impacts Group (2009).
[16] NASA (2010).

Future projections: Average annual temperature in the Northwest is projected to increase (relative to 1970-1999) approximately:

- 2°F by the 2020s (range of 1.1 to 3.4°F).
- 3.2°F by the 2040s (range of 1.6 to 5.2°F).
- 5.3°F by the 2080s (range of 2.8 to 9.7°F).[17]

Natural variability, including El Niño, La Niña, and the Pacific Decadal Oscillation (PDO), will continue to influence average temperatures, bringing colder or warmer than average years—or decades in the case of the PDO—to the Northwest, even as average global and regional temperatures increase over the long term as a result of rising greenhouse gas emissions.

Higher temperatures are expected to cause glacial and snowpack melt, sea level rise, more severe storms, increased wildfires, and increased diseases and pests.

3 Drier summers and reduced snowfall

Summers are expected to be drier, and winters are generally expected to be wetter, although some models project winter drying.[18] Because winter temperatures are projected to rise, Washington is expected to receive less snow and more rain on average in the future. As with temperature, natural variability will affect how we experience climate at any given point in time, producing wetter or drier than average years (or decades), even as climate change affects precipitation trends over the long term. Because of our region's large range of natural variation between wetter and drier years, it may be difficult to see how climate change is altering long-term precipitation trends for several decades.

Observed trends: Trends in annual precipitation in the Pacific Northwest vary depending on the time period, but overall, annual precipitation has increased. For the period 1920-2000, annual precipitation increased approximately 13 percent. Increases during this period were largest in the spring (37 percent), followed by winter (12 percent), summer (9 percent), and autumn (6 percent).[19] Cool-season precipitation also became more variable in the western U.S. from about 1973 to 2003.[20] Average snowpack in Washington's Cascades declined about 25 percent between 1950 and 2006, due in part to natural variability, with the largest decreases occurring at lower elevations.[21]

[17] Mote and Salathé (2010).
[18] Mote and Salathé (2010).
[19] Mote (2003).
[20] Hamlet and Lettenmaier (2007).
[21] Mote *et al*. (2008).

Future projections: For summer months, a majority of models project decreases in precipitation, with the average decline of 14 percent by the 2080s.[22] Some models project reductions of as much as 20 to 40 percent in summer precipitation.[23]

In winter, a majority of models project increases in precipitation, with an average of 8 percent increase by the 2080s under the moderate emissions modeling scenario (A1B). This figure is small relative to variability from year to year.[24] Although some models project modest reductions in fall or winter precipitation, others show very large increases (up to 42 percent).[25] Spring snowpack across the state is projected to decrease 29 percent by the 2020s, 44 percent by the 2040s, and 65 percent by the 2080s (relative to the 1971-2000 average) for the A1B scenario. Projected decreases in snowpack are slightly less for the low emissions modeling scenario (B1): a 27 percent decrease for the 2020s, a 37 percent decrease for the 2040s, and a 53 percent decrease for the 2080s.[26]

Snowmelt provides approximately 70 percent of annual streamflow in the mountainous regions of the western U.S.[27] Increased winter rain (as opposed to snow) and shifts to earlier spring snowmelt—both due to warmer winter temperatures—result in higher streamflows in winter and early spring. Late spring and summer streamflows are reduced in snow-dominated and transient watersheds (which receive a mixture of rain and snow).[28]

Lower summer streamflows could have major implications for fisheries, wildlife, water supply, and agriculture, particularly in drier regions of the state.[29] Although changes in total annual precipitation may be relatively small, reduced summer precipitation and warmer temperatures may lead to decreased soil moisture and higher rates of evapotranspiration. In some areas, these changes will likely lead to increased drought frequency and severity.[30]

[22] Mote and Salathé (2010).
[23] Mote and Salathé (2010).
[24] Mote and Salathé (2010).
[25] Mote and Salathé (2010).
[26] Elsner *et al*. (2010).
[27] Mote *et al*. (2008).
[28] Casola *et al*. (2005).
[29] Elsner *et al*. (2010).
[30] Mote and Salathé (2010).

4 Extreme weather events may increase

Climate change is expected to increase the frequency and intensity of extreme weather events such as floods, coastal storm surges, droughts, and heat waves.

Observed trends: The frequency of heavy downpours (defined as the top 1 percent of rainfall events) has increased by almost 20 percent on average in the U.S. and by about 12 percent in the Pacific Northwest.[31] Nationally, 8 of the top 10 years for extreme one-day precipitation events have occurred since 1990.[32] Record high temperatures have increased compared with low temperatures, and drought conditions have increased in many parts of the western United States.

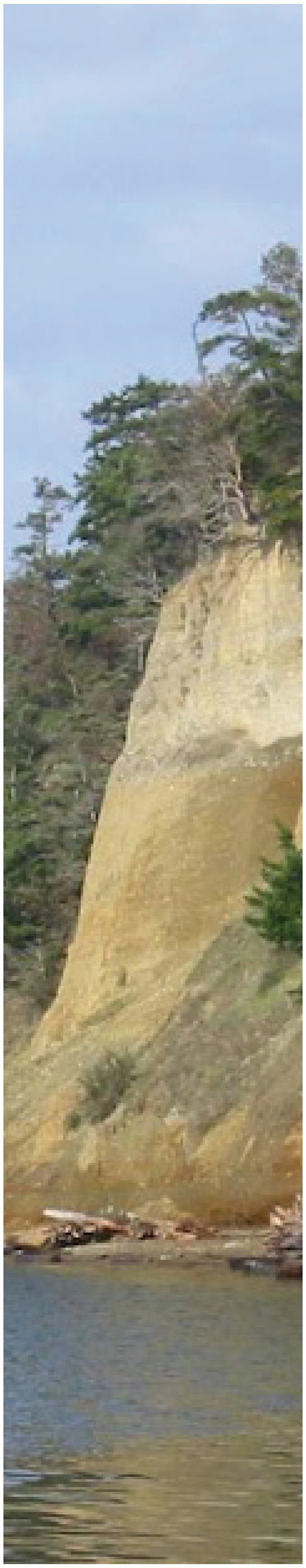
Atmospheric rivers: Narrow regions in the atmosphere that deliver large masses of warm, moist air, transporting large amounts of water vapor across the Pacific Ocean and elsewhere.

Future projections: Climate models project an increased risk for more frequent extreme precipitation in the Northwest by the second half of the 21st century, although the patterns and level of intensity is highly variable.[33] More intense atmospheric rivers along the West Coast of the United States are also possible.[34] Increases of 5 to 10 percent in storm intensity are projected for the North Cascades and northeastern Washington, while increases in other areas of the state are not significant.[35] In the Seattle-Tacoma area, the magnitude of a 24-hour storm is projected to increase 14 to 28 percent during the next 50 years.[36]

Increased extreme heat events are projected for the 2040s, especially in south-central Washington and the western Washington lowlands.[37] Increases in the average annual number of heat events, average event duration, and maximum event duration are projected for the Seattle, Spokane, Tri-Cities, and Yakima regions.[38]

Extreme weather events can cause significant damage to structures and property, depending on the exposure and vulnerability of the specific location. In Puget Sound, development in floodplains heightens the exposure and vulnerability to floods resulting from heavy downpours. Coastal development heightens the exposure and vulnerability to coastal storm surges and sea level rise.

31 U.S. Global Change Research Program (2009).
32 U.S. EPA (2010).
33 Salathé (2006); Rosenburg *et al*. (2010). Tebaldi *et al.* (2006).
34 Dettinger (2011).
35 Salathé *et al*. (2010).
36 Rosenberg *et al*. (2010).
37 Salathé *et al*. (2010).
38 Jackson *et al*. (2010).



Heat waves and drought will increase fire risk, reduce summer water supply, and increase water temperatures to lethal levels for coldwater fish species.

5 Sea levels are rising, but the relative effect varies by location

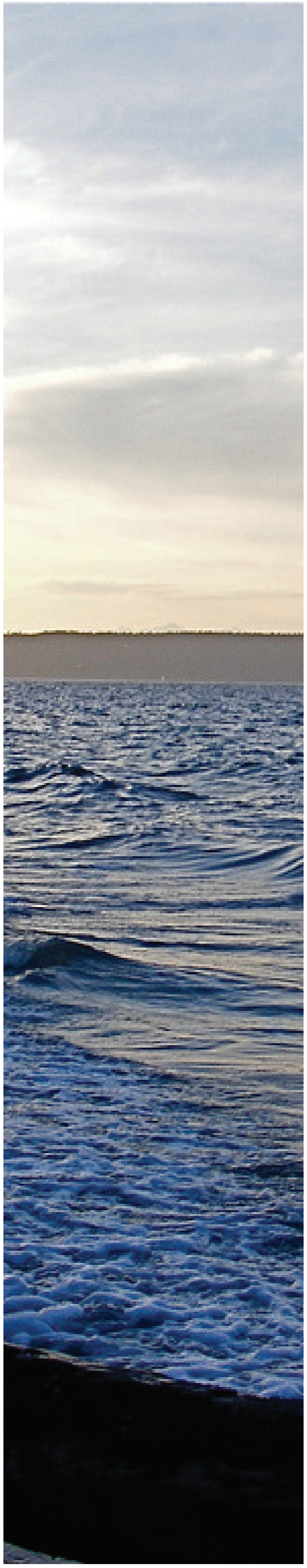
Rising sea levels are primarily caused by two processes: additional water in the ocean from melting of glaciers and land-based ice sheets like Greenland and Antarctica; and thermal expansion of ocean waters due to warmer sea temperatures. Sea level is rising globally, but the relative effect varies by location with changes in land elevation and wind patterns.

Observed trends: Globally, oceans rose approximately 8 inches from 1870-2008, an average of 0.06 inches (1.5 mm) per year. However, the rate of change has accelerated in recent years. Between 1993 and 2008, average sea level rose approximately 0.12 inches (3 mm) per year, which is roughly twice as fast as the long-term trend.[39] In Washington, sea levels are not changing uniformly. Because the edge of the Juan de Fuca oceanic plate is slowly moving under the North American continental plate in western Washington, the Olympic Peninsula is rising at a rate of about 2 millimeters (0.08 inches) a year, while south Puget Sound is subsiding at about the same rate.[40] If these trends continue, relative sea level rise will be greatest in south Puget Sound and least on the northwest tip of the Olympic Peninsula.[41]

Future projections: In the Puget Sound region, the medium estimate for sea level rise is 6 inches by 2050 and 13 inches by 2100. For the central and southern Washington coasts, the medium estimate is an increase of 5 inches by 2050 and 11 inches by 2100. If uplift on the northwest corner of the Olympic Peninsula continues through the 21st century, sea level rise in that area could be lower than other areas of the state. The medium estimate for the northwest Olympic Peninsula is 0 inches by 2050 and an increase of 2 inches by 2100. However, the potential for continued accelerated ice melt from Greenland and Antarctica means that higher sea level estimates are possible for Washington's coastal regions. Increases of up to 3 feet for the northwest Olympic Peninsula, 3.5 feet for the central and southern coast, and 4 feet for Puget Sound by 2100 cannot be ruled out at this time due to large ranges for accelerating rates of ice melt from Greenland and Antarctica.[42]

39 U.S. EPA (2010b).
40 Mote *et al*. (2008).
41 Huppert *et al*. (2009).
42 Mote *et al*. (2008).

Rising sea levels, combined with increased storm surge, will increase the frequency and intensity of coastal flooding. Periodic floods will likely pose a greater and more near-term risk than permanent inundation of low-lying areas from increases in average sea level. Coastal erosion and habitat loss are also projected due to higher sea levels. For much of Puget Sound, 1 foot of sea level rise will likely turn a flood event expected to occur once in 100 years into an event that occurs every 10 years. If sea level rises 2 feet, a flood event expected to occur once in 100 years would turn into an annual event.



6 Marine waters are becoming more acidic

The global oceans have absorbed approximately 30 percent of human-generated carbon emissions since the Industrial Revolution.[43] When dissolved carbon dioxide mixes with seawater it forms carbonic acid. As marine waters have absorbed increasing amounts of carbon dioxide, the carbonic acid has caused ocean pH to decline, making seawater increasingly acidic.

Observed trends: Globally, ocean pH has declined 0.1 units relative to its pre-industrial measure of 8.2.[44] In the Hood Canal area of Puget Sound, observed pH is substantially lower, ranging from 7.39 to 7.56.[45]

Future projections: If carbon emissions continue their current trends, global ocean pH is projected to decline to approximately 7.8 by 2100.[46]

The biological effects of ocean acidification are not well understood and will vary among organisms, with some coping well and others not at all. Marine organisms that use carbonate to build shells or skeletons are expected to be affected by changes in seawater chemistry. The long-term consequences of ocean acidification for marine organisms are unknown, but changes in many ecosystems and the services they provide to society appear likely.[47]

[43] Canadell *et al*. (2007).
[44] IPCC (2007a).
[45] Feely *et al*. (2010).
[46] IPCC (2007a).
[47] National Research Council (2010).

7 Warmer water temperatures

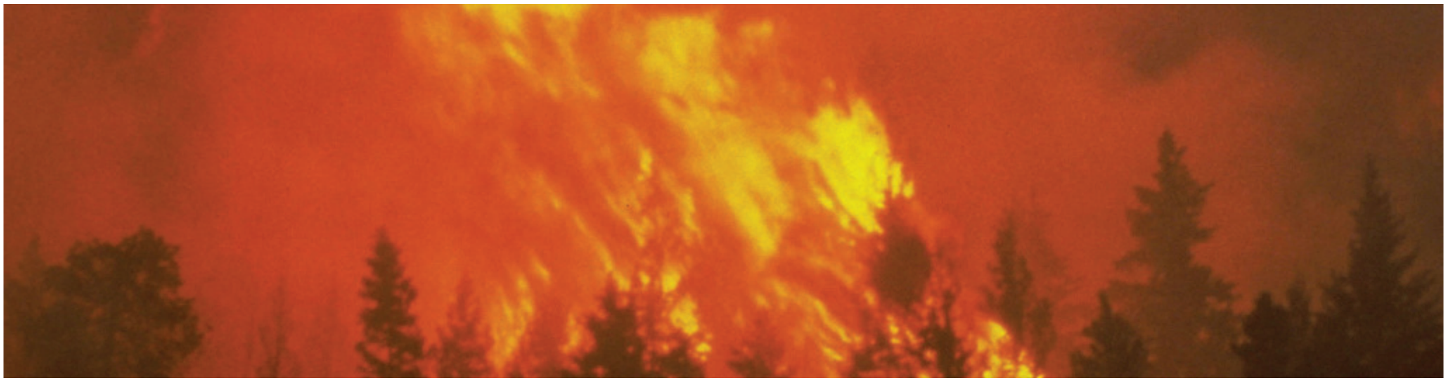
Increased water temperatures are caused by warmer air temperatures and reduced summer water inputs. Water temperatures are increasing in freshwater rivers, lakes, and wetlands as well as in marine waters and nearshore systems such as estuaries.

Observed trends: Annual average water temperature in Lake Washington increased about 1.6°F from 1964 to 1998.[48] In marine systems, average sea surface temperatures have risen globally by 1.1°F since 1950.[49]

Future projections: Average statewide summer stream temperatures are projected to rise about 1.8°F by the 2020s and between 3.6°F and 9°F by the 2080s.[50] In many of Washington's streams and lakes, the duration of periods that cause stress to salmon because of warmer temperatures and migration barriers is projected to at least double and perhaps quadruple by the 2080s.[51] Prolonged elevated water temperatures and thermal stress for salmon are expected particularly in eastern Washington along the Upper Yakima River, the Columbia River at Bonneville Dam, and the Lower Snake River near Tucannon, as well as in western Washington along the Stillaguamish River near Arlington and in the Lake Washington/Lake Union area. Sea surface temperatures near the Washington coast are projected to increase 2.2°F by the 2040s.[52]

Increased water temperatures can be lethal for salmon and other coldwater species. Lakes may also experience a longer stratification period in summer,[53] which could increase eutrophication and lead to oxygen depletion in deep zones during summer, eliminating refuges for coldwater fish species.[54] Warmer ocean temperatures contribute to sea level rise, increased storm intensity, and greater stratification of the water column.[55]

48 Arhonditsis *et al*. (2004).
49 Nicholls *et al*. (2007).
50 Mantua *et al*. (2010).
51 Mantua *et al*. (2010).
52 Mote and Salathé (2010).
53 Euro-Limpacs (2011).
54 Euro-Limpacs (2011).
55 Hoegh-Guldberg and Bruno (2010).



8 Wildfires are increasing in frequency and severity

While forest fires occur naturally and provide important ecological benefits for many ecosystems, the frequency and severity of fires is expected to increase due to climate change. Warmer air temperatures, reduced snowpack, and reduced summer precipitation lead to reduced soil moisture and longer dry seasons that prolong the period in which fires could occur.[56]

Observed trends: Over the period 1987-2003, major wildfire frequency in the western U.S. increased fourfold compared to the period 1970-1986. The area of forest burned was six times greater in 1987 to 2003 than during the previous 16-year period from 1970 to 1986.[57]

Future projections: In the Pacific Northwest, wildfires are projected to burn twice as many acres yearly by the 2040s and three times as much forest area by the 2080s (relative to 1916-2006). The probability that more than 2 million acres will burn in a given year is projected to increase from 5 percent currently to 33 percent by the 2080s.[58] In forested ecosystems such as the western and eastern Cascades, Okanogan Highlands, and Blue Mountains, the area burned is projected to increase by a factor of 3.8 by the 2040s, compared to 1980-2006.[59] Regionally, the area burned by wildfire each year on average is projected to increase from about 425,000 acres currently to 800,000 million acres in the 2020s, 1.1 million acres in the 2040s, and 2.0 million acres in the 2080s.[60]

More frequent and severe wildfires will raise the risk of injury or death for firefighters and the public as well as increase the costs of firefighting. Increased property damage and reduced timber yields are also likely, as well as reduced air quality, loss of forested habitat areas for fish and wildlife, and reduced water quality due to erosion and sedimentation of water bodies.

[56] Westerling *et al*. (2006).
[57] Westerling *et al*. (2006).
[58] Littell *et al*. (2009).
[59] Littell *et al*. (2010). Compared to the period 1980 to 2006.
[60] Littell *et al*. (2010).

9 Floods are increasing in frequency and severity

In western Washington, flood risk is generally highest in late fall and winter when precipitation is greatest. In eastern Washington, flood risk is generally highest during the spring snowmelt. An increase in winter rainfall (as opposed to snowfall) as a result of climate change is expected to lead to more winter flooding in rain-dominated and transient (rain/snow mix) watersheds.

Observed trends: Flood risks are increasing primarily in rain-dominated basins and warmer, transient basins in western Washington,[61] which tend to experience average winter temperatures near 32°F. Flood risk in colder snow-dominated basins and cooler transient basins was largely unchanged during the 20th century. Since 1990, Puget Sound has experienced 16 federally declared flood disasters, and Interstate 5 has closed four times due to flooding.[62]

Future projections: As the climate warms, flood frequency is projected to increase in the months of January to March and decrease in April to May.[63] Flood frequency is projected to increase progressively from the 2020s through the 2080s, with the largest increases predicted for mixed rain-snow runoff basins located in Puget Sound, the west slopes of the Cascades in southwest Washington, and in the lower elevations on the east side of the Cascades.[64] Rain-dominated basins are projected to experience small changes in flood frequency.

Floods can cause widespread damage to communities and property. Increased frequency and severity of floods will likely lead to greater taxpayer costs for cleanup and rebuilding as well as economic disruption. Floods have caused numerous deaths and put emergency responders at risk during rescue operations.

[61] Hamlet and Lettenmaier (2007).
[62] Washington State Department of Transportation (2008b).
[63] Vano *et al*. (2010).
[64] Mantua *et al*. (2010).