Summary of Observed Trends and Projected Climate Change Impacts

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INTRODUCTION

This document provides an overview of observed and projected climate changes relevant to Whatcom County. This overview is intended to provide the County with a foundation to understand and plan for anticipated climate impacts to assets, operations, and community services. The document focuses on the main *drivers* of climate change impacts, including changes in temperature, precipitation, hydrology, and sea level rise, as well as selected resulting impacts of wildfire and air quality. Additional secondary impacts are considered in the separate vulnerability assessments specific to identified focus areas.

This document provides the latest available climate science information from academic literature, research organizations, and institutions. Key sources of information consulted for this summary include the following:

SCALE	RESOURCE
NATIONAL	• ***Fifth National Climate Assessment Synthesis Report***, Intergovernmental Panel on Climate Change, 2014.
WASHINGTON STATE	• ***Projected Sea Level Rise for Washington State***, prepared by Washington Sea Grant, CIG, University of Oregon, University of Washington, and U.S. Geological Survey, 2018. • ***Implications of 21st Century Climate Change for the Hydrology of Washington State***, by Elsner *et al.*, 2010.
PUGET SOUND	• ***State of Knowledge: Climate Change in Puget Sound***, prepared by University of Washington Climate Impacts Group (CIG), 2015 (referenced in this document as SOK). • ***Modeling the Effects of Forecasted Climate Change and Glacier Recession on Late Summer Streamflow in the Upper Nooksack River Basin***, by Murphy, 2016. • ***Modeling the Effects of Climate Change on Stream Temperature in the Nooksack River Basin,*** by Truitt, 2018.
WHATCOM COUNTY	• **Nooksack Indian Tribe Natural Resources Climate Change Vulnerability Assessment,** Morgan and Krosby, CIG, 2017. • **South Fork Nooksack River Watershed Conservation Plan,** Nooksack Indian Tribe Natural Resources Department, 2017. • ***Community Research Project,*** Whatcom County Climate Impact Advisory Committee, 2019.

This document begins with an executive summary of key findings about future conditions. Following the summary is a brief overview of the science, methods, and geographic scales of climate change projections and their application to decision-making. The document then presents the observed trends and projected changes in climate for temperature, precipitation, hydrology, sea level rise and storm surge, wildfire, and air quality. In each of these sections, key findings are shown in blue boxes, followed by more detailed and technical information.

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EXECUTIVE SUMMARY

Temperature

- By the 2050s, the average year in Washington will likely be warmer than the hottest year of the 1900s, based on a business-as-usual emissions scenario (RCP 8.5), which is the highest emissions scenario typically used in climate change projections.
- By the 2050s, average annual temperatures in Puget Sound are projected to increase by 4.2 °F to 5.5 °F under low- and high-emissions scenarios, respectively, compared to the 1970-1999 average of 46.5 °F. By 2100, they are projected to be 5.5 °F to 9.1 °F warmer under low- and high-emissions scenarios, respectively.
- By 2080 under a high-emissions scenario, Bellingham's climate is projected to feel like Seattle's climate today, which is typically warmer and drier than Bellingham historically has experienced.
- By the 2050s, under a low-emissions scenario, projections indicate at least 1 to 2 days per year in Whatcom County and at least 2 to 3 days per year in Bellingham specifically when the heat index is above 90 °F, compared to zero days historically (1971-2000). By 2100, under a high-emissions scenario, those numbers are projected to rise to as many as 11 days per year in Whatcom County and 20 days in Bellingham.

Precipitation

- Average annual precipitation in Puget Sound is projected to increase by 4% to 5% by the 2050s under low- and high-emissions scenarios, respectively, and another 2% by the 2080s under both emissions scenarios (relative to the 1970-1999 average).
- Wetter conditions are anticipated in spring, fall, and winter, while summer will likely continue to get drier and warmer in Puget Sound. By the 2050s, summer precipitation is projected to decrease by 50% under a high-emissions scenario.
- Under a high-emissions scenario, heavy precipitation events west of the Cascades are projected to increase in intensity by 22% by the 2080s—meaning they will have 22% more rain. Meanwhile, those rain events will become more frequent, occurring five more days per year by the 2080s.

Hydrology

- Mountains draining into Puget Sound are projected to have 29% less snowpack by the 2040s.
- The Nooksack River basin is anticipated to transition from being a mixed snow and rain-dominant system to a rain-dominant system in the future. By the 2080s, peak streamflow in the Nooksack River is projected to shift approximately 27 days earlier in the year, under a moderate-emissions scenario (compared to the 1970-1999 average).
- Flooding in the Nooksack River is expected to become more intense and frequent. Under a moderate emissions scenario, streamflow in the Nooksack River during a 100-year flood event (1% probability) is projected to increase by 27% by the 2080s.
- Under a moderate emissions scenario, summer minimum streamflow in the Nooksack River is projected to decrease by 27% by the 2080s relative to the 1970-1999 average, and summertime stream temperatures are projected to increase, reaching levels that exceed the thermal tolerance of most fish species.

Sea Level Rise and Storm Surge

- By 2100, relative sea level rise in the Bellingham area is projected to be between 1.5 (likely range of 0.9-2.1 feet) and 1.9 feet (likely range of 1.3-2.7 feet) with a 50% likelihood of exceeding those values under low- and high-emissions scenarios, respectively.
- Puget Sound coastlines, including Whatcom County, are expected to experience increased storm surge and high tide flooding due to sea level rise.

Wildfire

- By the 2050s, Western Washington is projected to have 12 more days annually with very high fire danger compared to the 1971-2000 average.
- By 2100, the period of time between wildfires in the North Cascade ecoregion will shorten by a factor of 2.2 to 2.5 under low- and high-emissions scenarios, respectively [39].
- The median area burned annually from wildfire across the Northwest is projected to increase by 0.6 million hectares by the 2080s compared to 1980-2006 [40].

Air Quality

- In the future, Whatcom County's air quality is likely to decline during periods of increased wildfire activity in the Pacific Northwest, especially during the summer and early fall.
- Warmer temperatures and increases in ozone pollution may reduce Whatcom County's air quality.

CLIMATE CHANGE OVERVIEW

- **Climate projections are based on possible scenarios for how global population may generate greenhouse gas emissions in the future.** These scenarios are called Representative Concentration Pathways.
- **Recent observed GHG emissions have aligned more closely with the higher-emissions scenarios,** though all scenarios are possible.

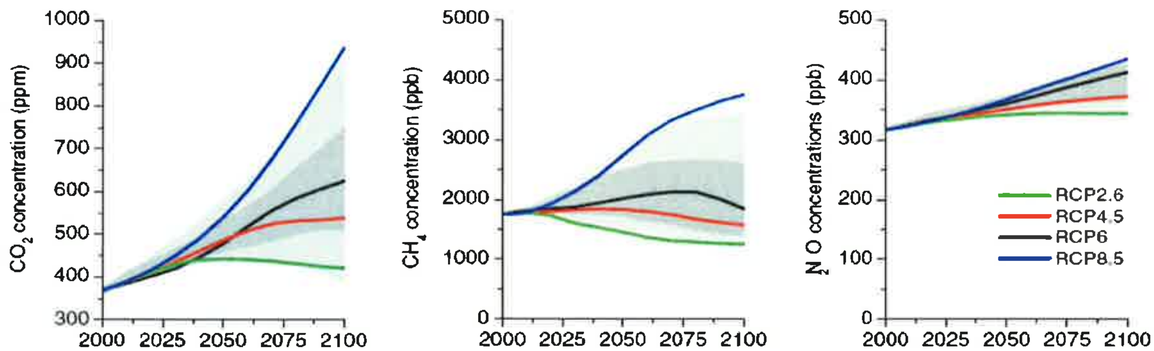
Understanding how human-caused emissions of greenhouse gases (GHG) are likely to affect our global climate requires the use of complex climate models. These models consider many factors that influence global GHG emissions, such as technology advancements, population growth, economic development, energy generation methodologies, and land use approaches. To remain consistent and comparable from study to study, researchers use a standard set of modeled greenhouse gas emissions trajectories, or scenarios, when determining the possible climate impacts of emissions.

The International Panel on Climate Change (IPCC) has published three different iterations of these climate change scenarios as our scientific understanding and computing capabilities have progressed. The newest set of scenarios, developed in 2013, consists of four commonly used Representative Concentration Pathways (RCPs): RCP 8.5, RCP 6.0, RCP 4.5, and RCP 2.6 (see Table 1 and Figure 1). These RCPs replace the second generation of projections known as the Special Report on Emissions Scenarios (SRES).

Table 1. Description of RCPs. The IPCC facilitated the development of the scenarios represented in this table. The rankings (e.g., "high," "low") are based on the scenario's projection of greenhouse gas emissions levels in 2100 **[1] [2] [3] [4]**.

RCP	Description	Comparable SRES Scenario
RCP 8.5	***High greenhouse gas emissions scenario:*** Assumes that greenhouse gas emissions increase over time, with high population growth, lower gross domestic product (GDP), and high coal and oil consumption. By 2100, carbon dioxide concentration reaches 1,370 ppm. This scenario is the business-as-usual pathway for global emissions unless significant reductions are achieved.	Most similar to the SRES A1F1 scenario.
RCP 6.0	***Moderate greenhouse gas emissions scenario*:** Assumes emissions stabilization shortly after 2100 through a range of GHG emissions reduction technologies and strategies. Assumes moderate population growth, low GDP, lower energy (primarily from natural gas and oil), and moderate oil consumption. By 2100, carbon dioxide concentration reaches 850 ppm.	Most similar to the SRES A1B and B2 scenarios.
RCP 4.5	***Low greenhouse gas emissions scenario:*** Assumes emissions stabilization at a target level of emissions shortly after 2100. Assumes low population growth, moderate GDP, lower energy (primarily from bio-energy, natural gas, coal, and oil), and moderate oil consumption. By 2100, carbon dioxide concentration reaches 650 ppm.	Most similar to the SRES B1 scenario.
RCP 2.6	***Very low greenhouse gas emissions scenario:*** Assumes greenhouse gas emissions peak and then decline significantly over time, with low population growth, high GDP, and lower energy (primarily from coal and bio-energy) and oil consumption. By 2100, carbon dioxide concentration reaches 490 ppm.	None

Figure 1. Greenhouse gas concentrations by RCP and greenhouse gas type—carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_20) [2].



It is difficult to verify which model most accurately matches future conditions. However, it is worth noting that **observed increases in GHG emissions over the past 15 to 20 years align most closely with those projected in the higher-emissions scenarios, such as RCPs 6.0 and 8.5** [5].

The IPCC's recent report urges cities and countries to take rapid action to keep global warming below 1.5 °C in the 21st century [6]. **The latest IPCC global climate change synthesis report indicates that RCP 2.6 is the only pathway that is likely to keep global warming below 2 °C. To achieve this goal, substantial net negative emissions are required—meaning that carbon must be removed from the atmosphere** (see Table 2) [7].

To reduce GHG emissions, it can be useful to aim for a low-emissions trajectory like RCP 2.6 when setting emissions reduction targets and planning mitigation strategies. **However, when preparing for climate change impacts and planning resilience strategies, it is important to prepare for more severe conditions projected in high-emissions scenarios that are unlikely to limit warming to 2 °C.** Given this, in this report we use RCPs 4.5 and 8.5 to provide a low and high projection of future emissions, which is aligned with common practices in national and regional climate projection reports.

Table 2. Key characteristics of the scenarios assessed in the IPCC Synthesis Report (2014). Adapted from Table 3.1 in report.

Corresponding RCPs	Likelihood of staying below a specific temperature level over the 21st century (relative to 1850-1900)			
	1.5 °C	2 °C	3 °C	4 °C
RCP 2.6	<50%		>65%	
RCP 4.5		<50%		
			>50%	
RCP 6.0	<33%		<50%	
RCP 8.5				<50%

Geographic Scale

Global climate models used to generate projections of future climate impacts simulate changes at broad geographic scales or resolutions, with about 50 to 100 miles between one "pixel" or grid cell to the next. At this scale, the projections are not representative of local-scale patterns in weather and climate. "Downscaling" refers to taking the coarse resolution projections from global climate models and applying them to a smaller geographic scale, achieving a level of detail that is more relevant to local management and decision-making. The increased resolution from downscaling is usually about 5 to 10 miles from one grid cell to the next; this is a 10-fold increase compared to global climate models. However, climate modeling results generally become less accurate at a smaller geographic scale, especially at the sub-regional level. Downscaling is also costly. As a result, it is uncommon to have climate projections at the city or county level.

Figure 2. Puget Sound region used for many downscaled projections in this report [9].

In this report, we most often use downscaled projections for the Puget Sound region (see Figure 2) created by the University of Washington's Climate Impacts Group (CIG). We also use some projections for Washington State or the Pacific Northwest more broadly to provide context and confirm the accuracy of downscaled projections. We use downscaled projections at the sub-regional level (Whatcom County, Bellingham, and Nooksack River) for changes in high-heat days, changes in streamflow, and sea level rise. Sub-regional downscaled projections were not available for other changes. In each section, the descriptions progress from larger to smaller geographic scales, beginning with the Pacific Northwest and the Puget Sound region and then scaling down to Whatcom County and Bellingham, where data are available.

Climate Variability and Climate Change

The climate in the Puget Sound region is complex and diverse with natural variability. Climate variability refers to the changes in climate that range over many time and space scales. Climate variability in Puget Sound is partially due to the year-to-year and decade-to-decade Pacific Ocean trends. These include the El Niño-Southern Oscillation (ENSO), also known as El Niño/La Niña, and the Pacific Decadal Oscillation (PDO) [8]. These patterns affect ocean and air temperatures, local winds, and precipitation. They affect Puget Sound by generating warmer or cooler winters compared to the long-term average, but do not strongly affect precipitation [9]. It is currently not known how ENSO may change as global warming progresses.

Seasonal weather variability in Puget Sound results from changes in the movement of moisture-saturated air that hits the Olympic and Cascade mountains. The way that circulation interacts with topography can lead to drastic climate differences between areas within the Puget Sound region.

Using Climate Projections for Adaptation Planning

Climate projections are an important tool for community and regional planning. In general, we recommend that resource managers and decisionmakers take a conservative approach to planning projects and investments by anticipating projected changes from a high-emissions scenario (RCP 8.5). This approach can reduce the risk of being underprepared for climate impacts. However, decisions to build infrastructure to withstand more severe impacts (e.g., more extreme precipitation and flooding) involve deciding the level of risk involved and how much risk decisionmakers are willing to accept.

OBSERVED TRENDS AND PROJECTED CHANGES FOR CLIMATE DRIVERS AND IMPACTS

Temperature

Observed changes to date

- During the 20th century, the **annual average temperature in Puget Sound lowlands has warmed approximately 1.3 °F** [10].
- **In Bellingham,** the **annual average temperature during the 20th century increased approximately 2.8 °F** (see Table 3) [11]. **All seasons in Bellingham have experienced statistically significant warming** [11].
- **Nighttime heat events have increased in frequency in the Puget Sound region** [12].

The Puget Sound region has experienced long-term warming trends and more frequent nighttime heat events. The Puget Sound lowlands (see Figure 3) warmed approximately 1.3 °F between 1895 and 2014 [10]. In the same area, all seasons except for spring show statistically significant warming trends during this period (see Table 3). In Bellingham, the annual average temperature increased by 2.8 °F between 1895 and 2018, and there was statistically significant warming during all seasons [11].

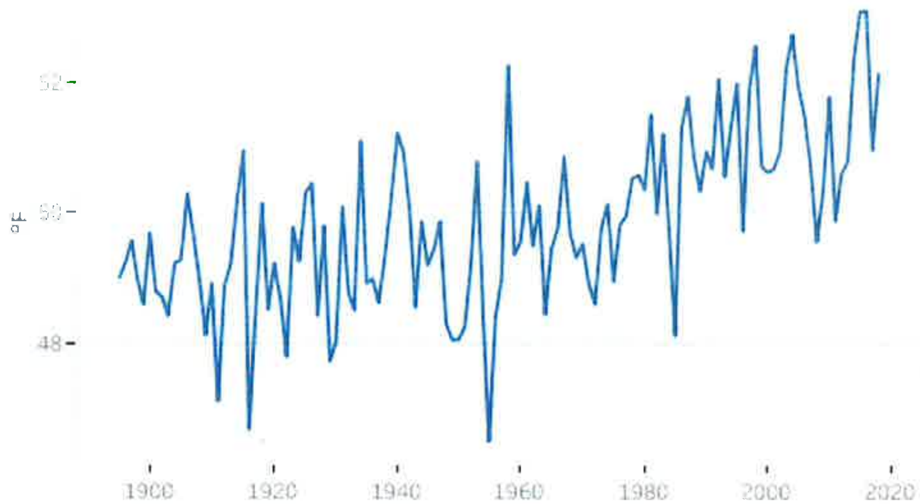
Nighttime air temperatures are increasing at a quicker pace than daytime air temperatures in the Puget Sound region. Annual minimum temperatures, which typically occur during the night, increased by 4.7 °F between 1895 and 2018 in the Bellingham area [11]. Additionally, the region's frost-free season, also known as the growing season, increased by 30 days between 1920 and 2014 [12].

Figure 3. Puget Sound lowlands climate division, which includes the low-lying areas surrounding Puget Sound. The analysis of observed changes for the Puget Sound lowlands was based on data from the U.S. Climate Divisional Dataset developed by the National Centers for Environmental Information **[9]**.

Table 3. Observed annual and seasonal trends in temperature for Puget Sound and Bellingham. All trends are significant. Note that data in this table was drawn from two separate sources that did not provide the exact same type of information for the two different spatial scales, as indicated by "N/A" **[10] [12] [11]**.

Time Period/Season	Temperature Change Puget Sound, 1895-2014	Temperature Change Bellingham, 1895-2018
Annual	+1.3 °F (+0.7 to +1.9 °F)	+2.8 °F
Fall (Sept/Oct/Nov)	+0.12 °F/decade (+.07 to +.17 °F)	+0.21 °F/decade
Winter (Dec/Jan/Feb)	+0.13 °F/decade (+.02 to +.24 °F)	+0.18 °F/decade
Spring (Mar/Apr/May)	*No significant change*	+0.22 °F/decade
Summer (June/July/Aug)	+0.13 °F/decade (+.07 to +.19 °F)	+0.31 °F/decade
Frost-Free Season	+30 days (+18 to +41 days)	N/A

Figure 4. Annual average temperature for Bellingham, 1895-2018 [11].

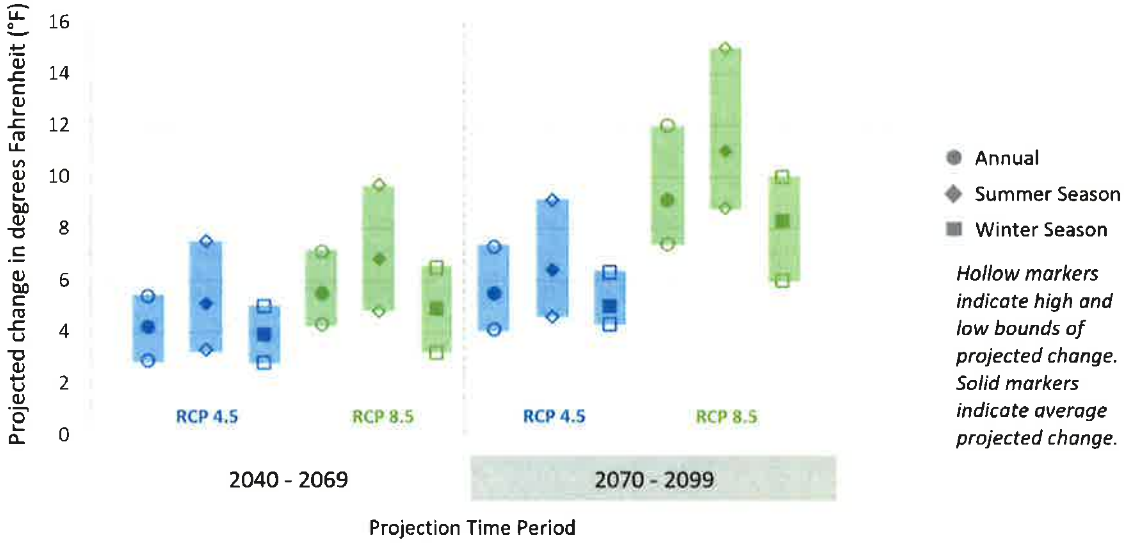


Projected future changes

- By the mid-21st century, **the average year in Washington will be warmer than the hottest year of the 20th century** under a high-emissions scenario [13].
- By the mid-21st century, **average annual temperatures in Puget Sound are projected to increase by 4.2 °F to 5.5 °F** under low- and high-emissions scenarios, respectively, compared to the average annual temperature between 1970-1999 of 46.5 °F (see Figure 5). **By 2100, they are projected to be 5.5 °F to 9.1 °F warmer** under low- and high-emissions scenarios, respectively [13].
- By the mid-century, projections indicate **1 to 2 days per year in Whatcom County and 2 to 3 days per year in Bellingham when the heat index is above 90 °F**. By 2100, those numbers are projected to rise to as many as 11 days per year in Whatcom County and 20 days in Bellingham [14].

Warming is projected to continue in Puget Sound for all emissions scenarios and all seasons, with summer seeing the largest temperature increases [15]. Until mid-century, the anticipated average temperature increases are relatively similar across all scenarios since most warming in these years is the result of greenhouse gas emissions already produced and changes that are already underway. After that time, additional warming will depend on the amount of emissions generated in the upcoming decades [9].

Figure 5. Projected changes in average annual and seasonal temperature for the Puget Sound region. All projected changes for the two time periods shown below (2040-2069 and 2070-2099) are relative to 46.5 °F, the average annual temperature for 1970-1999. Average seasonal temperature refers to the change in average temperature for a given season: summer (June through August) or winter (December through February). Both time periods include the low-emissions scenario (blue bar), and the high-emissions scenario (green bar). The hollow markers indicate the range of projected change. This figure was developed with data from CIG 2015 **[9]**.



As temperatures rise, Whatcom County's climate is projected to shift. By 2080, under a high-emissions scenario, the climate in Bellingham is projected to feel like the climate in Seattle [16]. For reference, the average summer in Seattle is 3 °F warmer and 30% drier than in Bellingham [16].

The frequency and strength of extreme heat events are projected to increase, especially nighttime heat events, while extreme cold events are projected to decrease relative to the 1970-1999 average. Compared to that period, the hottest days in the year for the Puget Sound region are expected to be 6.5 °F warmer and the coolest nights are projected to be 5.4 °F warmer by the 2050s (see Table 4) [9].

The heat index is a measure of how hot the air feels when humidity is considered in addition to the actual air temperature. A heat index greater than 90 °F indicates that outdoor workers and others who experience prolonged exposure or strenuous outdoor activity are more susceptible to heat-related illnesses and should take extreme caution. A heat index in the around 102 °F or higher indicates dangerous conditions posing greater risk of heat-related illnesses. **Whatcom County is projected to average two days per year with a heat index above 90 °F or higher by mid-century, and up to 11 days of 90 °F or higher by the end of the century if carbon emissions continue at their current rates** (see Figure 6) [14]. Whatcom County is still projected to be one of the relatively cooler areas in the continental United States, with comparably fewer days when the heat index surpasses 90 °F, 100 °F, or 105 °F—the point at which the National Weather Service recommends issuing excessive heat advisories [14].

A *degree day* compares the average daily temperature to a standard temperature to help assess climate and projected energy consumption and costs. The more extreme the temperature outside, the higher the number of degree days and generally the higher energy use for heating or cooling. A *cooling degree day* is a measure of how hot the temperature is on a given day based on a standard temperature of 75 °F, a potential threshold for turning on air conditioning. For example, a specific day with an average temperature of 80 °F equates to 5 cooling degree days. **Cooling degree days in the Puget Sound region are anticipated to increase by 17 degree days by mid-century compared to the 1970-1999 average** (see Table 4). This increase in cooling degree days suggests more need for air conditioning to provide cooler indoor spaces as outdoor air temperatures get warmer.

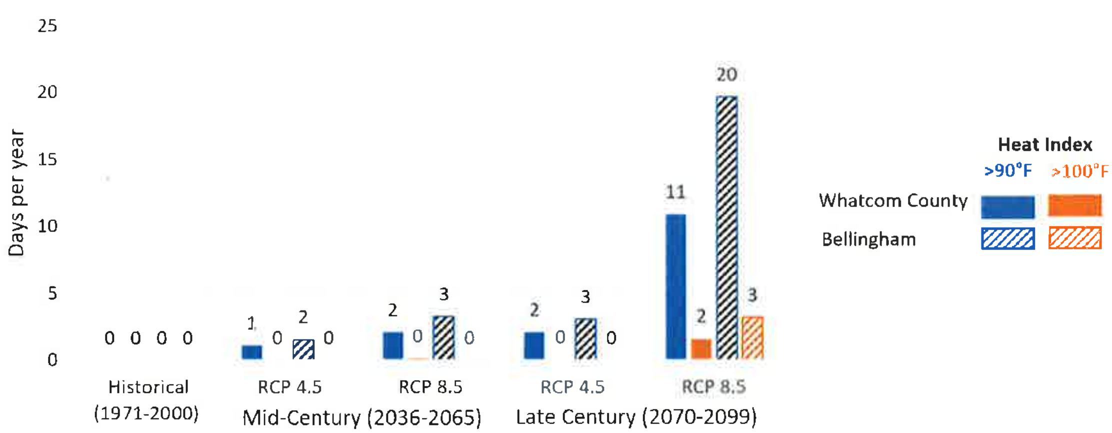
A *heating degree day* is a measure of how cold the temperature is on a given day based on a standard of 65 °F, which is when most heating systems turn on. **Heating degree days are expected to decrease by 1,600 degree days by mid-century compared to the 1970-1999 average** (see Table 4). This significant decrease in heating degree days indicates less need for heating as outdoor air temperatures get warmer.

A *growing degree day* is a measure to estimate the growth and development of plants and insects during the growing season and is measured to a standard temperature of 50 °F [9]. **Growing degree days in the Puget Sound region are projected to increase by 800 degree days by mid-century compared to the 1970-1999 average** (see Table 4).

Table 4. Projected changes in Puget Sound region temperature extremes. All changes are relative to the average for 1970-1999. Temperature of hottest days represents the projected change in the 99th percentile of daily maximum temperature. Temperature of coolest nights represents the projected change in the 1st percentile of daily minimum temperature. (Table adapted from CIG 2015 SOK) **[15]**.

Indicator	2040-2069			2070-2099		
	Average	RCP 4.5	RCP 8.5	Average	RCP 4.5	RCP 8.5
Temperature of hottest days	+6.5 °F	+4.0 °F	+10.2 °F	+9.8 °F	+5.3 °F	+15.3 °F
Temperature of coolest nights	+5.4 °F	+1.3 °F	+10.4 °F	+8.3 °F	+3.7 °F	+14.6 °F
Heating degree days (dd)	−1600 dd	−2300 dd	−1000 dd	−2306 dd	−3493 dd	−1387 dd
Cooling degree days	+17 dd	+5 dd	+56 dd	+52 dd	+6 dd	+200 dd
Growing degree days	+800 dd	+500 dd	+1300 dd	+1280 dd	+591 dd	+2295 dd

Figure 6. Projected days per year when the heat index will exceed specific temperature thresholds in Whatcom County and Bellingham compared to a simulated historical annual average between 1971-2000. [14].



Precipitation

Observed changes to date

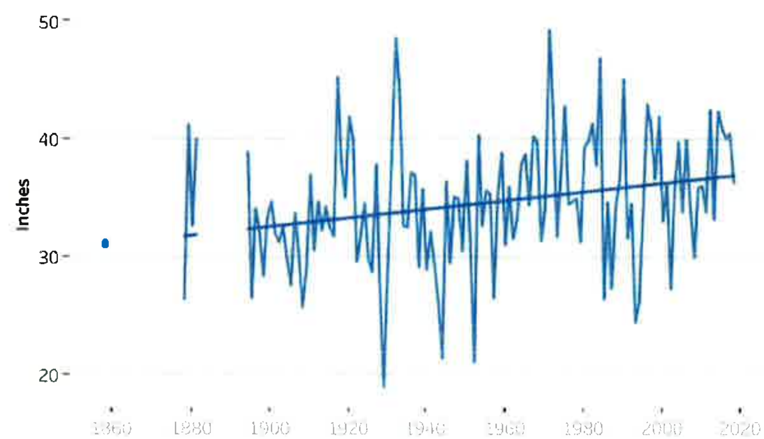
- **Spring precipitation increased by 27% in the Puget Sound lowlands** since the late 19th century. All other seasons show no significant trends in precipitation [11].
- **In the Bellingham area, average annual precipitation increased 19% since the late 19th century**. During that time, spring and fall precipitation both increased 3% and 3.5% per decade, respectively (see Figure 7 and Figure 9) [11].
- **Modest increases in extreme precipitation events** have been observed in Western Washington during the 20th century [9].
- **Since 1900, there have been 19 drought occurrences in Washington State** [17].

The Puget Sound region has naturally variable precipitation patterns, causing fluctuations between wet and dry years, as well as between wet and dry decades [10]. In Bellingham, average annual precipitation increased by 19% between 1858 and 2018, or about 2% per decade (see Figure 7. Historic average annual precipitation in Bellingham between 1858 and 2018. Trend line indicates a 1.9% change per decade [11].[1]

Trends in seasonal precipitation (changes in total precipitation across the three months of each season from year to year) are typically insignificant; the exception is spring and fall precipitation in Bellingham. In Bellingham, spring (March through May) precipitation increased by nearly 29% between 1858 and 2018, or approximately 3% per decade [11]. During that timeframe, Bellingham also experienced a statistically significant increase in fall (September through November) precipitation by about 35%, or 3.5% per decade (see Figure 9) [11]. Historical records indicate that heavy rainfall events in Western Washington have increased modestly in both frequency and intensity over the 20th century, but not all trends are statistically significant [9].

There have been 19 drought occurrences in Washington State since 1900. Within the past 10 years, Whatcom County has experienced impacts from drought. In 2010, the City of Bellingham implemented mandatory water use restrictions. The 2015 drought was primarily driven by low snowpack that accumulated during the winter of 2014-2015, as much of the precipitation fell as rain rather than snow due to above-average temperatures [17]. The snowpack acts as a water reservoir for Whatcom County and is an important water source for rivers, as lowland precipitation begins to decline in the late spring to early summer.

Figure 7. Historic average annual precipitation in Bellingham between 1858 and 2018. Trend line indicates a 1.9% change per decade **[11]**.



[1] Additional data is available for historic precipitation in Blaine and Clearbrook, but trends at those locations are not significant and thus not presented in this report. The data for those sites can be accessed through the PNW Precipitation Trend Analysis Tool from the Office of the Washington State Climatologist.

Figure 8. Historic average precipitation during spring (March through May) in Bellingham between 1858 and 2018. Trend line indicates a 2.9% change per decade **[11]**.

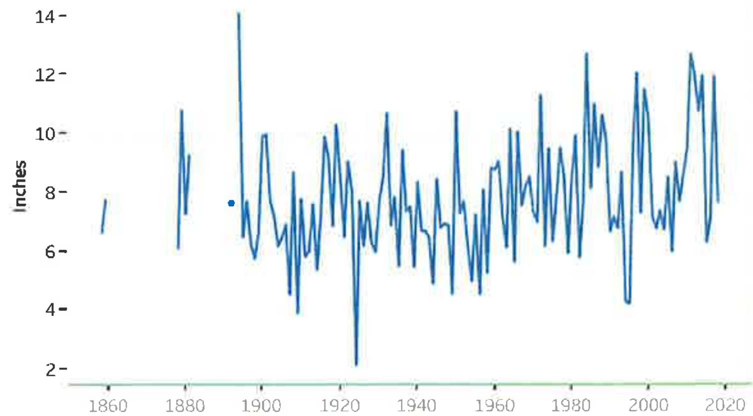
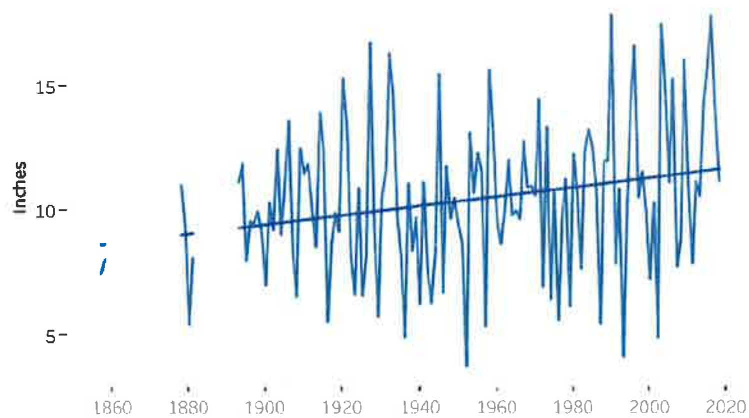


Figure 9. Historic average precipitation during fall (September through November) in Bellingham between 1857 and 2018. Trend line indicates a 3.5% change per decade **[11]**.



Projected future changes

- **Average annual precipitation in the Puget Sound region is projected to increase by 4-5% by the 2050s** under low- and high-emissions scenarios, respectively (relative to 19970-1990). **Annual precipitation is projected to rise another 2% by the 2080s** under both emissions scenarios (see Figure 10) [9].
- **Wetter conditions are anticipated in spring, fall, and winter, while summer will continue to get drier and warmer** [15]. In the Puget Sound region, summer precipitation is projected **to decrease 22%** (–2 to –50%) **by the 2050s** (see Figure 11) [9].

- **Under a high-emissions scenario, the intensity and frequency of heavy precipitation events west of the Cascades are projected to increase by the 2080s** by 22% and five more days each year, respectively [9].[2]
- Due to its reliance on lower elevation snowpack and precipitation, **Whatcom County is vulnerable to drought effects such as those that occurred in 2014 and 2015** [17].

Across the Puget Sound region, annual precipitation is projected to increase under both low- and high-emissions scenarios [9]. Projected changes in annual precipitation are small relative to year-to-year variability.

Most projections indicate an increase in precipitation intensity for the Puget Sound region for all seasons except for summer. Summer precipitation in the Puget Sound region is projected to decline approximately 22% for the 2050s compared to 1970-1999, for both low- and high-emissions scenarios (see Figure 11) [15]. Although some projections for fall, winter, and spring show ranges that project decreases in precipitation, the overall trend is upward [15]. The most pronounced increases for seasonal precipitation are in fall and winter under a high-emissions scenario. Fall precipitation is projected to increase between 5-6% by 2050 and between 10-12% by the 2080s, relative to 1970-1999 values. Winter precipitation is expected to increase approximately 10% by 2050 for both emissions scenarios and is projected to increase between 11-15% by 2080 under low- and high-emissions scenarios, respectively. By the 2050s, spring precipitation is projected to increase between 2.4-3.8% under low-and high-emissions scenarios, respectively. Spring precipitation is anticipated to have a smaller increase by the 2080s, with models projecting an increase of 1.6% under a low-emissions scenario and 2.5% under a high-emissions scenario, compared to 1970-1990 averages.

While models project decreases in summer precipitation, the overall trend in precipitation among the other seasons is upward.

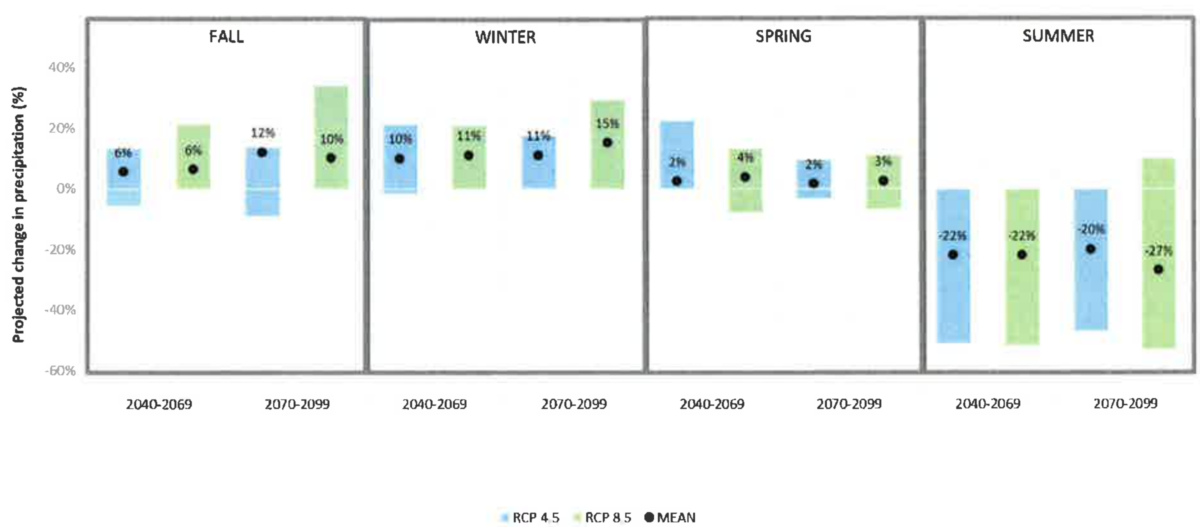
The intensity and frequency of heavy precipitation events west of the Cascades are projected to increase by the 2080s. Under a high emissions scenario, the intensity of heavy precipitation events (24-hour precipitation events with a 1% likelihood of occurring) are projected to increase by 22%. Furthermore, these heavy precipitation events are expected to occur seven days per year compared to only two days a year historically (1970-1999 average) [9].

Projections are not available for changes in frequency or intensity of droughts in Whatcom County or Washington State. However, due to Whatcom County's dependence on lower elevation snowpack and precipitation, the projected increases in temperature and projected decreases in summer precipitation could increase the county's vulnerability to drought effects. Vulnerabilities are projected to include drought effects such as those that occurred in 2014 and 2015 [17]. The historical patterns of water supply and runoff are shifting, and it is likely that low stream flows and elevated water temperatures often associated with drought conditions will become more common [17]. In addition, the typical pattern of higher water use during the driest part of the year is often exacerbated during droughts, where hotter and drier weather increases water use above normal levels at a time when water availability is more restricted.

[2] Heavy precipitation events are defined as 24-hour precipitation events that have a 1% likelihood of occurring.

Figure 10. Projected change in annual Puget Sound precipitation. All changes are relative to the average for 1970-1999. The average projected change is shown with the black dot, and the colored bars show the range of projected values from 10 climate models for both RCP 4.5 in blue and RCP 8.5 in green (Figure created using data from CIG 2015 SOK) **[9]**.

Figure 11. Projected change in seasonal Puget Sound precipitation. All changes are relative to the average for 1970-1999. The average projected change is shown with the black dot, and the colored bars show the range of projected values from 10 climate models for both RCP 4.5 in blue and RCP 8.5 in green (Figure created using data from CIG 2015 SOK) **[9]**.



Hydrology

Observed changes to date

- Puget Sound glacial numbers and volume are declining. **Between 1900 and 2009, glacier area in the North Cascades declined by 56%** [9].

- Spring snowpack in the Cascade mountains has declined about **25% between the mid-20th century and 2007** [9]. Since the mid-20th century, **peak snow water equivalent (SWE) declined at several locations in Whatcom County by 2 to 5%** [11].
- In some Puget Sound rivers, **peak streamflow is shifting earlier** in the year.

Changes in hydrology, such as changes in the amount of snowpack and rate of streamflow, are driven by changes in temperature, heavy rainfall events, and seasonal precipitation, as well as natural variability in the region. Most glaciers in the broader Puget Sound region are in decline, not only in terms of glacier area, but also in the total number of remaining glaciers. Between 1900 and 2009, glacier area in the North Cascades declined by 56% [9].

Current long-term trends in snowpack indicate a significant decline. Between the mid-20th century and 2007, snowpack in Washington's Cascade range has decreased approximately 25%, or almost 4% per decade [9].[3] Snow water equivalent (SWE) is a method of measuring snowpack and is the amount of water contained in a certain volume of snow, which changes based on the snow density and other factors. SWE can be thought of as the depth of water that would theoretically result if the entire amount of snowpack melted at once. Mountain snowpack plays a key role in the water cycle in Whatcom County by storing water during the winter when the snow falls and releasing it as runoff in spring and summer when the snow melts [18]. As peak SWE declines, there is a strong correlation with a shift in runoff timing to be earlier in the year as well as decreasing total runoff. These impacts could lead to lower summer streamflows and less water availability. Between the mid-20th century and 2019, peak SWE declined at several locations in Whatcom County by 2 to 5% (see Table 5) [11].

Table 5. Observed trends in snow water equivalent (SWE) at several locations in Whatcom County between the mid-20th century to 2019. All trends are statistically significant except those in italics **[11]**.

Location[4]	Change per decade
Beaver Pass	-4.6%
Beaver Creek Trail	*-2.7%*
Devil's Park	-2.8%
Freezeout Creek Trail	-5.4%
Marten Lake	*-1.9%*
Watson Lakes	-4.9%

Current trends in annual streamflow across the Puget Sound region are mixed, and there is no statistically significant trend in annual average streamflow. However, dry years are becoming drier for some rivers, and peak streamflow is shifting earlier in the spring for watersheds historically dominated by snow; it has moved up to 20 days earlier in some rivers between 1948 and 2002 [9]. Meanwhile, in watersheds historically dominated by rain, peak streamflow is shifting later in the spring. The Nooksack River watershed is a mixed

[3] Snowpack is directly measured using automated Snowpack Telemetry (SNOTEL) at various stations in the Cascades and Olympics. Studies may also use other data to determine long-term trends in snowpack, such as streamflow, precipitation, temperature, and the water-balance snowpack estimate.

[4] Location of Natural Resource Conservation Service snow data collection sites. Note that the beginning of the data record varies by location between 1944, 1950, and 1959.

rain-snow basin and historically has experienced peak streamflow in May, but available studies do not indicate how the timing of peak streamflow has changed [19]. Historic mean peak flow between 1967 and 2017 has been 23,500 cubic feet per second (cfs) (see Figure 14) [19]. For reference, peak flow during the extreme flood event on November 11, 1990, was 48,200 cfs [19].

Projected future changes

- **Snowpack for mountains draining into Puget Sound is projected to decrease by 29% by the 2040s** [19].
- The Nooksack Valley basin is anticipated to **transition from being a mixed snow and rain-dominant system to a rain-dominant system** [9] [19]. By the 2080s, peak streamflow in the Nooksack River is projected to shift **approximately 27 days earlier in the year compared to 1970-1999** [20].
- **Heavy rainfall events are projected to become more intense.** Regional models anticipate that heavy rainfall events in Western Washington will intensify by 22% by the 2080s [9]. **Under a moderate (A1B) emissions scenario, streamflow in the Nooksack River during a 100-year flood event is projected to increase by 27% by the 2080s** [19]. [5]
- **Summer minimum streamflow in the Nooksack River is projected to decrease** by 27% by the 2080s relative to the 1970-1999 average, and **summertime stream temperatures are projected to increase**, reaching levels that exceed the thermal tolerance of most fish species [20].

As the climate warms, the Pacific Northwest is projected to continue to face decreased snowpack and changes to streamflow timing and seasonal minimums. One study found that glaciers in the Nooksack River basin are projected to recede by approximately 90% by 2100, at which time smaller glaciers are projected to disappear completely, under a low-emissions scenario [21]. These projections indicate a decline in both glacier area and volume, which will reduce the amount of ice melt that contributes to streamflow. In the Nooksack River, glacial melt makes a critical contribution to streamflow, so the projected glacial loss poses significant implications for aquatic ecosystems and critical species like salmon that rely on snow and glacier-fed water resource [22]. In the same study, projections indicate a 50% and 69% decline in snow water equivalent in the Middle Fork Nooksack Basin under a low- and high-emissions scenarios, respectively, by 2075 [21]. Another study projected a 33-45% decline in monthly median snow water equivalent by 2050 in the Middle Fork Nooksack Basin, which was the highest elevation studied [23]. Thus, lower elevation locations are projected to experience even faster rates of snow water equivalent decline. In addition, peak snow water equivalent is also projected to shift earlier in the year, from approximately April 1 to March or even earlier by the 2050s, but that may occur even sooner for lower elevation locations. This shift contributes to a shift in peak streamflow.

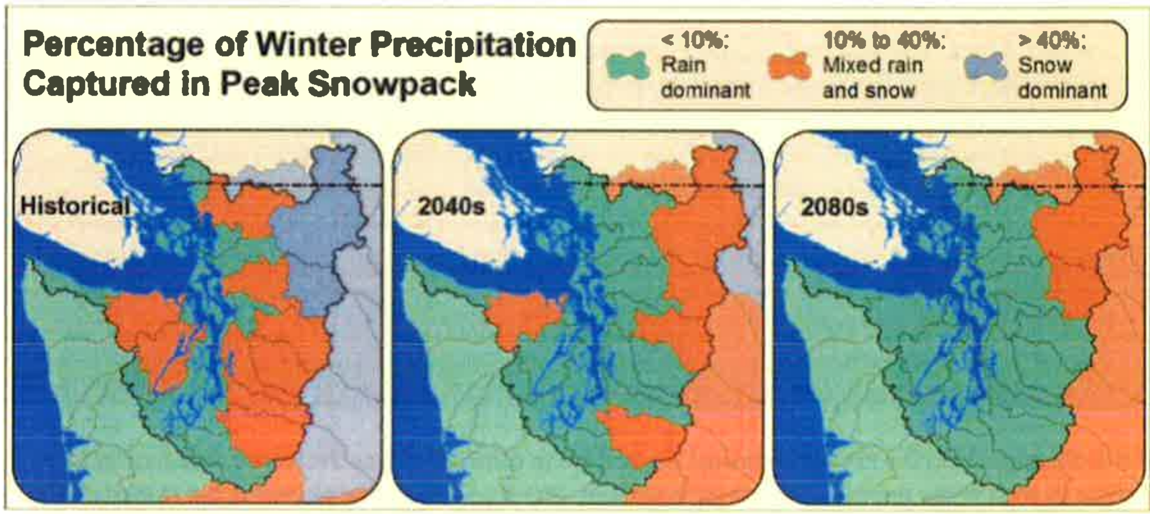
By the end of the 21st century, based on a low-emissions scenario, the main form of precipitation in Puget Sound watersheds is expected to be rainfall [9]. The Nooksack River basin and other Puget Sound watersheds that are currently dominated by a mix of rain and snow in the winter are projected to become progressively more rain-dominant [9]. This transition to mostly rainfall precipitation is expected to lead to an increase in winter streamflow, an earlier peak streamflow, and a decline in summer streamflow [9] [24]. By the 2080s,

---

[5] The moderate (A1B) emissions scenario is most similar to RCP6.0. The A1B scenario is one of a suite of scenarios commonly used in earlier climate change assessments (including IPCC reports). The new set of scenarios—, Representative Concentration Pathways (RCPs)—were developed for the 5th IPCC Assessment Report are now the industry standard for climate change assessments.

peak streamflow in the Nooksack River is projected to shift earlier in the year, occurring 19 to 40 days earlier compared to 1970-1999, based on a moderate (A1B) greenhouse gas scenario [9].

Figure 12. Model projections of Puget Sound watersheds suggest a transition to largely rain-dominant basins by the 2080s [9].



Heavy rainfall events, or atmospheric river events, are projected to become more intense in the future, increasing the risk of flooding in the Puget Sound region, particularly at low elevations. With a shift to a rain-dominant basin, the Nooksack River will likely experience an increase in frequency and magnitude of floods [23]. Regional models anticipate that heavy rainfall events in Western Washington will intensify by 22% by the 2080s [9]. In the Nooksack River, the streamflow during a 100-year flood event is projected to increase by 27% (range of 9% to 60%) by the 2080s relative to the 1970-1999 average [19].The return period magnitude is also projected to shift in the future. For instance, the magnitude of a historical 10-year flood in the Nooksack River is projected to have a return internal of only 3 years by 2050 [23].

While winter streamflow is projected to increase, summer streamflow is projected to decrease as peak streamflow shifts to earlier in the year and as snowpack decreases. Summer minimum streamflow in the Nooksack River is projected to decrease by 27% (range of –38% to –13%) by the 2080s relative to the 1970-1999 average [9]. Declining summer streamflows and increasing summertime air temperatures are expected to increase stream temperatures in the summer, reducing water quality in streams. By 2040, it is projected that 40 miles of the Nooksack River will exceed 64 °F, which is the thermal tolerance for adult salmon compared to zero miles in 2015 [25]. By the late 21st century, one study found that the South Fork of the Nooksack River, which is at a lower elevation than the Middle Fork and North Fork, is projected to have an average of 115 days per year when the 7-day average of daily maximum stream temperature exceeds 60.8 °F, which is considered a threshold for protecting aquatic habitats [26]. During that same period, the higher-elevation Middle and North Fork basins are projected to have 35 and 23 days, respectively, when that threshold is exceeded.

Figure 13. Projections of monthly streamflow for the Nooksack River for 2050s and 2080s compared to historical trends (1970-1999). Peak monthly streamflows are projected to shift from the average historical peak in May to a peak around January as early as the 2050s **[9]**.

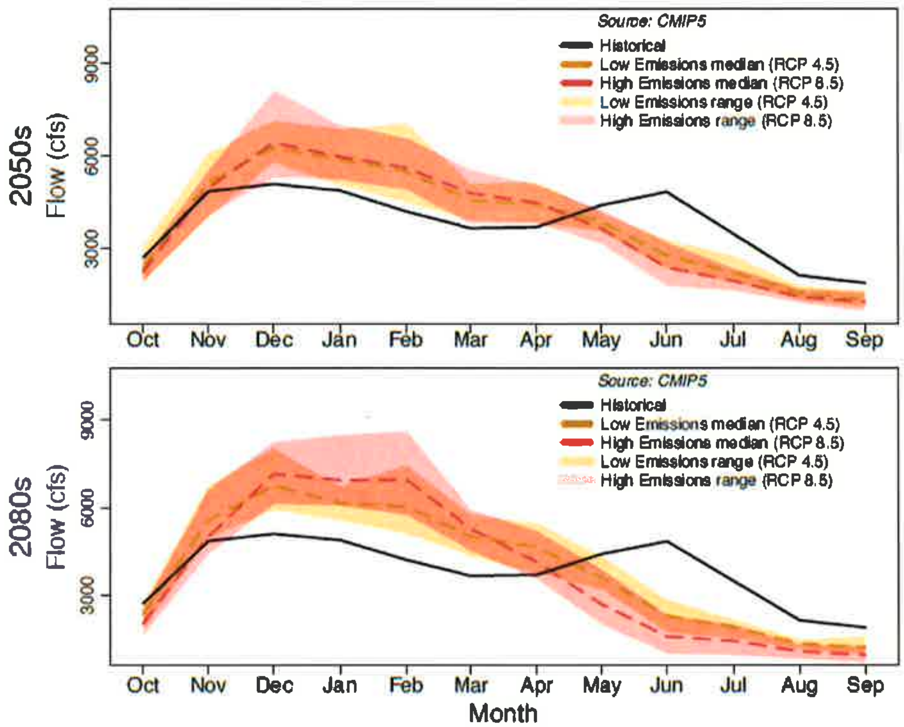


Figure 14. Peak annual streamflows in the Nooksack River, both observed flows (1967 to 2017) and future projections for the 2050s. Projections based on a moderate emissions scenario (approximately an average between RCP 4.5 and RCP 8.5). Middle numbers indicate mean peak flow, with the boxes indicating quartiles and lines indicating upper and lower ranges **[19]**.

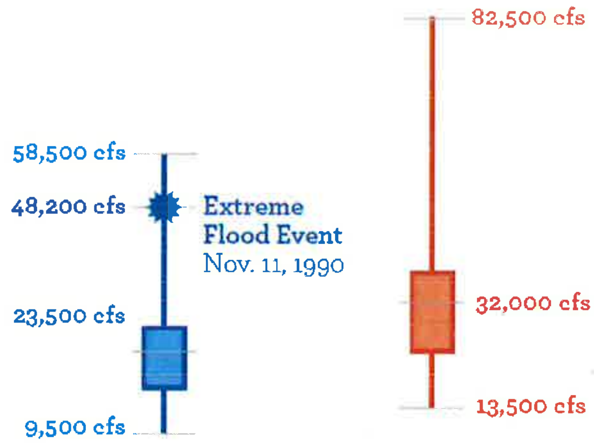
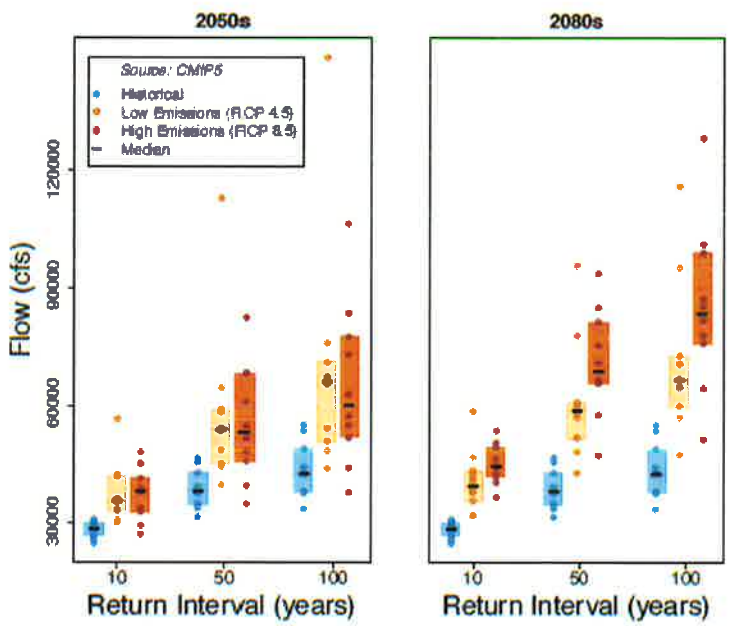


Figure 15. Projected peak streamflow for the Nooksack River during flood events for the 2050s and 2080s compared to the historical average (1970-1999). Return intervals are for 10-year, 50-year, and 100-year events **[9]**.



Sea Level Rise and Storm Surge

Observed changes to date

- Global sea level has risen **8 inches between 1900-2009** [27].
- On average, sea level in Puget Sound has risen **0.8 inches per decade between 1900-2009**, which has contributed to more coastal flooding [9].
- There is **no documented long-term trend in storm surge due to climate change**.

Global sea level has risen 0.7 inches per decade between 1901 and 2010 [27]. That rate has increased in more recent years—global sea level has risen 1.3 inches per decade from 1993 to 2010. The rate of global sea level rise since the mid-1800s is higher than the average rate during the last two millennia [27]. In Puget Sound during the last century, sea level rose along most shorelines in the region, though the rates varied depending on local land motion, weather patterns, and ocean currents [9]. At the Seattle tide gauge, which has one of the longest records of data in Puget Sound, sea level rose 8.6 inches between 1900 and 2008 [9]. Historical trends are not available for changes in sea level along Whatcom County's shoreline specifically.

During winter months, the breakdown of upwelling along the west U.S. coast pushes ocean water toward the shore, causing elevated sea level. This condition is enhanced during El Niño events. In Puget Sound, this can result in up to an approximate 20-inch increase in sea level compared to the summer [28]. During El Niño events, sea level can be as much as 12 inches higher than normal for several months at a time [28].

Storm surge and high tide flooding

Currently, there are no comprehensive studies looking at observed trends in storm surge within Puget Sound due to changes in frequency and intensity of storm events. However, one study found that trends in extreme high water levels (such as during high tide) along the northwest coast of the U.S. parallel the trends in sea level rise in this region [29].

Between 1970 and 1999, high tide flooding occurred an average of 3 days per year (0 to 13 days) at the Cherry Point tide gauge located just south of Birch Bay, but there is insufficient historical data to determine a long-term trend in tidal flooding. Historically, high tide flooding occurred when the tide exceeded 2 feet (the *Mean Higher High Water* (MHHW) mark for the Cherry Point tide gauge location (see Figure 16) [30]. *Mean Higher High Water* is the average height of the highest tide documented at a tidal gauge during an observed timeframe. High tide flooding most directly impacts coastal areas that are low in elevation and/or have high rates of relative sea level rise [30]. The Lummi Reservation and communities on the perimeter of Bellingham and Birch Bay are expected to continue to be the most vulnerable to high tide flooding (see Figure 17).

Figure 16. High tide flooding at Cherry Point, WA (1973-2017). Historical yearly inundation events from high tide flooding at the Cherry Point, WA tidal gauge #944924. Historically, high tide flooding occurred when the MHHW exceeded 2 feet. Data sourced from the Sea Level Rise Viewer tool from NOAA/NOS/Center for Operational Oceanographic Products and Services **[30]**.

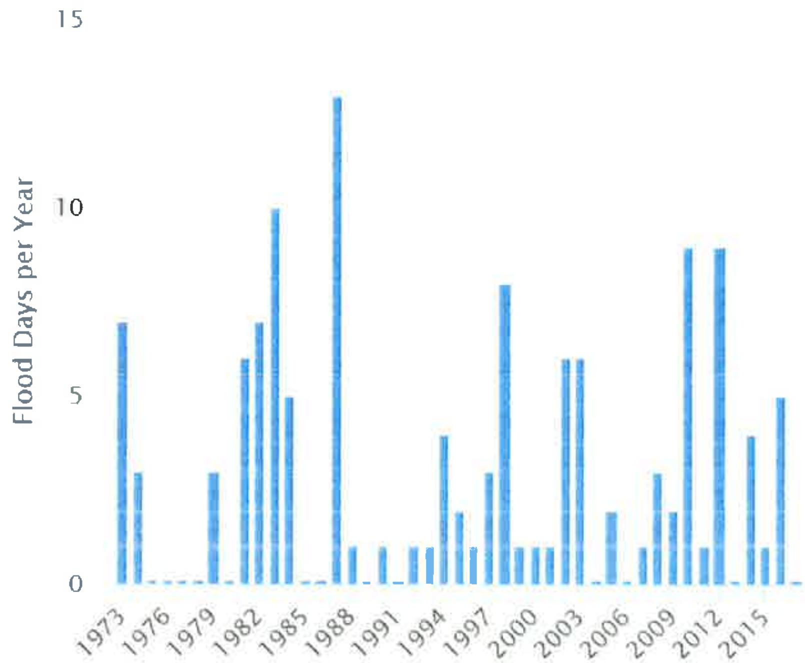


Figure 17. High tide flooding along Whatcom County's shoreline. The red coloration in the map identifies areas currently subject to tidal flooding that occurs when MHHW exceeds 2 feet. This type of flooding is also known as *recurrent or nuisance flooding* **[30]**.

Figure 18. High tide flooding near Bellingham Bay. The red coloration in the map identifies areas currently subject to tidal flooding that occurs when MHHW exceeds 2 feet. This type of flooding is also known as *recurrent or nuisance flooding* **[30]**.

Figure 19. High tide flooding near Birch Bay. The red coloration in the map identifies areas currently subject to tidal flooding that occurs when MHHW exceeds 2 feet. This type of flooding is also known as *recurrent or nuisance flooding* **[30]**.

Projected future changes

- **By 2100, relative sea level rise in the Bellingham area is projected to be:**
  - **Between 0.1 and 0.4 feet** with a **99% likelihood** of exceeding those values under low- and high-emissions scenarios, respectively [31].
  - **Between 1.5 feet** (likely range of 0.9-2.1 feet) **and 1.9 feet** (likely range of 1.3-2.7 feet) with a **50% likelihood** of exceeding those values under low- and high-emissions scenarios, respectively [31].
  - **Between 4.0 and 4.7 feet** with a **1% likelihood** of exceeding this value under both a low- and high-emissions scenarios [31].
- **Puget Sound coastlines are expected to experience significant increases in the frequency of storm surge and high tide flooding** relative to today as sea level rises [32].

The rate at which sea level rises in Puget Sound depends on the rate of global absolute sea level rise as well as regional factors such as vertical land motion, ocean currents, wind patterns, and ocean temperature. In areas where the land is sinking, the regional relative sea level rise will be greater than the absolute sea level rise, and in regions where the land is rising, relative sea level rise will be less than the absolute sea level rise.

Ocean processes (such as thermal expansion from warming waters), land-based glacier and ice cap melt, and ice sheet melt or deterioration also affect global sea level change [9].

Projected sea level rise is presented with the "likelihood of exceedance," or the probability that sea level will meet or exceed a certain amount. Likelihood is an important factor when considering the level of risk involved. Using a low-likelihood projection (e.g., 1%) as the given scenario for planning and decision-making is a more conservative approach because it means preparing for more significant impacts that are relatively less likely to occur. This approach may be considered for decisions regarding critical infrastructure (e.g., hospitals). In contrast, using a high-likelihood projection (e.g., 99%) as the given scenario is a less conservative approach because it means preparing for less significant impacts that are more likely to occur. This approach may be worth considering for situations where infrastructure and management can easily be adapted in the future (e.g., vegetation management). There is no single correct decision about what likelihood to use for decision-making; the decision depends on financial, logistical, and political factors specific to Whatcom County.

In this document, sea level rise projections are summarized from Miller et al (2018) for 1%, 50%, and 99% likelihoods of exceedance. In Washington, both absolute and relative sea level are projected to rise by 2150 under both low- and high-emissions scenarios [9]. The projected change in relative sea level along Whatcom County's shoreline by 2100 (compared to the 1991-2009 average) ranges across emissions scenarios and at different likelihoods of exceedance, listed below for the Bellingham area.[6]

- There is a 99% likelihood that relative sea level will increase by 0.1 to 0.4 feet under a low- and high-emissions scenarios, respectively (see Figure 21) [31].
- There is a 50% likelihood that relative sea level rise will exceed 1.5 (likely range of 0.9-2.1 feet) to 1.9 feet (likely range of 1.3-2.7 feet) under low- and high-emissions scenarios, respectively [31].
- There is a 1% likelihood that relative sea level will increase by 4.0 to 4.7 feet under low- and high-

Understanding Sea Level Rise & Storm Surge

Absolute sea level rise is the height of the ocean surface relative to a fixed, unmoving reference point, such as the center of the earth. The impacts of sea level rise will be felt via a change in height of the ocean surface relative to land. **Relative sea level rise projections** combine separate estimates of absolute sea level rise and local or site-specific variability (e.g., vertical land movements in terms of uplift or subsidence) that evaluates the change in sea level at any given location [31].

Storm surge is the product of falling atmospheric pressure and wind stresses on the water, which can cause a rise in sea level.

Sea level rise increases the potential for increased storm surge reach and increased coastal inundation, erosion, and flooding. Even minor amounts of sea level rise can shift the risk of coastal hazards in potentially substantial ways.

Figure 20. Segment of Whatcom County's shoreline used to report sea level rise projections in this document [31].

[6] The online visualization tool accompanying the 2018 Sea Level Rise in Washington State report provides projections for seven different segments of Whatcom County's shoreline. Projections did not substantially differ across the seven segments, we reported on the segment near Bellingham (48.8°, -122.5°) for this report (see Figure 20). Additional segments can be viewed by visiting the online visualization tool.

emissions scenarios, respectively [31].

Note that the projections given here for relative sea level rise in Bellingham factor in a vertical land movement estimate of 0.1 ± 0.2 feet per century [31]. The projections do *not* factor in any additional land level change that may occur in this area due to a subduction zone earthquake, which would result in raising local relative sea level.

Based on sea level rise data visualization tools, the areas of the Lummi Reservation, Birch Bay, and Bellingham Bay are expected to be more at risk of sea level rise under all emissions scenarios compared to other locations along Whatcom County's shoreline (see Figure 23 Figure 24). These areas are likely to experience at least 2 feet of sea level rise under both low- and high-emissions scenarios by 2100 [30].

Storm surge and high tide flooding
Coastlines throughout Puget Sound are expected to experience significantly more storm surge and high tide flooding due to sea level rise relative to today, but there currently are no projections available of the exact magnitude of changes [32]. Storms similar to the one that occurred in December 2018, which significantly damaged homes, businesses, and a coastal roadway in Blaine and Birch Bay, are expected to occur more frequently [33]. Sea level rise coupled with storm surge will likely increase erosion of coastal bluffs and shorelines and may cause damage to and loss of infrastructure and other assets [9].

Figure 21. Projected sea level change in feet for the Bellingham area. Projected sea level change is relative to the average sea level during 1991-2009 **[31]**.

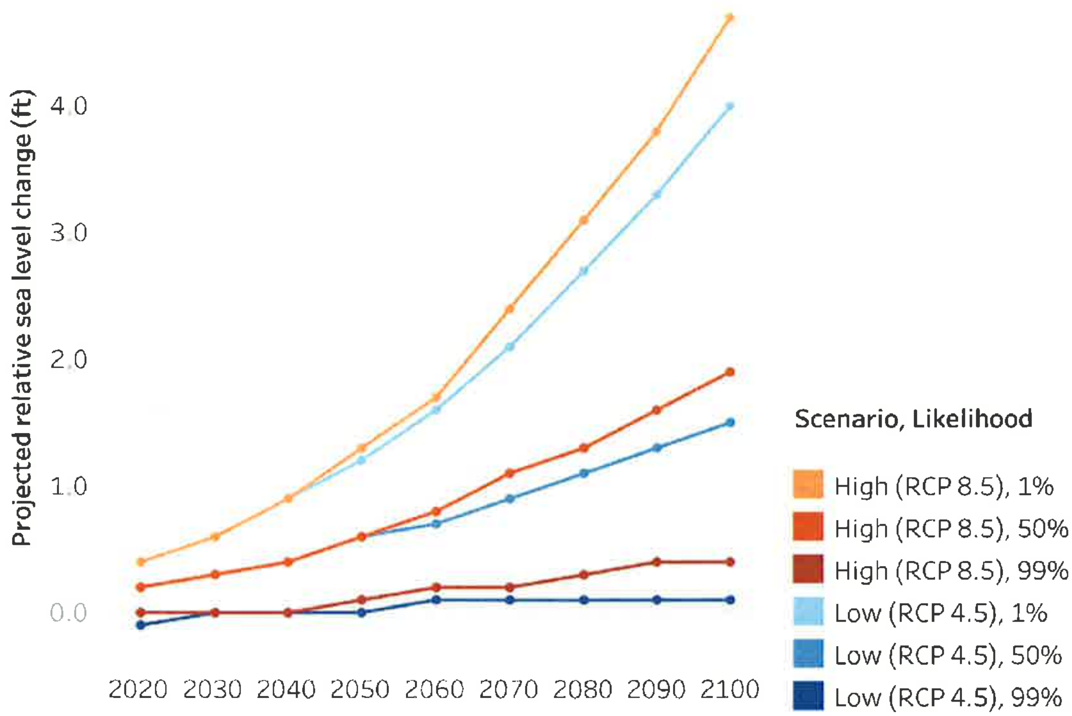


Figure 22. Projected likelihood of relative sea level change of specific levels for the Bellingham area. Projected likelihood of relative sea level change is relative to the average sea level during 1991-2009 **[31]**.

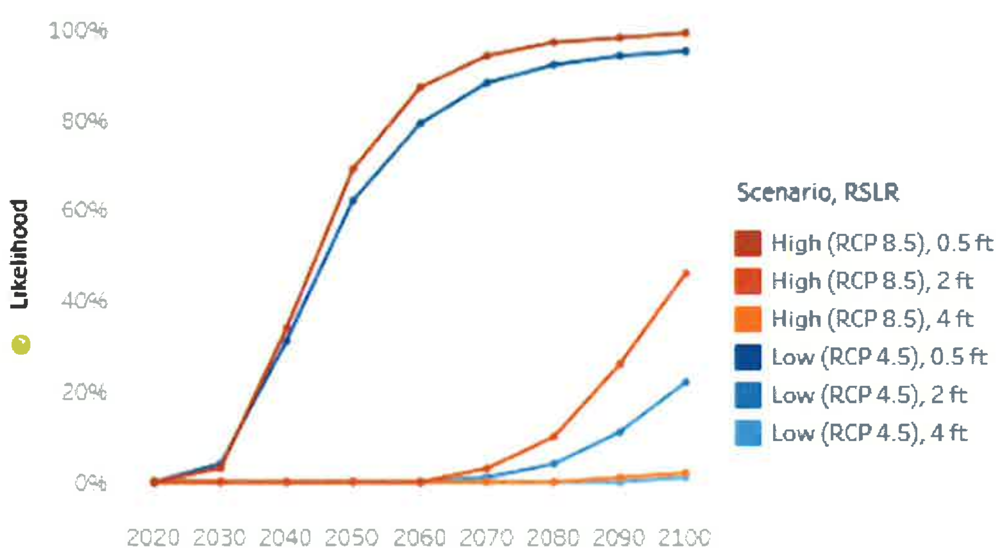


Figure 23. Map of projected 2 feet of relative sea level rise along Whatcom County's shoreline. There is a 50% likelihood of sea level exceeding 2 feet under a high-emissions scenario. Water levels are relative to local Mean Higher High Water. Areas that are hydrologically connected to the ocean, and therefore may flood due to sea level rise, are shown in shades of blue, with darker shades indicating greater depths). Areas in green are low-lying areas that are hydrologically "disconnected" and may also flood. Note that there is a high degree of uncertainty shown in this map due to many unknowns of future conditions and how they will occur on the landscape. More information can be found at https://coast.noaa.gov/slr/. **[30]**

Figure 24. Map of projected 4 feet of relative sea level rise along Whatcom County's shoreline. There is a 1% likelihood of sea level exceeding 4 feet under both low- and high-emissions scenarios. Water levels are relative to local Mean Higher High Water. Areas that are hydrologically connected to the ocean, and therefore may flood due to sea level rise, are shown in shades of blue, with darker shades indicating greater depths). Areas in green are low-lying areas that are hydrologically "disconnected" and may also flood. Note that there is a high degree of uncertainty shown in this map due to many unknowns of future conditions and how they will occur on the landscape. It is important to note that as projections increase in magnitude, the confidence of precise location of flooding decreases. **[30]**

Wildfire

Observed changes to date

- **In the Pacific Northwest**, the area burned, fire season length, and number of fires greater than 1,000 acres has increased since 1973 [34].
- **Washington State** has seen an increase in both the number of fires burning more than 99 acres and the total area burned by those fires since 2000 [35].
- The recent increase in fire activity has likely been influenced by decades of fire suppression and human settlement, natural climate variability, and human-caused climate change [36].

Wildland fires have long occurred naturally in western Washington; every few hundred years, large fires would burn tens or hundreds of thousands of acres. Indigenous tribes have also used intentional burns to clear paths for travel and to promote edible crops [34]. Because there have been gaps of 200-600 years between large wildfires in western Washington, it is unclear how climate change has affected this pattern.

On a more recent time scale, trends indicate an increase in fire activity that researchers link to climate change. In the Pacific Northwest, the area burned, fire season length, and number of fires greater than 1,000 acres has increased since 1973 [34]. Washington State has experienced more intense and more severe wildfires in recent years, with most of the burned acreage on the eastern side of the Cascades. One report indicates that both the number of fires burning more than 99 acres and the total area burned by those fires in Washington have increased since 2000 [35]. Comprehensive data is not readily available about historic trends in wildfire activity for Whatcom County specifically. Limited spatial data on fire incidences between 2002 and 2018 is shown in Figure 25.

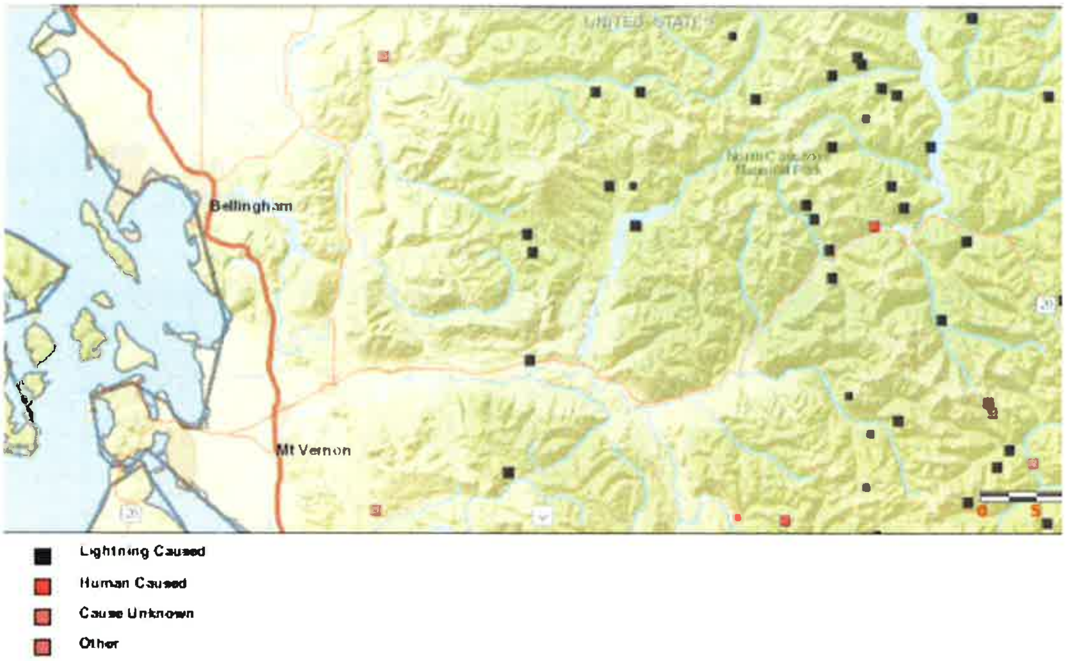
The recent increase in fire activity has likely been influenced by decades of fire suppression and human settlement, natural climate variability, as well as human-caused climate change [36]. Some researchers contend that, in the western United States, human-caused climate change is responsible for the majority of increases in forest fuel aridity since the 1970s and is responsible for doubling the cumulative forest fire area since 1984 [36].

Climate change influences wildfire potential by affecting the abundance of brush and trees and by creating drier conditions that allow fire fuel, such as brush and trees, to burn more easily [36]. While the relationship can be complex and may vary between the short term and long term, there are a few relevant factors. First, climate change can increase short-term productivity within a forest, as warming temperatures extend the growing season and higher levels of carbon dioxide are available for plants to photosynthesize. This may create more fuel available for fires. Second, within a particular year, climate change is linked to more intense and frequent heat waves, more variable precipitation, and earlier spring snowmelt, which can all contribute to dryness of fuel, or fuel aridity, in summer and fall, and can also increase the potential for wildfire [36].

Table 6. Changes in the number of wildfires and size of burnt area in the Northwest compared to the 1973-1982 average. *p*-values for two-sided Mann-Whitney test are provided in parentheses. Table adapted from Westering *et al.*, 2016 **[37]**.

Measure (compared to 1973-1982 average)	1983-1992	1993-2002	2003-2012
Percent change in total wildfires in the Northwest	+200% (0.046)	+514% (0.050)	+1000% (0.001)
Percent change in burnt area in the Northwest	+428% (0.034)	+2149% (0.061)	+4979% (0.001)

Figure 25. Wildland fire incidences in the Whatcom County area between 2002 and 2018. The incidences are reported as points rather than burned areas. The different colors indicate the cause of the fire, if known, based on the legend below the map. Map source is the Geospatial Multi-Agency Coordination (GeoMAC) Wildland Fire Map Viewer run by the U.S. Geological Survey. Data is based on large fire incidences entered into the National Interagency Fire Center. Note that this map may not include all wildland fires that occurred during this period of time **[38]**.



Projected future changes

- By the 2050s, Western Washington is projected to have **12 more days annually with very high fire danger** compared to the 1971-2000 average [34] .
- **By 2100, the period of time between wildfires in the North Cascade ecoregion will shorten** by a factor of 2.2 to 2.5 under low- and high-emissions scenarios, respectively [39].
- **Median area burned annually across the Northwest is projected to increase** by 0.6 million hectares by the 2080s compared to 1980-2006 [40].

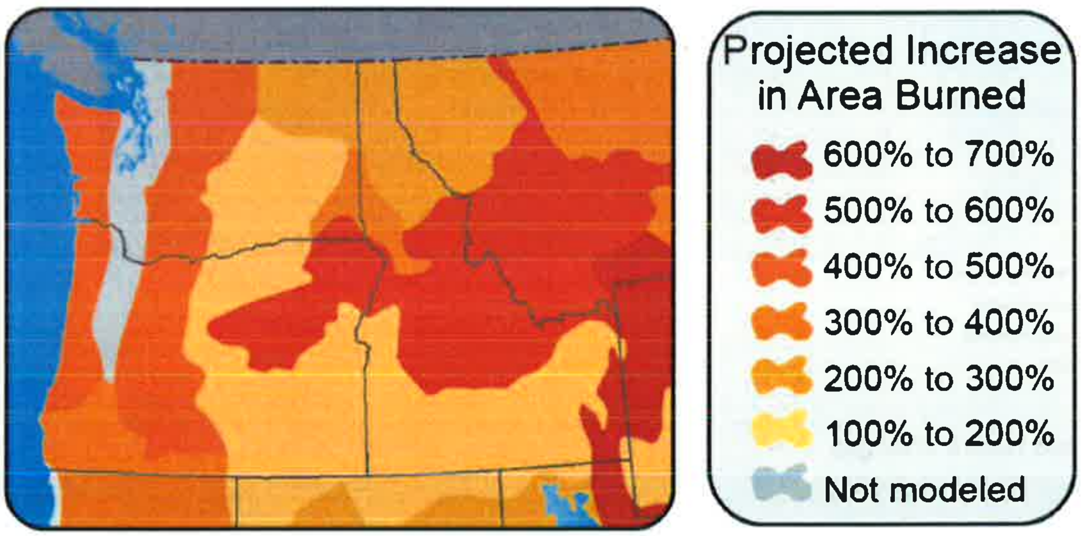
Climate change is expected to create conditions that are favorable for wildland fire in western Washington. Warming temperatures, decreases in summer precipitation, and snowmelt occurring earlier in the year all contribute to a longer fire season and drier fuels in the summer that can increase the potential for wildland fire. Western Washington is projected to see an increase in the number of days with very high fire danger (when the 100-hour fuel moisture is below the historical 10^{th} percentile) by 12 more days each year by the 2050s compared to the 1971-2000 average [34].

Fire rotation periods (FRP), or the period of time between fires, are projected to shorten under climate change in forested ecosystems across Washington by 2100 under both high- and low-emissions scenarios, with the greatest magnitude of shortening being in moister forests, such as those west of the Cascade Crest [39]. Historically, forests in the North Cascade ecoregion were considered to have low suitability for wildfires, which resulted in an FRP between 5,291 and 1,894 years. Projections show that by 2100, the FRP in the North

Cascade ecoregion will shorten by a factor of 2.2 to 2.5 under low- and high-emissions scenarios, respectively [39]. Projections of climate change impacts on fire indicate that the median regional area burned annually across the Northwest may increase by 0.3 million hectares by the 2040s and another 0.3 million hectares by the 2080s compared to the 1980-2006 period [40]. There are mixed findings on the magnitude of future change in area burned in moist forest ecosystems compared to dry forest ecosystems.

Due to insufficient historical data, there are no confident projections for changes in wildfire intensity in Whatcom County, yet warmer and drier conditions in the future is likely to increase the risk of moderate and small fires.

Figure 26. Projected increases in area burned. The map indicates the projected increases in burned area from wildfires due to regional temperature and precipitation changes associated with a 2.2 °F global warming. Areas are based on broad climatic and vegetation characteristics shared in these regions. Local impacts will vary greatly within these broad areas with sensitivity of fuels to climate **[41]**.



Air Quality

Observed changes to date

- In the past decade, **air pollution in Whatcom County has typically been infrequent and relatively low when it occurs.**
- Due to wildfires in the summer of 2018, Whatcom County experienced **poor air quality, with particulate matter concentration exceeding over 100 μg/m^3 in many areas.**

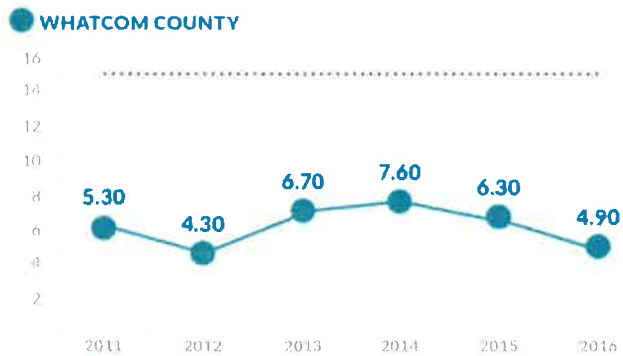
Two main outdoor air pollutants of concern are ozone (also called smog) and particulate matter (PM). Both are dangerous to public health, increasing risks of serious health issues such as lung cancer, asthma, cardiovascular damage, and developmental and reproductive harm [42].

Whatcom County has measured very limited ozone and particulate matter in the past decade. The county did not measure a single day from 2009 to 2017 where ozone air quality standards were exceeded. Ozone levels reached "moderate" on one measured day in 2017, only the second "moderate" measurement since 2009.

No measurements showed ozone pollution in the ranges of "unhealthy for sensitive groups" or more severe [43].

Particulate emissions have generally stayed at low concentrations as well; from 2009-2015, particulate matter levels did not exceed public health standards in Whatcom County [43].

Figure 27. Average Air Quality in Whatcom County 2011-2016. Chart shows the annual average of particulate matter (PM2.5) in Whatcom County. The average air quality has remained the same since 2011 and has been well below the national target of 15 μg/m^3 $PM_{2.5}$ (dotted line). Figure source is the Whatcom Community Health Assessment and is based on data from the Washington State Department of Health's Washington Tracking Network (data only available through 2016). **[44]**



However, between 2016 and 2018, wildfire smoke reduced air quality in Whatcom County. In August 2018, wildfires occurring in the region caused the highest concentration of particulate matter in Whatcom County in a decade, reaching the following levels at data collection sites in Whatcom County (see Figure 28):

- Nearly 125 μg/m^3 in Lyden/Custer
- 116 μg/m^3 in Bellingham
- 111 μg/m^3 in Anacortes [45].

These values are nearly 70 times higher than the daily average concentration in Whatcom County in August 2019, a month and year when wildfire activity was significantly lower compared to prior years (see Figure 27).

Figure 28. Average daily air quality in Whatcom County, August 2018. During the severe Canadian wildfires, Whatcom County experienced its highest concentration of particulate matter of the decade reaching nearly 125 $\mu g/m^3$. This concentration is nearly 70 times larger than the daily average during the month of August 2019 (see Figure 29) **[45].**

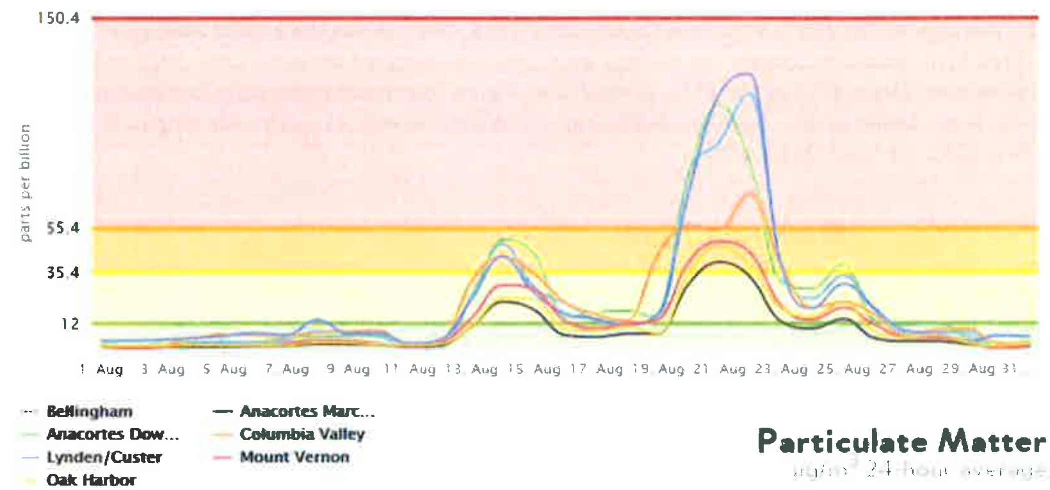
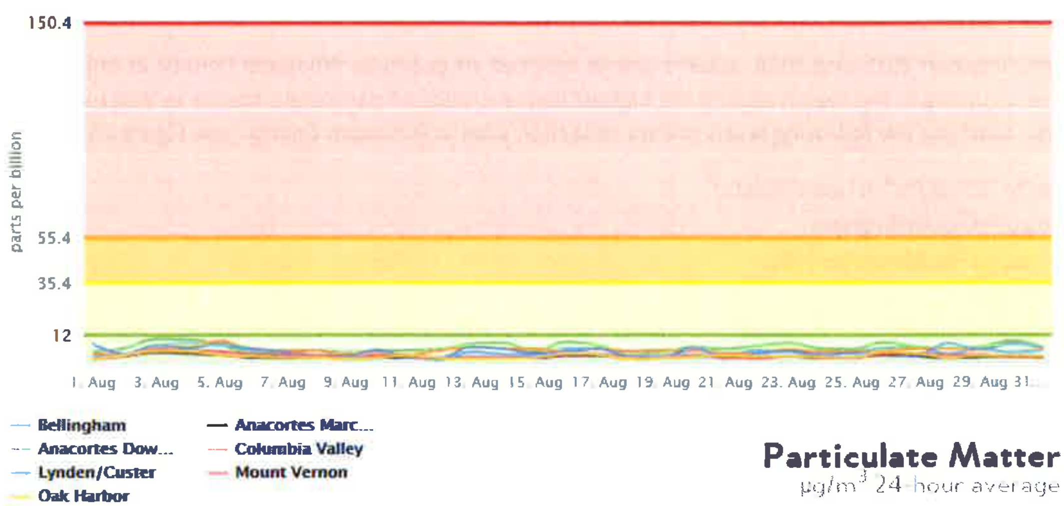


Figure 29. Average daily air quality in Whatcom County, August 2019. Daily averages for particulate matter concentration were more aligned with historical averages during this period when there were no major wildfires occurring in the region **[45]**.



Projected future changes

- **Specific projections of future air quality are not available, but in the future, Whatcom County can expect periods of poor air quality due to increased wildfire activity** in the Pacific Northwest, especially during the summer and early fall.
- Additionally, **warmer temperatures and increases in ozone pollution** may reduce Whatcom County's air quality.

The primary potential impact on Whatcom County's air quality in the future is increased wildfire occurrences and intensity across the Pacific Northwest. More wildfire activity may increase particulate pollution across Whatcom County [46]. Wildfires will also damage forests' ability to provide valuable ecosystem services, such as filtering pollutants from the environment. Ecosystem services will be further stressed by climate change impacts that are projected to damage Washington's forests in the long term by limiting some plant species' survival and increasing threats to plants such as fire, insect outbreaks, and disease [47].

Air quality may also worsen due to potential increases in ground-level ozone pollution. Ozone is generated when nitrogen oxides and volatile organic compounds (produced by vehicles and industrial processes) interact with heat and sunlight. With increasing air temperatures, ozone may increase and could reach levels that pose health risks for people engaged in outdoor activities [47].

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