Climate Vulnerability Assessment

City of Seattle

June 2023

Prepared by Cascadia Consulting Group for the City of Seattle

Table of Contents

Executive Summary

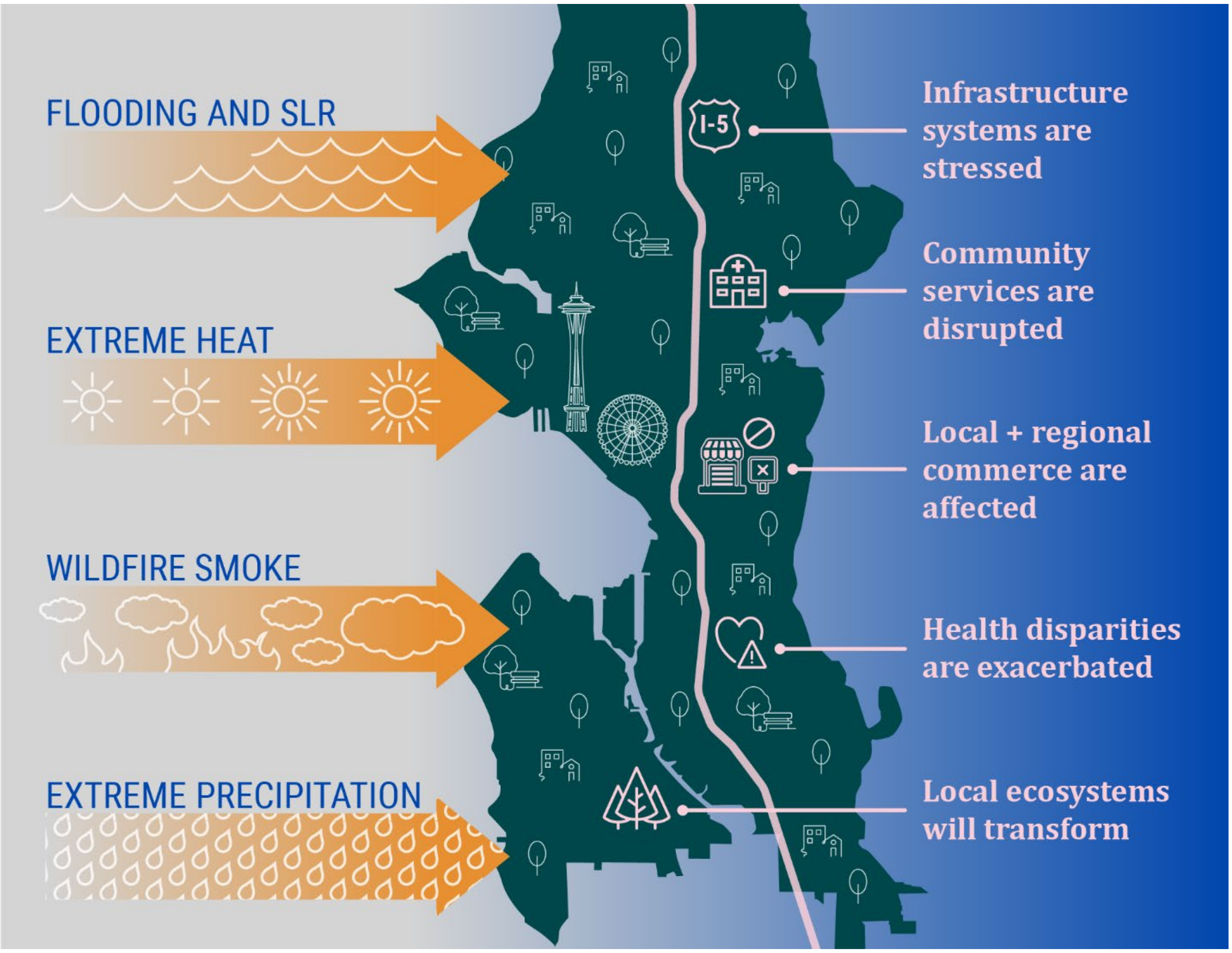
Seattle, along with the broader Puget Sound region, is already experiencing climate change impacts and climate-related hazards, such as warmer temperatures, more frequent extreme heat events, prolonged wildfire smoke episodes, extreme precipitation, and sea level rise. All of these impacts are projected to worsen under a variety of future climate scenarios, though how bad they will get is dependent on reducing greenhouse gas emissions and the ability to improve adaption options for City systems and communities.

Areas within Seattle | **Key Climate Risks and Impacts**

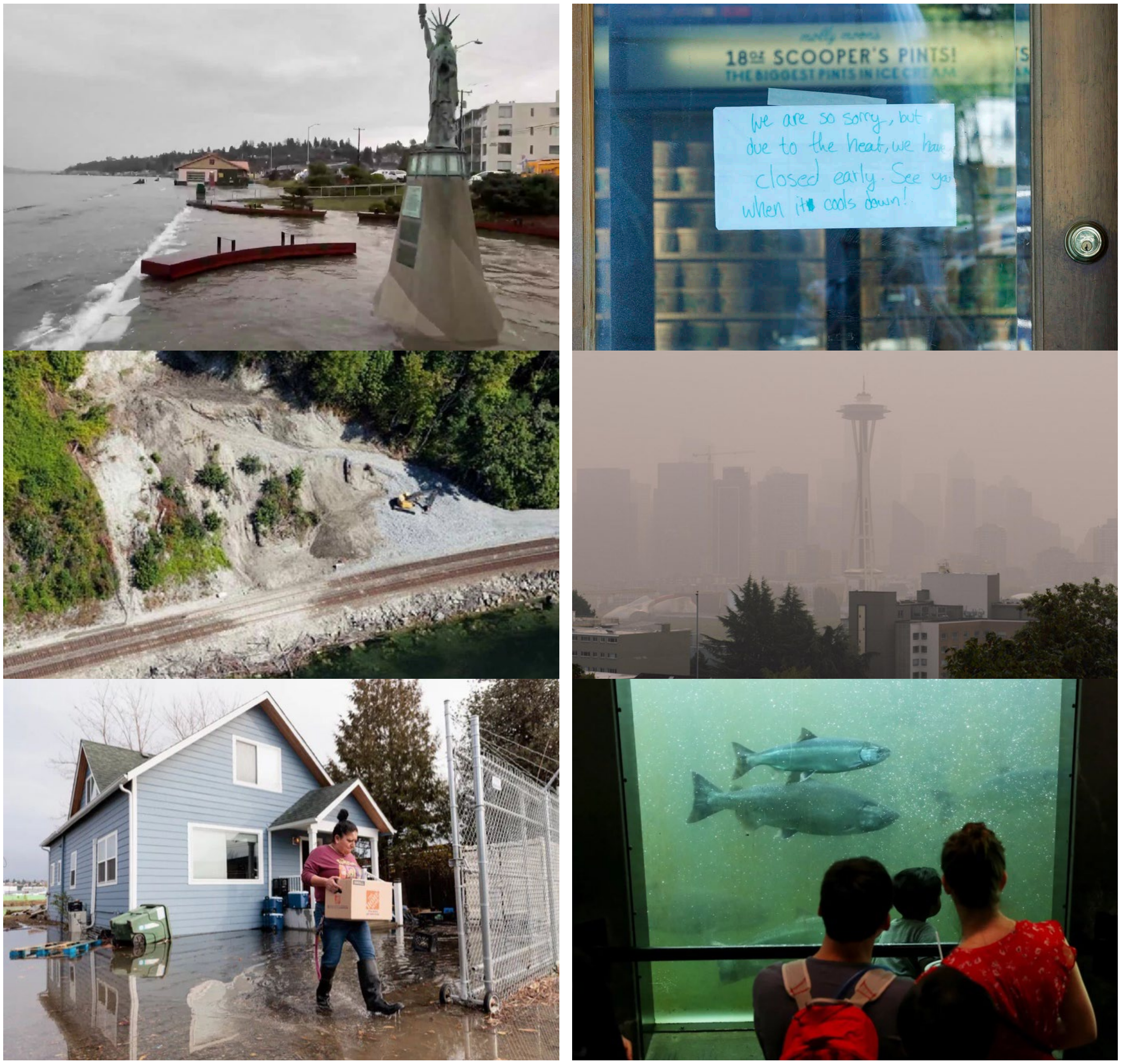
▲▲▲ High risk in associated areas
▲▲ Medium risk in associated areas
▲ Low risk in associated areas
— Risk does not affect associated area

	Extreme Heat	Sea Level Rise & Coastal Flooding	Urban Flooding	Landslides	Smoke
Duwamish Valley (e.g., South Park, Georgetown)	▲▲▲	▲▲▲	▲▲▲	▲▲	▲▲
South Seattle (e.g., Rainier Beach, Columbia City, Beacon Hill)	▲▲▲	—	▲▲	▲	▲▲
West Seattle	▲▲	▲▲	▲	▲▲▲	▲▲
Downtown, **Chinatown-International District**, and **South Lake Union**	▲▲	▲▲	▲▲	▲	▲
Central Seattle (e.g., Capitol Hill, Central District, North Beacon Hill)	▲▲	—	▲	▲	▲
Northwest Seattle (e.g., Queen Anne, Ballard, Fremont, Greenwood)	▲▲	▲	▲	▲▲	▲
North Seattle (e.g., Northgate, Maple Leaf, Green Lake)	▲▲	▲	▲▲	▲	▲
Northeast Seattle (e.g., Lake City, Wedgewood)	▲	—	▲▲▲	▲	▲

These climate change impacts and hazards will have multiple transformative impacts for Seattle—such as affecting the local economy, exacerbating public health disparities, stressing infrastructure systems, affecting community wellbeing and resiliency, and transforming local ecosystems and habitats. The burden of these impacts will be unevenly experienced across Seattle. Areas with less community services—such as grocery stores, parks, libraries, and transit options—often coincide with neighborhoods that were historically redlined and have a higher population of residents of color, non-English speaking residents, and older adults, and these areas will also be more vulnerable to climate-related extreme events.



Aging infrastructure systems will be more vulnerable to climate-related hazards, as they are less able to mitigate climate-related hazards or cope with extreme events. Many systems are inherently connected so impacts to one system will often cascading impacts to other systems, services, and assets. While Seattle's systems and assets are fairly resilient to the impacts of climate change, consequences and damages are still very likely to happen during and after extreme events.



Climate change is affecting all areas of Seattle. Photos show (top left) coastal flooding during a King Tide event in Alki Beach (KOMO); (top right) business closure during the 2021 heat dome event (AP); (middle left) rain-induced landslides between Seattle and Everett (KOMO); (middle right) smoky day in Seattle in 2020 due to wildfires (Getty Images), (bottom left) urban flooding in the South Park neighborhood (The Seattle Times), (bottom right) salmon migration at the Ballard Locks in 2018 (The Seattle Times).

Extreme events – such as the 2021 heat dome event or the 2022 King Tide flood event – are likely to continue to occur, leading to cascading and compounding impacts for residents, businesses, and systems. For example, the 2021 heat dome event led to peaks in heat-related emergency calls and heat-related injuries, impacts to highways and public transit systems, and temporary business closures. These extreme events may have long-term mental and community health impacts – such as anxiety or post-traumatic stress disorder.

While the City has already made strides to improve resiliency to future climate change, this vulnerability assessment can inform current and future efforts by the City, including its **One Seattle Comprehensive Plan**.

Acknowledgments

The City of Seattle's Climate Vulnerability Assessment (CVA) was funded by a Washington State Department of Commerce Early Implementation Climate Planning Grant, which is designed to support local governments across the Washington state to develop and integrate climate change adaptation and mitigation policies into their respective comprehensive plans. The following people contributed to this CVA.

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Introduction

Urgency to Address Climate Vulnerability

Climate change and climate-related extreme events are already affecting the residents, industries, natural systems, and infrastructure of Seattle in multiple ways. Coastal areas and shorelines – such as Alki Beach and South Park – have seen more frequent and more intense coastal flooding. Low lying areas – such as the Duwamish Valley and Georgetown area – are seeing more extreme urban flooding. Interactions between coastal and riverine flooding, such as the tidally influenced riverine flooding during the 2022 King Tide flooding in South Park, illustrate how compound events may lead to extreme events that exceed model projections. The consequences of some climate impacts are amplified by industrialization and historical disinvestment, leaving some residents and businesses with fewer resources and lower capacity to withstand climate-related hazards and extreme events.

Additionally, there have been unprecedented climate-related extreme events and impacts. Wildfire smoke days were historically rare occurrences in Seattle, yet have become an annual occurrence since 2015, affecting outdoor workers' health and the safety of outside activities. The 2021 heat dome event – where temperatures in June reached an unprecedented 108°F, are associated with hundreds of premature deaths across Washington state, and affected the city's infrastructure systems in a myriad of ways – is partially attributable to climate change (Philip et al., 2022; White et al., 2023).

The recent Intergovernmental Panel on Climate Change's Sixth Assessment Report (IPCC AR6) reaffirms the urgency to mitigate climate change by reducing greenhouse gas emissions and the need to adapt to the impacts of climate change through robust and comprehensive action. The IPCC AR6 projects that many climate change impacts will continue to worsen with the current emissions trajectory, and that adaptation will be necessary across multiple sectors and geographies to avoid some of the worst impacts. Additionally, there will be "climate surprises" – or impacts that we have not yet anticipated – that will occur in the future (Lee et al., 2023).

In response to the urgency to respond and address climate change, the state of Washington has enacted multiple policies and programs to mitigate and adapt to climate change. The Washington Department of Commerce is developing guidance for counties and cities to leverage climate mitigation and adaptation benefits into comprehensive planning – a planning process used to guide local governments to invest in development and growth in sustainable ways.

Purpose

The City of Seattle's Climate Vulnerability Assessment (CVA) is a detailed assessment of how climate change is already affecting and will continue to affect the community wellbeing, economy, health, infrastructure, and natural systems of the city. While this CVA illuminates how climate change impacts a variety of sectors, this CVA is not intended to be a comprehensive assessment of all risks and hazards to such systems. For example, this CVA is not meant to be used as a hazards risk assessment for emergency planners or an economic risk assessment for economic development professionals. Rather, this CVA is used to identify ways that climate change has already affected and will continue to affect various systems and complement other types of risk assessments.

This CVA was developed to inform the **One Seattle Comprehensive Plan**, or the City of Seattle's Comprehensive Plan update, which will guide City policies and decisions on housing and job development and how the City invests in transportation, utilities, parks, and other public assets. This CVA can support the development of specific climate-related policies in the One Seattle Comprehensive Plan to build resilience and reduce vulnerabilities from climate change across the city's communities, geography, and systems. Additionally, the CVA can support the implementation of One Seattle Comprehensive Plan's policies to ensure that investments are focused in areas that are more vulnerable to the current and future impacts of climate change.

This CVA was funded by the Washington Department of Commerce capacity building grants to support local governments across the Washington state to develop and integrate climate change adaptation and mitigation policies into their respective Comprehensive Plans.

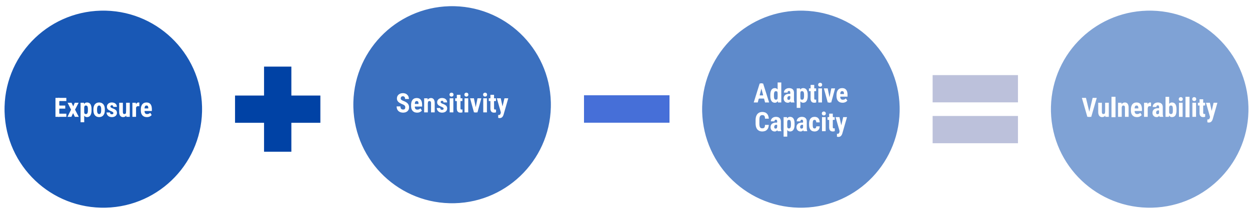
Climate Vulnerability Framework

Climate vulnerability is the propensity or the predisposition to be negatively affected by climate change and climate-related hazards. Exposure, sensitivity, and adaptative capacity are the components that influence a system's vulnerability to climate change. This assessment uses the following definitions of climate exposure, sensitivity, and adaptive capacity to better understand climate vulnerabilities for this CVA (Figure 1):

- **Exposure** is the degree to which a system is exposed to climate hazards. For example, coastal areas in towns and cities that are projected to experience sea level rise will have higher exposure to coastal flooding than inland cities will.
- **Sensitivity** is the degree to which that system is likely to be affected by climate change. For example, older adults are less able to regulate their body temperatures and thus more physically sensitive to extreme heat than younger people.
- **Adaptive capacity** is the ability to moderate the damage of, cope with, or adjust to climate change. For example, access to a vehicle and health insurance increase people's adaptive capacity to manage health impacts from extreme heat, smoke, and any injuries related to climate hazards.

Exposure and sensitivity increase vulnerability, while adaptive capacity helps to decrease vulnerability.

Figure 1. Climate Vulnerability Framework



Notes: The components of climate vulnerability are exposure, sensitivity, and adaptive capacity (Lee et al., 2023).

Climate vulnerability is influenced by environmental, institutional, economic, and cultural factors. Communities that have been historically marginalized and excluded from decision-making processes based on their race, income, age, gender identity or expression, or other factors are likely to have elevated exposure, sensitivity, and/or lower adaptive capacity as a result. Identifying and addressing structural inequities is an important step in documenting climate vulnerability and building a more resilient Seattle for all.

Structure of this Assessment

There are five primary focus areas within this CVA. They are designed to align with City departments' operations and planning processes. The focus areas are defined below (Table 1).

Table 1. CVA Focus Areas and Definitions

Focus Area	Definition
Economy	Climate change impacts to the local economy, including local businesses, workers, and other economic factors.
Public Health	Climate-related health outcomes in Seattle and relative health risks – including physical and mental health – across the city.
Community Amenities and Wellbeing	Likely climate change impacts to community assets and services, including food access, parks, and critical facilities, which benefit wellbeing.
Infrastructure	Effects and implications of climate change impacts to energy, transportation, and water infrastructure in Seattle.
Natural Systems	Climate impacts to local natural systems, including urban and regional watersheds, urban forests and open spaces, and aquatic habitats.

This CVA considers both physical and socioeconomic vulnerabilities to climate change within each focus area. It focuses within the geographic boundaries of the City of Seattle but acknowledges the effects of climate impacts beyond Seattle's borders. After the focus areas chapters, the CVA explores ways that climate vulnerabilities intersect, as seen during the 2021 heat dome event (see **Cascading and Compounding Climate Impacts** section).

Approach and Methodology

Methodology Overview

This CVA leverages research available across City, federal, state, and peer-reviewed sources to assess how vulnerable various systems across the city are to climate change. One key value-add of this assessment is that it provides a spatial analysis of relative vulnerability at the census tract level in the social and economic vulnerability assessment section, drawing on robust census tract-level data across the city and leveraging downscaled climate projection data.

Reviewed and Synthesized Documents

As a first step, the project team reviewed the landscape of current climate change risks and plans across multiple City and regional reports. This CVA builds on a solid foundation of climate research, data, and planning to provide an analysis specific to Seattle and areas within the city.

City of Seattle plans & documents:

- City of Seattle's Climate Preparedness Plan
- Seattle Public Utilities Drainage and Wastewater System Analysis
- Seattle Public Utilities' Shape of Our Water
- City of Seattle's Climate Action Plan
- Seattle Hazard Identification Vulnerability Assessment
- City of Seattle's Duwamish Valley Action Plan
- Seattle City Light's Climate Change Vulnerability Assessment and Adaptation Plan
- Seattle Parks and Recreation's Climate Resilience Strategy
- City of Seattle 2019 Water System Plan
- Seattle City Light's Climate Change Vulnerability Assessment and Adaptation Plan

Regional plans & documents:

- Our People, Our Planet, Our Power
- Powering the Transition: Community Priorities for a Renewable and Equitable Future
- State of Knowledge: Climate Change in Puget Sound
- 3rd National Climate Assessment's Northwest chapter
- 4th National Climate Assessment's Northwest chapter
- Peer-reviewed publications
- Additional government reports, plans, and studies

Assessed Elements of Climate Vulnerability

This CVA is broken into two primary sections: a **Social and Economic Vulnerability Assessment** and a **Physical Vulnerability Assessment.** The Social and Economic Vulnerability Assessment assesses the relative vulnerability to climate change across several focus areas, including the city's economy, amenity access and community wellbeing, and public health. The Physical Vulnerability Assessment assesses how ecological systems and infrastructure are affected by climate change. Objectives and focus areas for each type of vulnerability assessment are detailed in Table 2, below.

Table 2. CVA Social, Economic, and Physical Vulnerability Parameters

Assessment	Objective	Focus Areas	Spatial Resolution of Analysis
Social and Economic Vulnerability Assessment	Assess the **relative vulnerability** to climate change that **communities experience**; examines geographic distribution of vulnerability **by census tract**.	• Economy • Community Amenities & Wellbeing • Public Health	Census tract
Physical Vulnerability Assessment	Assess how various **infrastructure assets and natural systems** are vulnerable to climate change and **assess implications**.	• Infrastructure • Natural Systems	Citywide

Social and Economic Vulnerability Assessment

The Social and Economic Vulnerability Assessment utilizes an index approach, which is a method to quantitatively normalize multiple criteria that allows for comparability across indicators and categories. The project team developed a potential list of sensitivity and adaptive capacity indicators by referencing comparable vulnerability assessments, such as those from the City of Redmond (WA) and Los Angeles County (CA), as well as a technical guidance document from the University of Notre Dame (BERK Consulting, Inc.; Perteet; The Watershed Company; UW Climate Impacts Group, 2022; LA County, 2021; Chen, et al., 2015). After developing an initial list, the project team solicited additional potential indicators and data sources from City staff members and through additional data requests to City staff.

The project team then vetted the potential indicators by asking the following questions:

- **Is the data relevant?** The project team used indicators that are as recent as possible and that have clear connections to climate change.

- **Is the data available?** Datasets need to be publicly available or shareable without sensitive and identifiable data being shared.
- **Is the data high quality?** The project team avoided datasets that are incomplete and sought local datasets whenever possible.
- **Is the data at a census tract-level resolution?** The project team included all census tracts that are within city boundaries and that overlap with city boundaries.
- **Does the data show variability across the city?** Some datasets are relevant, high quality, and available at the census tract level, but do not show any variability across the city and are therefore not useful for the indices.

Once the project team selected indicators, we normalized each dataset into indices to allow for comparability between census tracts. The equation weights exposure, sensitivity, and adaptive capacity equally in the analysis to calculate a vulnerability index (see equation below) for each census tract. Indices are on a scale of zero to one, where zero means lower vulnerability and one means higher vulnerability.

$$\text{Vul. Index} = \frac{1}{3} \times \frac{1}{n_{\text{Exp.}}} \sum_{i=1}^{n} \text{Exp. Index} + \frac{1}{3} \times \frac{1}{n_{\text{Sen.}}} \sum_{i=1}^{n} \text{Sen. Index} + \frac{1}{3} \times \frac{1}{n_{\text{Adap.}}} \sum_{i=1}^{n} \text{Adap. Index}$$

Following the calculated percentiles, the project team mapped the results in ArcGIS to display the geographic distribution of vulnerability to climate change across the city.

Physical Vulnerability Assessment

The Physical Vulnerability Assessment examines how infrastructure and natural systems are at risk due to climate hazards. For this assessment, the project team mapped how different assets – such as open spaces and parks or transit infrastructure – are exposed to various climate impacts including heavy precipitation and urban flooding, extreme heat, and sea level rise.

To assess different exposure layers, the project team evaluated various data sources by asking similar questions as in the Social and Economic Vulnerability Assessment: **Is the data relevant? Is the data available? Is the data high quality? Does the data show variability across the city?**

Based on answers to these questions, the project team used the following data layers to assess the distributional exposure of assets to climate change impacts (Table 3).

Table 3. Climate Change Impacts and Data Sources

Climate Change Impact	Description	Data Source
Urban flooding	FEMA flood maps containing both the 100-and 500-year flood plain.	• **FEMA Flood Map Service Center**
Sea level rise	NOAA DEM, combined with NOAA tide level data, and sea level rise and storm surge projections for Seattle.	• **NOAA Digital Elevation Model** • **NOAA Tidal Datums** • **Interactive Sea Level Rise Data Visualizations** • **Puget Sound Storm Surge Modeling** • **Coastal Flood Exposure Mapper**
Extreme heat	Heat mapping project conducted by King County and the City of Seattle. Temperature measurements were recorded for three different times of day throughout King County during an extreme heat event in 2020.	• King County / City of Seattle **Heat Mapping Project**
Landslides	Areas at risk of potential landslides in Seattle.	• City of Seattle's **Potential Landslide Areas**

Finally, existing peer-reviewed research and published reports were used to qualitatively complement the spatial analysis to get a more comprehensive understanding of climate risks and vulnerability.

Compounding and Cascading Impacts Assessment

Following the Social and Economic Vulnerability Assessment and Physical Vulnerability Assessment in this document is a qualitative assessment of compounding events and cascading impacts. Traditional risk or vulnerability assessments typically treat hazards independent from one another. However, systems – social, economic, and infrastructure systems – are interconnected. Thus, climate change impacts to one system will inevitably have cascading or compounding effects across multiple systems (May et al., 2018). However, many of these impacts are difficult to model or predict because of their interdependent nature, leading to potential "surprises" – or events and impacts that fall outside the scope of climate models (Kopp et al., 2017).

Currently, there are limitations in how to quantitatively evaluate cascading and compounding impacts from these extreme events (Kopp et al., 2017). There is lag-time between the occurrence of extreme events and documentation of these events in the peer-reviewed literature base (Roesch-Mcnally et al., 2020). Thus, to assess the compounding and cascading impacts from climate change, we rely on a case study approach and a mix of sources including peer-reviewed literature, media reports, and City plans and documents. We used two different case studies to illuminate the new and emerging ways climate change is affecting local communities, which include: 1) the 2021 heat dome event, and 2) the 2022 King Tide flooding that coincided with a historic winter storm and atmospheric river events.

City Staff and Community Partner Engagement

City Staff Engagement

The City convened City staff to guide the CVA process. Eighteen representatives participated in two meetings to provide input on the methodology, data sources, and initial findings of the CVA. These representatives also participated in a draft review process to add comments to the full set of findings. The following departments had staff who engaged with the development of the CVA.

- City Budget Office
- Seattle Department of Construction & Inspections
- Office of Emergency Management
- Finance and Administrative Services
- Office of Planning & Community Development
- Office of Sustainability & Environment
- Office of Economic Development
- Seattle Department of Transportation
- Seattle City Light
- Seattle Public Library
- Seattle Public Utilities
- Seattle Parks and Recreation

In addition to meeting with City staff, there were meetings with individuals from the Office of Planning & Community Development and Emergency Management.

Meetings with Key Community Partners

The City held a meeting to review the CVA methodology and initial results of the CVA with a set of key community partners. The same group of partners provided feedback on the full draft CVA. Community partners represented the following organizations:

- Duwamish River Community Coalition
- 350 Seattle

- League of Women Voters City Climate Action Committee
- Public Health, Seattle & King County
- Seattle 2030 District
- Zero Waste Washington
- The Nature Conservancy
- Environmental Coalition of South Seattle
- Tilth Alliance
- SM Watts Consulting
- Futurewise

The City and Cascadia convened separately with Public Health, Seattle & King County staff to better understand available health-related datasets.

Climate Change Trends and Projections

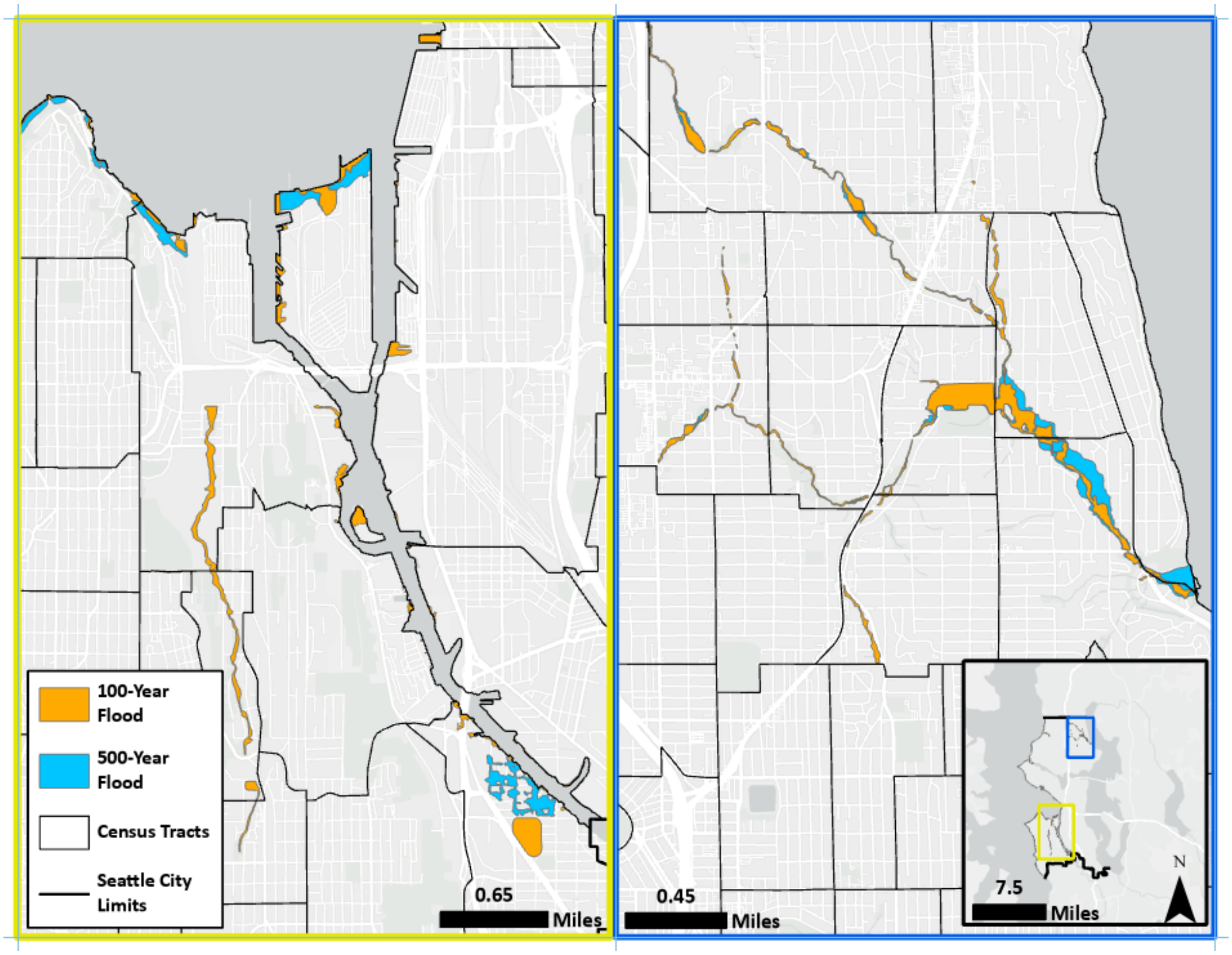
The climate of western Washington has been rapidly changing since the 1900s (Mauger et al., 2015; May et al., 2018). The region has experienced warmer air temperatures, reduced mountain snowpack, increasing wildfire risk, sea level rise, and changing precipitation patterns that affect the region's communities, economies, and infrastructure systems. The climate in the Pacific Northwest is affected by natural climatic patterns and processes—such as the El Niño-Southern Oscillation (ENSO)—that can make some impacts more pronounced in individual years.

The following sections provide an overview of various climate change impacts and how exposure to these impacts are unevenly distributed across the City of Seattle.

Flooding

Historically, flooding has affected various parts of Seattle and is one of the most costly and destructive types of climate-related events (Seattle Office of Emergency Management, 2019). Seattle experiences three types of flooding: riverine flooding, coastal flooding, and urban or pluvial flooding. For example, areas around Longfellow and Thornton creeks experience riverine flooding, areas along West Seattle's shores experience coastal flooding, and areas along Madison Valley experience urban flooding (Figure 2).

Figure 2. FEMA 100-year and 500-year Flood Zones in Seattle

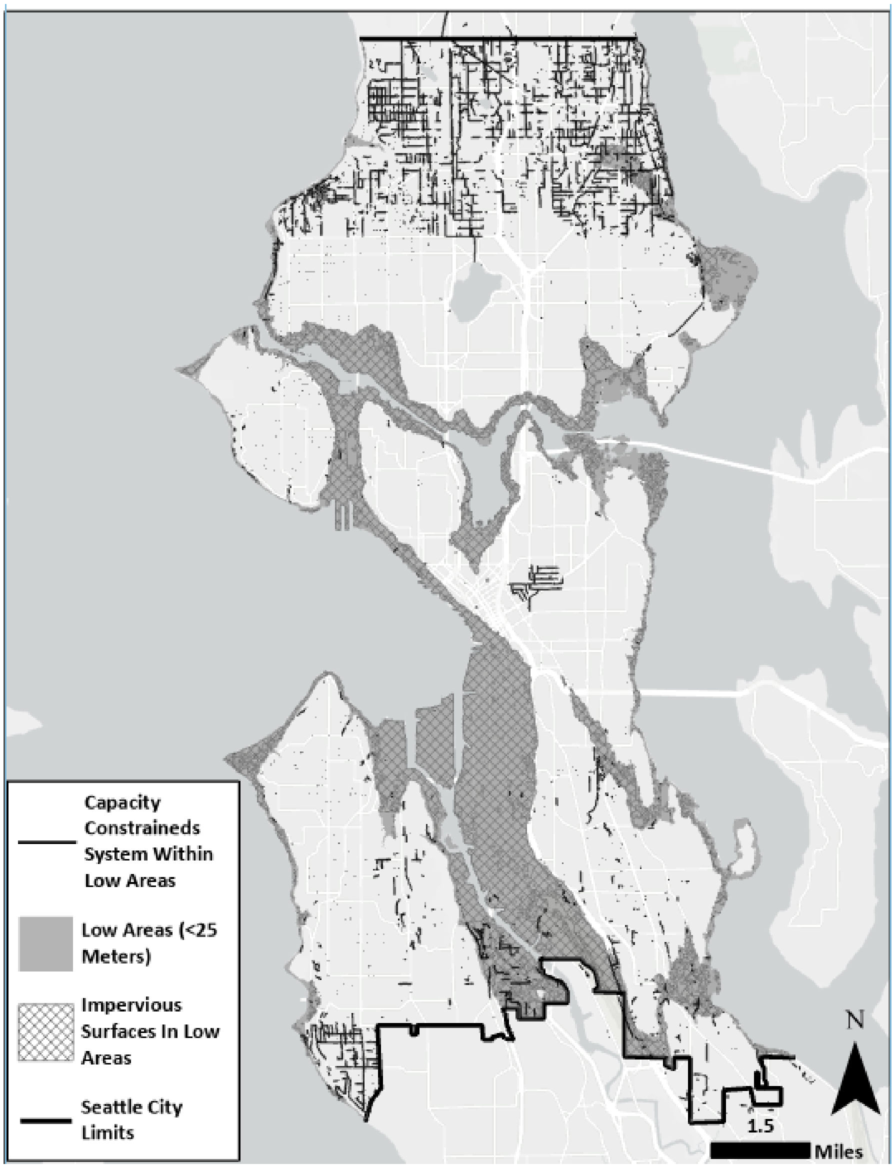


Notes: This map shows sea level rise of 3.1 feet (using a 1% likelihood scenario and including storm surge) in the Duwamish Valley of Seattle. There are several blocks along the river shown to be inundated with seawater (City of Seattle, 2022).

Flooding impacts can be exacerbated by impervious surfaces, often associated with development and industrialization. The coincidence of low-lying areas – or areas where water is likely to pool and collect in the city – with areas of more impervious surface coverage can lead to amplified flooding risks, especially during heavy rain events that increase volume and flow into these areas. Impervious surfaces are correlated with pluvial flooding in Seattle; systems with inadequate conveyance capacity will not be able to effectively cope with flooding events. Some areas, like the Duwamish Valley and South Park, experience a confluence of flooding types, amplifying the flooding impacts and associated consequences (Figure 3).

Historically redlined areas in Seattle generally have a higher extent of impervious surfaces (Conzelmann et al., 2022). Some of these areas, such as the Georgetown neighborhood, experience a significantly higher risk of flooding than other low-lying areas, such as Montlake (Figure 3) (Risk Factor, 2020).

Figure 3. Low-lying Areas with Capacity-constrained Drainage and Impervious Surfaces that are at High-Risk of Urban Flooding



Notes: The map indicates several areas in South Park, Georgetown, Rainier Beach, Sunset Hill, and Meadowbrook neighborhoods where low-lying areas with capacity-constrained drainage and impervious surfaces overlap, making it more likely for these areas to experience flooding after heavy rains. Low-lying areas are areas in Seattle that lie under 82 feet (25m) of elevation; capacity constrained systems layer from SPU; and areas of impervious surfaces are from the City of Seattle. These layers are used as proxy layers to assess current urban flooding risk (City of Seattle, 2022).

Flooding risks will continue to affect Seattle. Areas that have historically flooded will flood more often and new areas may experience infrequent flooding events in the future. All flooding types are expected to become more intense and more frequent, due to climate drivers such as sea level rise and extreme precipitation events, whose trends and impacts are documented in subsequent sections (Table 4).

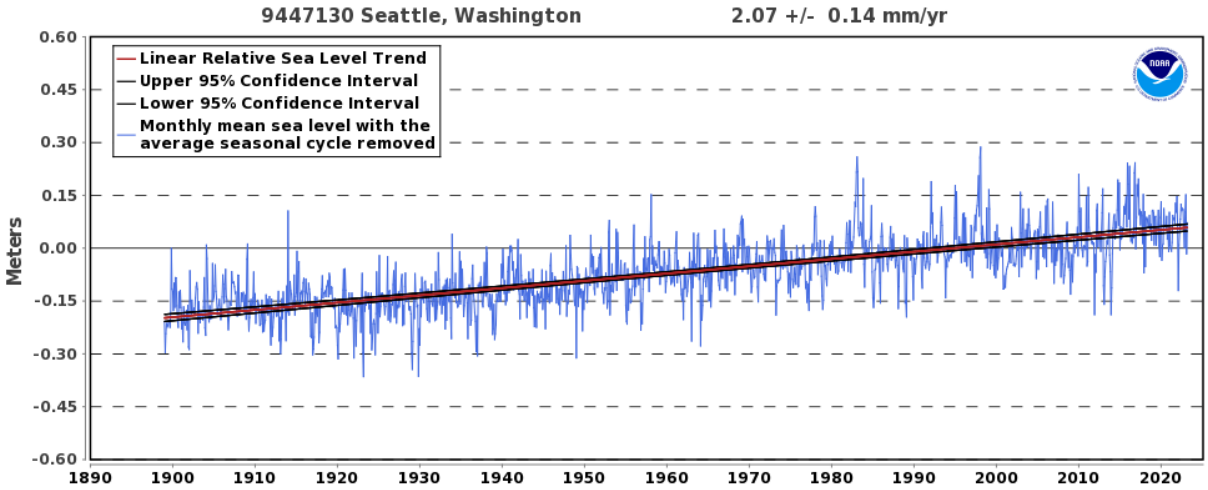
Table 4. Summary of Sea Level Rise and Extreme Precipitation Effects on Flooding in Seattle

	Sea Level Rise	Extreme Precipitation
Coastal Flooding	Sea level rise will worsen coastal flooding events, often associated with winter storms or high tide events. Exceptionally high tide events, such as King Tides, can happen during winter storms, amplifying flooding impacts.	Extreme precipitation events can lead to an influx of water volume from rivers and streams, potentially contributing to a "squeeze" effect that can amplify coastal flooding events.
Riverine Flooding	Sea level rise can raise water levels around river mouths and can reduce the capacity of rivers to discharge higher flows.	Extreme precipitation can increase river volume and flow, leading to river overflow and riverine flooding. Warm spring temperatures can lead to rapid snowmelt, increasing riverine flooding risks.
Urban Flooding	Sea level rise can raise groundwater tables, affecting conveyance systems and reducing capacity of flood water infiltration.	Extreme precipitation can increase the water volume and flow into low-lying areas, increasing urban flooding risk.

Sea Level Rise

Sea level rise is driven by a variety of factors related to global climate change, including ocean warming, thermal expansion of water as the ocean warms, and influx of water from melting ice sheets and glaciers (Sweet et al., 2022). Localized geologic processes in the Puget Sound region, such vertical land movement, can worsen or slow the effects of sea level rise (Miller et al., 2018). Relative sea levels in Seattle have already risen approximately 0.68 feet, or 8.2 inches, between 1899 and 2022 (Figure 4). During El Niño years, sea levels can rise another 7.9 inches in the region, increasing risks of coastal flooding (Sweet et al., 2022).

Figure 4. Relative Sea Level Rise in Seattle, WA



Notes. Plots show monthly mean sea levels without regular seasonal fluctuations from other atmospheric and oceanographic processes. The relative sea level trend is shown with a 95% confidence interval. Value measurements are from NOAA Tide Gauge 9447130 in Seattle, WA.

Sea levels are projected to rise across Seattle's shorelines in the coming decades, though sea level rise will be variable due to local geological conditions such as the rate of vertical land movement (Miller et al., 2018). Downscaled sea level rise projections for Washington state use different likelihood scenarios that allow for planners to tailor efforts based on a variety of factors, including planning horizons and risk tolerance (Raymond et al., 2020). For this CVA, we have decided to use the 17 percent and 1 percent likelihood scenarios to illustrate a range of potential impacts associated with sea level rise in alignment with other jurisdictions across Puget Sound (Raymond et al., 2020). By 2050, it is projected that Seattle will experience sea level rise that will exceed 1.1 feet (17% likelihood scenario) to 1.6 feet (1% likelihood scenario) (RCP8.5). By 2100, it is very likely that sea level rise will exceed 3.2 feet (17% likelihood scenario) to 5.2 feet (1% likelihood scenario) (Table 5) (Roop et al., 2018).

Table 5. Relative Sea Level Rise Probabilities in Seattle by 2050 and 2100, under RCP8.5

Latitude and Longitude	Seattle Region	Likelihood of Exceedance	2050	2100
47.5°, -122.4°	Duwamish	17%	1.1 feet	3.2 feet
		1%	1.6 feet	5.2 feet
47.6°, -122.4°	West Seattle, Duwamish, Georgetown and SODO	17%	1.1 feet	3.1 feet
		1%	1.5 feet	5.1 feet
47.6°, -122.4°	Downtown, Lower Queen Anne	17%	1.1 feet	3.1 feet
		1%	1.5 feet	5.1 feet

Latitude and Longitude	Seattle Region	Likelihood of Exceedance	2050	2100
47.7°, -122.4°	Discovery Park, Ballard, Broadview	17%	1.1 feet	3.1 feet
		1%	1.5 feet	5.2 feet

In addition to increasing the height of mean higher high water (MHHW), sea level rise will also expand the reach and impacts of storm surge, a coastal phenomenon where water levels are higher than the predicted astronomical tides, brought on from a combination of high tide, low atmospheric pressure, and wind-driven waves (Roop et al., 2018).[1] When combined with the 100-year Puget Sound storm surge event, coastal flooding impacts in low-lying areas will be amplified, and sea levels are likely to increase by an additional 3.1 feet (Table 6) (Yang et al., 2019). For example, the December 2022 King Tide flood events saw flooding reach almost 13 feet in the Duwamish Valley, leading to damaging floods for communities and businesses.

Table 6. Projected Sea Level Rise and Storm Surge Impacts under RCP8.5

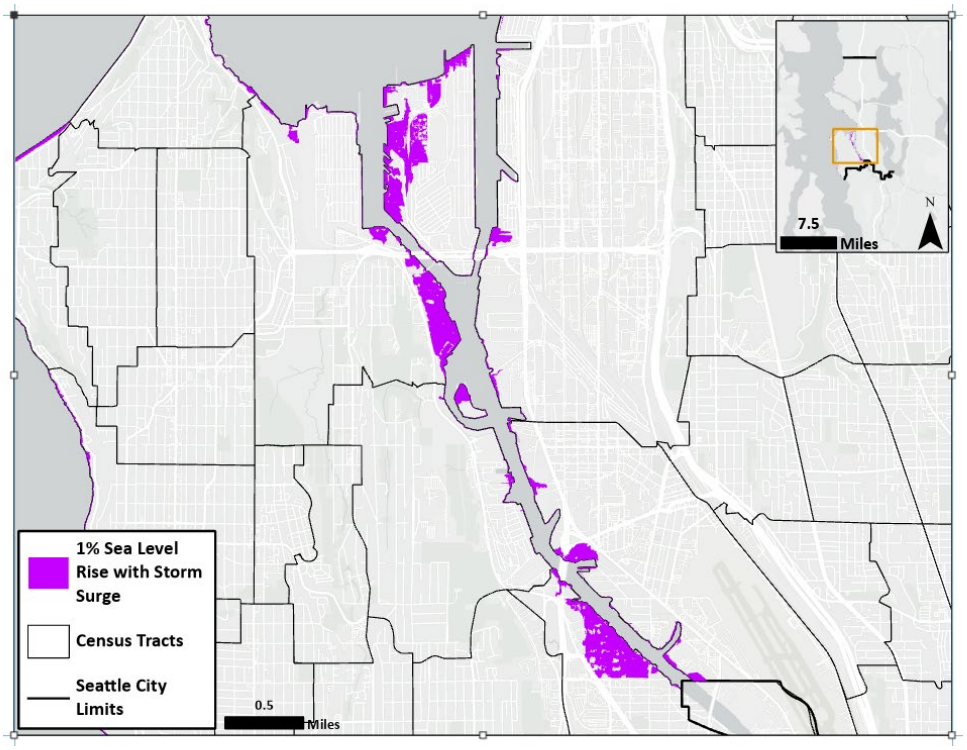
Projection	Year	2023 MHHW Levels (feet)	Sea Level Rise (feet)	1% Storm Surge Event (feet)	Coastal Flooding Projected Water Level (feet)
17% Likelihood SLR Event	2050	11.63	1.1	3.1	15.83
	2100		3.1		17.83
1% Likelihood SLR Event	2050	11.63	1.5	3.1	16.23
	2100		5.1		19.83

Notes: Sea levels are described in relation to the North American Vertical Datum of 1988, or NAVD88, which is a standard when measuring the heights of tides and sea levels. Storm surge events are documented from Petersen et al., 2015.

The neighborhoods around the Duwamish River are among the lowest-lying areas in Seattle and are already seeing repeated flooding events. This area is projected to be disproportionately impacted by coastal flooding driven by sea level rise (Figure 5). Additionally, this area has lower conveyance capacity and more impervious surfaces, exacerbating localized flooding impacts (Figure 3).

[1] *Additional data on coastal flooding and storm surge will be forthcoming in 2024 through the King County Puget Sound CoSMoS project.*

Figure 5. Sea Level Rise Along the Duwamish River by 2050 under RCP8.5

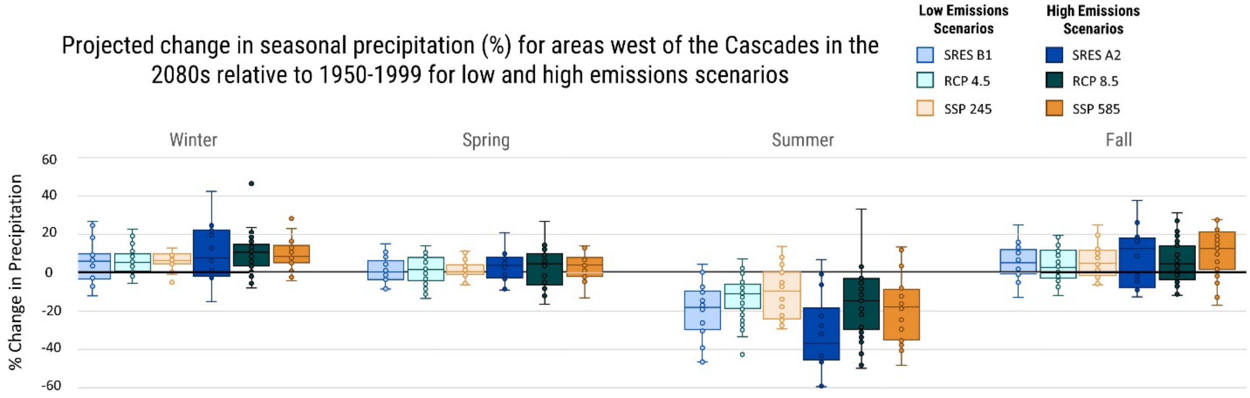


Notes: This map shows sea level rise of 3.1 feet (using a 1% likelihood scenario and including storm surge) in the Duwamish Valley of Seattle. There are several blocks along the river shown to be inundated (Miller et al., 2018; National Oceanic and Atmospheric Administration, 2021; Roop et al., 2018).

Extreme Rain and Precipitation

Precipitation trends are shifting across Seattle and the Puget Sound region. While annual precipitation will continue to remain variable, there will be seasonal shifts in precipitation. Winter and fall precipitation are expected to increase and precipitation will increasingly fall as rain rather than snow. Additionally, winter precipitation may be concentrated in extreme rain events, which can exacerbate flooding risks. Summer precipitation is projected to decrease across all scenarios, contributing to regional heat stress, drought conditions, and water supply impacts.

Figure 6. Projected Changes in Seasonal Precipitation for Areas West of the Cascades by the 2080s



Notes: Projected changes in seasonal precipitation for the areas in Washington state that are west of the Cascades for the 2080s relative to 1950-1999 for winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug), and fall (Sep-Nov). Projections are shown for CMIP3, CMIP5, and CMIP6 models and include low emissions scenarios (SRES B1, RCP4.5, and SSP245) and high emissions scenario (SRES A2, RCP8.5, and SSP585). Individual climate model projections for each scenario are shown using colored dots. Boxes show the average projected change (expressed as percent change), along with the 10th, 25th, 75th, and 90th percentile values among all climate model projections. The black horizontal line denotes zero changes. Figure adapted from **Pacific Northwest Climate Projection Tool** and created by Cascadia Consulting Group (Rogers & Mauger, 2021).

While the magnitude of seasonal shifts in precipitation will vary, summer precipitation is predicted to decrease and winter precipitation is predicted to increase. Under the RCP8.5 scenario, total summer precipitation is projected to decrease by 13 percent by 2050 and 15.9 percent by 2080, and winter precipitation is projected to increase by 7 percent by 2050 and 10.6 percent by 2080. Under the SSP585 scenario, summer precipitation is projected to decrease by 14.2 percent by 2050 and 19.5 percent by 2080, and winter precipitation is set to increase by 5.3 percent by 2050 and 9.8 percent by 2080 (Figure 6) (Morgan et al., 2021).

As winter precipitation volume increases, extreme precipitation events – many of which are driven by atmospheric rivers – are likely to be more intense (Slinskey et al., 2020). The magnitude of the average 25 year-storm is expected to increase by 13 percent by 2050 and 12 percent by 2090 (Raymond & Rogers, 2022). In winter months, most extreme precipitation events are driven by atmospheric rivers (Slinskey et al., 2020). When compounded with other events – such as King Tides or storm surge – flooding impacts can be amplified.

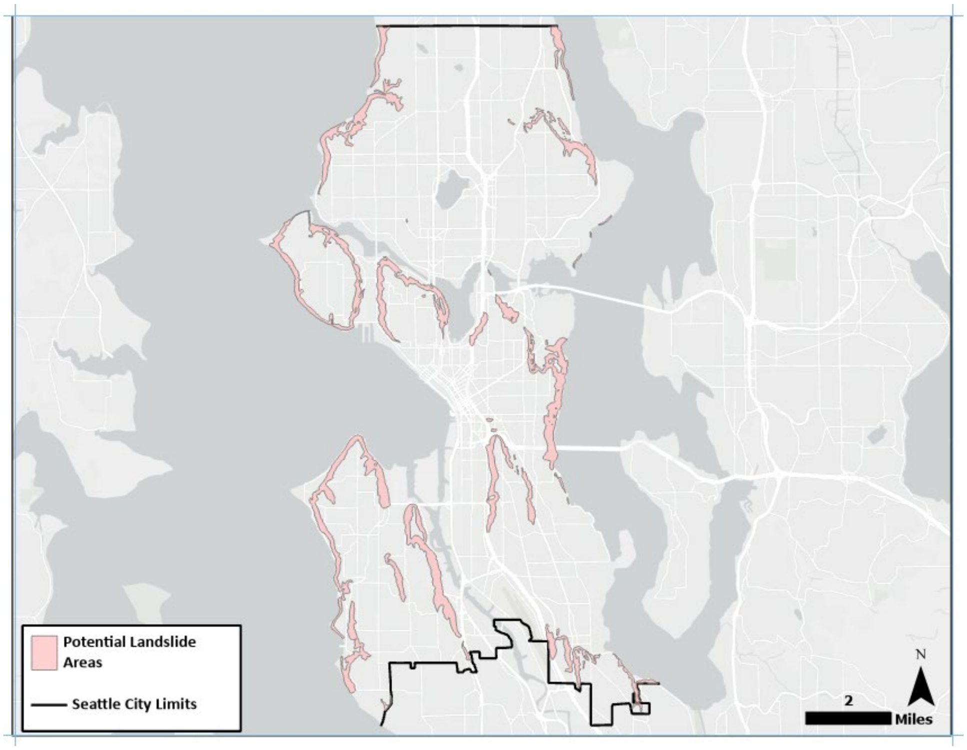
Geologic Hazards

Seattle Municipal Code designates geologic hazards, flood-prone areas, wetlands and habitat conservation areas, and abandoned landfills as environmentally critical areas (ECAs). Protecting the functioning and integrity of these ECAs reduces the city's exposure to geological and flood hazards and ensures the health of sensitive habitats and the species they support. Climate change can impact these areas directly, and can also act indirectly as a risk multiplier, exacerbating the effects of non-climate related events such as earthquakes and tsunamis.

LANDSLIDES

Landslides are likely to occur in areas with steep slopes, such as in the Delridge and Interbay areas, especially in winter and spring months when heavy precipitation events typically occur (Strauch et al., 2019). Heavy precipitation, particularly over prolonged periods, can contribute to slope instability and failure (Strauch et al., 2018). Events like these will likely increase in frequency and intensity into the future, contributing to increased risks of landslides that cause damage and blockage to transportation routes, buildings, other infrastructure, and natural areas across the city (Figure 7) (Strauch et al., 2019).

Figure 7. Landslide Hazard Areas in Seattle

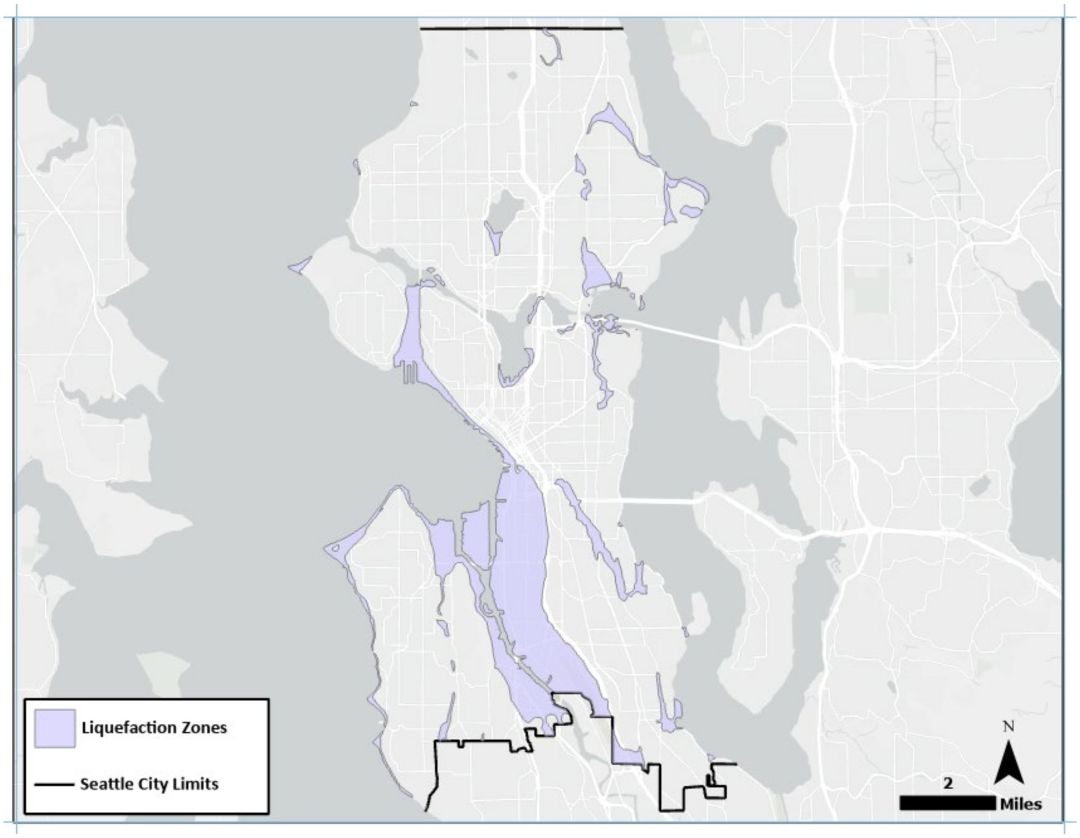


Notes: This map shows potential landslide areas in the City of Seattle (Seattle Office of Emergency Management, 2019).

LIQUEFACTION

Sea level rise associated with climate change could magnify liquefaction risk during an earthquake (Figure 8). Liquefaction occurs when soil that is saturated with groundwater acts more like a liquid under the intense shaking of an earthquake. As sea level rises along the Seattle shoreline, water tables will also rise, increasing soil saturation and the likelihood and severity of liquefaction (Poitras et al., 2022). Increased urban flooding could especially amplify liquefaction risk during the winter. Conversely, lower water tables during projected temporary drought periods could reduce liquefaction risk during the summer.

Figure 8. Liquefaction-prone Areas Within Seattle

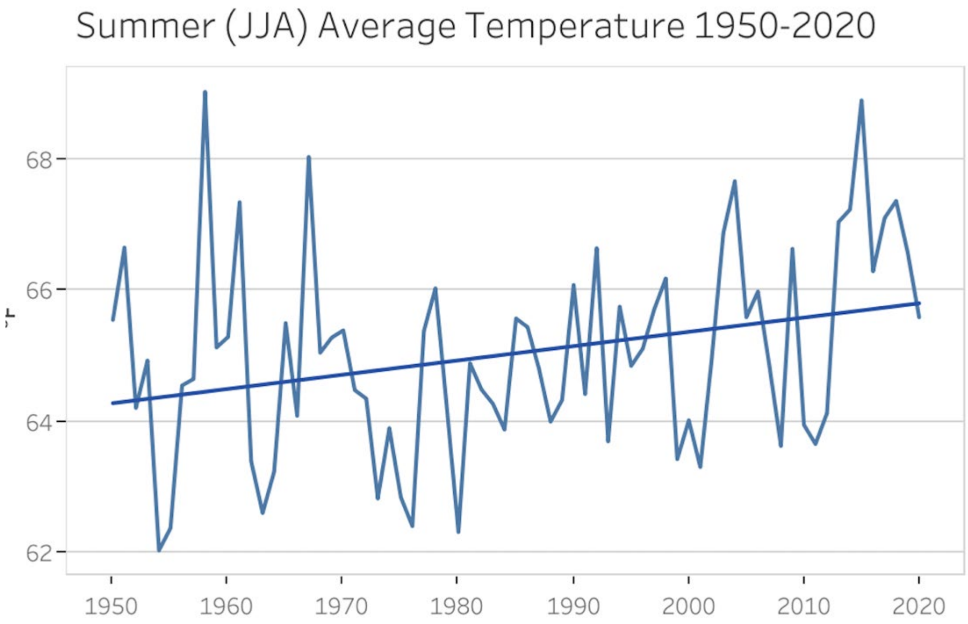


Notes: This map shows liquefaction-prone areas in the City of Seattle (Seattle Office of Emergency Management, 2019).

Extreme Heat

Average temperatures in Washington State have already increased 2.0°F over the past century (Frankson et al., 2022). Within the City of Seattle, the average summer (June-August) temperature has already warmed approximately 1.5°F between 1950 and 2020 (University of Washington Office of the Washington State Climatologist, 2021) (Figure 9).

Figure 9. Average Summer (June-August) Temperature in Seattle from 1950 to 2020

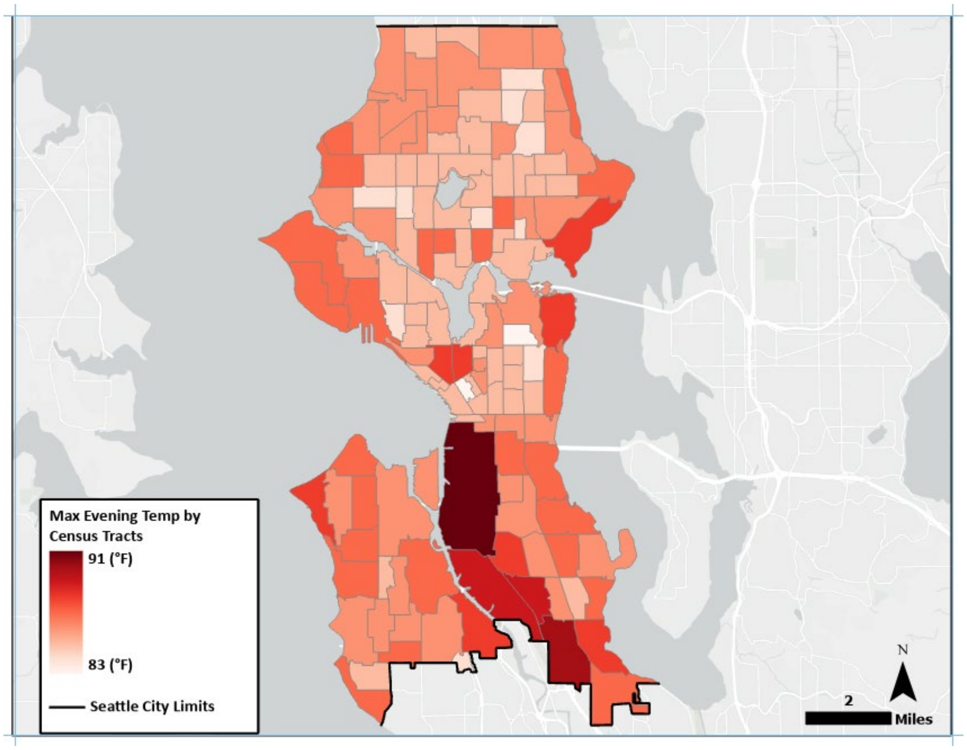


Notes: Average summer temperature data collected by NOAA's U.S. historical Climatology Network, version 2.5.5.20210712 (University of Washington Office of the Washington State Climatologist, 2021).

While temperatures have generally been warming across the city, heat burden is not equally distributed across the city. Factors such as level of industrialization, impervious surface coverage, and tree canopy coverage – all of which are associated with land use and redlining policies – can increase heat burden, or the heat island effect, for some areas of Seattle (Conzelmann et al., 2022). Industrialized areas and historically redlined areas—such as Georgetown and Rainier Beach—can be almost 8°F warmer than other areas (Figure 10).

Summertime maximum temperatures in Seattle is projected to increase by 6.3°F by 2050 and 10.5°F by 2100 under RCP8.5 relative to the 1980-2009 median, increasing the frequency of extreme heat days in the city (Raymond & M. Rogers, 2022). Additionally, the likelihood of a heatwave (i.e., when the "feels like" temperature is above 86°F) to last three consecutive days or longer, which is currently about 67 percent, will increase to 86 percent by 2050 (First Street Foundation, n.d.). Due to Seattle's historically temperate climate, the impacts of warmer temperatures will be relatively more severe for Seattle residents, especially when compared to other cities. Additionally, Seattle has a relatively higher percentage of households without air conditioning (46%) (American Housing Survey, 2021), making residents vulnerable to heat waves because of the lack of cooling capacity (see **Public Health Vulnerability to Climate Change** section).

Figure 10. Evening Heat and Heat Islands in Seattle

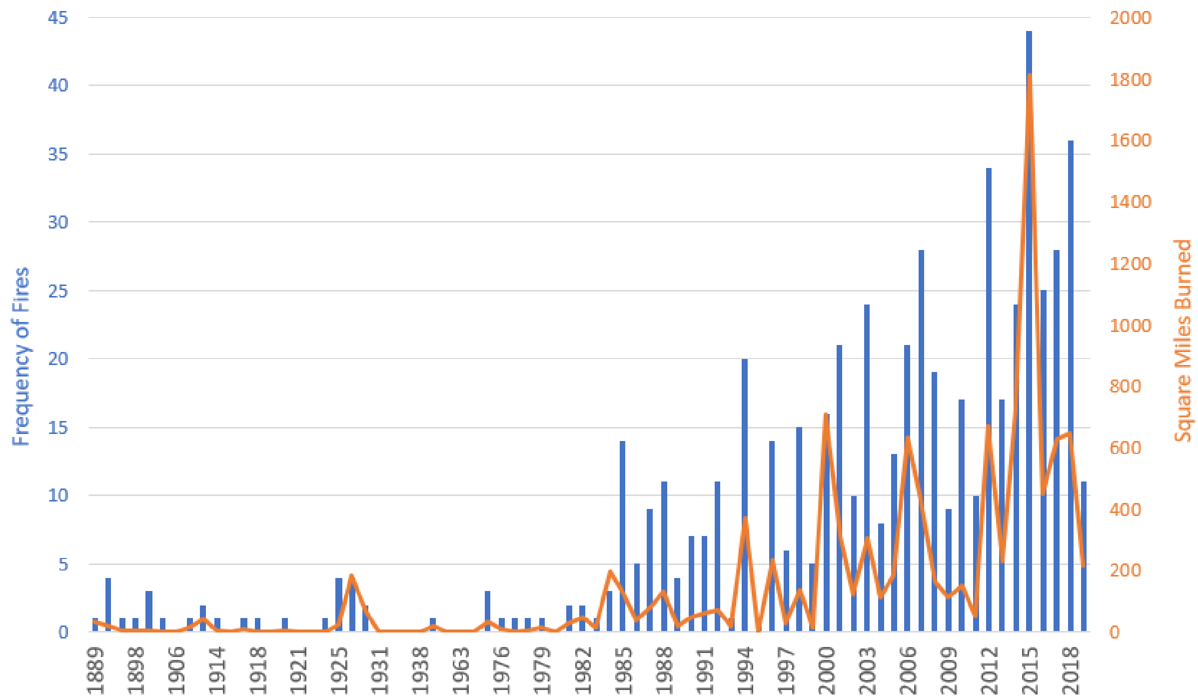


Notes: This map indicates results of a Seattle and King County heat mapping project, which found that urban areas are more prone to higher temperatures than areas with vegetation. SODO and the Industrial District are areas projected to be most impacted by extreme heat (CAPA Strategies et al., 2021). This map illustrates maximum evening temperatures, which typically are a period of the day that allows for cooling from cooler ambient night temperatures, demonstrating how some areas may not get this cooling respite at night.

Wildfire Smoke Days

Wildfire smoke is notoriously difficult to forecast, but poor air quality days due to wildfire smoke have been increasing and will become more prevalent and intense due to climate change. In recent decades, wildfires In Washington state have not only become more prevalent, but their intensity has also increased (Figure 11) (Welty & Jeffries, 2020).

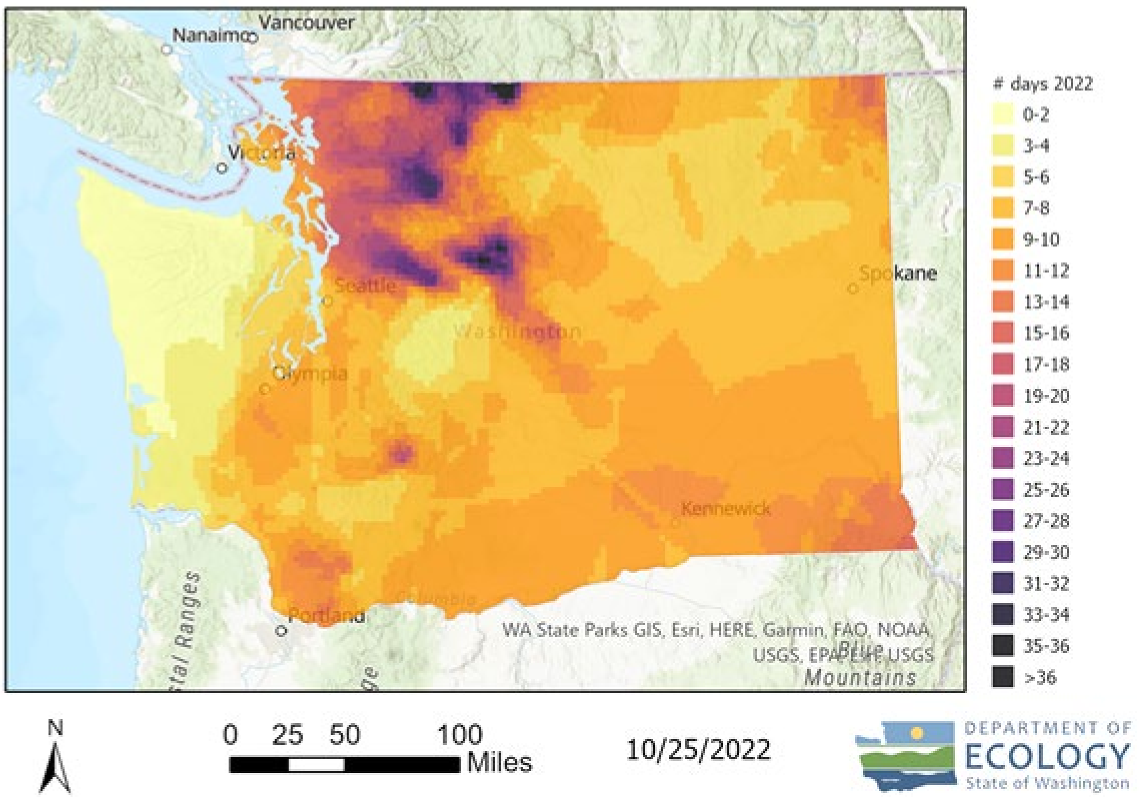
Figure 11. Number of Large Fires in the Northwest between 1899-2018



Notes: Frequency of large wildfires (greater than 1,000 acres) and the total area burned in Washington State from 1889 to 2019 (Welty & Jeffries, 2020). Figure created by Cascadia Consulting Group.

In 2022, wildfire smoke days in western Washington extended into October for the first time ever (Figure 12). This was primarily due to the warmest and driest September the state had experienced in recent history (Vaughn, 2011). As wildfires are projected to be more intense, wildfire smoke days are expected to be more frequent and prolonged, increasing $PM_{2.5}$ exposure due to wildfire smoke, subsequently increasing the risk for smoke-related health-related consequences, particularly for sensitive groups such as elders, youth, low-income communities of color, outside laborers, and people without health insurance.

Figure 12. Smoke-filled Days in 2022



Notes: This figure shows smoke-filled days across the state of Washington in 2022, on a scale of 0-2 smoke-filled days to over 36 smoke-filled days. Seattle appears to have experienced approximately 7-8 smoke-filled days, but areas directly north of Seattle are darker, indicating more smoke-filled days in 2022 (Vaughn, 2022).

Climate “Surprises”

Climate change models have limits in quantifying and predicting some climate change impacts and climate-related extreme events. While climate models provide insight into the range of possible futures, these models are limited by the fact that they do not encapsulate all types of processes, feedback loops, and factors that affect global and local climate. Thus, there are some types of impacts and extreme events that may fall outside the limit of model outputs – or climate “surprises” (Kopp et al., 2017). Some recent examples of “surprises” in Seattle includes the occurrence of wildfire smoke events each year, the severity of flooding associated with some King Tide events (i.e., 2022 King Tide flood events), and the 2021 heat dome event that saw temperatures exceed 100°F over multiple consecutive days.

Social and Economic Climate Vulnerability Assessment

Community Amenities and Wellbeing

Introduction to Community Amenities and Wellbeing

Community wellbeing refers to the variety of social, economic, environmental, cultural, and political conditions identified by community residents that allow their communities and neighborhoods to flourish and fulfill their potential (Wiseman & Brasher, 2008). The definition of community wellbeing can vary across and within communities, and can be subjective (e.g., how happy does a person feel within their community?) or objective (e.g., does a person or group have access to services and amenities that can allow them to flourish?) (Atkinson et al., 2017). Proximity and access to amenities have been shown to lead to beneficial health and wellbeing outcomes, including improved physical and mental health (City of Seattle, 2016). This CVA focuses on community exposure to climate change impacts and how access, or lack of access, to various community amenities and services – such as healthcare services, grocery stores, and shade – will positively or adversely affect local communities in preparing for and coping with the impacts of climate change.

Community services and amenities are both at risk from climate change and supportive of communities' adaptive capacity to prepare for, cope with, and be resilient to climate change. For example, access to amenities and services such as parks and open spaces and grocery stores can provide spaces for recreation and healthy food options, respectively. However, extreme events such as flooding or heat waves can disrupt access or make it more difficult for residents to access these services, likely leading to increased burden for those who already have limited access these services (e.g., those without cars, those in sensitive population groups, or older residents). Acute, but prolonged, extreme events that affect amenity access – such as the 2021 heat dome event or the 2022 King Tide floods – can lead to acute illnesses or premature deaths.

Climate Vulnerability to Community Amenities and Wellbeing

METHODOLOGY AND RESULTS

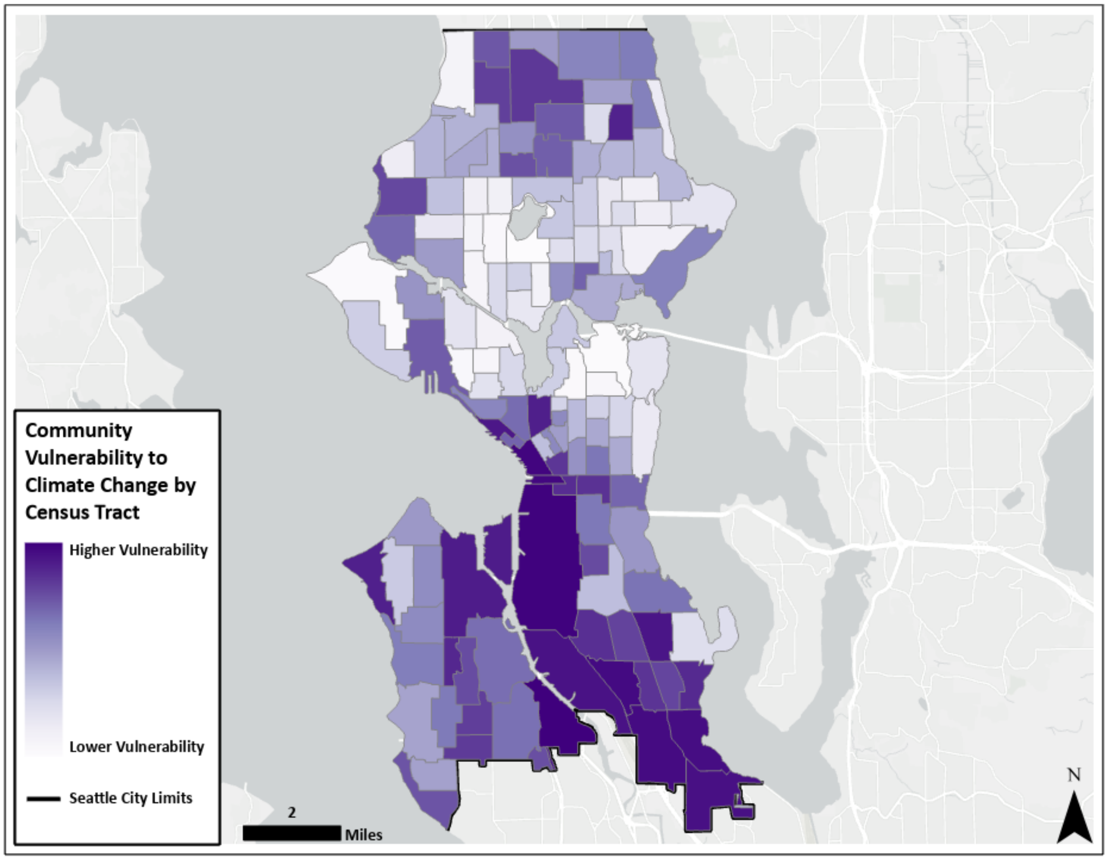
While many factors contribute to community resiliency, the following indicators were selected due to data availability, quality, and relevance (Table 8). While not comprehensive, these indicators illustrate how climate change will affect community resiliency, particularly as it relates to community amenities, services, and wellbeing, and how these impacts are not evenly distributed across the city.

Table 7. Community Indicators of Climate Vulnerability Selected for Analysis

Indicator	Vulnerability Element	Relevance & Considerations
Climate exposure to flooding, heat, sea level rise, and urban flooding	Exposure	This indicator was chosen to assess exposure to climate change impacts for each census tract.
Food Security and Access	Sensitivity	People with lower access to food services – such as grocery stores or restaurants – are more sensitive to impacts of climate change due to further distance to access food and a decreased ability to quickly access food amenities and stores.
Access to Parks	Sensitivity	People with lower access to parks and green spaces, particularly those that rely on these spaces to improve mental and physical health, are more sensitive to the impacts of climate change.
Race & Social Equity Index	Sensitivity	Race and social equity considerations – such as health and socioeconomic disadvantages – increase vulnerability and risk to climate impacts and how a community adapts and copes before, during, and after these events.
Tree Canopy	Adaptive Capacity	Lack of tree canopy coverage increases the relative vulnerability and risk of heat-related impacts for the residents and workers that reside in these areas
Critical Facilities	Adaptive Capacity	People who have less access and are further from critical facilities – or facilities that provide important community services – increase vulnerability for frontline communities to access these services during extreme weather events.

Climate impacts – such as extreme heat and urban flooding – will disrupt access and level of service for a variety of community amenities, including parks and open spaces, grocery stores, and critical facilities. These disruptions often exacerbate existing health and socioeconomic disparities and affect the ability of residents to respond and recover from climate impacts and extreme events. Some areas in Seattle will experience more community vulnerability to climate change, such as the Duwamish Valley, SODO, Rainier Valley, Lake City, Northgate, and Bitter Lake (Figure 13).

Figure 13. Map of Community Vulnerability to Climate Change at the Census Tract Level



Notes: This index map of community vulnerability to climate change shows darker areas with higher vulnerability and lighter areas with lower vulnerability. The darkest areas are in SODO, the International District, South Park, Lower Duwamish, and Rainier Beach (City of Seattle, 2022).

COMMUNITY RESILIENCE IMPLICATIONS OF CLIMATE CHANGE

Community vulnerability to climate change will not be distributed across the city equally. Generally, the **Duwamish Valley, Georgetown, and Rainier Valley** are relatively more vulnerable to climate change's impacts on community resiliency. The following sections detail the various community resilience implications of climate change for the city and its neighborhoods.

Parks, Open Spaces, and Tree Canopy

Seattle's parks, open spaces, and tree canopy have played an outsized role in making the city safe and more livable for communities by improving health and wellbeing (see **Urban Tree Canopy and Open Spaces** section) (Seattle Parks and Recreation, 2022). Parks and urban forests are particularly important for communities without air conditioning because they provide heat refuge and no-cost shaded spaces. Many parks also have drinking fountains, which provide access to clean water for a variety of users, including children and people who are houseless. Urban forests can also improve local air quality, as they can uptake and remove a variety of air pollutants. Finally, parks and urban forests can increase beneficial mental health outcomes – such as reducing stress and anxiety, increasing happiness, and improving cognitive function (Bratman et al., 2019).

While these amenities strengthen community resilience, impacts to these resources will also have outsized impacts on communities that may have less access to these amenities in the first place. Climate impacts to parks and urban forests can compound existing vulnerabilities to climate change for surrounding communities. Impacts such as flooding or heatwaves can limit access to parks, undercutting City efforts to make parks more accessible and improve community wellbeing. Disruption to park and urban forest access – even for a limited time – can contribute to an acute decrease in community wellbeing if residents are unable to access key features and amenities and potentially contribute to an overall decrease in community wellbeing, especially if there is associated post-trauma stress after extreme events.

In particular, the **lower Duwamish Valley** (i.e., Georgetown, South Park and SODO) and **Rainier Valley** areas will have higher relative vulnerability due to lack of access to parks and open spaces and relatively lower tree canopy coverage than other parts of the city (Figure 13). The lack of robust tree canopy coverage increases the risk of heat-related impacts – such as heat exhaustion, heat stroke, and mortality – for the people who reside or work in these areas (Isaksen et al., 2014; Schramm et al., 2020). As urban forests are stressed due to heat, low water availability, and development, park access and urban tree health are expected to worsen, potentially exacerbating health disparities.

Additionally, many of these neighborhoods are considered higher equity priority areas, which means that a relatively large portion of their population are BIPOC, have socioeconomic disadvantages (e.g., low income, no college degree), or have higher rates of health challenges (e.g., higher rate of asthma) (City of Seattle Office of Planning & Community Development., 2021). These same factors that already make these neighborhoods higher priority areas also make these neighborhoods more sensitive to the impacts of extreme heat. Furthermore, many of these neighborhoods that have less tree canopy coverage, access to parks, and experience more extreme urban heat island effects are areas that have been historically redlined (Hoffman et al., 2020). Areas that received Home Owners' Loan Corporation grades[2] of C or D – such as the Duwamish Valley area, Rainier Beach, Central District – have average temperatures that are 3.6-4.0°F warmer than the rest of the city (Figure 14). Additionally, households in these areas are more likely to have limited or no access to personal vehicles, compounding disparities in ability to access amenities and services like parks and health care.

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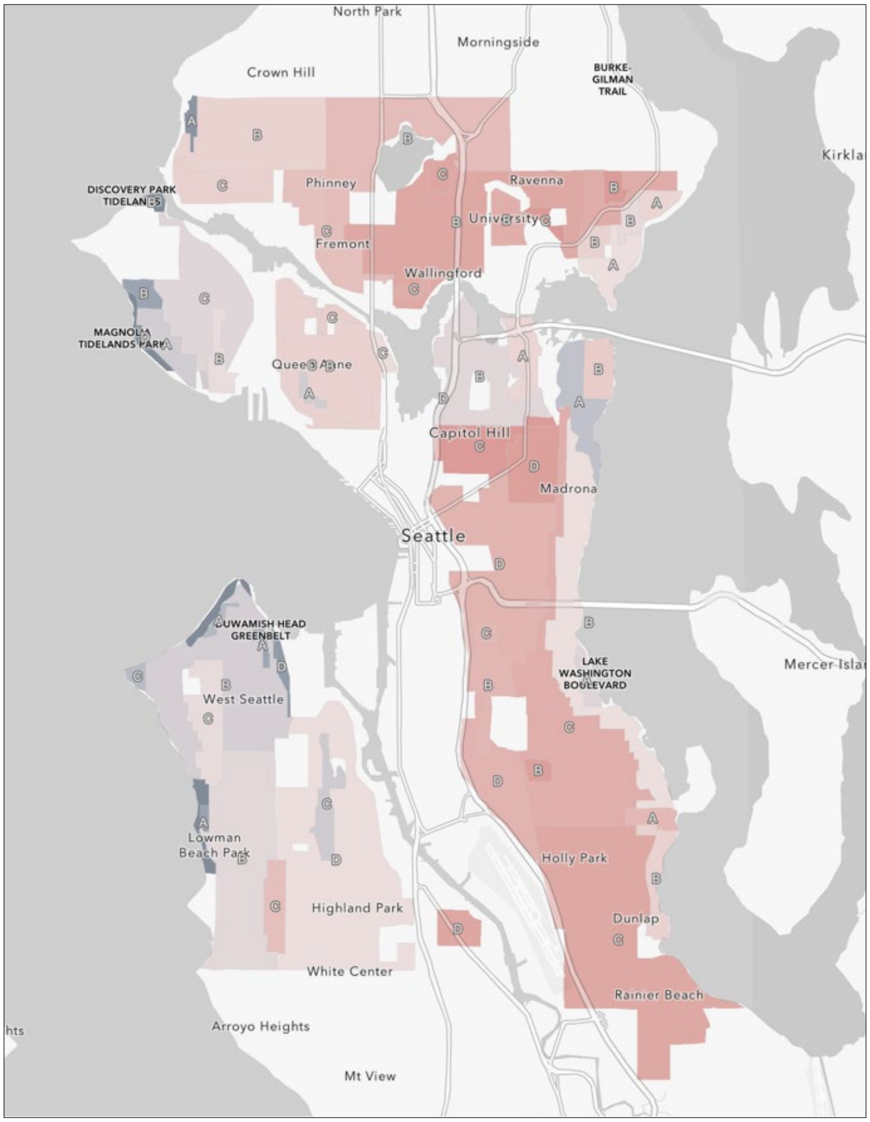
[2] The Home Owners' Loan Corporation (HOLC) was created during the New Deal Era and created a neighborhood ranking system, now known as "redlining". Developers and appraisers assigned grades that ranger from A to D, where A grades were considered "best", and C and D grades were considered "declining" or "hazardous". Generally, neighborhoods with C and D grades – now referenced as formerly redlined neighborhoods – received these grades because of they had higher proportions of Jewish, Asian, Latino/x, and Black families. Because of these grades, many cities diverted public investments – such as quality schools, grocery stores, health care facilities, parks, among others – away from these neighborhoods and sited facilities – such as industrial facilities – within or near these neighborhoods. Disparities in health outcomes and wealth accumulation of residents in formerly redlined neighborhoods are associated with these historical policies and decisions.

Figure 14. Redlining and Exposure to Urban Heat Islands in Seattle



Notes: Red areas indicate temperatures that are warmer than the citywide average. Blue areas indicate temperatures cooler than the citywide average (Hoffman et al., 2020).

Parks and open spaces located along the Duwamish River and within the 100-and 500-year floodplain will have an increased potential for flooding from future sea level rise. For example, the confluence of heavy precipitation and a King Tide event brought the worst flooding that Seattle's South Park neighborhood has seen in years, with flooding and damage to at least 13 homes and the Duwamish Waterway Park and disrupted access to community amenities and critical facilities (see **Cascading and Compounding Impacts**) (Daisy Zavala Magaña, 2022).

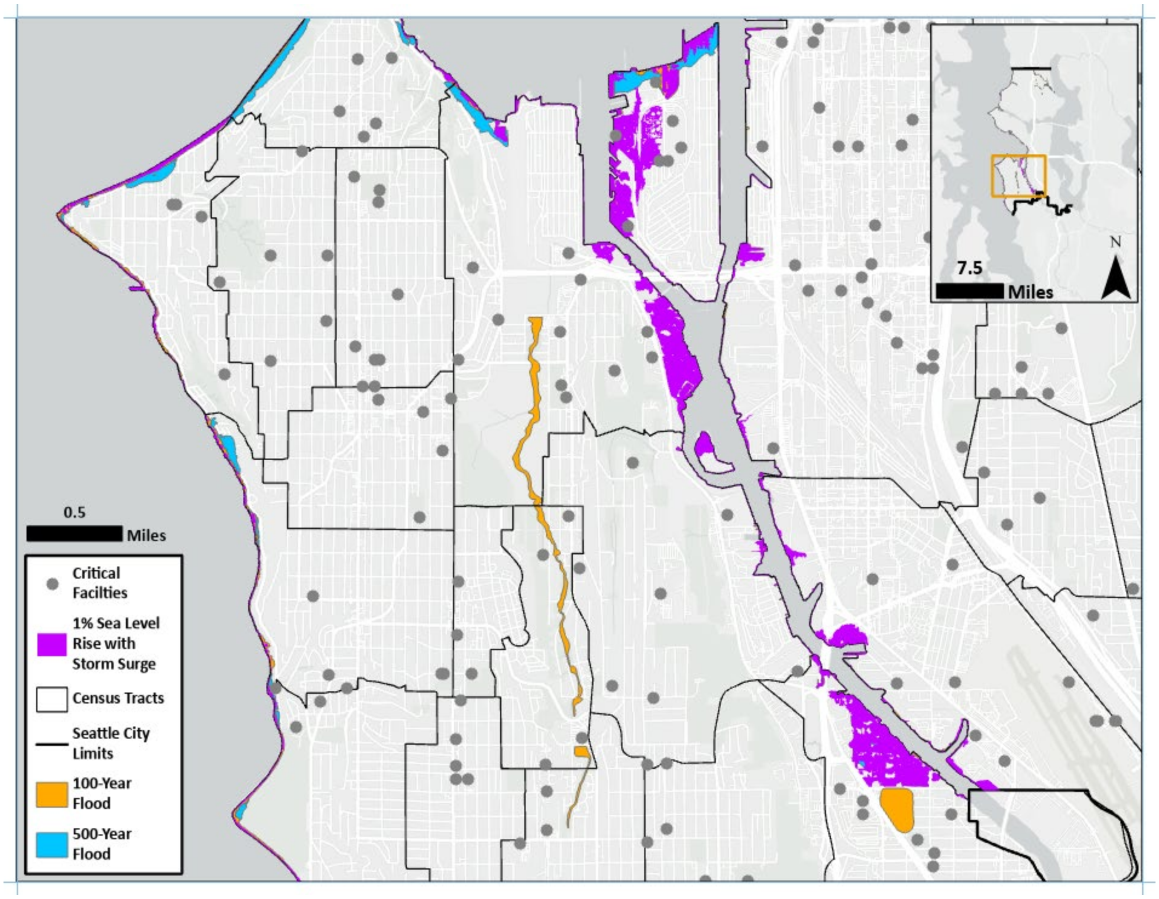
Repeated or extensive flooding events can increase the spread of water-borne diseases such as Shigellosis and worsen some environmental health impacts, such as from the prevalence of mold in housing structures (May et al., 2018). Impacts from water-borne diseases will disproportionately affect people who are houseless and people who are low-income and living in older housing structures.

The City of Seattle anticipates increased use of parks and open spaces (e.g., pools, beaches, community centers) during heat events, particularly in Equity & Environment Initiative (EEI) focus areas (Seattle Office of Sustainability and Environment, 2017). Reducing climate risks to parks and urban forests – such as through investments in conservation and restoration, maintenance of tree canopy, and planting of heat-tolerant plants and trees – will simultaneously increase the adaptive capacity of parks and open spaces and the resiliency of the surrounding communities dependent on them (Seattle Parks and Recreation, 2022).

Critical Facilities

Critical facilities – which include public and private facilities such as hospitals, clinics, fire stations, police stations, and grocery stores – are essential for the delivery of vital services for a community's function and protection. As climate impacts such as flooding become more frequent and intense, there will likely be disruptions and damage to critical facilities that decrease the ability of some frontline communities to access these services during extreme events – disproportionately affecting some groups such as people without access to a car, people with mobility issues, older residents, or people with chronic health conditions (see **Public Health** section) (SAMHSA, 2017). People in this sensitive group may also have difficulty quickly evacuating during emergencies (U.S. Environmental Protection Agency, 2016).

Figure 15. Critical Facilities, Flooding and Sea Level Rise



Notes: Some critical facilities, especially in the Duwamish and Montlake areas, will be affected by flooding and sea level rise (City of Seattle, 2022; Miller et al., 2018; National Oceanic and Atmospheric Administration, 2021; Roop et al., 2018).

Some critical facilities will be impacted by flooding and sea level rise (Figure 15). The following table notes critical facilities that are located within the 100-year floodplain and SLR zones (Table 9).

Table 8. Critical Facilities Located in 100-year Floodplain or Sea Level Rise Inundation Zone

Climate Change Hazard	Critical Facilities Impacted
100-year floodplain	• Trident Seafoods • Nathan Hale High School • Carkeek Park Sewage Disposal Treatment • King County Wastewater – Matthews Park Pump Station • Seattle Cruise Ship Terminal, Pier 91 • Colman Dock • Hawkins • Port of Seattle PD
Sea level rise	• BP West Coast Production • Shell Oil Products Seattle Terminal Harbor Island • Seattle Bulk Rail • Fire Station No. 05

Food Security and Access

A healthy food system ensures that everyone, regardless of socioeconomic status, has regular access to healthy and culturally acceptable foods through non-emergency sources. Food security means that an individual or community has the resources necessary to acquire food, which includes affordable food prices and proximity to food amenities and retail outlets. Food access can increase the adaptive capacity and resilience of communities to extreme events; however, impacts from climate change can also exacerbate food access inequities, increasing the vulnerability of communities with less access to food or that are more cost burdened. Based on a survey conducted by Puget Sound Sage, limited access to healthy and affordable food is a top climate change-related concern for communities along the Duwamish River (i.e., South Park) and Rainier Valley (Sage, 2020). As of 2020, approximately 60 percent of housing units in Seattle are within a half mile of a grocery store (Seattle Office of Planning and Community Development, 2020). However, some neighborhoods lack grocery stores within a half mile, including areas in **West Seattle**, the **Duwamish Valley**, and parts of **Rainier Beach** that have over a third of their households living more than 0.5 miles away from the closest grocery store (Figure 13).

Additionally, a community's social and cultural norms can inform food access and distribution channels. For example, communities with P-Patches can provide a space to grow fresh and healthy foods for surrounding households. Cultural gardens, like the Yes Farm or the Danny Woo International District Community Garden, aim to empower specific groups, like the Black community or the Asian and Pacific Islander communities, to steward and connect residents to culturally relevant food systems (City of Seattle, 2023). Other groups, such as urban Native residents or immigrants and refugees, may rely on subsistence methods, such as harvesting or fishing, within or around the city (City of Seattle, 2023).

Flooding and extreme events are projected to be more frequent and intense, which will affect food access across the city, particularly in the Duwamish Valley area, where there is a lower median household income, poorer air quality and associated health outcomes, and more children who require nutritious foods for their growth and development (City of Seattle, 2016). These events can exacerbate existing food access inequities for these neighborhoods. For example, flood events can disrupt access to local grocery stores by reducing transit options for residents and affect the hours of local food businesses, placing additional burden on households with limited access to personal cars or residents that walk or bike to stores. Additionally, coastal flooding impacts can affect the access of harvesting and gathering sites of residents reliant on subsistence foods (Figure 13).

The City has many ongoing programs and community-led efforts that address gaps in access to food retailers that promote affordability, individual and cultural preferences, and food quality and variety (City of Seattle, 2016). For example, the City supports emerging local businesses to fill the healthy food gap by connecting them to City resources and implements alternative efforts to fill the healthy food gap, such as establishing a farmers' market in South Park.

Economic Vulnerability to Climate Change

Introduction to Local Economy

While economic activity contributes to climate change, climate change also affects the economy – both at micro and macro scales. Climate change is expected to have direct and consequential effects across the regional economy, particularly for natural resource economies and outdoor-based industries (Lee et al., 2023). Climate change and extreme events can directly affect crops, infrastructure, and labor through increased exposure to various climate-related hazards. These direct effects will have indirect impacts across economic systems. For example, impacts to local produce may lead to reduced revenue for agricultural producers; lost labor hours due to extreme event may lead to less spending power within the community; or repeated exposure to flooding for homes and businesses can lead to increase in insurance premiums or affect property values (Lee et al., 2023). Furthermore, a strong local economy also depends on things indirectly affected by climate change, including community amenities that support a thriving local workforce, such as affordable cost of living, parks and open spaces, and good quality of life (see **Community Amenities and Wellbeing** section).

Seattle's economy is characterized by a mix of industries, including industries that are part of Seattle's history – such as timber, maritime, and fishing – along with new types of industries such as technology companies, start-ups, retail, construction, and health sciences. While many large companies have headquarters in Seattle, the city has a strong ethos of supporting local businesses.

While the city has a strong economy, many workers reside outside of the city and many residents commute to work outside of the city, such as to Bellevue, Redmond, Everett, and SeaTac. Additionally, the Port of Seattle acts as an important hub for regional, national, and international commerce, serving as an important hub for commercial fishing industries, tourism, and a part of many different supply chains.

The city also has relatively low unemployment rates compared to the rest of Washington state and the U.S., and average wages in Seattle are relatively higher than average wages in the country (U.S. Bureau of Labor Statistics, 2023). However, like many other urban areas, the city of Seattle's wealth and economic assets are inequitably distributed, and communities that were historically redlined and BIPOC residents generally have relatively less income, accumulated wealth, and higher unemployment rates (Oliver & Shapiro, 2019).

In Seattle, climate change is likely to have both direct and indirect effects on the local economy, affecting land use and availability, transportation routes (both commercial and commuting), utilities and associated costs, natural resource commodities, and public health. These impacts will affect Seattle's economy in a myriad of ways. Some businesses will be damaged or forced to close during extreme weather events or will suffer reduced foot traffic due to disruption of transit and walking routes. Extreme heat events will result in lost labor hours across the city, with consequences for businesses and for workers' wages. Storms, heat, and flooding will likely disrupt transportation systems, with repercussions for both employees' commutes and business supply chains. Business' costs will increase – whether due to scarce materials, rising insurance costs, or higher energy demand for cooling. Workers in some occupations, such as construction, will be particularly exposed to extreme weather and will likely experience negative physical and mental health outcomes. Across the city, communities have unequal access to jobs, education, and new opportunities in the face of disrupted employment.

Climate Vulnerability to the Local Economy

METHODOLOGY AND RESULTS

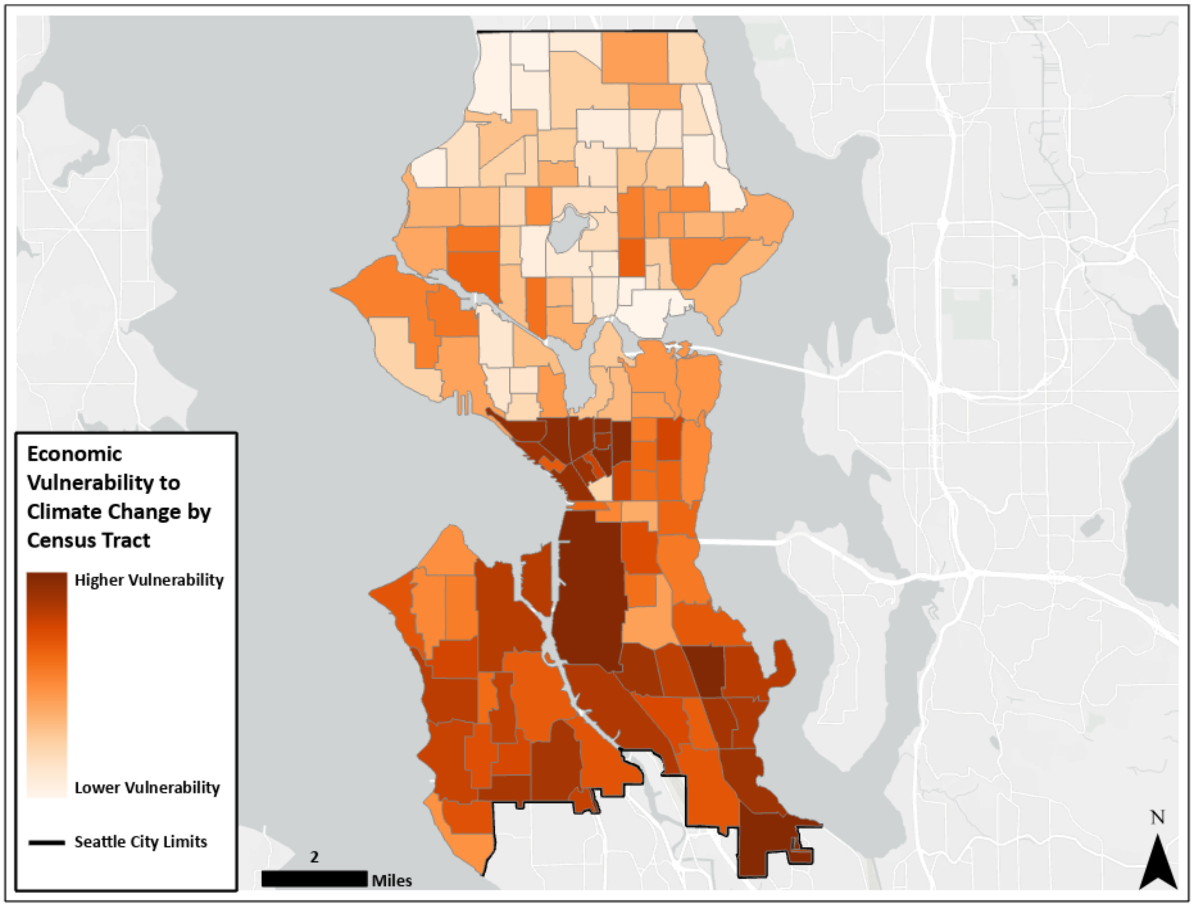
While many factors contribute to a strong local economy, several indicators of economic vulnerability to climate change were selected due to data availability, quality, and relevance (see **Appendix A).** Table 10 lists these indicators and how they inform an assessment of economic vulnerability to climate change. While these indicators are not comprehensive, they provide a general illustration in how the City of Seattle will be economically affected – and how that economic burden is distributed – by climate change.

Table 9. Economic Indicators of Climate Vulnerability Selected for Analysis

Indicator	Vulnerability Element	Relevance & Considerations
Current Lost Labor Hours due to Extreme Heat	Exposure	An estimate of lost labor hours due to extreme heat events.
Projected Lost Labor Hours in 2050 due to Extreme Heat	Exposure	An estimate of lost labor hours due to extreme heat events in 2050.
Climate Exposed Occupations	Sensitivity	Indicates types of occupations that are more susceptible to climate extremes.
Number of Small Businesses	Sensitivity	Small businesses are more sensitive to external disruptions than large businesses.
Unemployment Rates	Adaptive Capacity	Unemployment indicates whether a household or community can withstand economic shocks.
Owner-Occupied Housing	Adaptive Capacity	Home ownership is one primary mechanism for wealth accumulation, generally associated with higher adaptive capacity.

Figure 16 depicts the distribution of economic vulnerability to climate change at the census-tract level.

Figure 16. Map of Economic Vulnerability to Climate Change



Notes: This index map of economic vulnerability to climate change shows darker areas with higher vulnerability and lighter areas with lower vulnerability. The darkest areas are in SLU/Downtown, SODO, the International District, and Rainier Beach (City of Seattle, 2022).

ECONOMIC IMPLICATIONS OF CLIMATE CHANGE

Economic vulnerability from climate change will not be distributed across the city equally. Generally, the **Duwamish, SODO, Georgetown, Rainier Valley, Downtown**, and **South Lake Union** neighborhoods have higher economic vulnerability to climate change than other neighborhoods in Seattle. The following sections unpack the various economic implications of climate change for the city, and how vulnerability is distributed.

Workforce Impacts due to Extreme Weather

Climate change has affected and will affect Seattle's workforce in multiple ways. Over the past 30 years, workers in these climate-exposed industries have made up 4.5 percent to 5.6 percent of all workers in King County, representing 5.4 percent of workers in 2022 (United States Census Bureau, 2022). In 2019, there were approximately 25,851 workers who worked in climate-exposed industries – such as natural resource industries (e.g., agriculture, forestry, fishing, and hunting) and outdoor-based industries like construction – in the city, encompassing 4.4 percent of the regional labor force (Table 11). These industries are considered to be climate-exposed because the industries themselves provide goods and/or services that will be directly affected by climate change (e.g., natural resources) or the workers will be occupationally exposed to climate change because of the outdoor nature of their work (Got Green & Puget Sound Sage, 2016; Seattle Office of Sustainability and Environment, 2017). During extreme anomaly events—such as the 2021 Heat Dome event—workers who were not in climate-exposed industries, such as service workers or first emergency responders, were also affected by business closures or responding to emergency calls (see **2021 Heat Dome Event** section). Thus, estimates of lost labor hours likely underestimate the true cost of climate impacts on the workforce.

Extreme heat and other climate-related hazards will result in lost wages for climate-exposed workers. With 2°F of additional warming relative to the 1986-2005 average, which is expected by the 2050s under the RCP8.5 scenario, the city will see approximately 25,851 lost labor hours, or the equivalent of $595,090 (2017 dollars) in lost wages per year, due to extreme heat for climate-exposed occupations.[3] Any impacts to local wages – whether acute or chronic – will decrease the spending power of households, affecting potential market demand for goods and services provided by local businesses.

Additionally, increased ambient temperatures are correlated with additional workplace injuries, (Page & Sheppard, 2016) and communities with more residents who work in outdoor occupations—such as areas like Rainier Valley, Highline, Duwamish Valley, and Georgetown areas—have higher rates of heat-related hospitalizations and emergency department visits than other communities (see **Public Health** section) (Riley et al., 2018). As a result, workers in climate-exposed workers may experience additional healthcare cost burdens to cope with occupational heat-related injuries in addition to losing wages associated with lost labor hours.

Table 10. Seattle Jobs in Climate-exposed Industries (2019)

Industry	People who work in Seattle (count)	People who work in Seattle (percent)	People who live in Seattle (count)	People who live in Seattle (percent)
Climate-Exposed Industries	**25,851**	**4.4%**	**12,686**	**3.5%**
Agriculture, Forestry, Fishing and Hunting	1,261	0.2%	1,131	0.3%
Construction	24,590	4.2%	11,555	3.2%
All Other Industries	**556,945**	**95.6%**	**346,240**	**96.5%**
Total Jobs	**582,796**	**100.0%**	**358,926**	**100.0%**

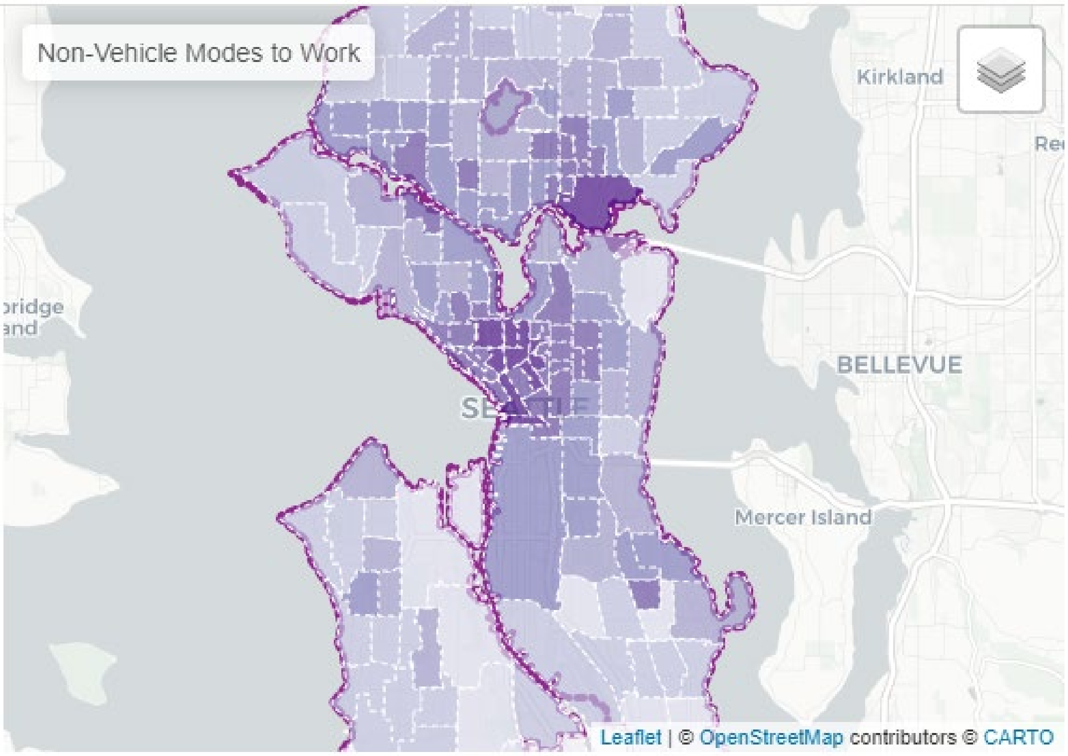
Note: This table counts all jobs, so someone with jobs in two industries will be counted twice.

Disruptions to businesses and transit will affect workers unevenly, and will particularly affect those who need to commute. Extreme events can disrupt commutes, damage

[3] Based on average national wage estimated for climate-exposed industries ($23.02) and a total estimated number of climate-exposed jobs (people who work in Seattle) of 25,851 jobs.

transportation systems, and make some commute conditions unsafe, potentially preventing employees from traveling to work or increase risk of physical injury during those commutes (see **Public Health** section). All commuters are likely to experience some kind of impact due to extreme weather; those most at risk of negative health impacts will be those who walk, bike, and use transit to get to work. In particular, there is a large commuter base concentrated in the Downtown and University District areas (Figure 17) Before the COVID-19 pandemic, over one third of workers in Seattle traveled to get to work using transit (20.5%), walking (10.8%), or another method (4.7%) such as biking. Half (50%) of Seattle workers drove or carpooled to work, and the rest worked from home.

Figure 17. Map of Seattle Workers Who Use Transit, Walking, or Other Non-vehicle Commute Modes



Notes: This map shows concentrations of Seattle residents who take non-vehicle transportation modes to work, including working from home. Areas in central Seattle and near the University of Washington show the highest concentrations of non-vehicle commuters (Puget Sound Regional Council, 2021).

Climate Risks to Small Businesses in Seattle

Small businesses are an important part of the economic fabric of Seattle and are more vulnerable to climate change impacts than larger businesses. They generally have fewer resources (e.g., staff, financial resources, insurance coverage) than larger businesses to withstand climate-related disruptions, including closures during extreme weather events or impacts to staff (e.g., weather-related injuries, disruptions to commute routes) that result in acute or chronic absences. They also have increased financial burdens to cover costs for insurance, energy usage, and materials, and generally are less resilient to withstand economic shocks (Sadeghi, 2022). For example, during the 2021 heat dome event, many businesses had to shut down due to unprecedented heat, putting an acute strain on local businesses who were already trying to recover from economic disruptions from COVID-19 (see **Cascading and Compounding Climate Impacts** section).

In Seattle, small businesses with fewer than 50 employees make up 95 percent of companies and provide nearly 200,000 jobs – about one third of total jobs in Seattle (Seattle Office of Economic Development, 2020). **Downtown Seattle** is home to the highest number of small businesses – approximately 300 small businesses in total. These businesses are at risk of not only impacts from extreme heat, which are captured in the economic vulnerability index, but also impacts from flooding due to the amounts of impervious surfaces and proximity to the waterfront. Additionally, businesses in some areas, such as the **Duwamish Valley** and **Georgetown**, will likely experience damage from flooding associated with extreme precipitation and sea level rise, affecting customer visitation rates and local commerce, such as the disruption experienced during the 2022 King Tide flood event (Sadeghi, 2022). Insurance coverage for these businesses in high-risk areas such as the 100-year floodplain may increase, placing additional cost burden on small businesses in these areas.

Finally, small businesses may be disproportionately affected by climate risks within the energy sector. The commercial sector accounts for more than half of electricity use in Seattle (56%, compared to 10% industrial and 34% residential) (Raymond, 2013). As energy systems become more strained due to climate change (see **Energy Systems** section), there may be additional burden on some small businesses that may experience brown outs or demand-driven energy price increases (Seattle Office of Sustainability and Environment, 2017, Got Green & Puget Sound Sage, 2016).

Supply Chain Disruptions

Seattle is a central commerce hub that is critical to multiple supply chains and industries. Damage to key transportation assets such as port facilities and rail infrastructure from flooding, storms, and increased rates of degradation due to extreme heat will likely impact supply chains for local, regional, and international commerce (Seattle Office of Sustainability and Environment, 2017). Impacts to commodities such as agricultural products and fisheries, can affect regional food supply, restaurant operations, and reliability of grocery stores to stock fresh and local produce (May et al., 2018), potentially affecting local food security (see **Community Amenities** section). Global disruptions to natural resource commodities may affect both small and large retailers, restaurants, and other businesses in Seattle as well.

Climate Impacts to Wealth Accumulation

Home ownership has historically been one means to build wealth for households and their future generations. However, emerging research indicates that climate change may affect home ownership in multiple ways (Becketti, 2021). These include:

- Decreasing home values for housing structures in at-risk areas, such as the 100-year or 500-year floodplain.

- Increasing the physical risks to housing structures from flooding, extreme rain, wildfire smoke, and extreme heat, affecting costs to fortify or repair homes for homeowners.
- Increasing costs and challenges to homeowners as climate adaptation and mitigation policies and codes – such as usage of green building materials and shifts away from natural gas – are adopted.
- Increasing uncertainty in home insurance markets for housing in high-risk areas, such as a 100-year floodplain.
- Increasing risks of a mortgage default if employment is disrupted by climate-related event or if damage exceeds the sum of insurance coverage.

Individuals that already have less generational wealth – including BIPOC residents and immigrants – may experience additional climate-related challenges to purchase and maintain homes.

Public Health Vulnerability to Climate Change

Introduction to Public Health

There are already existing public health disparities – such as prevalence of chronic health issues and expected lifespan – across the city of Seattle. These health disparities have resulted from a variety of factors, including access to care, socioeconomic conditions, environmental conditions, linguistic barriers, and historical policies such as redlining.

Climate change will affect public health in a myriad of ways, such as exacerbating existing public health risks and introducing new types of health consequences for residents. For example, extreme heat events have led to increases in hospital room visits in King County and Seattle (Isaksen et al., 2014, 2016). More frequent wildfire smoke events are decreasing local air quality and increasing $PM_{2.5}$ exposure for residents, leading to more physical health consequences such as asthma incidences and cardiovascular injuries. Allergy seasons are starting earlier and extending for longer due to warmer spring temperatures. Vector-borne diseases – such as West Nile virus – are also becoming more prevalent. Emerging research is beginning to document additional mental health consequences of climate change, such as increased stress from extreme events or increased anxiety, especially in youth, from learning and experiencing the negative impacts of climate change.

Climate Vulnerability to Public Health

METHODOLOGY AND RESULTS

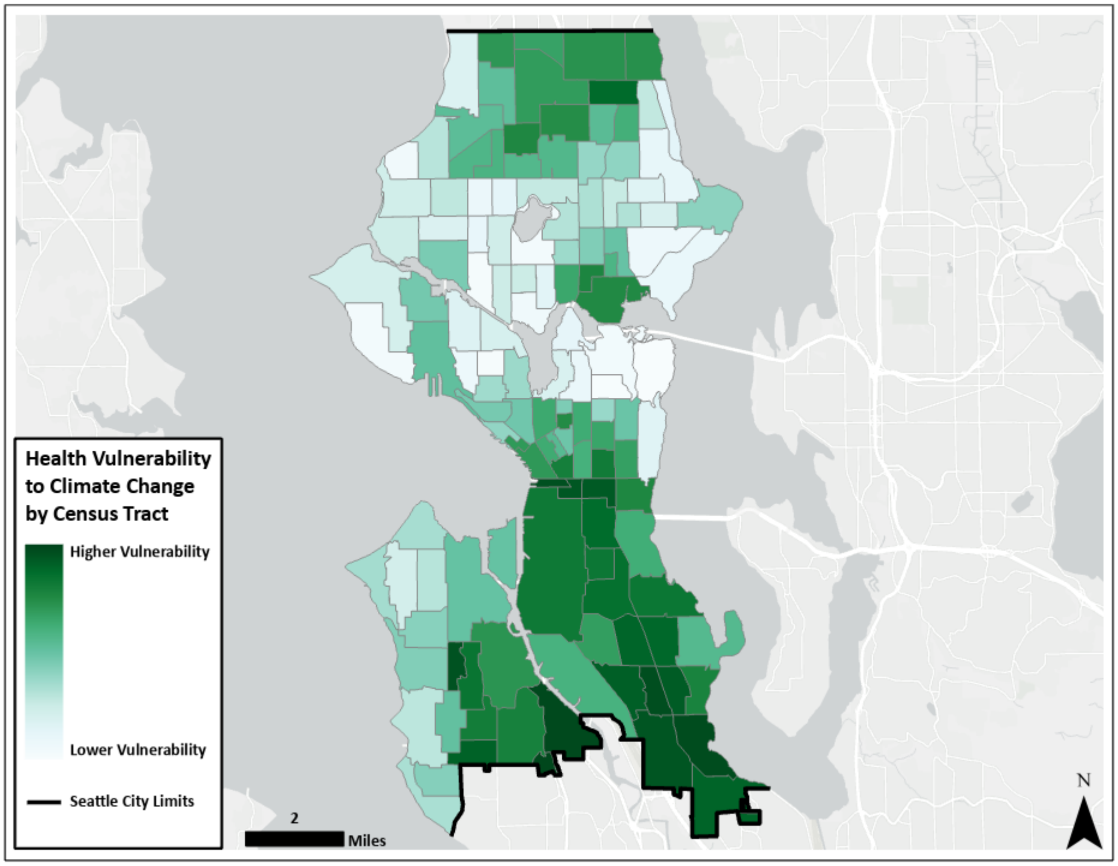
There are many factors that affect health risks and vulnerability to climate change, including climate projections on future health impacts, social determinants of health, and access to health care services. Several indicators were selected due to data availability, quality, and relevance such as mortality associated with $PM_{2.5}$ for adults older than 65, new incidences of asthma and emergency visits associated with $PM_{2.5}$ for children under 18, Seattle's Race & Social Equity Index, and insurance rates (Table 12). While these indicators are not comprehensive, they provide a general illustration how climate change will affect health outcomes for residents and communities across Seattle.

Table 11. Public Health Indicators of Climate Vulnerability

Indicator	Vulnerability Element	Relevance & Considerations
Mortality associated with $PM_{2.5}$	Exposure	Assesses how future $PM_{2.5}$ increases (e.g., wildfire smoke, air pollution) due to climate change increases mortality for adults 65 and older.
New incidences of asthma associated with $PM_{2.5}$	Exposure	Assesses expected new incidences of asthmas associated with climate change for youth 18 and under.
Asthma-related emergency room visits associated with $PM_{2.5}$	Exposure	Assesses expected changes in emergency room visits due to $PM_{2.5}$ impacts from climate change for youth 18 and under.
City of Seattle's Race and Social Equity Index	Sensitivity	Assesses race and social equity considerations based on a variety of variables.
Health insurance rates	Adaptive Capacity	Assesses percent of population within a census tract that do not have health insurance coverage.

Figure 18 depicts the distribution of public health vulnerability to climate change at the census-tract level. Generally, the areas that have higher health vulnerability to climate change include the **Duwamish Valley, International District/Chinatown, Rainier Valley, Beacon Hill, Lake City**, and the **University District**.

Figure 18. Map of Public Health Vulnerability to Climate Change



Notes: This index map of public health vulnerability to climate change shows darker areas with higher vulnerability and lighter areas with lower vulnerability. The darkest areas are in South Park and Rainier Beach (City of Seattle, 2022).

PUBLIC HEALTH IMPLICATIONS OF CLIMATE CHANGE

Public health impacts due to climate change are not felt equally across communities and are likely to be disproportionately felt by certain populations, such as people with chronic physical or mental health conditions, older residents, low-income households, renters, people living in older housing structures, and youth. Systemic and institutional racism – such as policies of redlining and siting of industrial facilities – has resulted in increased sensitivity and more limited adaptive capacity among socially and economically vulnerable populations (Gee & Ford, 2011). Areas with the highest relative health vulnerability to climate change are in the **Duwamish Valley**, **International District/Chinatown**, and **Rainier Valley** communities, where there are relatively more low-income and more ethnically diverse populations (Figure 18). These are the same areas that also have relatively less access to community amenities and services – such as health care and grocery stores – that contribute to underlying health disparities (see **Community Amenities and Wellbeing** section).

Communities living in floodplains, areas with poor air quality, or landslide and wildfire prone areas will likely experience increased exposure to climate-related hazards.

Additionally, outdoor workers (e.g., construction workers, urban farmers) will experience increased occupational exposure to certain impacts, such as extreme heat, affecting their health and livelihoods (see **Economic Vulnerability** section).

Physical Health

Physical health will be affected in multiple ways due to climate change. Heat-related injuries and deaths are expected to increase across all climate scenarios. Increases in wildfire smoke will affect respiratory-related illnesses. Environmental health challenges – such as presence of mold – will worsen as flooding events become more severe and frequent. Vector-borne diseases are expected to become more prevalent.

Extreme Heat

Extreme heat accounts for more deaths annually than any other single weather event-related hazard in the Pacific Northwest (Isaksen et al., 2016; US Department of Homeland Security, 2022). Summertime maximum temperatures in Seattle will continue to increase by 6.3°F by 2050 and 10.5°F by 2100 under RCP8.5 scenario (Raymond & Rogers, 2022) (see **Extreme Heat** section). King County already experiences an influx of emergency room visits and heat-related mortality during hot days and mortality is expected to increase for everyone in Seattle, (Isaksen et al., 2016). For every 1°F of warming, heat-related mortality in King County is expected to increase an average of 1.83 percent for all age groups. However, older adults will be disproportionately affected, as their heat-related mortality is expected to increase from 2.3 to 22.3 times the average (Isaksen et al., 2014).

In addition to older adults, groups such as people with chronic medical conditions – such as cardiovascular, cerebral, or respiratory diseases – and children under the age of five are more sensitive to heat exposure, even for short periods (Antonia et al., 2018). Residents who live in older housing structures are also more sensitive to extreme heat, as older housing units are likely to have less insulation that lets in the hot ambient air while preventing retention of any cool air indoors. Additionally, types of outdoor workers – such as construction, agriculture, and emergency response – that are considered “climate-exposed” are more likely to experience health impacts from occupational exposure to hazards such as extreme heat, wildfire smoke, flooding, and poor quality. Heat-related fatigue can affect cognitive decision-making capabilities and heat-related injuries can stress worker livelihood due to lost labor hours and wages. Heat-related injuries can also induce financial stress and anxiety from costs of medical care (see **Economic Vulnerability** section). Furthermore, some of these jobs may be contract workers, so workers may not have employer-subsidized health insurance as a safety net in case medical care is required.

Within Seattle, the **International District, SODO** area, and **Lower Duwamish** (i.e., South Park, Georgetown) areas are likely to experience hotter temperatures due to the heat island effect, a phenomenon that occurs in urban areas due to higher prevalence of impervious or hard surfaces like parking lots, rooftops, and roads that absorb heat and less tree canopy coverage for shade and cooling respite (see **Community Amenities and Wellbeing** section) (Hsu et al., 2021). Additionally, many of Seattle’s major transit systems – such as I-5, State Routes 99 and 509, East Marginal Way, railroads, and the Boeing Airport Field – run through the SODO area, Georgetown, and South Park neighborhoods, creating more impervious surfaces and less tree canopy coverage.

Approximately 46 percent of Seattle's households do not have access to air conditioning, suggesting that Seattle residents are not as prepared to cope with heatwaves than other cities' residents. While air conditioning and cooling capacity has increased across the city since the 2021 heat dome event, some groups such as renters, low-income households, and people who live in older housing units that may have structural challenges for air conditioning retrofits, do not have equal capacity to install air conditioning. The City of Seattle is continuing to invest in and improve access to cooling centers across the city, which can help some residents cope with extreme heat events.

Smoke and Air Quality

As temperatures increase across the region, the risk of $PM_{2.5}$ exposure will increase due to air quality impacts and wildfire smoke events. Hotter temperatures will likely influence humidity, precipitation, and wind patterns, resulting in increases of secondary formation of ground-level ozone and $PM_{2.5}$ (Fann et al., 2021). Exposure to $PM_{2.5}$ and ground-level ozone can result in increased hospitalizations, emergency room visits, absences from school or work, and restricted activity days. Those with chronic heart or lung disease, older people, and children will be particularly sensitive to these impacts.

Table 12. Average Excess Cases per 100,000 Persons for Various Health Outcomes Associated with Changes in $PM_{2.5}$ Associated with Climate Change with 3.6°F (2°C) and 7.2°F (4°C) of Warming in Seattle

Health Outcome	Excess Cases per 100,000 Persons for 3.6°F (2°C) Warming	Excess Cases per 100,000 Persons for 7.2°F (4°C) Warming
Mortality associated with $PM_{2.5}$	10.11 [8.51 to 22.41]	22.68 [19.09 to 50.36]
New incidences of asthma associated with $PM_{2.5}$	12.81 [0 to 37.76]	29.04 [0 to 85.63]
Asthma-related emergency room visits associated with $PM_{2.5}$	0.89 [0.68 to 1.35]	1.99 [1.53 to 3.03]

Notes: Average excess cases across all Seattle census tracts are shown in the table, with the range indicated in brackets.

Premature mortality associated with increases in ozone and $PM_{2.5}$, asthma-related emergency room visits, and new asthma cases in youth are all expected to increase with even just 1°C of warming (Table 13) (U.S. Environmental Protection Agency, 2021). Some communities across Seattle – such as those in the **Duwamish Valley, International District, Central District,** and **Rainier Valley** – already have relatively higher asthma rates and air quality-climate interactions will affect these communities more than others (Seattle Office of Sustainability and Environment, 2017). Some of these neighborhoods, such as

SODO, South Park, and Rainier Valley, are close to major highways such as I-5 and I-90 that can contribute to elevated $PM_{2.5}$ from car traffic in these areas. These areas can have compounding air quality impacts during wildfire smoke events and are projected to have relatively more new asthma incidences (up to an additional 38 asthma incidences out of 100,000 people) attributed to climate change (U.S. Environmental Protection Agency, 2021).

Vector-Borne Diseases and Environmental Health

Some environmental health hazards, such as mold, are expected to become more common as flooding becomes more frequent, leading to health impacts such as aggravation of asthma or other respiratory-illnesses, allergy symptoms, rashes, and infections (Paudel et al., 2021). Additionally, a variety of other vector- and water-borne diseases are expected to increase in the Pacific Northwest due to warmer weather and extreme precipitation, including Lyme diseases, West Nile virus, cryptococcal infections, Salmonella, *E. coli*, and Shigellosis, among others. Some of these diseases – such as Shigellosis – will disproportionately affect people who are houseless (May et al., 2018). Finally, some foods that residents harvest – such as shellfish – can accumulate additional toxins associated with harmful algal blooms, leading to illnesses for those who consume them (see **Community Amenities and Wellbeing** section).

Mental Health

There is an emerging body of peer-reviewed evidence that establishes the connections between climate change and mental health outcomes. There is consensus that exposure to changing climate conditions and extreme weather events can add to mental distress and worsen a variety of mental health illnesses such as stress, anxiety, depression, post-traumatic stress disorder (PTSD), and increases in substance use and domestic violence (Crimmins et al., 2016). Additionally, income loss associated with climate-related extreme events – such as those experienced when some industries had to shut down during the 2021 heat dome event or small businesses affected by the 2022 King Tide flooding in South Park – can negatively affect mental health of people who are outside laborers or small business owners or employees (see **Economic Vulnerability** section). Children, older adults, people with chronic mental illness, immigrants, refugees, people who are houseless, and those who are low-income are more likely to be psychologically vulnerable to extreme events.

Neighborhoods that have relatively higher health vulnerability to climate change are the **Duwamish Valley, International District/Chinatown, Rainier Valley, and Lake City**. These areas will likely be disproportionately affected by, and less resilient to, the psychological risks associated with climate-related hazards (Figure 18). Generally, these communities have less access to amenities that can confer positive mental and community health outcomes (see **Community Amenities and Wellbeing** section). Additionally, these areas also have higher relative rates of older residents, who can be socially isolated, and higher rates of people without health insurance coverage, which may prevent residents from attaining mental health services.

Across the U.S., each degree of warming will lead to an increase in suicide rates, and the Pacific Northwest is expected to experience a higher suicide burden relative to the rest of the U.S. with each degree of warming (Belova et al., 2022). Access to parks and open spaces has been shown to have positive mental health benefits by providing opportunities for people to de-stress with physical recreational activity and enjoy green spaces, which can increase happiness (Bratman et al., 2019; Crimmins et al., 2016). However, park access is inequitable across Seattle. For example, while the Duwamish Valley has access to parks, those parks are about half the size of the average City park and are harder to access due to reduced transit infrastructure (e.g., walkable sidewalks, bus routes) (City of Seattle, 2016).

Social cohesion can improve a community's adaptive capacity, as more connected and socially cohesive communities often fare better during and after natural disasters; more specifically, social cohesion can improve cooperation, which can increase the resilience immediately after natural disasters (Cherng et al., 2019). Despite high exposure and sensitivity to public health impacts of climate change, neighborhoods such as the Duwamish and Rainier Valley areas also have a strong history of social and civic organization that can facilitate community and social cohesion, increasing their resilience. Quantifying social cohesion is particularly difficult, and thus not we have not included social cohesion as a quantitative indicator in this assessment. However, these areas are also experiencing relatively higher rates of cost-of-living increases and associated gentrification impacts, which can affect their social cohesion (Rice et al., 2020; Weems, 2016).

Social Safety Net: Emergency Response and Healthcare

Critical facilities play a crucial role in delivering vital services to the community. They include facilities such as hospitals and fire stations. They also include facilities such as libraries, schools, community centers, and grocery stores that provide necessary services – such as cooling centers or food – during extreme events (see **Community Amenities and Wellbeing** section). Climate change and extreme events will affect access to these facilities in multiple ways. For example, urban or coastal flooding can lead to road closures or increase traffic congestion, impacts to energy systems can lead to more frequent outages or damage to energy infrastructure, and emergency services can be strained during extreme events. Disruptions and diminished access to these services can increase the risk of negative health impacts to the surrounding communities, leading to acute and chronic stress on health systems and the social safety net (May et al., 2018).

Inadequate health care coverage is one of the largest barriers to health care access, which contributes to health disparities (U.S. Department of Health and Human Services., 2022). **South Park** has the highest uninsurance rates compared to other areas in the city, with 17 percent of residents without health insurance. Uninsured adults are less likely to receive care for chronic conditions such as diabetes and other cardiovascular diseases, while uninsured children are less likely to receive preventative care for conditions such as asthma (Michael McWilliams, 2009). Limited availability and access to healthcare services will likely increase the risk of residents to experience negative health outcomes associated with extreme heat and poor quality, which lowers their ability to adapt and recover before, during, and after these events.

While outside the geographic scope of this CVA, there may also be spillover impacts to other regions. For example, Seattle has the largest concentration of medical facilities and the only Level 1 trauma center in the broader four-state region (WA, ID, MT, and AK) of the Great Northwest. Thus, acute health impacts from extreme events – such as those experienced during the heat dome event – will have cascading impacts for level of service for emergency medical response to other regions.

Physical Vulnerability Assessment

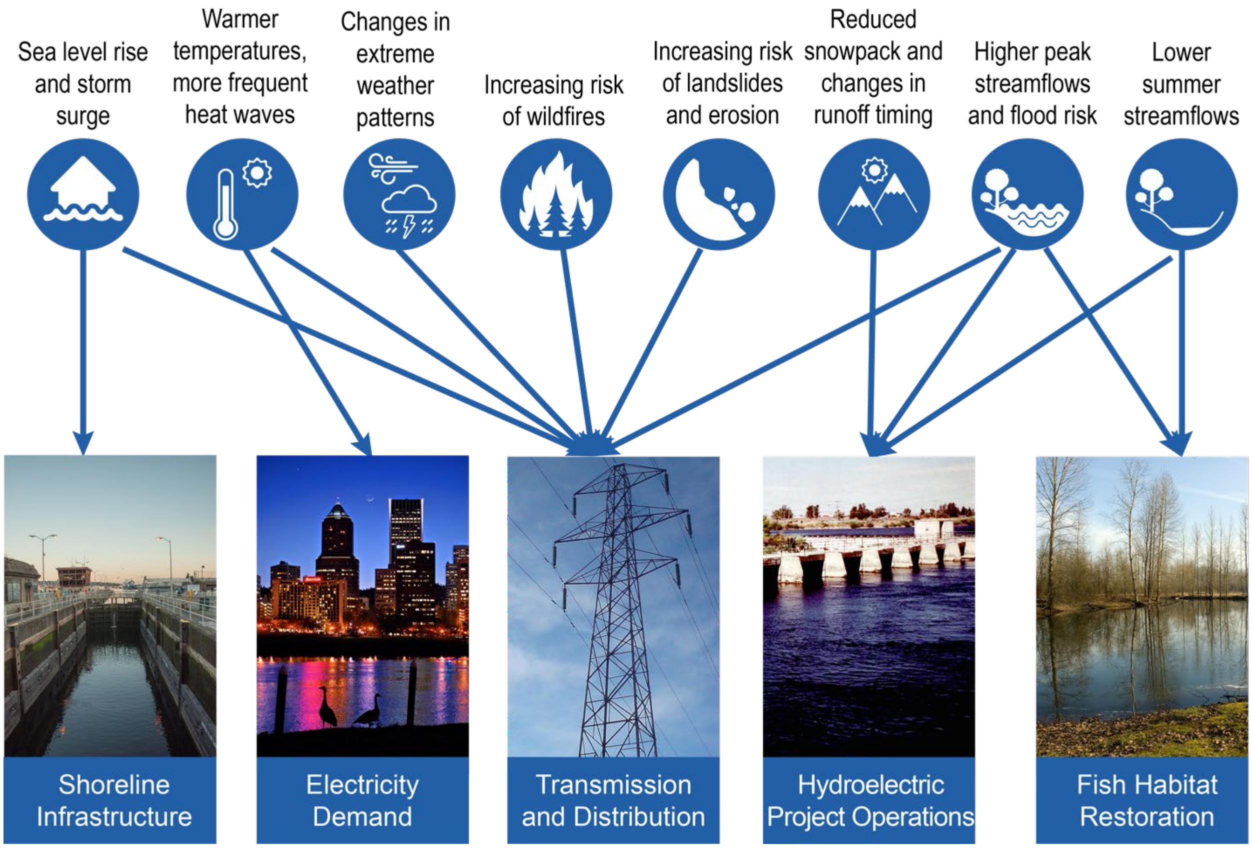
Infrastructure Vulnerability to Climate Change

Infrastructure systems are inherently interdependent and connected, and climate impacts and risks in one system will inevitably have cascading impacts to other infrastructure systems (Figure 19). For example, impacts to snowpack will affect the reliability of hydroelectric power sources throughout the summer and fall, potentially jeopardizing the energy supply for cooling needs during heatwaves, when energy demand is higher for cooling (May et al., 2018; Raymond, 2013). This also presents tradeoffs for climate mitigation and adaptation investments. For example, investments to electrify transportation systems may reduce the resiliency of energy systems as it needs to balance electrification needs and other energy demands. Impacts to infrastructure systems will also disrupt the delivery of critical services, which are especially important during extreme events (see **Public Health** and **Community Amenities and Wellbeing** sections).

To assess the climate vulnerability to Seattle's infrastructure systems, the project team considered the risk of the following systems to different climate impacts:

- **Energy infrastructure systems**, including transmission lines and substations.
- **Transportation infrastructure systems**, including bus, streetcar, commuter rail routes, bridges, rail lines, ports and ferry terminals, and airports.
- **Water, sewer, and stormwater infrastructure systems**, including the Carkeek Park Sewage Treatment Plant, the West Point Wastewater Treatment Plant, pump stations, wastewater detention, reservoirs, and mainlines.

Figure 19. Climate Stressors Affect Infrastructure Systems



Notes: This figure depicts climate-related impacts and the types of infrastructure each one is likely to affect. Most climate-related impacts will have effects on multiple types of infrastructure, and most types of infrastructure will be impacted by multiple climate hazards (May et al., 2018).

Energy Infrastructure Systems

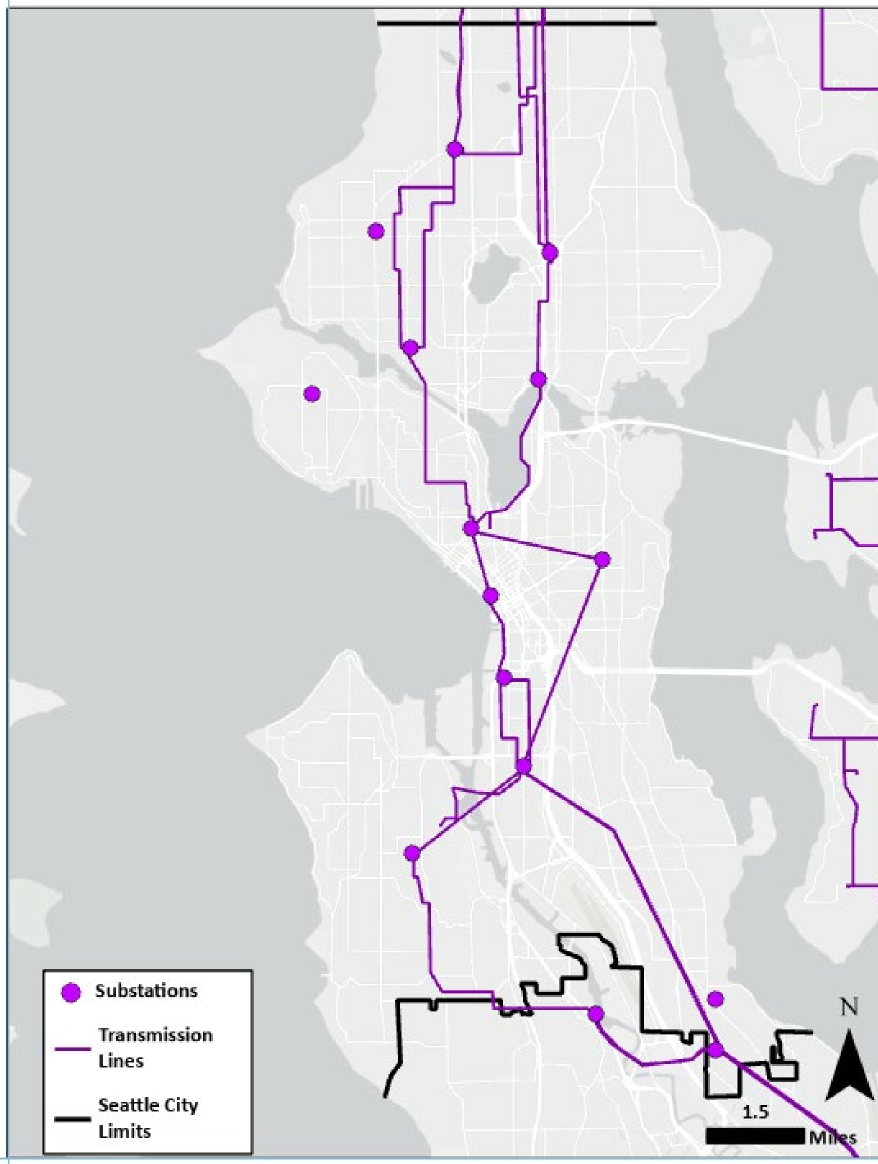
Seattle City Light (SCL) provides electricity to the city, and its energy system is comprised of components such as power stations that produce electricity, transformers that convert electricity from high voltage to low voltage, and transmission and power lines, and substations, which distribute it to residential homes and commercial facilities. Every component of the energy system will be affected by climate change, and due to their interconnectedness, disruptions in one system can lead to disruptions and delays in other parts of the system.

Seattle's energy system will be affected in a myriad of ways by climate change, including:

- **Energy supply disruptions**, particularly in the summer months. While Seattle currently has sufficient supply to meet current energy demands in the summer, decreased snowpack and more intense and prolonged droughts are affecting the seasonal water supply and future reliability of hydropower operations (see Regional Watersheds section) (Wood, 2015).

- **Electricity transmission damage and interruptions** from extreme events, such as winter storms, atmospheric rivers, and heatwaves, can damage transmission lines or decrease the carrying capacity of transmissions lines (Zamuda et al., 2018). Additionally, warmer temperatures and extreme heat days can overheat the substations across the city, potentially affecting energy distribution.
- **Energy demand increases**, especially in summer months as air conditioning and cooling capacity increases across the city. While the city of Seattle currently sees increased demand in winter months for heating needs and electrification of heating systems, air conditioning and HVAC adoption is increasing across residential and commercial structures. This transition may cause an increase in energy demand for cooling during the summer. While anticipated energy supply is expected to meet expected increases in energy demand in the summer months, extreme events such as heatwaves can cause brownouts due to acute energy shortfalls or prolonged power outages from impacts to transmission and distribution systems (Zamuda et al., 2018).

Figure 20. Substations and Transmission Lines in Seattle



Notes: This map shows energy infrastructure (15 substations and several transmission lines) in and immediately outside the city of Seattle (City of Seattle, 2022; U.S. Energy Information Administration, 2020).

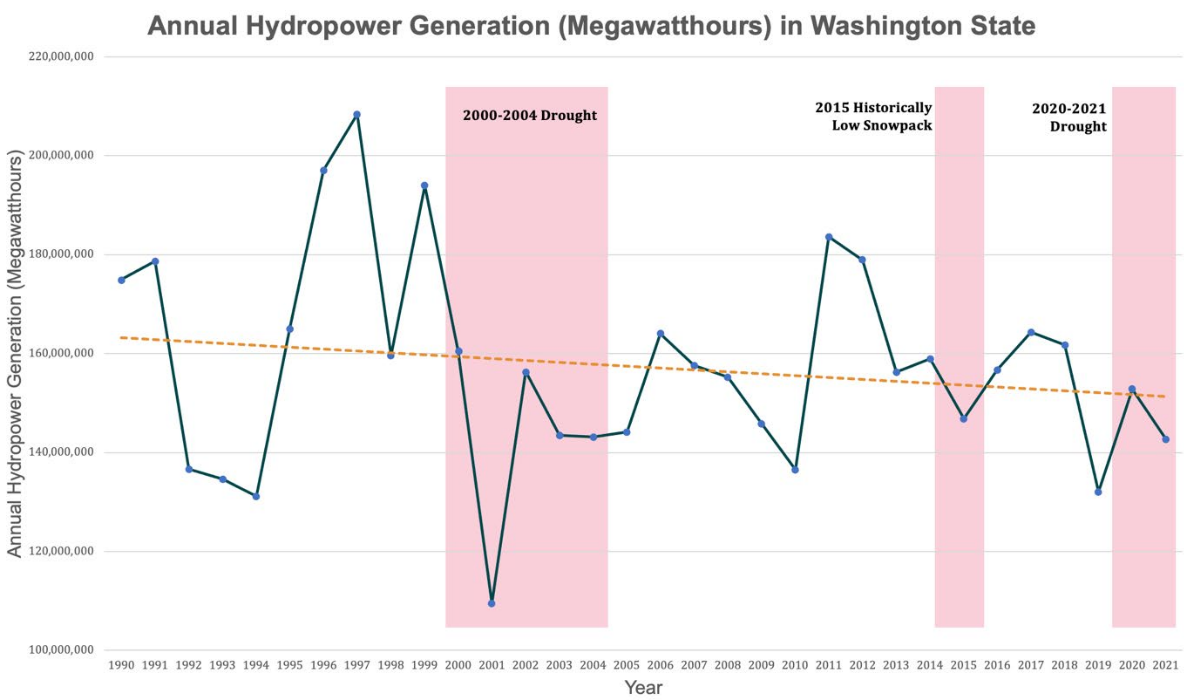
ENERGY SUPPLY

Generally, Seattle's energy generation has moderate vulnerability to climate change.

The majority of SCL's generation comes from hydropower, with approximately 80 to 90 percent of Seattle's electricity being derived from seven hydroelectric sources (Seattle City Light, 2022). Hydropower supply is dependent on several watersheds – such as the Cedar and Tolt watersheds – in the region. The Cedar River and the Tolt rely on runoff from the Cascade mountains, which historically has experienced a decrease in its snowpack ranging from 15 percent to 35 percent relative to 1930 to 1970, and these trends are projected to worsen by the 2080s (see **Regional Watersheds** section) (Snover et al., 2013). Shifts in winter precipitation will affect flow volume and timing, as peak flows are expected to increase in winter months and decrease in summer months, where energy demand is growing (Mauger & Won, 2020). Despite these impacts, Seattle's hydropower supply is generally resilient to changes in snowpack and peak flows due to water storage management that can manage flows to hydroelectric facilities, the diversity and redundancy of SCL hydroelectric facilities, and the ability to offset electricity shortfalls with purchases from other utilities, such as the Bonneville Power Administration and BC Hydro (Raymond, 2013).

While the city's hydroelectric sources are generally resilient, extreme droughts can affect the water supply and energy reliability for the entire state (Turner et al., 2022) (Figure 21). While historic droughts have yet to affect energy reliability for the state, repeated and prolonged droughts that extend across the state have the potential to affect seasonal reliability of hydroelectric power.

Figure 21. Associations Between Hydropower Generation and Droughts in Washington State from 1990-2021



Notes: Annual hydroelectric generation in Washington State between 1990 and 2021 (EIA, 2022). The dotted orange line shows a decreasing trend over the past 30 years. Additionally, drought years are mapped onto this chart to illustrate the association between hydroelectric generation and droughts. Figure produced by Cascadia Consulting Group.

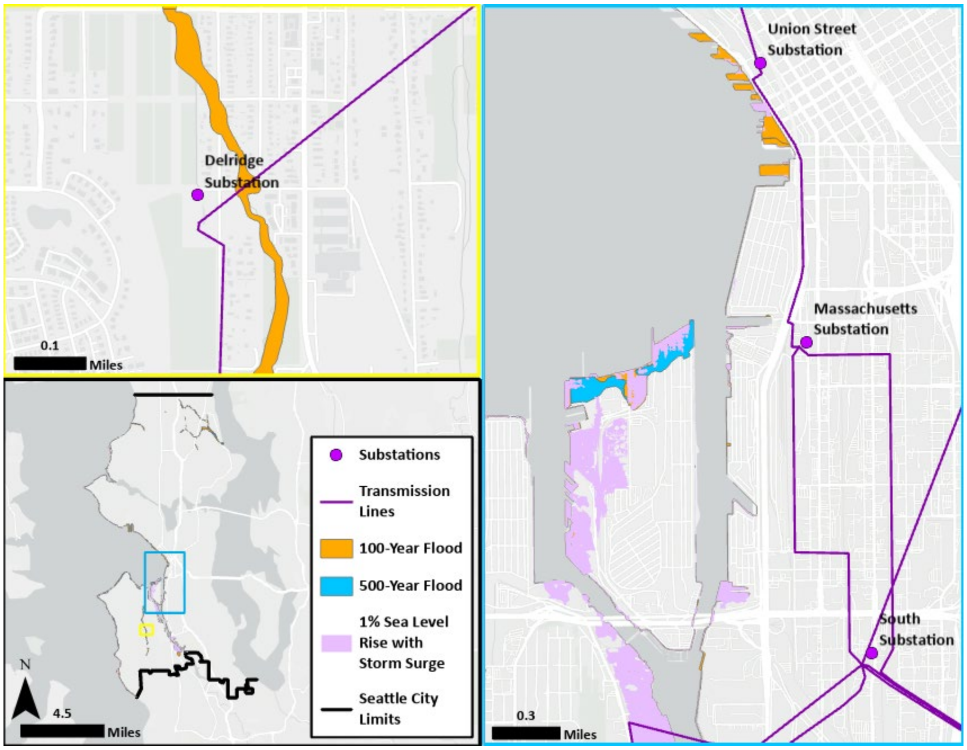
ENERGY TRANSMISSION AND DISTRIBUTION

Generally, **Seattle's energy transmission and distribution systems have a low vulnerability to climate change.** The transmission and distribution system deliver energy to over 400,000 residential and commercial customers in Seattle (Seattle City Light, 2022). Underground and overhead transmission wires can be weakened or damaged and experience operational issues if inundated (Energy Networks Association, 2018). Additionally, overhead transmission and distribution lines can be damages during winter storms, where high winds can cause tree falls that damage overhead lines.

Flooding can also lead to high voltage equipment damage, de-energization, fire, or catastrophic loss of substation equipment. While no substations are in the 100- or 500-year floodplain or are exposed to 2050 sea level rise impacts (RCP8.5), some substations in low elevation areas or close to flood zones – such as the Delridge, Union Street, Massachusetts, and South substations – may flood as flooding risks change in the future (Figure 22).

While the industry standard is for substations to be built one-foot higher than the historic 100-year flood elevation, this may be insufficient as flooding becomes more intense due to climate change or if extreme flooding happens during compound extreme events, such as during the 2022 King Tides flooding (Costa & McAllister, 2017). Additionally, some of these substations in low-lying areas – such as the Massachusetts and South substations – are also in areas with high levels of impervious surfaces, which may make these substations particularly vulnerable to urban flooding impacts.

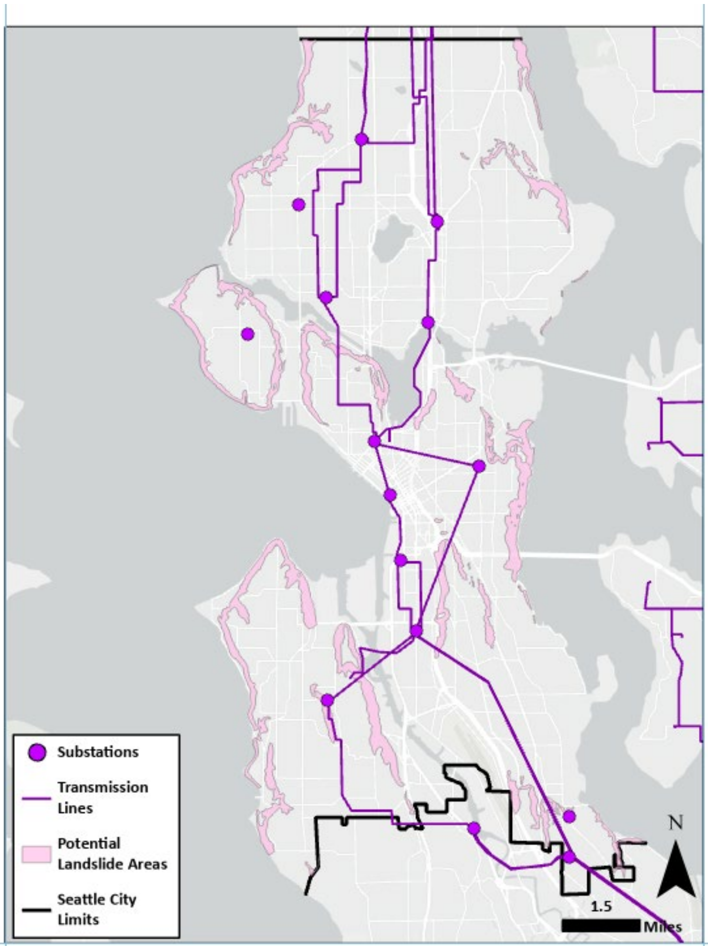
Figure 22. Flooding and Sea Level Rise Impacts on Energy Infrastructure in the Delridge, and SODO Areas of Seattle



Notes: This set of maps overlays the 100-year and 500-year floodplains and likely 2050 sea level rise of 3.1 feet (using a 1% likelihood scenario and including storm surge). Inset maps indicate areas where the Delridge substation and Union Street Substation are near the 500-year floodplain (City of Seattle, 2022; Miller et al., 2018; National Oceanic and Atmospheric Administration, 2021; Roop et al., 2018; U.S. Energy Information Administration, 2020).

Several miles of transmission lines pass through landslide prone areas and there are some substations that occur or are in close proximity to these zones (Figure 23). However, large landslides are low probability but high consequence events, and parts of the city that historically experience more landslides, such as the West Seattle and Interbay areas, may be more prone to energy disruption due to landslides (Seattle Office of Emergency Management, 2019). SCL has taken measures to reduce the sensitivity and increase the reliability of their transmission system to landslides, such as building redundancy in transmission line routes and designing a higher energy load capacity for each transmission line to distribute more energy if other lines are damaged from hazards such as landslides. Additionally, the majority of SCL transmission towers are made of steel and concrete, making them less susceptible to damage during a landslide.

Figure 23. Landside Risk to Transmission Lines and Substations



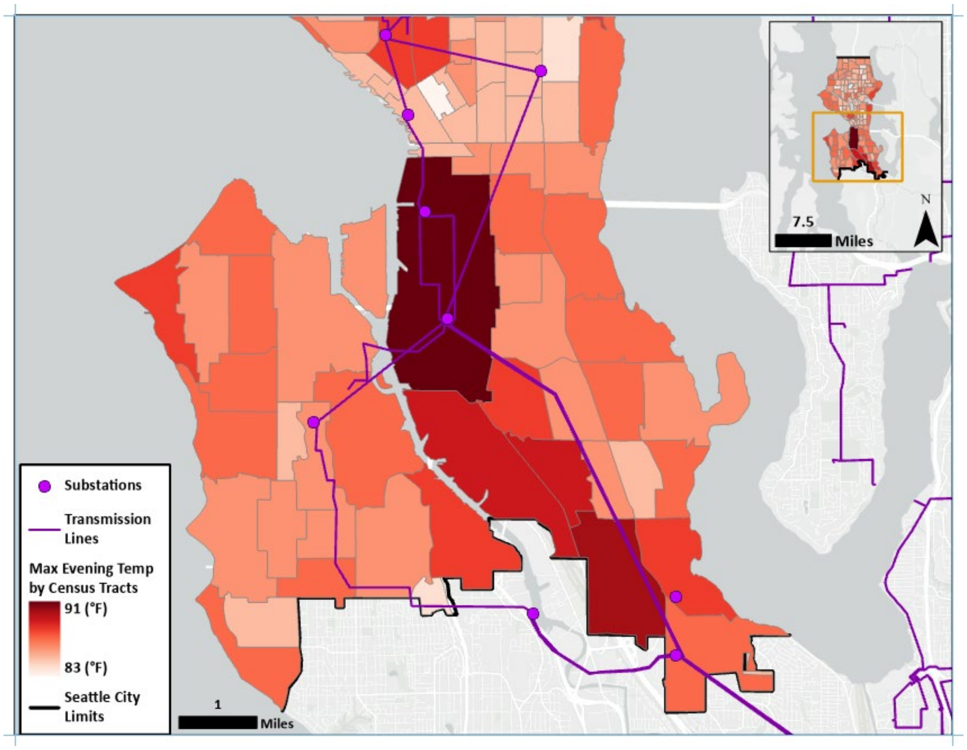
Notes: This map overlays potential landslide areas with substations and transmission lines in Seattle. Two substations border potential landslide risk areas(City of Seattle, 2022; U.S. Energy Information Administration, 2020).

Extreme heat can increase power line sagging of overhead transmission lines and reduce the capacity and efficiency of overhead and underground transmission and distribution lines (Burillo et al., 2019; Fant et al., 2020). For example, by 2050, higher temperatures will reduce peak summertime load transmission capacity by 1.9 percent to 5.8 percent (Bartos et al., 2016). Additionally, warmer temperatures and extreme heat events can reduce the lifespan and efficiency of energy substations and transformers. Older energy assets are more sensitive to extreme heat and warmer ambient temperatures. For example, older transformers, which typically have a lifespan of about 40 years, are more likely to malfunction or overheat during heatwaves.

While the city's entire distribution and transmission systems will likely face impacts brought on from extreme heat, the most severe of these affects would be felt in areas of the city that are more prone to urban heat island effect, such as areas in south Seattle and Georgetown (Figure 24). Heatwaves, such as the 2021 heat dome event (see **Cascading and**

Compounding Climate Impacts section), will continue to test the resiliency of Seattle's energy systems.

Figure 24. Extreme Heat and Energy Infrastructure in Seattle

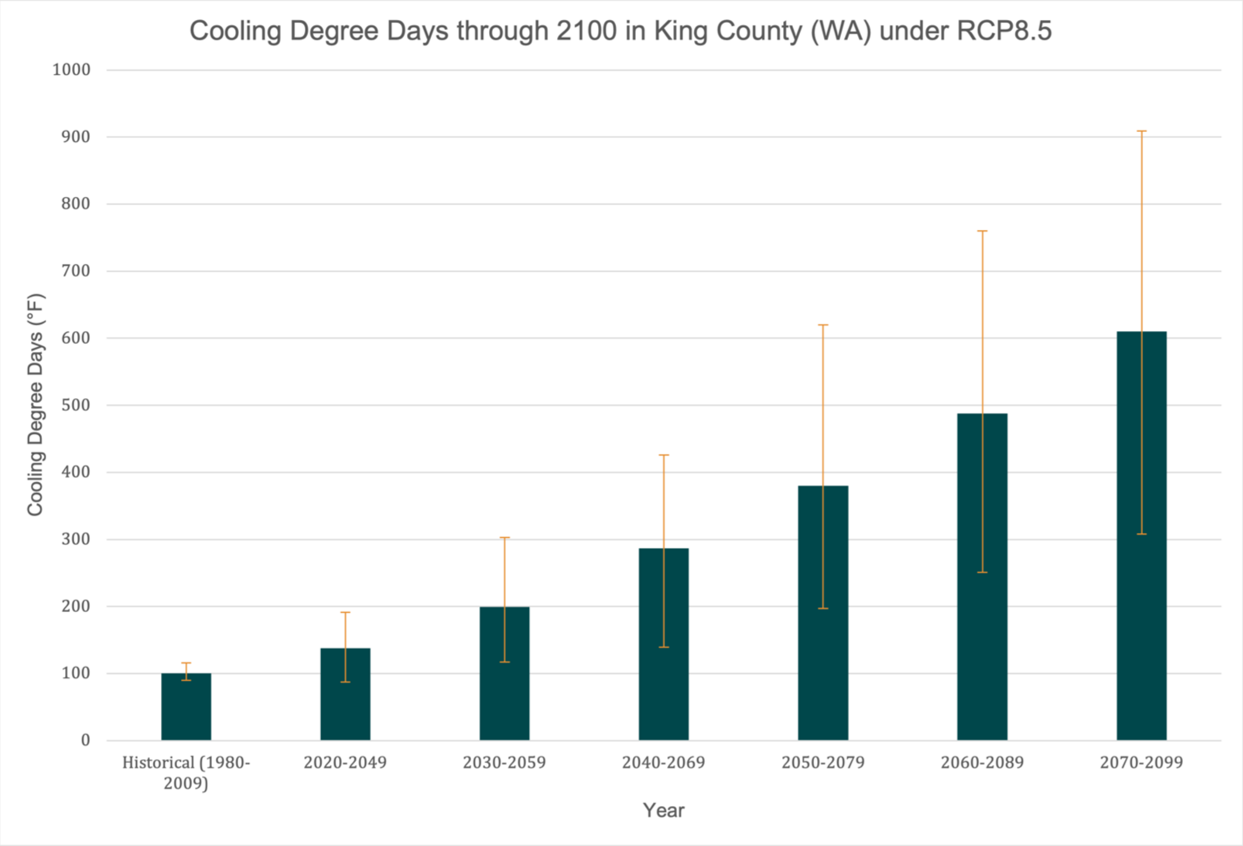


Notes: This map overlays areas in Seattle that experience higher temperatures with substations and transmission lines. The areas that have highest temperatures are SODO and the International District. There are two substations in this area and transmission lines that connect southern and northern Seattle (CAPA Strategies et al., 2021; City of Seattle, 2022).

ENERGY DEMAND

Historically, peak electricity demand is in the winter months for heating needs. However, as summers become warmers and heatwaves become more likely, energy demand is expected to increase in summer months as more residents rely on air conditioning (Raymond, 2013). Expected future population growth will also add increased energy demand across all seasons. Cooling degree days, or a measurement of the demand for cooling based on the daily average temperature compared to a baseline temperature for comfort (65°F), are expected to increase under all scenarios. Relative to 1980-2009, Seattle is expected to see projected increase in cooling degree days ranging from 430 to 493 days by mid-century under RCP8.5 (Figure 25) (Raymond & Rogers, 2022). Despite increases in future energy demand, energy supply is anticipated to meet this future demand.

Figure 25. Cooling Demand in King County through 2100 under RCP8.5



Notes: Data from the Climate Mapping for a Resilient Washington tool (Raymond & M. Rogers, 2022). Bars show the median cooling degree days in King County, and error bars show the range from the 10th to 90th percentile. Figure developed by Cascadia Consulting Group.

Transportation Infrastructure Systems

Transportation is the largest source of GHG emissions in the city, as well as the U.S. (King County, 2022). While efforts to mitigate emissions in this sector will affect the energy sector, this sector is also at risk to the impacts of climate change. Flooding and landslides, driven by intense precipitation, have washed out roads and highways, and extreme heat is causing train tracks to warp and bridges to swell (Hernandez, 2021). In extreme cases these impacts can lead to closure or failure of transportation infrastructure, but even more moderate impacts will reduce the capacity, efficiency, and lifespan of assets.

Due to its geographic nature of being on an isthmus – or a narrow body of land surrounded by water – Seattle's transportation network is a critical backbone that connects the city's neighborhoods and promotes commerce to the broader region. Residents rely on many types of transportation systems to move around the city, including roadways, buses, commuter rail, street cars, bridges, tunnels, and ferries. Additionally, freight networks – such as rail, trucking, air, and maritime shipping – are vital to the local economy and broader supply chains (see **Economic Vulnerability** section). If an emergency occurs, transportation systems will also serve as a critical lifeline, providing routes that allow first responders to provide critical services and residents to evacuate. Within this analysis, 368 bridges, 339 public transit routes, 22 rail line segments, 17 Metro (Link) stations, eight miles of streetcar lines, three ferry/port terminals, and two airports were analyzed (Figure 26).

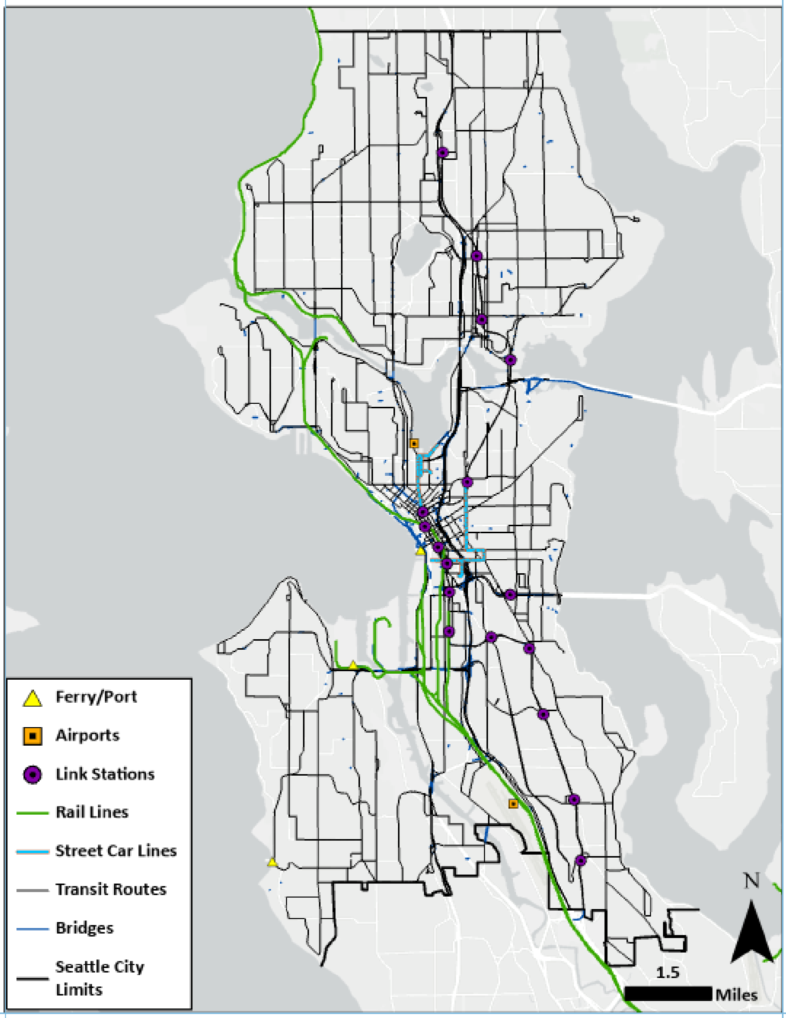


Figure 26. Seattle Transportation Routes and Assets

Notes: This map shows many types of Seattle transportation infrastructure considered in the analysis for this CVA: Link stations, rail and street car lines, bridges, transit routes, ports, and airports (City of Seattle, 2022; King County, n.d.; WSDOT, 2017).

Transportation systems are vulnerable to a variety of climate impacts (Figure 27). Some impacts, such as flooding and extreme heat, can have immediate effects on assets like ferry terminals, roads, and railways (Spector, 2019). Public transit services can also be disrupted or limited by extreme events, which can affect the ability of residents who are dependent on public transportation. While transportation infrastructure failure is very unlikely to happen due to climate change, climate impacts can reduce the effectiveness and performance of transportation networks that can make them more sensitive to failure during and after natural disasters (Jacobs et al., 2018).

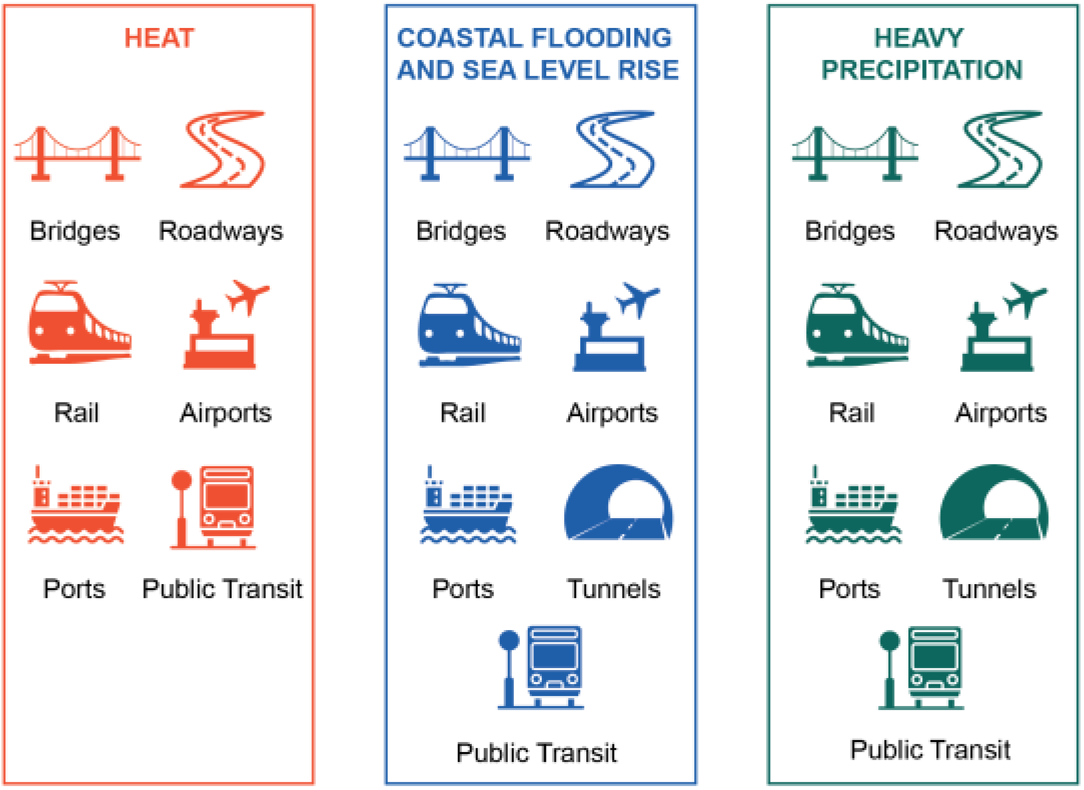


Figure 27. Transportation Assets at Risk of Damage from Heat, Flooding, and Heavy Precipitation

Notes: This graphic shows which types of transportation infrastructure are most likely to be damaged by heat, coastal flooding and sea level rise, and heavy precipitation (Jacobs et al., 2018).

FLOODING

Generally, **Seattle's transportation system is moderately vulnerable to climate change**. Increasing flooding risks, driven by sea level rise, extreme precipitation, and land use, have already affected and will continue to pose challenges for Seattle's transportation infrastructure. Repeated flooding – even minor flooding – can damage transit routes and systems, such as railways. Additionally, flooding can increase the likelihood of injury or death for passengers, increase congestion due to slower traffic, and disrupt trips for residents and freight commerce (Abenayake et al., 2022; Suarez et al., 2005). For example, the rail line running along Carkeek Park in Northwest Seattle and transit routes operating in the Thornton Creek area will face coastal and urban flooding impacts. The most profound impacts of flooding can be seen along the Duwamish and Downtown areas due to their low elevations, where flooding risks and high levels of impervious surfaces will likely affect transit routes, bridge stability, rail lines, and port facilities (Figure 28).

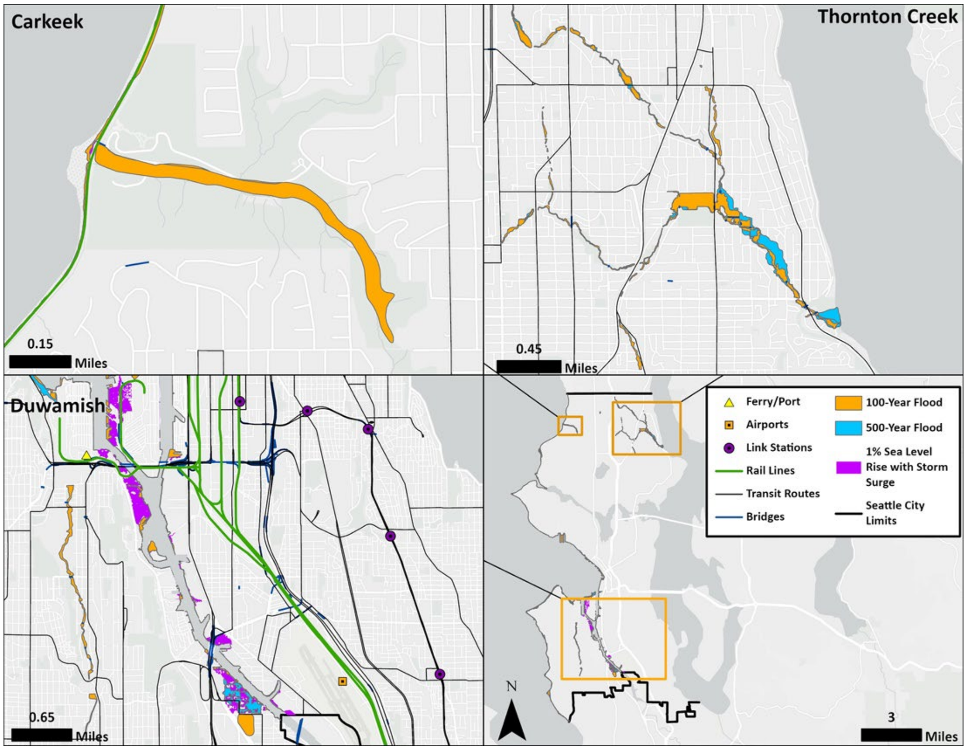


Figure 28. Transportation Assets and Flooding

Notes: This figure consists of three inset maps overlaying transportation infrastructure with the 100-year and 500-year floodplains and 2050 sea level rise of 3.1 feet (using a 1% likelihood scenario and including storm surge). It shows that the rail line along Carkeek Park, transit routes in Thornton Creek, and many types of transportation infrastructure in the Duwamish and Downtown areas will be affected by flooding and sea level rise (City of Seattle, 2022; King County, n.d.; WSDOT, 2017).

In addition to projected increase in flooding frequency and intensity, future sea level rise brought on by climate change will increase the exposure from flooding, storm surge and erosion transportation assets will face. Older assets – such as roads that have not been improved or retrofitted – are more prone to damage from repeated flooding events. Additionally, because of the lengthy processes to plan, permit, and retrofit or construct, there is a lower capacity of transportation systems to structurally prepare for future flooding impacts.

LANDSLIDES

In addition to urban flooding, more frequent and intense extreme precipitation is associated with an increase in landslide risk. While minor landslides occur more frequently, they can temporarily block routes such as railways or roads. While a major landslide is unlikely to happen, it can lead to minor to major disruptions and potentially damage some transportation assets.

Approximately 8.4 percent of Seattle is considered landslide-prone, particularly due to steep slopes (Seattle Office of Emergency Management, 2021). Some of Seattle's transportation assets and routes are within or adjacent to potential landslide areas such as the BNSF railway in Northwest Seattle or light rail routes and stations – such as Rainier

Beach Link Station and the railways along Boeing Field Airport – that run along Interbay and south Seattle areas (Figure 29).

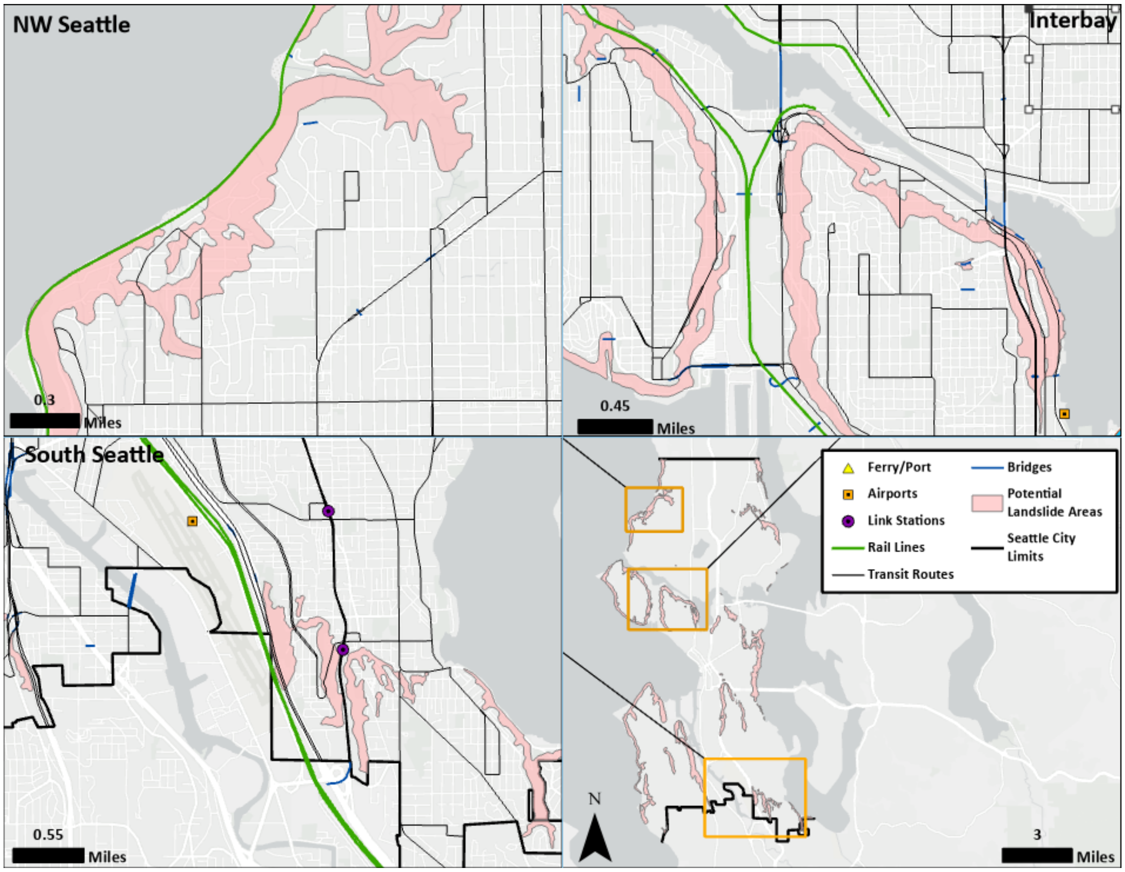


Figure 29. Transportation Assets and Landslide Hazards

Notes: Figure 22 overlays transportation infrastructure with potential landslide areas. It consists of three inset maps that show that the BNSF in Northwest Seattle and the Rainier Beach Link Station, Boeing Field Airport, and railways in Interbay and South Seattle Areas are adjacent to potential landslide areas (City of Seattle, 2022; Seattle Office of Emergency Management, 2021).

While rare, landslides have disrupted many of these routes, affecting regional commerce and commuting routes for residents and workers. Between 1890 to 2000, 1,326 landslides have been recorded in the Seattle areas with a large proportion of them being connected to heavy winter precipitation and snowfall events. Some of these landslides have damaged roadways and public rights of way. Landslide impacts to rail have been very prevalent, with over 540 passenger train service disruptions occurring in the Puget Sound corridor between 2015 and 2018 (Boiko-Weyrauch, 2018). Since 2011, two train derailments caused by landslides have also occurred on routes running from Seattle to Everett (Seattle Office of Emergency Management, 2021).

As heavy precipitation events become more prevalent, landslide risks will also increase due to the saturation and destabilization of soil (Crowe, 2018). This increases the likelihood of landslides around some new areas, such as the I-5 and I-90 intersect around the Beacon Hill neighborhood (Seattle Office of Emergency Management, 2021). Because both routes handle such large amounts of traffic, closure or reduced capacity due to a landslide would lead impacts felt across Seattle and could affect the City's ability to deliver services and evacuate residents.

EXTREME HEAT

Extreme heat can cause pavement buckling and rutting, present safety hazards for drivers, pedestrians, and bikers. Extreme heat can also affect the city's Light Rail system by causing rail buckling or line sagging in the overhead catenary system. Many of these impacts were witnessed during the 2021 heat dome event (see **Cascading and Compounding Impacts** section).

Extreme heat impacts to transportation infrastructure will be most prominent in the Georgetown and South Seattle areas, as these parts of the city experience more intense heat island effects (Figure 30). Specific assets – such as the SR 99-First Avenue Drawbridge – may experience higher than average ambient temperatures during extreme heat days that affects bridge opening and closing. Railways in this area are also more likely to buckle and are already monitored by rail operators during extreme heat days. Additionally, airplane takeoffs from King County International Airport can experience disruptions as warmer temperatures make it more difficult for airplanes to generate lift needed for takeoff. The International District, Stadium, and SODO light rail stations are all open-air facilities, and Link Light Rail customers waiting for trains may face additional exposure to extreme heat and heat-related illnesses (see **Public Health Vulnerability** section).

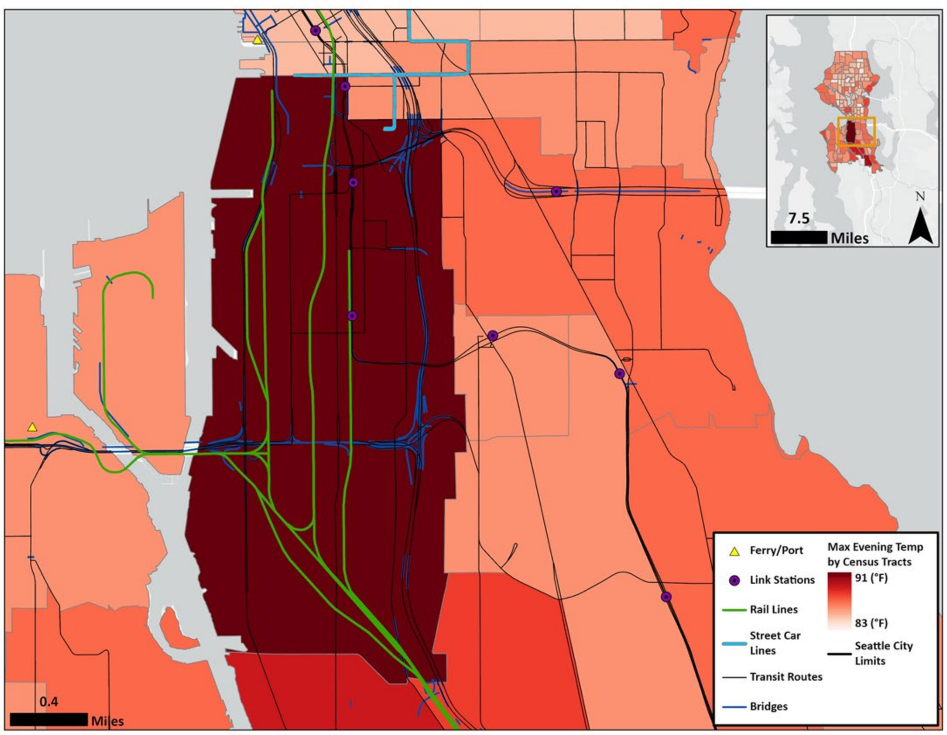


Figure 30. Transportation Assets and Extreme Heat Exposure

Notes: This map overlays areas in the city most likely to experience extreme heat (the SODO and International District areas) with transportation infrastructure. Several types of infrastructure: street car lines, Link stations, rail lines, and transit routes – are located in the areas most likely to experience extreme heat (CAPA Strategies et al., 2021; City of Seattle, 2022; King County, n.d.; WSDOT, 2017).

Transportation systems are usually designed based off historic climate conditions and standards. However, as temperatures continue to increase with climate change, these design standards will no longer be sufficient to prevent roadway ways from buckling and railways from bending. Air travel is also expected to feel drastic impacts from rising temperatures, as studies indicate, that in coming decades, up to 30 percent of all flights that depart at the hottest part of the day will be delayed or canceled due to takeoff challenges (Worland, 2021).

Water, Wastewater, and Drainage Infrastructure Systems

Water, wastewater, and drainage infrastructure are each exposed to a variety of climate change impacts, and some water infrastructure assets will be impacted and/or overwhelmed by impacts such as climate-induced extreme precipitation and sea level rise. Coastal wastewater treatment and conveyance infrastructure are at higher risk from coastal flooding impacts, some of which is driven by sea level rise, which can lead to overflow in sewer and combined systems and have cascading water quality impacts. Drinking water infrastructure near the coast is susceptible to saltwater intrusion, and heat and droughts are linked to an increase in demand for water, leading to water supply reductions and impacts (see **Regional Watersheds** section).

Seattle's water, wastewater, and drainage systems serve 1.5 million people in the greater Seattle area (Figure 31) (Seattle City Light, 2021). Seattle's wastewater and drainage infrastructure are serviced by Seattle Public Utilities (SPU), which operates over 1,400 miles of wastewater pipes and over 400 stormwater lines 33 percent of the wastewater lines are combined to handle stormwater, while 40 percent is partially separated, and 27 percent are fully separated (Seattle Public Utilities, n.d.).

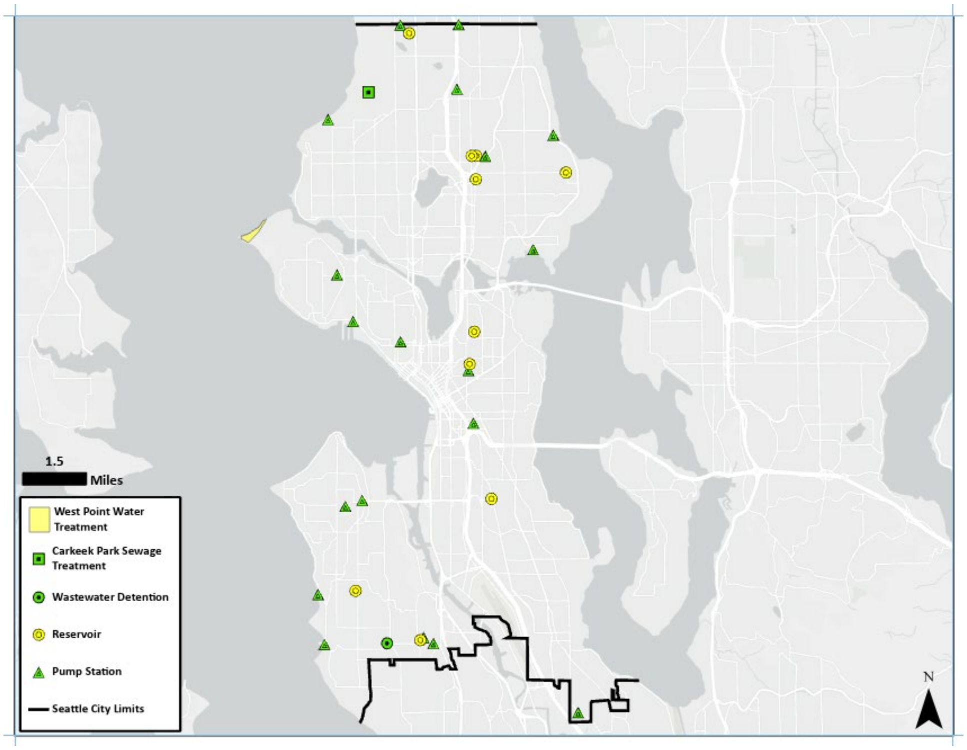


Figure 31. Wastewater Treatment and Drinking Water Reservoirs in Seattle

Notes: This map shows stormwater, wastewater, and water infrastructure in Seattle, including the West Point Water Treatment Plan, the Carkeek Park Sewage Disposal Treatment Plant, Wastewater Detention site, reservoirs, and pump stations (City of Seattle, 2022).[4]

DRAINAGE AND WASTEWATER INFRASTRUCTURE

Generally, **Seattle's drainage and wastewater infrastructure system is moderately vulnerable to flooding associated with sea level rise and extreme precipitation**. Seattle has three primary types of sewer systems that combine drainage and wastewater infrastructure: 1) combined sewer systems that convey wastewater and stormwater together to treatment plants; 2) separated systems where sewer pipes convey wastewater to treatment plants and different pipes convey stormwater to drainage outlets; and 3) partially separated sewer system where some pipes convey wastewater and stormwater to treatment plants and other pipes convey stormwater to drainage outlets (Seattle Public Utilities, 2021).

[4] *Additional construction is already underway – such as the* ***Ship Water Quality Project*** *– that will be part of the wastewater and drainage systems.*

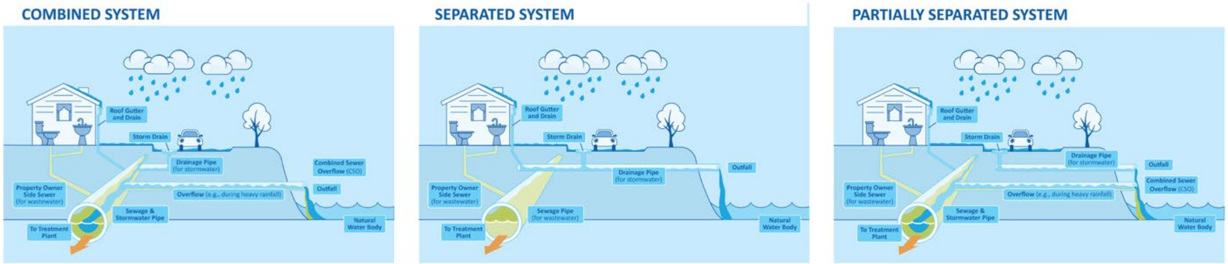


Figure 32. Types of Sewer Systems in Seattle

Notes: From SPU's Shape Our Water plan (Seattle Public Utilities, 2021).

There are a few key mechanisms that sea level rise and flooding will impact stormwater and wastewater facilities. Some wastewater facilities near coastal areas on Puget Sound and Elliott Bay are susceptible to inundation due to sea level rise and coastal flooding (Figure 33). Additionally, wastewater lines can also experience backups during flooding events, which can exacerbate flooding and bring cascading impacts to areas that are not directly experiencing flooding (Hummel et al., 2018). Coastal flooding driven by storm surge and sea level rise could cause saltwater inflow, corroding equipment and reducing conveyance capacity (NOAA, 2022).

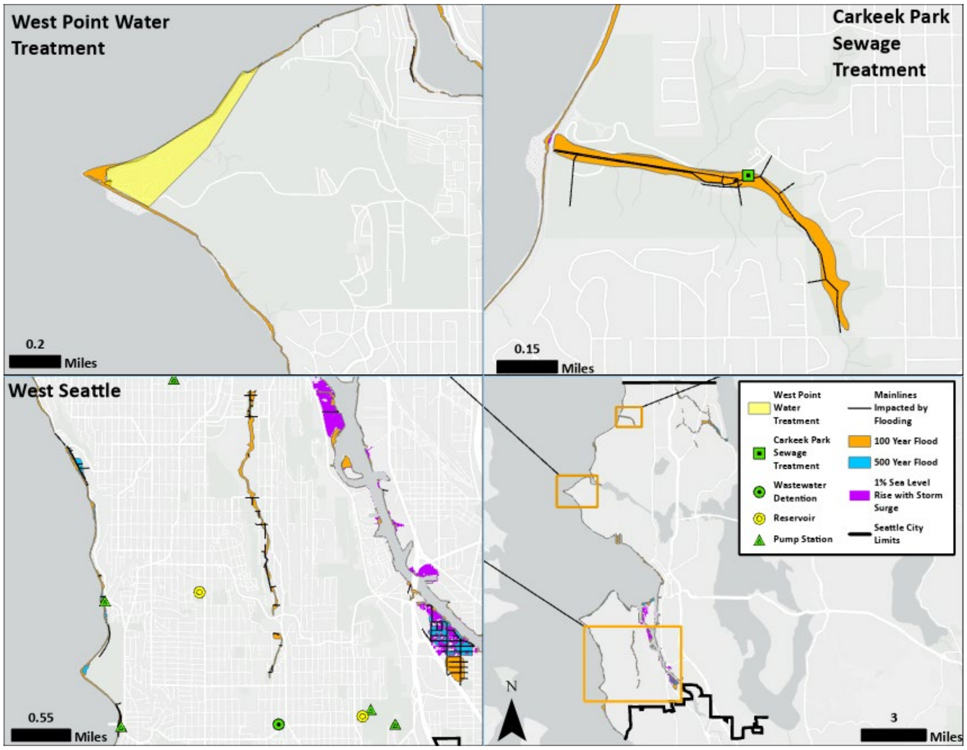


Figure 33. Sea Level Rise and Flood Risks to Wastewater Infrastructure and Drinking Water Reservoirs

Notes: There are three inset maps overlaying stormwater, wastewater, and water infrastructure with the 100-year and 500-year floodplains and 2050 sea level rise of 3.1 feet (using a 1% likelihood scenario and including storm surge). It shows that the West Point Treatment Plan, Carkeek Wet Weather Treatment Station, and three pump stations in West Seattle could be affected by flooding and sea level rise(City of Seattle, 2022; Miller et al., 2018; National Oceanic and Atmospheric Administration, 2021; Roop et al., 2018).

In Discovery Park, the West Point Treatment Plant is in the 100-year floodplain. The Carkeek Wet Weather Treatment Station also lies within the 100-year floodplain, as do several combined sewer and runoff mainlines. A 2015 study identified 17 different facilities, including pump stations, regulator stations, and outfalls, along the Duwamish River, West Seattle, and Downtown areas that will be affected by saltwater inflow (Phillips et al., 2015).

Figure 34. Outfall Locations at Risk of Saltwater Inflow from Sea Level Rise

Notes: Figure from Phillips et al., 2015.

The West Point Treatment Plan has historically been impacted by flooding. In February 2017, high tides and heavy rains induced electrical circuit malfunction that shut down the operating system (Department of Ecology State of Washington, 2017). This led to the release of 235 million gallons of untreated wastewater – including 30 million gallons of raw sewage – into Puget Sound (Willmsen & Mapes, 2017). This event endangered staff at the facility and caused water quality impacts for local beaches and nearshore habitats as much as a year after the event (King County, 2018; Willmsen & Mapes, 2017). Events like this, even though are unlikely, may happen again as compounding weather events such as winter storms and heavy rains will be exacerbated by sea level rise and increasing intensity of atmospheric rivers. Aging water systems are generally more sensitive to climate change impacts, and many combined systems were designed to convey flows based on historic precipitation records rather than future climate data (Lall et al., 2018).

In the past, extreme precipitation has also overwhelmed drainage and sewer systems and caused combined sewer overflows (CSOs) that affect local water quality and nearshore habitats (Grodnik-Nagle et al., 2023). CSOs can cause beach closures, affect quality of local shellfish, increase potential for harmful algal blooms, reduce dissolved oxygen levels in local waterways, and increase public health risks. As extreme precipitation intensity increases (see **[Extreme Rain and Precipitation](#)** section), CSO potential is expected to persist. Some areas with constrained drainage capacity that are in floodplains or sea level rise inundation zones – such as areas along Thornton Creek in northeast Seattle and along the Duwamish River – will likely be more affected by drainage issues related to extreme rains, leading to unsafe urban flooding (Figure 35).

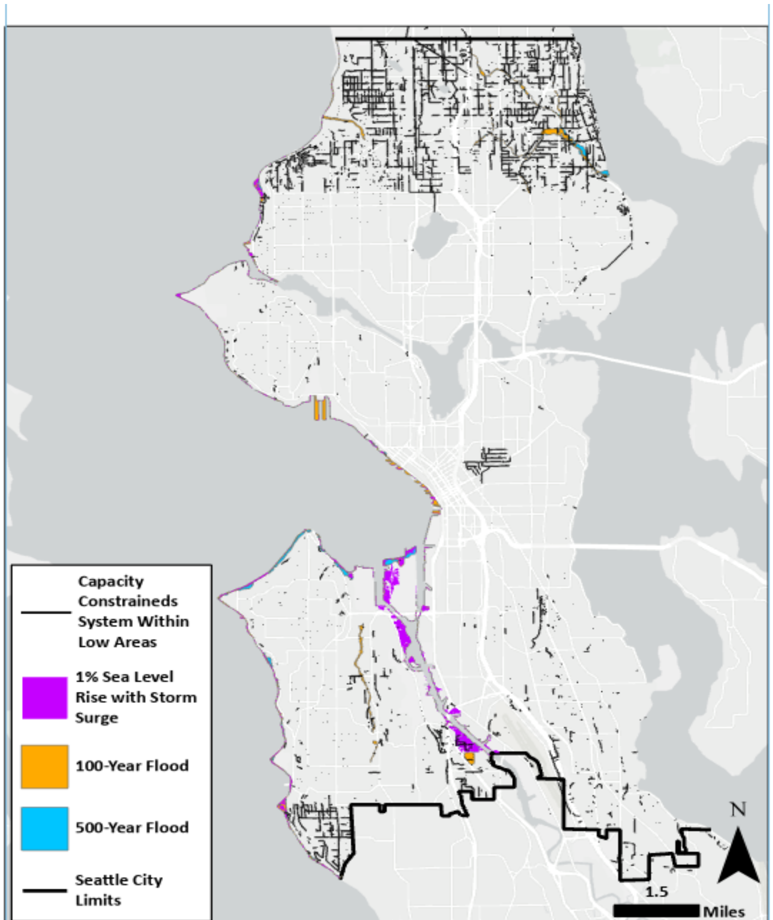


Figure 35. Capacity Constrained Drainage Systems with Sea Level Rise and Flood Risks

Notes: The map overlays capacity constrained drainage systems onto the 100- and 500-year floodplain, and 2050 sea level rise of 3.1 feet (using a 1% likelihood scenario and including storm surge) (City of Seattle, 2022).

Several of Seattle's sewer lines run along the base of potential landslide areas, such as those in West Seattle, Interbay, and Carkeek Park. In total, there are more than seven instances where sewer mainlines run through landslide hills in Seattle (Seattle Office of Emergency Management, 2021).

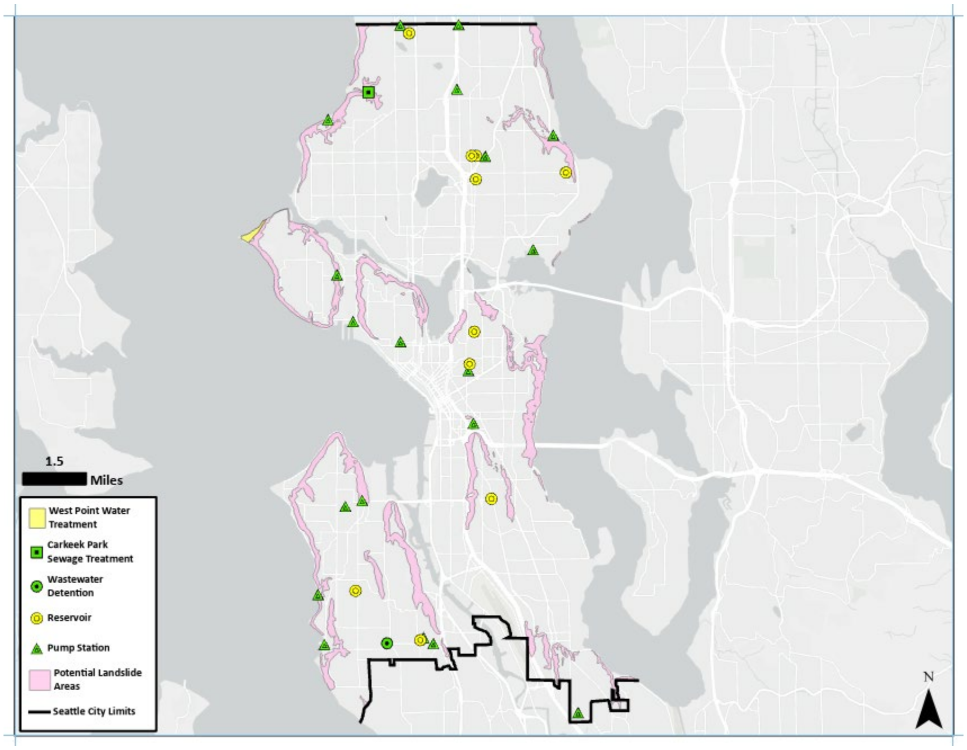


Figure 36. Wastewater Infrastructure and Drinking Water Reservoirs with Potential Landslide Areas

Notes: The map overlays wastewater infrastructure and drinking water reservoirs with potential landslide areas. Some facilities and pump stations are in potential landslide areas (City of Seattle, 2022; Miller et al., 2018; National Oceanic and Atmospheric Administration, 2021; Roop et al., 2018).

Seattle's drainage system is also at risk of damage from landslides. While all underground utilities are vulnerable to landslides, drainage systems are even more so due to their proximity to slopes (Seattle Office of Emergency Management, 2019). Several stormwater facilities and pump stations, as well as several combined sewer and stormwater mainlines are in potential landslide risk zones (Figure 36). In Seattle, eight percent of reported landslides have damaged elements of Seattle's drainage system (Seattle Office of Emergency Management, 2021). As heavy and extreme precipitation are projected to increase in future years, the landslide risk to drainage systems also increases.

WATER SUPPLY

Seattle is dependent on multiple watersheds for its drinking water, with the two largest sources being the Tolt and the Cedar River Watersheds. The **Regional Watersheds** section goes into further detail on the climate risks and vulnerabilities of Seattle's drinking water supply.

Natural Systems' Vulnerability to Climate Change

There are many natural systems – including urban forests, wetlands, rivers and creeks, and shorelines – in Seattle that provide a multitude of environmental benefits and ecosystem services. For example, urban forests can provide shade for residents and habitat for birds and wildlife. Riparian areas can provide a natural flood buffer that protects residents and infrastructure while also providing critical habitat for salmon, a Treaty-protected species for regional Tribes.

This section evaluates the vulnerability to climate change of Seattle's natural systems, including Seattle's watersheds, habitat for salmon, urban tree canopy and green spaces, and environmentally critical areas.[5]

Watersheds

A watershed is a basin of land that funnels rain and snow from higher elevation to lower elevation. This precipitation eventually collects in a shared waterway, such as a stream, river, or lake. Watersheds provide important terrestrial and aquatic habitat for wildlife, but conditions within watersheds can also impact flood risk, drinking water quality, and hydropower availability for communities in and adjacent to them. Climate change disrupts the spatial and temporal distribution of water within watersheds, impacting both natural ecosystems and human-made infrastructure.

The city relies on two large watersheds, the Cedar River Municipal Watershed and South Fork Tolt Municipal Watershed, for its drinking water supply and a small portion of its hydroelectric power (Raymond, 2013). Cedar River supplies 70 percent of Seattle's drinking water, reserved in Chester Morse Lake and the Lake Youngs Reservoir, and has a hydropower capacity of 30 megawatts (MW). Jointly, the reservoirs have a storage capacity of approximately 14.5 billion gallons of water (Seattle Public Utilities, 2019a). South Fork Tolt supplies the remaining 30 percent of Seattle's drinking water and provides a hydropower capacity of 16.8 MW. The South Fork Tolt Reservoir has a storage capacity of 18.3 billion gallons (Raymond, 2013). Although outside City limits, both watersheds are fully or majority-owned by Seattle City Light (SCL).

Generally, the Cedar River and South Fork Tolt Watersheds have a moderate to high vulnerability to climate change due to reduced snowpack (Figure 37), increased winter rainfall, and lower summer flows. The effects of climate change on the natural systems within these watersheds have the potential to affect infrastructure within the city (see **Infrastructure** section). Reduced snowmelt and summer rainfall within the Cedar River and South Fork Tolt watersheds will increase the likelihood of temporary summer

[5] *The City also owns additional assets within regional watersheds, however, those assets are not assessed as part of this vulnerability assessment because it resides outside City borders.*

droughts, which could impact drinking water supply for the city. Although Seattle is not projected to need a new water supply before 2060, seasonal drawdowns are expected under climate change. Hydropower capacity could also be impacted as a result.

The following sections discuss climate impacts to regional watersheds – such as the Cedar River and South Fork Tolt Watersheds – that affect regional water supply and urban watersheds within the city, such as Thornton and Longfellow Creeks as well as the lower Duwamish River.

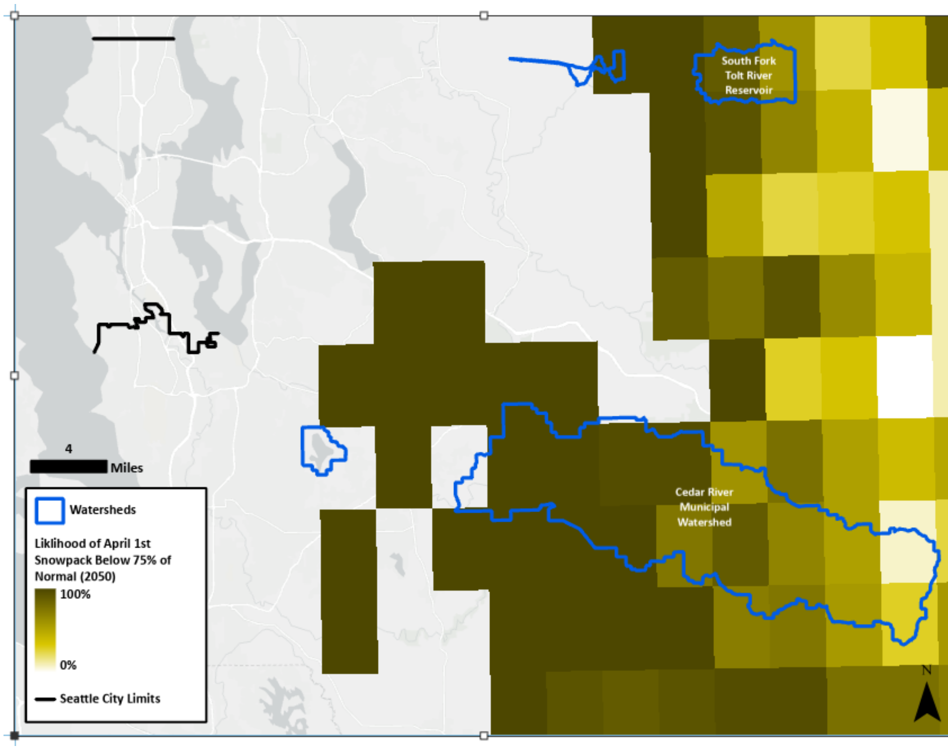


Figure 37. April 1st Snowpack at Drought Levels Under RCP8.5 by 2050

Notes: This figure shows regional changes to snowpack, which are likely to affect water availability to the city of Seattle. It shows that most areas are likely to experience decreased snowpack and several areas are 100 percent likely to have 75 percent less snowpack – which is considered drought levels – by 2050 under RCP8.5 (City of Seattle, 2022; Raymond & M. Rogers, 2022).

REGIONAL WATERSHEDS AND WATER SUPPLY

Snowpack and rainfall within the Cedar River and South Fork Tolt watersheds supply drinking water for the city. However, the snowpack and summer rainfall within these reservoirs have diminished due to warmer temperatures. In the Cedar River watershed, increases in spring flows and decreases in summer flows from 1949-2003 reflect an earlier start to snowmelt and a reduced snowpack overall (Mote et al., 2018). This trend is consistent with watersheds throughout the western US: between 1955 and 2016, 92 percent of snow monitoring sites in the West experienced a decrease in mountain snowpack (Mote et al., 2018). Reduced snowpack contributed significantly to the state-wide drought in 2015, which was reflective of projected conditions in the 2050s (Marlier et al., 2017; Mote et al., 2016).

Seattle's overall drinking water supply is projected to exceed demand through at least 2060 (Seattle Public Utilities, 2019a). However, demand may periodically exceed supply due to future shifts in temperature and precipitation regimes that affect water recharge in the Cedar River and South Fork Tolt watersheds (Raymond & Rogers, 2022). Further reduced snowpack, earlier snowmelt, and reduced summer rainfall will lead to temporary seasonal droughts that could impact drinking water availability for the city. This impact may be amplified if customer water demand increases, especially during the hotter and drier summer months (Seattle Public Utilities, 2019a).

By the 2050s, winter temperatures are projected to increase by 5.8°F under RCP8.5 in the Pacific Northwest relative to 1950-1999, leading to a 56-70 percent decrease in mountain snowpack throughout Washington by the 2080s (relative to 1916-2006 average; Snover et al., 2013). Many of the watersheds currently characterized as mixed snow-and-rain basins, including the Cedar River and South Fork Tolt watersheds, will shift to rain-dominant basins (<10% winter precipitation captured as snowpack) by the 2040s, under A1B (Snover et al., 2013). The likelihood of snowpack at drought levels (below 75% normal snowpack) will be 100 percent by 2050 for many of the areas within the Cedar River and South Fork Tolt watersheds (Figure 37).

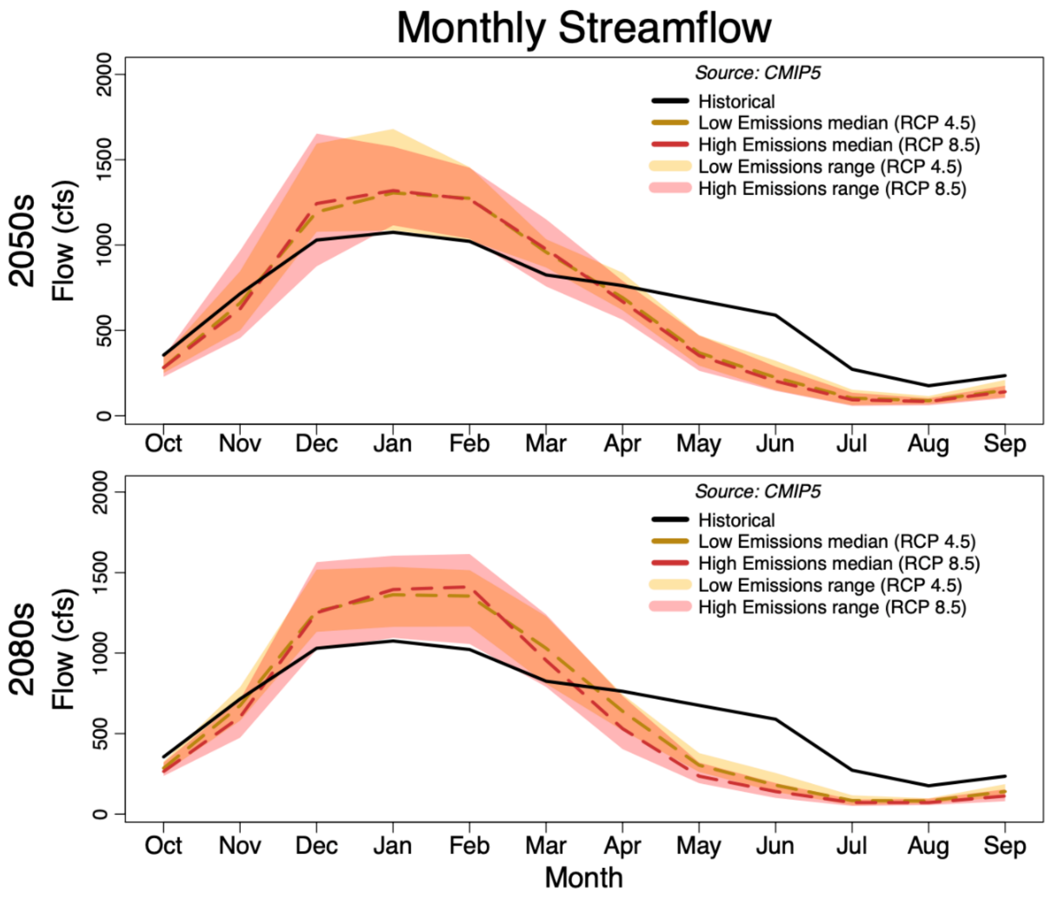


Figure 38. Changes in Monthly Streamflow in the Cedar River Watershed under RCP4.5 and RCP8.5 by the 2050s and 2080s

Notes: Plots show monthly average streamflow for the water year compared to historical streamflow by the 2050s and 2080s under CMIP5 scenarios. The thick colored lines show the median among 10 climate models (Mauger et al. 2015).

Even for areas with snowpack, warmer temperatures will lead to an earlier start to snowmelt each spring. For the Cedar River and Tolt watersheds, flows are predicted to peak 4-9 weeks earlier than their 1917-2006 start dates by the 2080s (Figure 38) (Snover et al., 2013). Reduced and earlier snowmelt, coupled with predicted declines in summer precipitation rates, will lead to low summer stream flows that are 34-44 percent less than their historic averages, under the same climate scenario (Snover et al., 2013). These changes are likely to impact water availability during the summer (Seattle Public Utilities, 2019a).

Finally, while rare, there have been wildfires within King County (King County Emergency Management, 2020). Fire risk is increasing for the western Cascades due to climate change and population growth that is expanding the wildland-urban interface. By the 2040s, the area burned is expected to triple (from 2,700 acres to 8,000 acres per year) relative to 1980-2006 in the western Cascades (Morgan et al., 2019). Wildfires within the forested Tolt and Cedar watersheds will have impacts to water quality, supply, and habitats and could damage various infrastructure assets.

Reservoir Infrastructure

Water from the Cedar River and South Fork Tolt watersheds collects into a series of reservoirs and regulating basins and is then conveyed to customers through SPU-owned transmission and distribution systems. Operations at these reservoirs and the associated Masonry, Landsburg, Lake Youngs, and South Fork Tolt dams can be disrupted by both flooding and very low stream flows, both of which are more likely to occur under climate change (Seattle Public Utilities, 2019a).

Winter precipitation is projected to increase by about 6 percent west of the Cascades by 2050, relative to 1950-1999 levels under RCP8.5 (Morgan et al., 2021). Greater winter rainfall will contribute to increased winter flood risk, which could impact reservoir capacity at Masonry and Tolt dams, affect hydropower infrastructure on the Cedar River and South Fork Tolt, and lead to flooding downstream (Raymond, 2013). However, the impact of increased flows downstream of Cedar River and South Fork Tolt reservoirs has not been fully evaluated (Seattle Public Utilities, 2019a). Extreme precipitation can also decrease water quality by increasing turbidity, putting additional strain on water treatment facilities (Seattle Public Utilities, 2019b).

As with the drinking water supply, reduced snowpack and declines in summer rainfall will lead to lower summer stream flows that could affect the reliability of hydropower generation (Raymond, 2013) (see **Energy Infrastructure Systems** section). Summer precipitation is projected to decrease by about 12 percent west of the Cascades by 2050, relative to 1950-1999 levels under RCP8.5 (Morgan et al., 2021). Although Cedar River and South Fork Tolt represent only 2 percent of SCL's hydropower capacity, they are likely to experience the effects of climate change sooner than higher-elevation watersheds supporting hydroelectric operations on the Pend Oreille and Skagit Rivers, because they are mid-elevation basins near the present snowline (Raymond, 2013; Seattle Public Utilities, 2019a).

URBAN CREEKS AND URBAN WATERSHEDS

Within the city, smaller watersheds that drain into urban creeks like Thornton, Pipers, and Longfellow or the Lower Duwamish River influence the distribution of flood risk and opportunities for flood control (Figure 39). They also provide vital riparian habitat for wildlife and fish and serve as an important connector between freshwater and nearshore marine habitat.

Generally, **urban watersheds have a moderate to high vulnerability to high winter and low summer flows, increasing temperatures, and sea level rise due to climate change**. Under all climate scenarios, more winter precipitation will increase urban flood risk and the potential for runoff and toxins to accumulate in sensitive waterways. During the summer, reduced rainfall will affect riparian habitat and impact fish populations, as water temperatures increase and dissolved oxygen concentrations drop. Where creeks and rivers flow into estuaries, sea level rise is likely to limit habitat quality and availability.

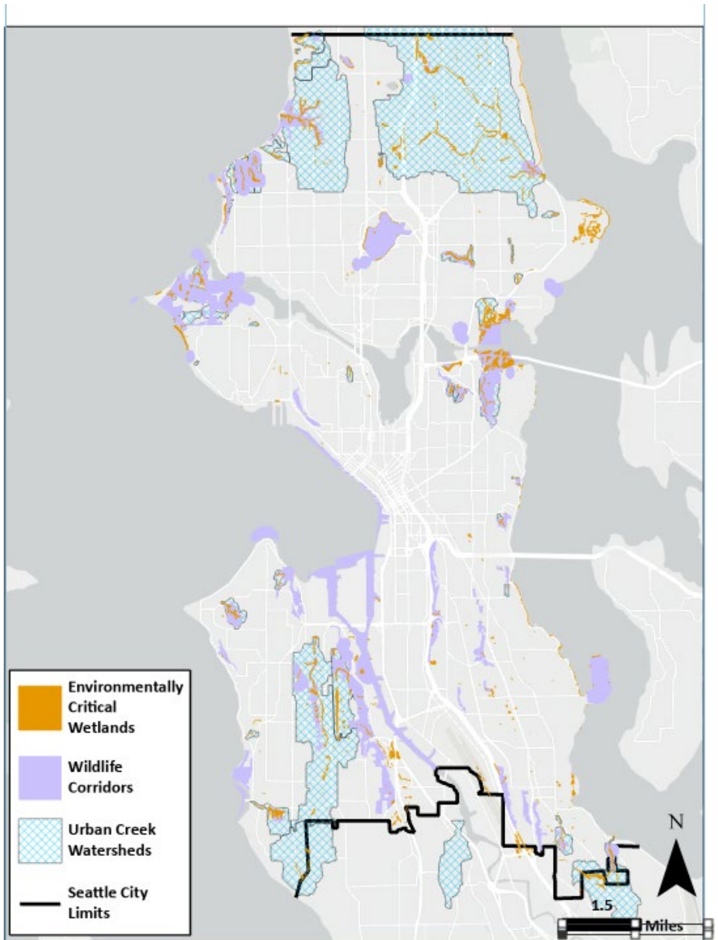


Figure 39. Distribution of Urban Watersheds, Wetlands, Riparian Corridors, and Wildlife Habitat within Seattle

Notes: This figure shows urban watercourses, environmentally critical wetlands, wildlife corridors, and urban creek watersheds in and immediately outside the City of Seattle (City of Seattle, 2022).

Local Flood Risk

Within the city of Seattle, increased winter peak flows in urban creeks and waterways are likely to expose infrastructure and buildings to greater flood risk (see **Infrastructure Vulnerability** section). Low-lying areas that are already more prone to flooding, such as developed areas surrounding the Lower Duwamish (Figure 3), are especially at risk for greater riverine flooding.

Flooding may also impact water quality, as sediment, nutrients, and pollutants accumulate in urban waterways. Excess sediment and particulate matter can suffocate the eggs, larvae, and adults of many fish species, as well as invertebrates (Panthi et al., 2022). Increased nitrogen and phosphorous loading – which can be amplified by runoff or sewer overflows associated with development – cause hypoxic and anoxic conditions that can also lead to detrimental algal blooms that impact the entire aquatic ecosystem (Carey et al., 2013).

Ecosystem Effects of Warmer Temperatures and Drought

In the Seattle region, maximum summertime air temperatures are predicted to increase 6.3°F by 2050 (Raymond & Rogers, 2022). Bodies of water absorb heat as air temperatures rise and are therefore also projected to experience temperature increases under all scenarios, especially during the summer (Land Trust Alliance, 2023; Van Vliet et al., 2012). This will negatively impact cold water-adaptive native fish, which have lower thermal tolerances. It may also benefit nonnative, warm water-adapted species, who compete with native species (Steel et al., 2018). Additionally, dissolved oxygen concentrations are lower in warmer water, which is likely to cause additional stress and facilitate harmful algal blooms (Urgenson et al., 2021).

Low summer streamflows due to reduced summer precipitation and reduced shading from riparian trees will only exacerbate these problems for shallower waterways (Mantua et al., 2009). Seattle's current focus on increasing canopy cover throughout the city has the potential to mitigate some of these effects, if focused on areas directly adjacent to urban waterways and associated estuaries (see **Urban Tree Canopy and Open Spaces** section).

Sea Level Rise and Nearshore Habitat

Sea levels are projected to rise by 3.1 to 3.2 feet by 2100 under RCP8.5 (see **Sea Level Rise** section) (Roop et al., 2018). This increase, coupled with storm surge impacts (Yang et al., 2019), has the potential to eliminate or alter existing estuarine habitat in Seattle. Habitat responses to sea level rise are highly variable and depend on site-specific factors, and there are currently no models for the Duwamish or Salmon Bay estuaries (Hall et al., 2023; Thorne et al., 2018). However, a recent model evaluating five other estuaries in Washington State, including three in Puget Sound, found that under a high sea level rise scenario (+4.6 feet, or +142 cm), 68 percent of existing wetland area will be submerged by 2110 (Thorne et al., 2018). This would significantly limit wetland and nearshore habitat in and around Seattle, affecting the ability of habitat to mitigate coastal flooding risks, the survival of various shellfish species that can improve water quality, and nearshore habitat that provide juvenile habitat for native fish species.

While unlikely, sea level rise could create new nearshore habitat farther up the shoreline (Thorne et al., 2018).

Throughout its urban watersheds, the City of Seattle is already involved in infrastructure improvements and remediation work that can reduce the risk and consequences of increased flooding under climate change. Connecting floodplains and improving drainage are two significant goals. For example, the City is partnering with the Mid Sound Fisheries Enhancement Group, Green Seattle Partnership, and King County Noxious Weeds Program to create the new Lake City Floodplain Park, which will improve water quality, reduce erosion, and minimize future flooding in Thornton Creek. In the Longfellow Creek watershed, Seattle Public Utilities and the Seattle Department of Transportation are constructing natural drainage systems that will reduce flooding and pollution from storm runoff. The City is also re-imagining shoreline areas around the Duwamish River to reduce flooding risks while increasing community resiliency for neighborhoods like South Park.

Salmon Habitat

As an important ecological and cultural keystone species in the Pacific Northwest. Salmon connect predator, prey, and scavenger populations throughout their food webs, as their populations support freshwater invertebrates to marine mammals to terrestrial carnivores to avian scavengers. As a result, salmon are vital to the health and stability of freshwater, marine, and terrestrial habitats in the Pacific Northwest, and any effect of climate change on salmon populations will be felt throughout these ecosystems.

Salmon are also a critical First Food and cultural symbol for tribal communities, such as the Duwamish, Suquamish, Muckleshoot, Snoqualmie, Tulalip Tribes, and the city's urban Native community. Their populations also sustain local, regional, and recreational fisheries. More broadly, salmon are woven into the fabric of the Pacific Northwest and the region's sense of identity (May et al., 2018). However, salmon populations have been declining in Washington State since the late 1800s due to a variety of factors including dam construction, overfishing, and development. Despite significant investment in habitat recovery, protected hatcheries, and stricter fishing regulations, populations continue to shrink, and many are now listed under the Endangered Species Act. Climate change represents another threat to an already-vulnerable species, along with overfishing, reduced habitat availability, and loss of genetic diversity.

Throughout its urban waterways and estuaries, the city provides critical habitat for many salmonid species, including federally threatened populations of Chinook, steelhead, and bull trout (City of Seattle, 2015). The city overlaps with two Water Resource Inventory Areas (WRIA), the Lake Washington/Cedar/Sammamish Watershed (WRIA 8) and the Green/Duwamish and Central Puget Sound Watershed (WRIA 9). In Seattle, salmon migrate through the Ballard Locks, the Ship Canal, and Lake Washington or through streams that connect directly to Puget Sound, such as Pipers Creek.

Maintaining and recovering viable salmon populations in Seattle and throughout WRIAs 8 and 9 requires preserving existing high-quality habitats that collectively support all phases of the salmon life cycle, from spawning and incubation through rearing and outmigration back into Puget Sound. Locally, Seattle's waters are especially important during juvenile migration, when salmon transition from their natal freshwater rivers, tributaries, and creeks into the saltier Duwamish estuary and Salmon Bay, where they undergo physiological transformations that allow them to survive in a fully marine environment.

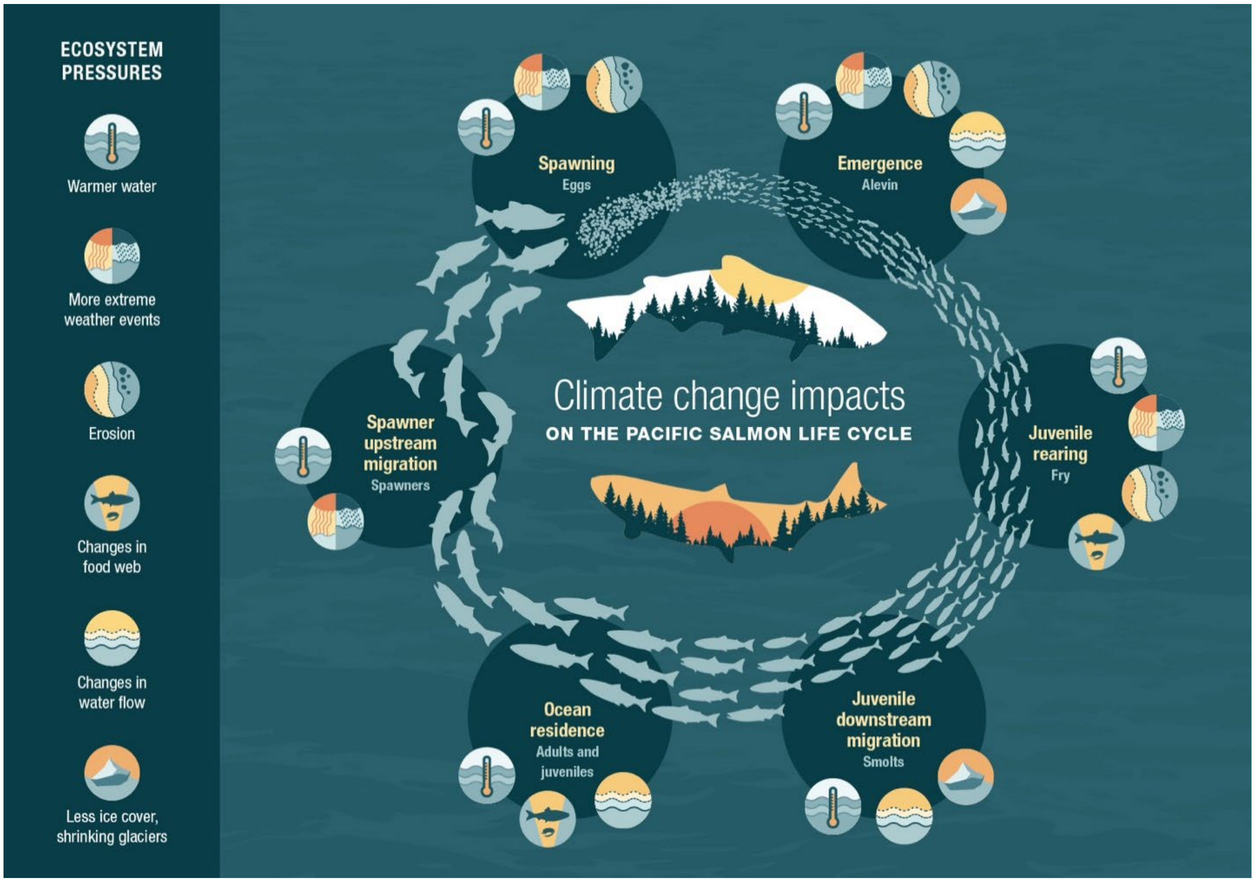


Figure 40. Climate Change Impacts on Pacific Salmon

Notes: Figure depicts climate change impacts across the lifecycle of Pacific salmon (Fisheries and Oceans Canada, 2021).

Generally, salmon are extremely vulnerable to the impacts of climate change, though there is some variability depending on salmonid species and life stage (Figure 40). Some of the key climate risks to salmon include: 1) increased winter peak flows could disrupt salmon eggs and fry and expose juvenile salmon to increased pollutants and storm runoff as flood risk increases in urban areas, 2) warmer water temperatures and associated dips in dissolved oxygen levels could directly or indirectly increase mortality rates of salmon in freshwater habitat, especially in the Lake Washington Ship Canal, and 3) sea level rise could eliminate existing nearshore habitat, which is crucial for out-migrating juvenile salmon.

WINTER PEAK FLOWS

Higher peak streamflows due to increased winter rainfall will negatively impact Seattle's salmon populations by increasing flood risk (see **Urban Watershed** section). Streambed scour caused by more frequent and intense flooding physically disrupts salmon redds and increases egg and parr mortality rates (Mantua et al., 2009). Excess sediment and particulate matter can also suffocate sensitive salmon eggs and larvae (Panthi et al., 2022). Additionally, the potential increase in pollutant-laden storm runoff is a particular threat to salmon, which accumulate and retain PCBs and other toxins as they move up the food chain

(Meador et al., 2010). This is especially a risk in the highly polluted Duwamish estuary, where parts of the watershed is designated as an EPA Superfund site.

WARMER WATER TEMPERATURES

Warmer water temperatures will threaten the survival of fish species with lower thermal tolerances (see **Urban Watersheds** section). Water temperatures consistently above 71.6°F (22°C) lead directly to salmon mortality, while temperatures above 59.0°F (15°C) can decrease reproductive success and increase infection rates from a variety of pathogens (Mantua et al., 2009; Urgenson et al., 2021; Water Quality Program, 2002).

Because shallower and smaller bodies of water absorb heat more quickly than deeper and larger bodies of water, smaller creeks and the Lake Washington Ship Canal are especially susceptible to temperature increases (Mantua et al., 2009; Urgenson et al., 2021). As a result, they will have fewer cold-water refugia available for migrating salmon. High water temperatures in the ship canal already serve as barriers to migration for spawning adults. They also negatively impact out-migrating juveniles by allowing predators with higher thermal tolerances to flourish (Mantua et al., 2009; WRIA 8, 2017). The WRIA 8 Salmon Recovery Council lists the current high temperatures and water quality within the Lake Washington Ship Canal as some of the greatest barriers to Chinook recovery within WRIA 8 (WRIA 8, 2017).

SEA LEVEL RISE AND NEARSHORE SALMON HABITAT

Sea level rise in Seattle has the potential to limit critical habitat for juvenile salmon in the Duwamish and Salmon Bay estuaries (see **Urban Watersheds** section). Estuaries provide vital refuge and resources for juveniles during the smolt stage, when their bodies acclimate to higher saltwater concentrations and their growth rates accelerate before moving into marine waters as mature adults. The habitat diversity within estuarine nurseries provides the prey and nutrient abundance growing salmon need, while also offering protection from predators.

Even without full submergence, rising sea levels could disrupt the temporal patterns of prey availability and productivity on which salmon have evolved to depend, as tides and water temperatures shift within estuaries (Davis et al., 2022).

FRESHWATER HABITAT AVAILABILITY AND CONNECTIVITY

Freshwater riparian and lake ecosystems provide critical overwintering refugia and rearing habitat for juvenile salmon, as well as spawning areas for adult salmon. These urban ecosystems also provide habitat for other wildlife, shade for surrounding residents, and opportunities for recreation. Climate-related hazards – such as extreme heat and flooding – interact with land use, placing some of these habitats at-risk. While the city is engaged in numerous initiatives to preserve, improve, and restore this freshwater habitat (WRIA 8, 2017).

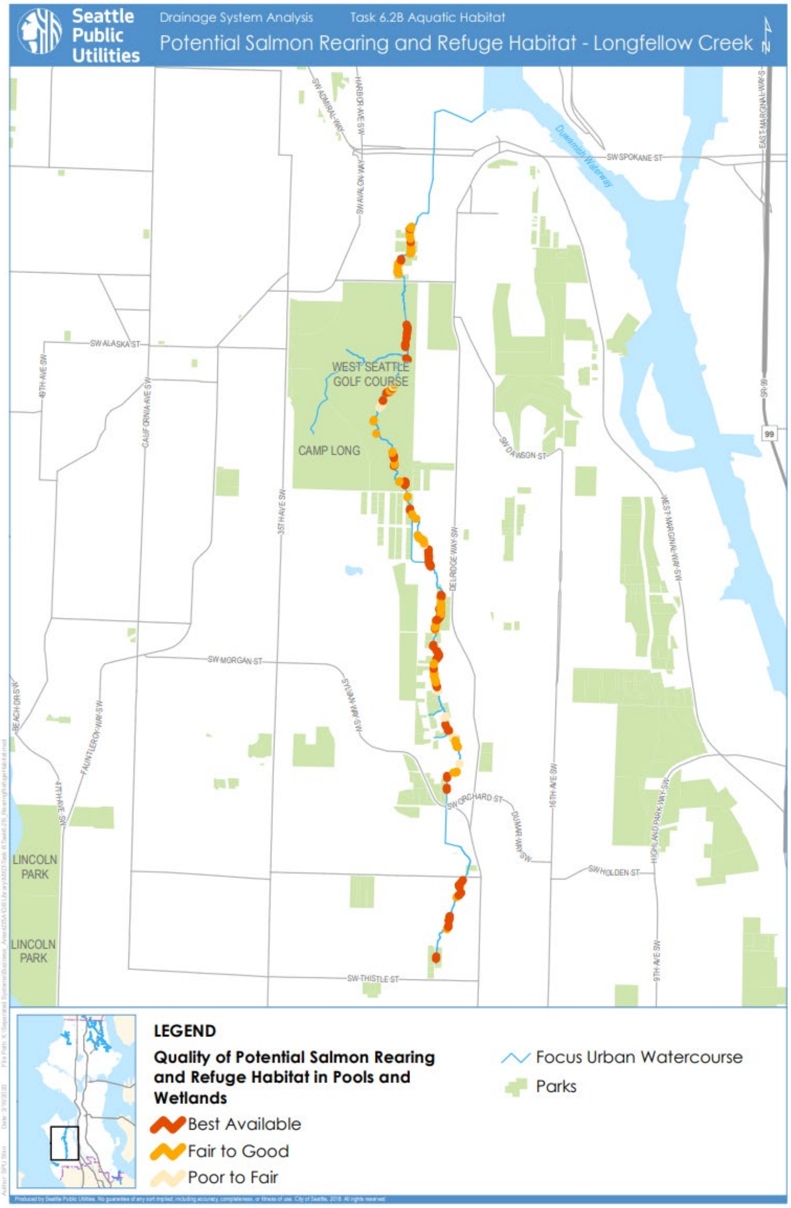


Figure 41. Areas of Potential Salmonid Habitat for Rearing and Refuge in Longfellow Creek

Notes: The figure shows areas of best, fair, and poor potential for salmon rearing and refuge in Longfellow Creek. Most areas indicated on the map appear to be rated at fair to best (Lyons, 2022).

Restoring floodplain connectivity is one of the best ways to improve salmon rearing capacity in the Cedar River watershed and smaller urban watersheds (WRIA 8, 2017). The City has also already identified areas within urban waters that have the greatest potential to provide refuge, rearing, and/or spawning habitat, which could be the focus of future conservation efforts (Figure 41) (Lyons, 2022). For example, in some waterways, such as Taylor and Longfellow Creeks, the best available habitat remains upstream of significant fish passage barriers. Helping fish overcome these obstacles could provide greater access to existing higher quality upstream habitat.

Urban Tree Canopy and Open Spaces

The thermoregulatory, filtration, and flood control benefits that urban trees and their canopies provide are critical tools in adapting Seattle communities to its hotter and more seasonally extreme future climate (see **Community Amenities and Wellbeing** section). At the same time, however, climate change poses many risks to urban trees themselves, and threatens their capacity to provide these important ecosystem services.

Urban tee canopy currently covers 28.1 percent of the city and has declined since the 2016 tree canopy assessment that showed about 28.6 percent coverage (Figure 42) (City of Seattle Office of Sustainability & Environment, 2021). The majority of canopy cover is concentrated in residential neighborhoods on private land, where the City regulates and supports tree planting, maintenance, and removal (47%; Figure 43). An additional 23 percent of canopy exists on right-of-way property, including streets, sidewalks, and planting strips. While private property owners adjacent to right-of-way land are usually responsible for tree maintenance, various City departments also manage urban forests and permitting processes throughout the City. The City of Seattle also owns and directly manages public trees in natural and developed park areas, accounting for 19 percent of canopy cover (Figure 43).

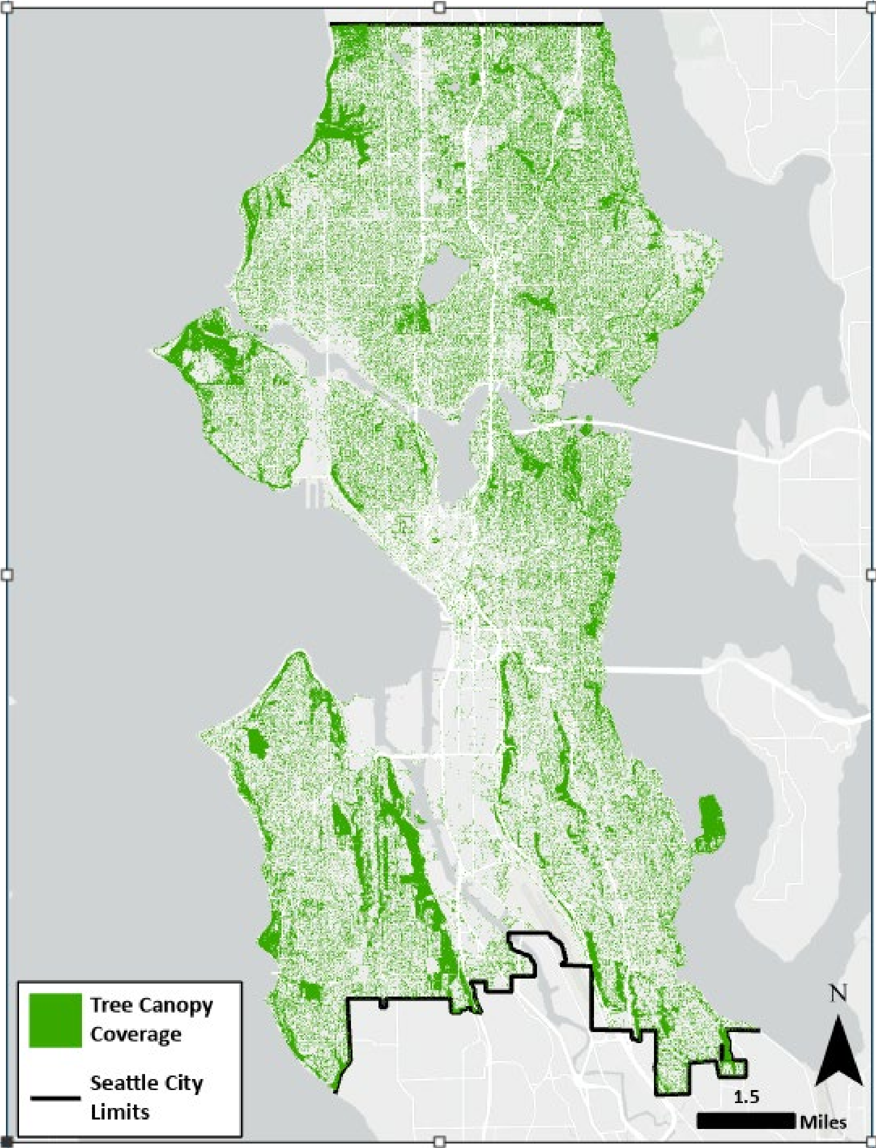


Figure 42. Tree Canopy Coverage and Street Trees in Seattle in 2021

Notes: This figure shows areas of green where there is tree canopy coverage in Seattle (City of Seattle, 2022).

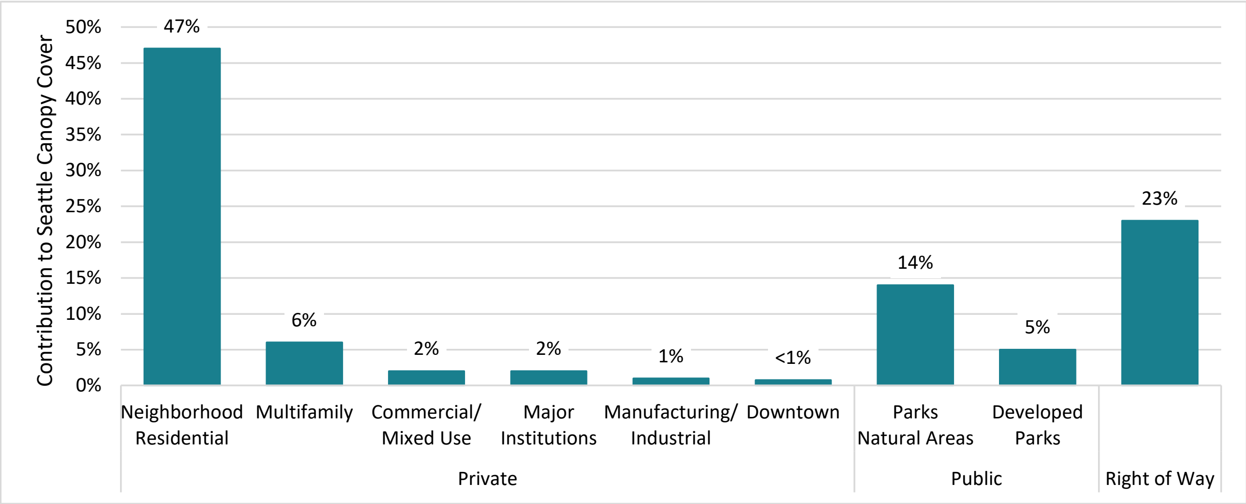


Figure 43. Distribution of Seattle's 2021 Canopy Coverage by Land Management Unit

Notes: The chart shows how tree canopy coverage in Seattle is distributed by land use type, including across types of private, public, and right-of-way land (City of Seattle Office of Sustainability & Environment, 2021).

At the neighborhood level, canopy cover is not distributed equitably throughout Seattle. Neighborhoods that scored as most disadvantaged on the Racial and Social Equity Composite Index, designated as environmental-justice priority areas for the city, have 31 percent less cover than the most advantaged neighborhoods (City of Seattle Office of Sustainability & Environment, 2021). These areas are already most at risk from climate change, and any impacts to their limited existing canopy cover may be felt more acutely than elsewhere in the city (see **Community Amenities and Wellbeing** section).

Where canopy cover exists, trees cool their surrounding air through shade and evapotranspiration, cutting energy costs, reducing strain on the power grid, and mitigating the effects of urban heat islands (Safford et al., 2013). For every additional 13 percent of canopy coverage across several Seattle blocks, air temperature decreases by 0.5°F (City of Seattle Office of Sustainability & Environment, 2021). In 2012, urban trees saved the City an estimated 43,000 mega-watt-hours of electricity and 1.6 million BTUs each year (Green Cities Research Alliance, 2012). Shade from trees can also insulate urban waterways from high temperatures that would otherwise negatively impact salmon and other fish populations (see **Urban Watersheds** section).

Urban canopies can play an additional role in intercepting precipitation and airborne pollutants, depending on species composition and season (see **Public Health** section). For both deciduous and coniferous trees, rainfall is distributed across the collective leaf surface area, slowing the rate at which it is absorbed into the ground below or is shed as runoff (Green Cities Research Alliance, 2012). Pollutants and particulate matter may also be deposited onto leaves and other tree surfaces, temporarily suspending them and improving air quality (Pace & Grote, 2020; U.S. Environmental Protection Agency, 2008). Seattle's trees eliminate approximately 725 metric tons of pollutants each year (Green Cities Research Alliance, 2012).

Generally, Seattle's urban trees and the benefits they offer have a moderate to high vulnerability to climate change, due to increased heat, drought, and pathogen stress, limiting their ability to provide these important ecosystem benefits.

INCREASED HEAT STRESS

The longer and warmer summers predicted for the Pacific Northwest under climate change will negatively impact the city's urban tree population through increased exposure to heat stress and pathogen pressure. The probability of Seattle experiencing a heatwave that lasts more than 3 days will increase from 67 percent to 86 percent by 2050 (First Street Foundation, n.d.).

Heat stresses trees primarily by causing dehydration, which is also more likely to occur under climate change due to reduced summer rainfall (see **Climate Change Trends and Projections** section). Heat can also interact with other drivers and increase the risk of tree mortality. For example, leaves tend to accumulate higher sugar concentrations in response to hot and dry conditions, which can make them more attractive to herbivorous insects (Safford et al., 2013). Longer summers may also translate into longer breeding seasons and accelerated population growth for existing pests, while an influx of new pest species from warmer climates will exert additional pressure on the city's urban forests (City of Seattle Urban Forestry Core Team, 2020).

SHIFTING PRECIPITATION PATTERNS AND DROUGHT

Reduced precipitation rates during the summer, coupled with an increase in winter rainfall and more intense winter storms, will also impact Seattle's urban tree community. The greater likelihood of summer drought conditions will exacerbate heat and pathogen stress, and will affect both the recruitment of new, young trees into the urban tree population and the survival of existing older trees (City of Seattle Urban Forestry Core Team, 2020). Stressed trees are also more at risk of injury or being uprooted during winter precipitation events, as snow and ice accumulate on branches and as trees are exposed to severe wind (City of Seattle Urban Forestry Core Team, 2020; Safford et al., 2013). Additionally, flooding from these storms may waterlog soils and overwhelm root systems, leading to tree death.

Ultimately, changing temperature and precipitation regimes will lead to range shifts for some trees that have historically been well-suited to the Seattle region, including many species of conifer (City of Seattle Urban Forestry Core Team, 2020). However, both the conifer and deciduous tree populations within the city are at risk. The current deciduous population is primarily composed of older, second-growth trees that are approaching the end of their natural lifespan, increasing their sensitivity to the stressors described above (City of Seattle Office of Sustainability & Environment, 2021; City of Seattle Urban Forestry Core Team, 2020).

Cascading and Compounding Climate Impacts

Systems – social, economic, and infrastructural – are interconnected. These systems both rely on one another and provide support. Thus, climate change impacts to one system will inevitably have cascading or compounding effects across multiple systems (May et al., 2018). However, many of these impacts are difficult to model or predict because of their interdependent nature, leading to potential "surprises" – or events and impacts that fall outside the scope of climate models (Kopp et al., 2017).

Changes in the climate – such as warmer temperatures, decreased snowpack, sea level rise – have already led to direct impacts to some of our systems. However, not all effects occur in the same way or emerge at the same time, leading to impacts that propagate across timescales and contexts – or cascading impacts (Lawrence et al., 2020).

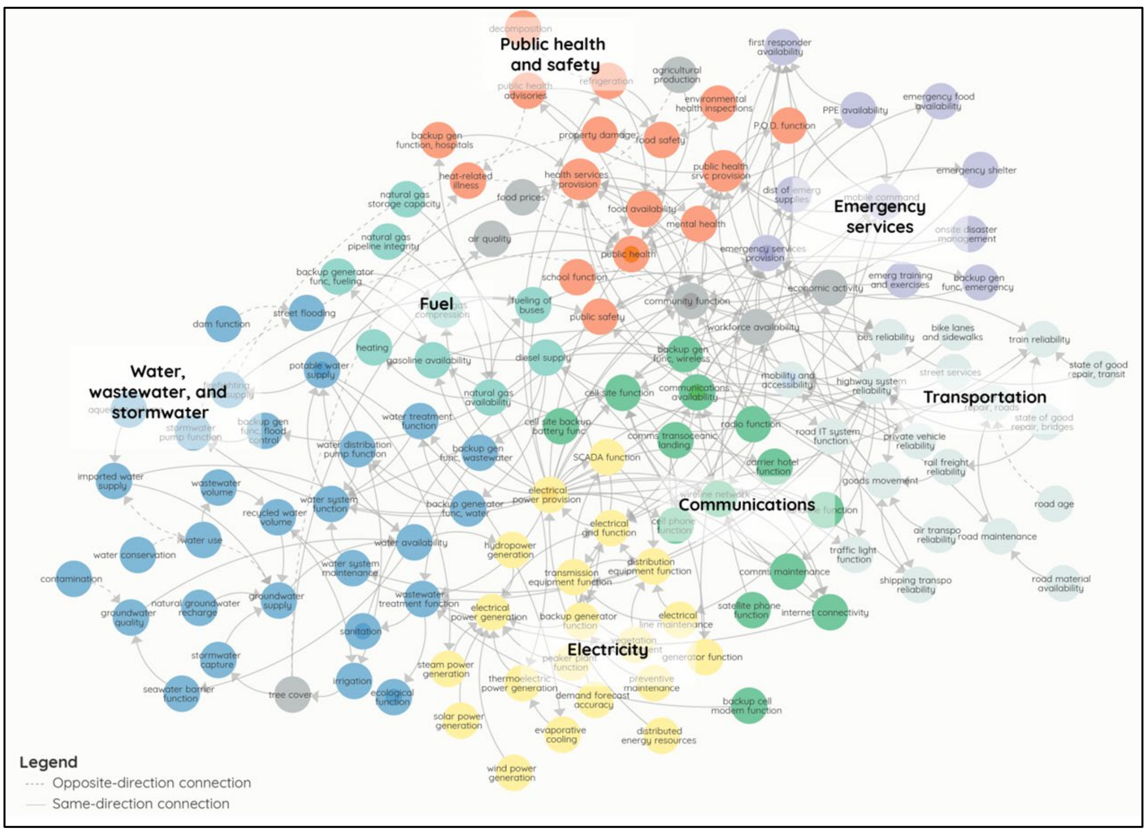


Figure 44. Framework on Interrelated Systems and Potential Cascading Impacts across Systems

Notes: Figure from LA County Climate Vulnerability Assessment (LA County, 2021).

Traditional risk or vulnerability assessments typically treat hazards independent from one another. However, climate change is increasing the likelihood of multiple simultaneous or consecutive climate-related hazards or extreme events to occur, leading to damages and consequences that are exponentially worse than a singular event – or compounding impacts (*Resilience for Compounding and Cascading Events: Consensus Study Report*, 2022; Zscheischler et al., 2018). Additionally, climate hazards and extreme events that co-occur with other non-climatic extreme events – such as the COVID-19 pandemic – often amplify burdens and limit response options (Ford et al., 2022; Zang et al., 2021). For example, the co-occurrence of dramatic increases in $PM_{2.5}$ concentrations due to wildfires in the Northwest were associated with increased exposure to COVID-19 incidences and deaths in the Puget Sound region (Zhou et al., 2021). Furthermore, preliminary evidence suggests that there are cascading mental health implications when extreme events or disasters co-occur (Sugg et al., 2022).

The city of Seattle has experienced multiple extreme events – such as the Heat Dome event in 2021. Currently, there are limitations in how to quantitatively evaluate cascading and compounding impacts from these extreme events. Additionally, there is lag-time between the occurrence of extreme events and documentation of these events in the peer-reviewed literature base (Roesch-Mcnally et al., 2020). Thus, these sections rely largely on media outlets, which often are the first to describe and report on extreme events and associated acute impacts.

This section attempts to illuminate some of these potential impacts from cascading and compounding events using the 2021 heat dome event as a case study.

2021 Heat Dome Event

The city of Seattle – along with the rest of the Pacific Northwest, from northern California through southeast Alaska – experienced an unprecedented extreme heat wave from mid-June through early July, known as a heat dome event. The 2021 heat dome event – which was caused by a high-pressure system that blocked cool maritime winds and cloud formation – is a highly improbable and extreme weather event, even under current climate change conditions (White et al., 2023). However, the likelihood of an event like the 2021 heat dome was made more likely in part due to climate change (Philip et al., 2022; White et al., 2023).

During the heat dome event, Seattle experienced temperatures that were 30°F warmer than the historical average for the same time period. Seattle set temperature records of 108°F, and there were three consecutive days with temperatures that exceeded 100°F. Other neighboring cities saw temperatures exceed 110°F (National Weather Service, 2021). Nighttime temperatures, which often serve as a period of cooling respite, were warmer than historical daytime averages for the same periods.

Access to air conditioning or cooling centers during heat events is critical for a community's ability to adapt to extreme heat impacts, particularly for sensitive populations. In response to the 2021 heat dome, the City and its partners opened 36 "cooling centers" at community facilities (i.e., senior centers, community centers, libraries), hygiene centers, and emergency shelters for people experiencing homelessness, and 30 beaches, pools, spray parks, and wading pools for people to cool off (City of Seattle Opens Additional Cooling Centers and Updated Guidance for Staying Cool in Extreme Heat, 2021).

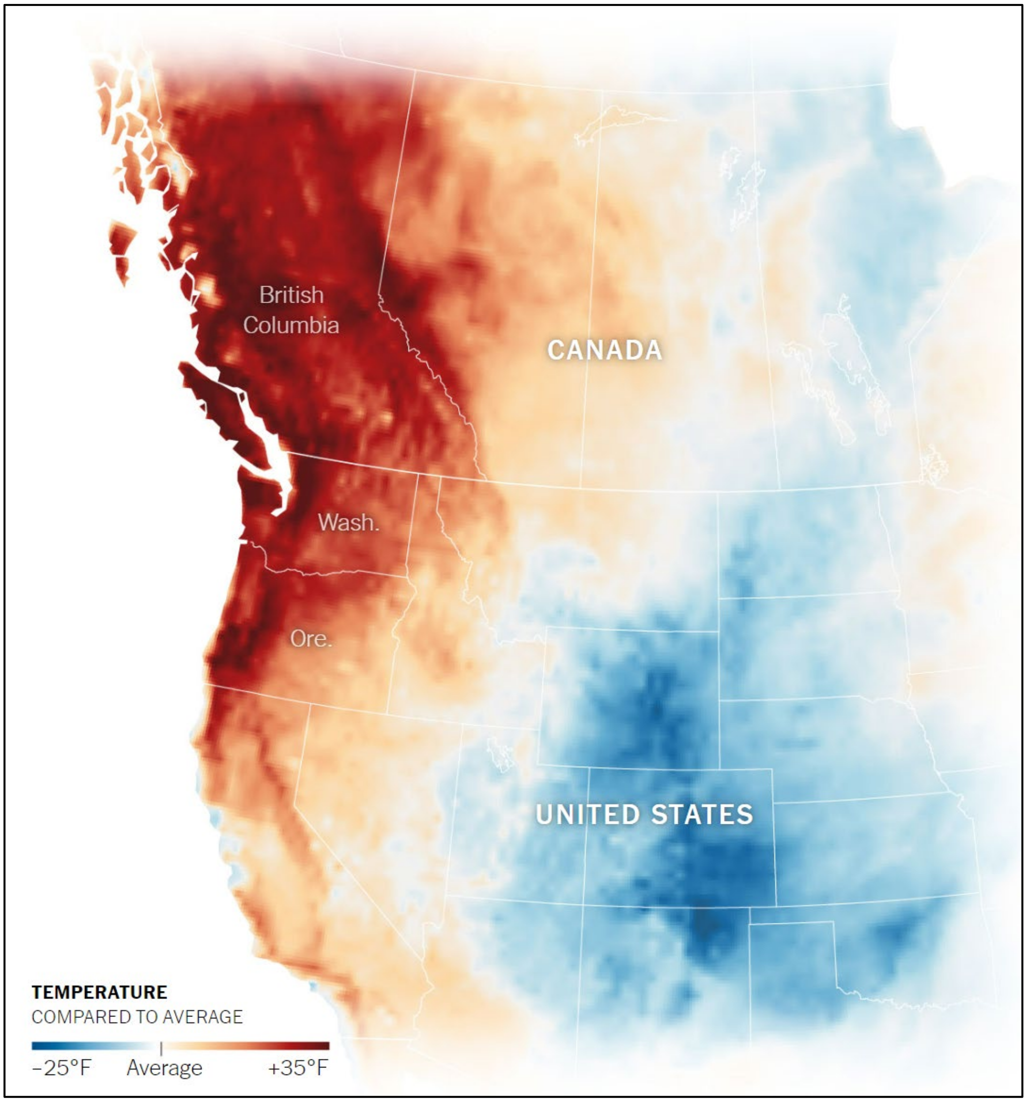


Figure 45. Temperature Anomalies for June 27, 2021 Relative to Average Temperatures for the Same Date from 2014-2020, Adapted from NASA Earth Observatory

Notes: This figure shows elevated temperatures on June 27, 2021 across the western United States and Canada. In some areas, temperatures were 35 degrees F higher than they were on average from 2014-2020 (Popovich & Choi-Schagrin, 2021).

Because of the heat dome, the city of Seattle saw a lot of cascading impacts across its communities and systems – from impacts to public health and the built environment to the local economy. Some of these impacts are still being studied, and research is underway to attribute some of these consequences to the 2021 heat dome event. Below are some of the key cascading impacts that have already been documented. There are likely additional impacts that have yet to be documented and/or are still emerging.

Public Health Impacts

The 2021 heat dome led to extremely significant increases in heat-related illnesses and deaths (Schramm et al., 2020; Weinberger, 2022). Across the Pacific Northwest, heat-related emergency room visits were 69 times higher during the heat dome event compared to 2019 (Schramm et al., 2020) (Figure 46Figure 1). In King County, there were 30 heat-related deaths and many other heat-related injuries (Weinberger, 2022). The excess morbidity and mortality attributed to the heat dome event disproportionately affected older residents and low-income households without air conditioning capacity (Fisher et al., 2021; Schramm et al., 2020). Furthermore, emergency responders and emergency room staff were overextended in treating heat-related injuries and illnesses during the heat dome event, acutely stressing the regional health safety net after a period of chronic stress caused by the COVID-19 pandemic (Weinberger, 2022).

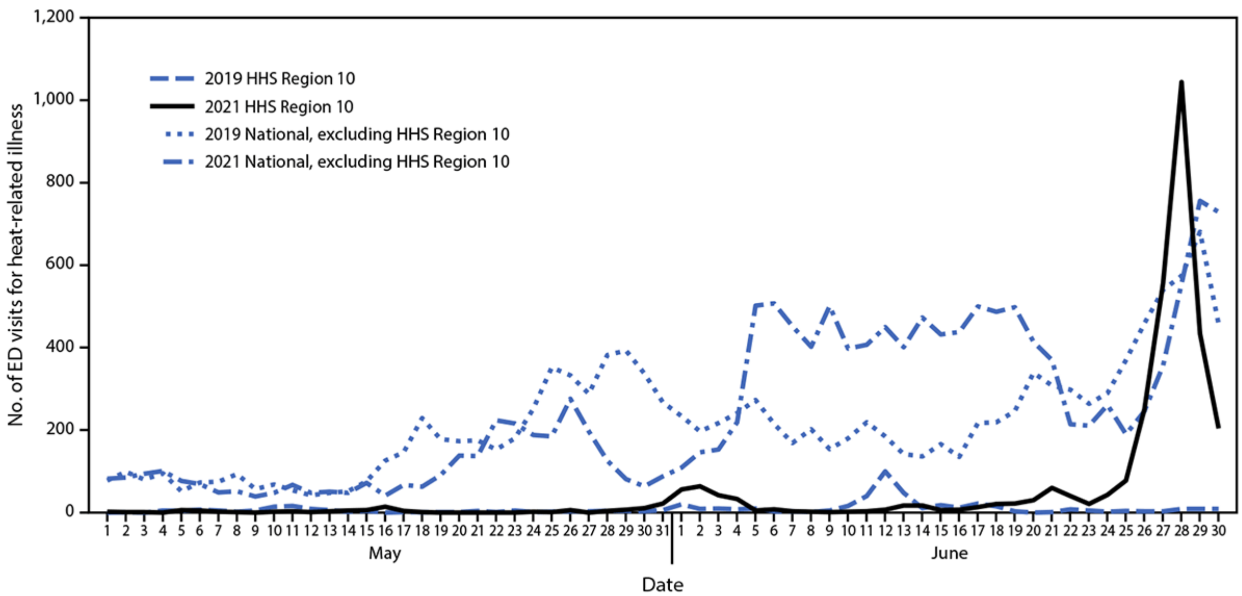


Figure 46. Number of Emergency Department Visits for Heat-Related Illness in U.S. Department of Health and Human Services Region 10 (WA, OR, ID, And AK) and Nationwide (Excluding Region 10) from May 1–June 30, 2019 and 2021

Notes: The figure shows elevated emergency department visits for heat-related illness in the Pacific Northwest and nationwide during the period of the 2021 heat dome event (Schramm et al., 2020).

Documented heat-related illnesses and deaths almost certainly underestimate the true health toll of the heat dome event (Popovich & Choi-Schagrin, 2021). People without health insurance, low-income households, socially isolated individuals, BIPOC, women, and people who do not fluently speak English are underserved by emergency medical services (Farcas et al., 2022; Schramm et al., 2020; USDA Northwest Climate Hub, n.d.). Thus, documented heat-related illnesses and deaths during and after the heat dome event likely undercounts the rates of heat-related morbidity and mortality for these groups (Popovich & Choi-Schagrin, 2021).

Preliminary research is beginning to document the mental health toll – such as increased anxiety – of the heat dome event on residents across the Pacific Northwest (Bratu et al., 2022). Additional mental health consequences – both acute and chronic mental health illnesses – are likely to continue emerging as scholarship around extreme heatwaves continues to evolve. For example, evidence suggests associations between heatwaves with domestic violence, abnormal birth outcomes, adverse maternal health outcomes, and self-harm and suicide (Cil & Cameron, 2017; Sanz-Barbero et al., 2018; Thompson et al., 2018). As of yet, no research has been conducted on the community health outcomes associated with the 2021 heat dome event.

Infrastructure Impacts

The heat dome event also had dramatic impacts on the city of Seattle's infrastructure systems. Across the greater Seattle area, there were at least five instances of pavement buckling on I-5 and I-90 that required maintenance from WSDOT responders (Crowe, 2021) (Figure 47). The City also had to spray cool water on the city's moveable steel bridges (Crowe, 2021), as extreme heat can expand the joints that connect two bridge spans (Palu & Mahmoud, 2019). Additionally, public transit agencies such as Sound Transit had to implement slow orders to monitor rail tracks, which can expand during extreme heat events, and the overhead catenary system, which can sag and loosen during extreme heat events (Whitely Binder et al., 2013). These collective impacts to the transportation system disrupted traffic, increased congestion, and increased occupational exposure to extreme heat conditions for maintenance workers and responders.

While other localities around Washington experienced energy blackouts and brownouts due to high energy demand for cooling (Geranios & Selsky, 2021), the city generally has capacity to accommodate additional energy loads during peak demand times (Alexander et al., 2022; Raymond, 2013). This allows greater resiliency during events such as the heat dome. However, as additional changes to the climate affect regional snowpack and precipitation patterns, the timing of energy supply for hydroelectric sources may be insufficient to meet future energy demand (Raymond, 2013), especially during extreme events (e.g., 2021 heat dome) that that require systems to be resilient and continue to function at increased capacity.

Figure 47. Pavement Buckling During the 2021 Heat Dome Event on Southbound I-5 at NE 130th St.

Notes: The photo shows buckling pavement on southbound I-5 during the 2021 heat dome event ("Pavement on I-5 Buckles in Extreme Seattle Heat," 2021).

Economic Impacts

The heat dome event also had many acute, and likely chronic, economic consequences for residents and businesses. Many restaurants in Seattle had to temporarily shut down due to excessive heat and insufficient ventilation or cooling capacity for its workers (Figure 48) (Pae, 2021). Many other workers and businesses – from factory workers to educators to construction workers – had work temporarily halted due to the extreme heat (Layne, 2021). This led to lost labor hours and associated wages for these workers. Lost wages associated with extreme heat are projected to continue increasing in the future (see **Economic Vulnerability** section). Financial instability – even short-term instability – from the heat dome event has also been linked to additional anxiety for residents in the Pacific Northwest (Bratu et al., 2022). Additional health burden for workers exposed to extreme heat may place increased financial burden on these individuals, especially for workers that lack health insurance coverage from their employers (S. Lawrence, 2021). Additionally, small businesses will have more difficulty recovering revenue and operational efficiency due to economic shocks like the heat dome event (see **Economic Vulnerability** section). It is very likely that the long-term economic consequences – for businesses and workers – have yet to be fully understood.

Figure 48. Business Closure During the 2021 Heat Dome Event

Notes: A sign shows that Molly Moon's Ice Cream store in Capitol Hill is closed during the heat dome event. Source: Ted S. Warren/AP.

2022 King Tide Flood Event

In late December 2022 – between December 22nd through December 28th – the city experienced multiple consecutive events that led to compounding flooding impacts across the city. Seattle experienced a historic winter storm that included snowfall and freezing rain on December 22nd and December 23rd (Bleed & Hollingsworth, 2022). Several days later, on December 27th, the city also experienced a king tide – a colloquial term that references exceptionally high tides – combined with storm surge during a low-pressure storm to create a flood event across shoreline areas in Seattle that was the highest recorded flood in over 30 years (Sundell, 2022). Finally, the city and the Pacific Northwest experienced a series of heavy rains driven by atmospheric rivers between December 27th and December 31st (Bekiempis, 2022).

Figure 49. Multiple Consecutive Events in December 2022 Led to Severe King Tide Flooding and Limited Response Capacity

Independent from each other, each of these events would have resulted in mild to severe flooding – rain-on-snow snowmelt, atmospheric rivers, and King Tides can all cause flooding. However, in sequence, these events lead to compounding and amplifying flooding impacts as systems may not have conveyed all water before the next event and response capacity may be limited due to safety concerns of first responders (Figure 49). Additionally, the December 2022 King Tide event was an exceptionally high King Tide that led to unprecedented flooding – with flooding approximately 13 feet (NAVD88) – for neighborhoods like South Park, which was further worsened by the winter storm immediately before and the atmospheric rivers immediately after the King Tide event. While it is difficult to attribute a specific King Tide event to climate change, King Tides provide a glimpse into what future sea levels will look like. The 2022 King Tide event is similar to projected sea levels in the 2080s under RCP8.5.

Water overtopped the riverbanks first at the lowest points along the bank in South Park, including the intersections of 5th Ave. S and S Fontanelle St. and S Riverside St. and S Austin St. As the water rose higher, higher elevation areas of the bank began to overflow, including the intersection of S Riverside Dr. and S 7th Ave. and the intersection of S 8th Ave. and S Portland St. In addition to flooding coming over the riverbanks, 13 households were displaced, and families and businesses in South Park experienced sewer overflows inside homes and buildings as the high river water pushed backward into combined sewer and stormwater pipes. Street flooding from stormwater was also observed in low-lying areas in Georgetown affecting multiple industrial properties.

Conclusion

Climate Resilience Opportunities

This CVA outlines the city of Seattle's physical and social vulnerabilities to the most critical known climate hazards. The areas of vulnerability discussed in this assessment overlap and intersect with social injustices – including income inequality, disparities in health outcomes and access to amenities and services, and access to safe, adequate housing. The City is committed to responding to the multitude of challenges presented by climate change and supporting a more equitable and resilient future for all residents.

This CVA has assessed climate change impacts and social and physical vulnerability across Seattle. It has identified that flooding and sea level rise, extreme heat, wildfire smoke, and extreme precipitation will have wide-ranging and interconnected impacts for the city. There are some key, broad areas that the City can invest in to address these:

- **Invest in community services**, including cooling and clean air centers, access to cooling and air filtration systems for homes, and tree canopy. Focus these community services in the International District, SODO area, Lower Duwamish, Rainier Valley, Northgate, and Lake City, which are rated as exposed and vulnerable to multiple climate impacts, and where communities have been subject to historic inequities.
- **Support communities in the Duwamish and Georgetown area and downtown businesses** that will be increasingly impacted by flooding.
- **Further research potential supply chain impacts** for local businesses due to climate change.
- **Monitor and maintain transportation systems**, particularly after extreme heat and flooding events. Transportation systems in the Duwamish and Downtown are most vulnerable to flooding.
- **Improve grid capacity and resilience** to ensure a reliable energy supply as reliance on electricity increases and systems are stressed by climate impacts.
- **Prioritize water and wastewater systems' resilience to flooding impacts.**
- **Protect and expand the city's tree canopy** to benefit both local communities and ecosystems, prioritizing areas in the International District, SODO area, Lower Duwamish, which experience an urban heat island effect.
- **Collaborate regionally to protect the Cedar River and South Fork Tolt watersheds and salmon habitats.**

Integration into One Seattle Comprehensive Plan

Next, the City will integrate findings from this CVA into the Seattle One Plan, or the City's Comprehensive Plan Update, to both reflect the City's goals and priorities and comply with a new requirement to include a Climate Element. The City will develop policies to address areas of vulnerability outlined in this CVA, including to protect assets across the city and to recognize, improve the social roots of vulnerability for communities in Seattle, and integrate climate resilience considerations into City decision-making processes – ensuring that research and initiatives across departments are shared and can drive citywide planning.

To further develop adaptation actions using the results of this CVA, the City can:

1. **Set a vision, objectives, and goals to guide adaptation planning.**
2. **Identify an initial list of policies.** The Washington State Commerce Department's climate planning resources include a model climate element and a menu of resilience options for cities to consider adopting into their comprehensive plans.
3. **Refine the list of policies based on Seattle's specific context** and identify costs, benefits, and constraints of each action. Align actions with ongoing work across departments and consider collaborating with K4C, the King County-Cities Climate Collaboration, for regional alignment of policies.
4. **Continue to engage the community** to ensure that actions match community context and priorities.
5. **Write the final list of policies** and determine a final decision about how the City will incorporate adaptation actions into the Seattle One Plan – whether as part of a standalone Climate Element, integrated throughout other plan elements, or adopted as part of a hazard mitigation plan that meets all requirements of a climate element.
6. **Establish an implementation schedule and action plan** for seamless implementation of policies.

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Appendix A. Detailed Methodology and Results

This section will describe the methodology and detailed results of the index approach Cascadia used to determine relative social vulnerability of census tracts. The Social and Economic Vulnerability Assessment utilizes an index approach, which is a method to quantitatively normalize multiple criteria that allows for comparability.

Full List of Indicators Considered

We developed a potential list of sensitivity and adaptive capacity indicators by referencing comparable vulnerability assessments, such as those from the City of Redmond (WA) and Los Angeles County (CA), as well as a technical guidance document from the University of Notre Dame (BERK Consulting, Inc.; Perteet; The Watershed Company; UW Climate Impacts Group, 2022; LA County, 2021; Chen, et al., 2015).

After developing the initial list, we solicited additional potential indicators and data sources from City staff and through additional data requests.

We then vetted all potential indicators by asking the following questions:

- **Is the data relevant?** We used indicators that are as recent as possible and that have clear connections to climate change.
- **Is the data available?** Datasets need to be publicly available or shareable without sensitive and identifiable data being shared.
- **Is the data high quality?** We avoided datasets that are incomplete and sought local datasets whenever possible.
- **Is the data at a census tract-level resolution?** We included all census tracts that are within city boundaries and that overlap with city boundaries.
- **Does the data show variability across the city?** Some datasets are relevant, high quality, and available at the census tract level, but do not show any variability across the city and are therefore not useful for the indices.

The full list of indicators can be found below. The first table lists indicators that apply across the focus areas; subsequent tables show indicators by focus area.

Cross-cutting Indicators

Vulnerability Element	Indicator	Relevant?	Available at High Quality?	Appropriate Spatial Resolution?	Included in Analysis?	Source
Exposure	100-year floodplain	Yes – flooding is directly tied to climate impacts	Yes	Yes	Yes	FEMA Flood Map Service Center (2020)
Exposure	500-year floodplain	Yes – flooding is directly tied to climate impacts	Yes	Yes	Yes	FEMA Flood Map Service Center (2020)
Exposure	Extreme heat	Yes – includes maps of average, max, and min temps by census tract	Yes	Yes	Yes	King County Heat Mapping Project (2020)
Exposure	Sea level rise	Yes – sea level rise is directly tied to climate change	Yes	Yes	Yes	• NOAA Digital Elevation Model (2020) • NOAA Tidal Datums Interactive Sea Level Rise Data Visualizations (2018) • Puget Sound Storm Surge Modeling (2019)
Exposure	Extreme precipitation, 2040-2069 and 2070-2099	Yes – extreme precipitation is directly tied to climate change	Yes	Yes	No – only described in Climate Impacts chapter	University of Washington Climate Impacts Group (2022)
Exposure	Landslide risk: slope hazards	Yes – climate-related extreme precipitation and wildfires are linked to increased landslide risk	Yes	Yes	Yes	City of Seattle GIS (2023)

Vulnerability Element	Indicator	Relevant?	Available at High Quality?	Appropriate Spatial Resolution?	Included in Analysis?	Source
Sensitivity	City of Seattle's Race and Social Equity Index	Yes – social factors are predictors of severity of climate change impacts on some groups	Yes	Yes – this Seattle based dataset does provide useful information at the local level	Yes	Racial and Social Equity Composite Index Current (2023)

Community Amenities & Wellbeing Indicators

Vulnerability Element	Indicator	Relevant?	Available at High Quality?	Appropriate Spatial Resolution?	Included in Analysis?	Source
Exposure	Climate exposure to flooding	Yes	Yes	Yes	Yes	FEMA Flood Map Service Center (2023)
Sensitivity	Food Security and Access	Yes	Yes	Yes	Yes	USDA Economic Research Service (2022)
Sensitivity	Access to Parks	Yes	Yes	Yes	Yes	Seattle Parks (2023)
Adaptive Capacity	Tree Canopy	Yes	Yes	Yes	Yes	City of Seattle (2021)
Adaptive Capacity	Critical Facilities	Yes	Yes	Yes	Yes	Office of Emergency Management (2021)
Sensitivity	Cultural Centers	Yes	No	N/A – did not locate	No	N/A
Sensitivity	Wildland Urban Interface (WUI)	Yes – this is not a projection of wildfire, but indicates that some variables contribute to wildfire risk	Yes	Yes	No – there was no variability across the city	Washington State Department of Natural Resources (2021)

Economy Indicators

Vulnerability Element	Indicator	Relevant?	Available at High Quality?	Appropriate Spatial Resolution?	Included in Analysis?	Source
Exposure	Current Lost Labor Hours due to Extreme Heat	Yes – an estimate of lost labor hours due to extreme heat events	Yes	Yes	Yes	US EPA (2021)
Exposure	Projected Lost Labor Hours in 2050 due to Extreme Heat	Yes – an estimate of lost labor hours due to extreme heat events in 2050	Yes	Yes	Yes	US EPA (2021)
Sensitivity	Climate Exposed Occupations	Yes – some occupations are more climate-exposed than others	Yes	Yes	Yes	US Census Bureau (2021)
Sensitivity	Number of Small Businesses	Yes – small businesses are more sensitive to disruptions than large businesses	Yes	Yes	Yes	Office of Emergency Management (2021)
Adaptive Capacity	Unemployment Rates	Yes – unemployment indicates community ability to withstand economic shocks	Yes	Yes	Yes	US Census Bureau (2021)
Adaptive Capacity	Owner-Occupied Housing	Yes – home ownership is a mechanism for wealth accumulation, generally associated with higher adaptive capacity	Yes	Yes	Yes	City of Seattle (2016)

Public Health Indicators

Vulnerability Element	Indicator	Relevant?	Available at High Quality?	Appropriate Spatial Resolution?	Included in Analysis?	Source
Exposure	Mortality associated with PM2.5	Yes – assesses how future climate-related $PM_{2.5}$ increases (e.g., wildfire smoke, air pollution) increase mortality for adults 65 and older	Yes	Yes	Yes	US EPA (2022)
Exposure	New incidences of asthma associated with PM2.5	Yes – assesses expected new incidences of climate-related asthma for youth 18 and under	Yes	Yes	Yes	US EPA (2022)
Exposure	Asthma-related emergency room visits associated with PM2.5	Yes – assesses expected changes in emergency room visits due to climate-related $PM_{2.5}$ impacts for youth 18 and under	Yes	Yes	Yes	US EPA (2022)
Sensitivity	City of Seattle's Race and Social Equity Index	Yes	Yes	Yes	Yes	Race and Social Equity Index (2023)
Adaptive Capacity	Uninsured rates	Yes – assesses % of population within a census tract that does not have health insurance	Yes	Yes	Yes	US Census Bureau (2021)

Infrastructure Indicators

Vulnerability Element	Indicator	Relevant?	Available at High Quality?	Appropriate Spatial Resolution?	Included in Analysis?	Source
Exposure	Transmission and distribution lines	Yes – this is a component of infrastructure	Yes	Yes	Yes	US Energy Information Administration (2021)
Exposure	Public transit routes	Yes – this is a component of infrastructure	Yes	Yes	Yes	King County GIS (2020)
Exposure	Bridges and tunnels	Yes – this is a component of infrastructure	Yes	Yes	Yes	City of Seattle GIS (2022)
Exposure	Rail lines	Yes – this is a component of infrastructure	Yes	Yes	Yes	WSDOT GIS (2012)
Exposure	Water facilities	Yes – this is a component of infrastructure	Yes	Yes	Yes	SDOT Asset List (2018)
Exposure	Sewer facilities	Yes – this is a component of infrastructure	Yes	Yes	Yes	Office of Emergency management (2019)
Exposure	Stormwater facilities, stormwater lines, stormwater outfalls, stormwater culverts	Yes – this is a component of infrastructure	Yes	Yes	Yes	Office of Emergency management (2019)
Exposure	Coastal flooding and traffic impacts	Yes – shows traffic volume for Seattle arterial streets	Yes	Yes	No – data limited to arterial streets	Seattle Department of Transportation (2019)

Natural Systems Indicators

Vulnerability Element	Indicator	Relevant?	Available at High Quality?	Appropriate Spatial Resolution?	Included in Analysis?	Source
Exposure	Snowpack at drought level projections, 2050	Yes – shows regional changes to snowpack that will likely affect water availability	Yes	Yes	Yes	University of Washington Climate Impacts Group (2017)
Sensitivity	Critical Habitat for Salmon	Yes	Yes	Yes	Yes	Seattle Public Utilities (2019)
Sensitivity	Environmentally Critical Areas (ECA)	Yes – assesses liquefaction-prone areas within Seattle	Yes	Yes	Yes	City of Seattle (2022)
Adaptive Capacity	Tree Canopy	Yes	Yes	Yes	Yes	City of Seattle (2022)

Social Vulnerability Calculation

After selecting indicators, we normalized each dataset into indices to allow for comparability between census tracts. We weighed exposure, sensitivity, and adaptive capacity equally in the analysis. Indices are on a scale of zero to one, where zero means lower vulnerability and one means higher vulnerability.

$$\text{Vul. Index} = \frac{1}{3} \times \frac{1}{n_{\text{Exp.}}} \sum_{i=1}^{n} \text{Exp. Index} + \frac{1}{3} \times \frac{1}{n_{\text{Sen.}}} \sum_{i=1}^{n} \text{Sen. Index} + \frac{1}{3} \times \frac{1}{n_{\text{Adap.}}} \sum_{i=1}^{n} \text{Adap. Index}$$

To find the associated percentiles, we calculated the percentile of each index and highlighted census tracts with the highest relative vulnerability to climate change across each focus area. We mapped the results in ArcGIS.

Social and Economic Vulnerability Results

We opted to use common neighborhood names to describe CVA results, rather than census tract numbers, to make the results clearer. The table below correlates census tracts with neighborhood names we use in the body of the document for full transparency into the results. Percentiles are ranked on a scale of zero to one, where zero means lower vulnerability and one means higher vulnerability.

	Neighborhood	Climate Exposure Percentile	Community Wellbeing Percentile	Economic Percentile	Public Health Percentile
1	Lake City	0.57	0.64	0.20	0.82
2	Lake City	0.85	0.60	0.43	0.81
3	Northgate	0.37	0.51	0.09	0.69
4.01	Bitter Lake	0.07	0.75	0.01	0.75
4.02	Bitter Lake	0.39	0.80	0.06	0.53
5	Broadview	0.61	0.09	0.03	0.32
6	North Park	0.59	0.82	0.25	0.72
7	Leschi	0.02	0.16	0.77	0.63
8	Greenwood	0.95	0.62	0.15	0.33
9	Crown Hill	0.76	0.13	0.04	0.20
10	Lake City	0.98	0.89	0.10	0.68
11	Northgate	0.38	0.24	0.12	0.62
12	Northgate	0.58	0.74	0.07	0.74
13	Northgate	0.39	0.55	0.26	0.77
14	Broadview	0.07	0.13	0.51	0.19
15	Greenwood	0.73	0.12	0.04	0.10
16	Broadview	0.59	0.41	0.16	0.28
17.01	Greenwood	0.39	0.43	0.22	0.58
17.02	Greenwood	0.39	0.46	0.24	0.57
18	Northgate	0.81	0.35	0.24	0.04
19	Maple Leaf	0.07	0.73	0.15	0.56
20	Maple Leaf	0.39	0.43	0.29	0.46
21	Wedgewood	0.84	0.63	0.40	0.92
22	Lake City	0.74	0.40	0.05	0.16
24	Wedgewood	0.88	0.34	0.31	0.59
25	Ravenna	0.07	0.15	0.46	0.29
26	Rosevelt	0.07	0.29	0.55	0.29
27	Green Lake	0.07	0.33	0.18	0.23

	Neighborhood	Climate Exposure Percentile	Community Wellbeing Percentile	Economic Percentile	Public Health Percentile
28	Greenwood	0.39	0.01	0.47	0.13
29	Greenwood	0.07	0.10	0.21	0.05
30	Ballard	0.07	0.36	0.35	0.26
31	Ballard	0.94	0.78	0.37	0.22
32	Ballard	0.89	0.83	0.81	0.50
33	Ballard	0.02	0.17	0.59	0.13
34	Phinney Ridge	0.02	0.08	0.26	0.07
35	Phinney Ridge	0.07	0.04	0.07	0.27
36	Green Lake	0.07	0.31	0.18	0.24
38	Ravenna	0.07	0.23	0.44	0.30
39	View Ridge	0.07	0.11	0.36	0.17
40	Sandpoint	0.62	0.18	0.40	0.39
41	Laurelhurst	0.77	0.61	0.35	0.11
42	Bryant	0.77	0.76	0.89	0.03
43.01	Ravenna	0.39	0.21	0.27	0.55
43.02	University	0.02	0.39	0.19	0.60
44	University	0.62	0.24	0.66	0.54
45	Wallingford	0.02	0.21	0.11	0.35
46	Wallingford	0.07	0.01	0.10	0.06
47	Ballard	0.39	0.51	0.65	0.37
48	Fremont	0.07	0.07	0.32	0.01
49	Fremont	0.62	0.25	0.60	0.18
50	Wallingford	0.62	0.27	0.33	0.21
51	Wallingford	0.99	0.93	0.90	0.32
52	Wallingford	0.62	0.56	0.08	0.64
53.01	University	0.07	0.72	0.02	0.71
53.02	University	0.07	0.44	0.01	0.76
54	Wallingford	0.39	0.15	0.54	0.68
56	Magnolia	0.07	0.67	0.38	0.54
57	Magnolia	0.01	0.02	0.45	0.04
58.01	Interbay	0.39	0.54	0.58	0.44
58.02	Interbay	0.93	0.74	0.42	0.48
59	Queen Anne	0.07	0.19	0.13	0.14
60	Queen Anne	0.07	0.10	0.32	0.21
61	Eastlake	0.07	0.30	0.28	0.10
62	Montlake	0.07	0.37	0.50	0.09
63	Madison Valley	0.77	0.18	0.48	0.02
64	Madison Valley	0.83	0.04	0.54	0.31
65	Capitol Hill	0.39	0.03	0.34	0.12

	Neighborhood	Climate Exposure Percentile	Community Wellbeing Percentile	Economic Percentile	Public Health Percentile
66	South Lake Union	0.07	0.28	0.30	0.15
67	Westlake	0.07	0.26	0.46	0.38
68	Queen Anne	0.07	0.06	0.14	0.01
69	Queen Anne	0.02	0.05	0.13	0.08
70	Queen Anne	0.07	0.20	0.21	0.35
71	Queen Anne	0.39	0.60	0.93	0.40
72	South Lake Union	0.77	0.70	0.96	0.38
73	South Lake Union	0.77	0.90	0.94	0.57
74.01	Capitol Hill	0.07	0.26	0.95	0.45
74.02	Capitol Hill	0.39	0.58	0.91	0.70
75	Capitol Hill	0.60	0.49	0.41	0.60
76	Madison Valley	0.07	0.54	0.78	0.52
77	Central District	0.07	0.35	0.57	0.93
78	Madison Valley	0.62	0.14	0.51	0.26
79	Central District	0.07	0.46	0.63	0.66
80.01	Belltown	0.07	0.07	0.17	0.15
80.02	Belltown	0.07	0.71	0.68	0.65
81	Downtown	0.93	0.99	0.93	0.65
82	Downtown	0.01	0.38	0.92	0.61
83	First Hill	0.07	0.59	0.79	0.47
84	Capitol Hill	0.39	0.50	0.96	0.42
85	First Hill	0.07	0.84	0.23	0.71
86	First Hill	0.07	0.40	0.97	0.43
87	Central District	0.07	0.66	0.61	0.83
88	Central District	0.07	0.45	0.65	0.73
89	Central District	0.39	0.71	0.64	0.79
90	Central District	0.39	0.85	0.39	0.91
91	SODO	0.39	0.86	0.53	0.87
92	SODO	0.96	0.98	0.63	0.93
93	Industrial District	0.92	0.99	0.99	0.76
94	Central District	0.62	0.65	0.74	0.86
95	Mount Baker	0.62	0.53	0.57	0.67
96	North Admiral	0.87	0.52	0.49	0.43
97.01	Alki	0.96	0.90	0.71	0.34
97.02	Alaska Junction	0.39	0.29	0.52	0.24
98	Alaska Junction	0.62	0.57	0.56	0.25
99	South Park	0.75	0.49	0.80	1.00
100.01	Beacon Hill	0.39	0.38	0.43	0.85
100.02	Beacon Hill	0.39	0.77	0.60	0.78

	Neighborhood	Climate Exposure Percentile	Community Wellbeing Percentile	Economic Percentile	Public Health Percentile
101	Mount Baker	0.62	0.68	0.69	0.84
102	Seward Park	0.62	0.92	0.98	0.94
103	Columbia City	0.62	0.93	0.99	0.88
104.01	Beacon Hill	0.39	0.79	0.82	0.90
104.02	Beacon Hill	0.07	0.22	0.38	0.07
105	Genesee	0.62	0.57	0.76	0.40
106	Seaview	0.86	0.63	0.82	0.49
107.01	Delridge	0.36	0.42	0.29	0.18
107.02	Delridge	0.07	0.88	0.62	0.95
108	Delridge	0.82	0.69	0.68	0.82
109	Georgetown	0.91	0.94	0.85	0.51
110.01	Rainer Valley	0.39	0.85	0.67	0.96
110.02	Rainer Valley	0.87	0.96	0.75	0.90
111.01	Rainer Valley	0.07	0.79	0.88	0.89
111.02	Rainer Valley	0.62	0.87	0.86	0.79
112	South Park	1.00	1.00	0.71	0.99
113	White Center	0.39	0.68	0.88	0.85
114.01	White Center	0.61	0.81	0.76	0.80
114.02	Delridge	0.62	0.82	0.87	0.88
115	Delridge	0.39	0.65	0.73	0.51
116	Fauntleroy	0.76	0.47	0.79	0.36
117	Beacon Hill	0.90	0.96	0.70	0.96
118	Rainier Valley	0.77	0.95	0.90	0.98
119	Rainier Beach	0.39	0.32	0.83	0.63
120	Abor Heights	0.07	0.48	0.72	0.46
121	South Park	0.99	0.76	0.49	0.41
260.01	Rainier Valley	0.90	0.32	0.85	0.97
263	Delridge	NA	NA	0.74	0.74
264	Delridge	0.84	0.91	1.00	0.99
265	Delridge	0.97	0.97	0.84	0.49

Appendix B. Excel Tool Guide

Introduction to the Tool

In addition to the Seattle CVA report, the project team developed a dynamic climate vulnerability assessment Excel tool for City planners. This tool will enable City staff to:

- **Use the latest data as it becomes available.** Updating climate projections and/or indicator data within the tool will enable staff to stay up to date with climate impacts to City populations across focus areas.
- **Choose which indicators to include to customize outputs for different purposes**. City planners can select certain combinations that the results of the assessment would be based on. For example, City staff interested in climate impacts on small businesses could choose to view a subset of indicators in the Economy focus area.
- **Adjust indicator weights to explore the impacts of each indicator.** The tool also has a weighting attribute that would allow staff to understand the contribution of specific indicators. For instance, City staff who are interested in the effects of park access and tree cover on economic, community, and/or health vulnerability to climate change could choose to weight those indicators higher than others and see how overall vulnerability ratings change.

Tool Contents

The tool has three main tabs:

- **An introductory tab.** This tab describes the tool, its contents, and its caveats, as well as instructions to use and update it. The tab also contains a color-coded legend to inform users what cells are drop downs to select from, outputs, or if they are informational.
- **An analysis tab.** This tab contains indicators in a table. Here, users can decide which to include and how to weight each one out of the following choices: not important, neutral, somewhat important, important, and very important (see Table 1 for an example).

Table 13. Example Selection of Indicators and Weights

Climate and Vulnerability Indicators	Sector	Y/N (drop down)	Weighting
100-year Floodplain INDEX	Exposure	No	Not Important
Average Temp INDEX	Exposure	Yes	Very Important
Max Temp Index	Exposure	Yes	Very Important
500-year Floodplain - INDEX	Exposure	No	Not Important
SLR 17% INDEX No Storm Surge	Exposure	Yes	Not Important

Seattle Office of Planning & Community Development

SLR 1% INDEX	Exposure	Yes	Nuetral
SLR Storm Surge - 1% INDEX	Exposure	Yes	Nuetral

Once the desired combination of indicators and their associated weights are selected, a separate "Outputs" table on the tab generates both census tract indexes and rankings of economic, community, and public health vulnerability to climate change (Table 2). A low ranking signifies that the census tract is less vulnerable to climate change in its respective category. Users would also be able to single out results for specific census tracts or neighborhoods by filtering for the census tracts/neighborhoods of choice in the outputs table.

Table 14. Example Dynamic Output Table with Census Tract Rankings for Economic, Community, and Public Health Vulnerability to Climate Change

Census Tract	Neighborhood	Exposure Ranking	Community Amenities and Resiliency	Economic Ranking	Public Health Ranking
Census Tract 1	Lake City	77	84	35	102
Census Tract 10	Sunset Hill	126	125	13	83
Census Tract 100.01	Holly Park	79	56	65	115
Census Tract 100.02	Beacon Hill	79	100	88	105
Census Tract 101	Alaska Junction	96	98	93	119
Census Tract 102	Rainier Beach	79	117	134	101
Census Tract 103	White Center	96	120	135	108
Census Tract 104.01	White Center	79	103	116	120
Census Tract 104.02	University	37	40	42	91
Census Tract 105	Highline	79	81	100	7
Census Tract 106	Highline	117	112	111	50
Census Tract 107.01	Phinney Ridge	13	37	39	128
Census Tract 107.02	Georgetown	37	99	89	117
Census Tract 108	Alki	123	122	91	114

Census tracts rankings are color coded using a white to red gradient, with lower-ranking tracts marked by a white hue and higher-ranking tracts designated with a dark red hue. By being able to select the indicators and their weighting factors, users will be able to investigate the level of severity a census tract faces for every combination of indicators and their desired weights. In addition, users will be able to keep the data in this tool up to date by populating the data tabs (marked in yellow) with new information as it becomes available.

Appendix C. Community Partner Meeting Summary

Introduction and Meeting Objectives

This document summarizes participation, activities, and feedback from the Seattle CVA Stakeholder Meeting on Tuesday, February 28th. The purpose of this meeting was to:

- Present vulnerability assessment methodology and preliminary results to stakeholders; and
- Solicit expert stakeholder feedback on methodology and criteria indicators.

Meeting Overview

Date & Time	Tuesday, February 28, 2023 2:30 pm to 4:00pm
Location	Online – Microsoft Teams
# of Participants	15
Participants	▪ Patrice Carroll, City of Seattle ▪ Adrienne Hampton, Duwamish River Community Coalition ▪ Alice Lockhart, 350 Seattle ▪ Callie Ridolfi, League of Women Voters City Climate Action Committee ▪ Richard Gelb, King County Public Health ▪ Hannah Collins, King County Public Health ▪ Daniel Poppe, Seattle 2030 District ▪ Heather Trim, Zero Waste Washington ▪ Addison Houston, King County Public Health ▪ Jamie Stroble, The Nature Conservancy ▪ Jessie Israel, The Nature Conservancy ▪ Jose Chi, ECOSS ▪ Melissa Spear, Tilth Alliance ▪ Sean Watts, SM Watts Consulting, LLC ▪ Tim Trohimovich, Futurewise

Consultant Team Attendees	▪ Mike Chang, Cascadia Consulting Group ▪ Maddie Seibert, Cascadia Consulting Group ▪ Celine Fujikawa, Cascadia Consulting Group

Workshop Agenda

Timing	Activity
10 min	**Objectives & Introductions** ▪ Welcome ▪ Introductions ▪ Meeting purpose and agenda ▪ Icebreaker activity: Team cake or pie?
5 min	**Review the VA process** ▪ Brief overview of VA process & scope
75 min	**Present VA methodology and findings by sector** ▪ Present overall approach ▪ For each sector, present methodology, criteria, and findings.
5 min	**Share reflections and next steps** ▪ Share reflections from discussion ▪ Next Steps

Meeting Outcomes

Review the VA process

The consultant team's methodology for the social and economic vulnerability assessment uses a census-tract scale. Key findings from this agenda item are in the table below.

Discussion Theme	Comments
Risk communication	▪ Ensure risks are communicated by both event type and aggregate exposure (e.g., recognize air quality has big impacts for public health, but extreme heat is a big risk to infrastructure).
Gaps in existing models	▪ Existing models might be missing information and recognize that models are imperfect (e.g., extreme heat models that predict

Discussion Theme	Comments
Geographic effects beyond City borders	impacts will be felt equally across the city, but know the impacts are not felt homogenously). ○ Example: In Duwamish Valley – DRCC has advocated for more extensive air quality monitoring network. How is Cascadia accounting for gaps like this? ▪ Contextualize the results in the broader fabric of the city, acknowledging some of the data is incomplete. ▪ Include narrative that considers wider geographic effects (e.g., displacement to suburbs). ▪ Investigate population at different times of day as part of analysis (I.e., City of Redmond Vulnerability Assessment) ▪ Include land-based results in natural spaces sector to address vulnerabilities of natural spaces that have been altered or re-engineered (e.g., Duwamish River) ▪ Effects of displacement from Seattle on food systems and forests.

Discussion Themes by Sector

In this section, we provide the discussion themes with the stakeholder group in response to the consultant team's review of the VA methodology and the preliminary findings. We consolidated comments from the Jamboard activity and discussion to provide an overview of additional considerations for Cascadia to incorporate in the methodology.

For each sector, we had three primary questions:

1. Do the methodology and results resonate?
2. What might we be missing from our methodology?
3. What other caveats and considerations should we keep in mind?

Key discussion themes for each sector are in the table below.

<table>
<tr><th>Sector</th><th>Preliminary Results from VA Methodology[1]</th><th>Stakeholder Recommendations</th></tr>
<tr><td rowspan="2">Public Health</td><td>Key Findings</td><td></td></tr>
<tr><td>International District, Duwamish, and Rainier Valley are most vulnerable due to higher relative exposure and sensitivity and lower adaptive capacity across the board
Northgate and Lake City areas have higher relative vulnerability due to relatively higher uninsurance rates and race/social equity indices</td><td>EPA social vulnerability data was published in 2021 to look at downscaled climate projects and manipulated to understand the social vulnerability implications of climate change.
Connect with Hannah Collins (APDE) to check if data source is better than what is generated locally.
Considerations:
Heating and cooling in homes
People get stressed about environmental/climate impacts (e.g., King Tide in South Park). Use this to help shape climate narrative in analysis.
Distance to clinics/hospitals
Exposure to wildfire smoke
Indoor air quality/housing conditions
Water and soil quality
Access to green space for mental and physical well-being</td></tr>
<tr><td>Community Wellbeing</td><td>Duwamish, SODO, and Rainier Valley are more vulnerable due to higher relative exposure and sensitivity and lower adaptive capacity
Northgate and Lake City's higher relative vulnerability driven by higher exposure ratings
Bitter Lake's higher relative vulnerability due to less access to park amenities</td><td>Considerations:
Include end of day temperatures instead of the highest temperature registered throughout the day. Some places cool off quicker than others at night, which affects exposure.
Analyze tree canopy data for where people live, not just parks.
Distance from public transportation.
Availability of cooling in residential buildings.
Extreme cold, in addition to extreme heat.
Water quality and proximity to contamination (e.g., combined sewer overflow systems)
Substandard housing in flood prone areas (potential exposures to mold, toxics release).
Access to local source information in appropriate language or cultural context.</td></tr>
</table>

Sector	Preliminary Results from VA Methodology[1]	Stakeholder Recommendations
Economy		▪ Landslide hazards due to increased storm intensity ▪ Land use and zoning impacts to social cohesion ▪ Exposure to poor air quality due to wildfires ▪ Effects of displacement on social cohesion
	▪ Duwamish, SODO, and Rainier Valley are more vulnerable due to higher relative exposure and sensitivity and lower adaptive capacity across the board ▪ South Lake Union and Downtown areas are more vulnerable due to more exposure from lost labor hours	Considerations: ▪ Renters are likely to have lower adaptive capacity due to living in older buildings that are not updated during periods of low air quality. Unpacking risks between vs. Owners. ▪ Household and transportation burdens by household – averaged to the census tract. ▪ Accumulated wealth by household at the census tract level and/or homeownership rates and/or credit score averages as a proxy. ▪ Intensity of pavement and impervious surfaces may be relevant toward heat, flooding, and related outcomes.

[1] Screenshots from the Jamboard activity are attached in Appendix C1.

Reflections and Next Steps

The consultant team will follow up with participants for data sources and follow up on comments as needed. In addition, the project team will do the following next steps:

- Develop Physical Climate Vulnerability Assessment methodology,
- Assess compounding and cascading impacts, and
- Begin synthesis and documentation of vulnerability assessment

Appendix C1. Google Jamboard Responses

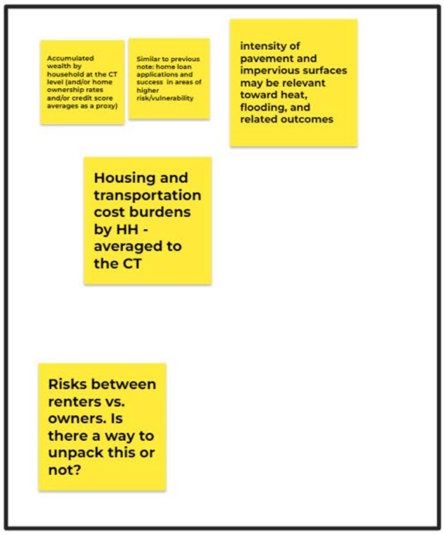
Economy: Indicators

Indicator	Vulnerability Element	Relevance & Considerations
Current Lost Labor Hours due to Extreme Heat	Exposure	Assesses lost labor hours due to extreme heat events.
Projected Lost Labor Hours in 2050 due to Extreme Heat	Exposure	Assesses lost labor hours due to extreme heat events in 2050.
Climate Exposed Occupations	Sensitivity	Assesses sensitivity by indicating types of occupations that are more susceptible to climate extremes.
Number of Small Businesses	Sensitivity	Assesses sensitivity of the # of small businesses, which are more sensitive to external disruptions.
Unemployment Rates	Adaptive Capacity	Assesses adaptive capacity, as unemployment indicates whether a community can withstand economic shocks.

Economy: Other Considered Indicators

Indicator	Vulnerability Element	Relevance & Considerations
Economic resilience to climate change integration in other City plans	Adaptive Capacity	Not at census tract level.
Supply chains	Sensitivity	Not at census tract level. Research is more general.
Industrial and commercial land use zones	Exposure	More relevant for Physical Vulnerability Assessment. Not at census tract level.
Business revenue	Exposure	Poorer data quality.
Economic opportunities	Adaptive Capacity	Discussed more as general opportunities. Include in discussion of this section.
City tax revenue	Exposure	Deemed outside scope of this project.

What are we missing?



Public Health: Indicators

Indicator	Vulnerability Element	Relevance & Considerations
Mortality associated with PM2.5	Exposure	Assesses how future PM2.5 increases (e.g., wildfire smoke, air pollution) due to climate change increases mortality.
New Incidences of Asthma associated with PM2.5	Exposure	Assesses expected new incidences of asthmas associated with climate change.
Asthma-related Emergency Room Visits associated with PM2.5	Exposure	Assesses expected changes in emergency room visits due to PM2.5 impacts from climate change.
City of Seattle's Race and Social Equity Index	Sensitivity	Assesses race and social equity considerations based on a variety of variables.
Uninsured Rates	Adaptive Capacity	Assesses % of population within a census tract that is uninsured.
% Tree Canopy Coverage	Adaptive Capacity	Assesses % tree canopy coverage of each census tract.

Public Health: Other Considered Indicators

Indicator	Vulnerability Element	Relevance & Considerations
Premature Mortality associated with Ozone Exposure	Exposure	No variability at the census tract level.
Premature Mortality associated with Extreme Heat	Exposure	No variability at the census tract level.

What are we missing?

Community Wellbeing: Indicators

Indicator	Vulnerability Element	Relevance & Considerations
Exposure to: • Flooding • Heat • Sea level rise • Extreme precipitation	Exposure	Census tract-level exposure to a variety of climate change impacts.
Food Security and Access	Sensitivity	Includes proximity to grocery stores by walkability at census tract level.
Access to Parks	Sensitivity	Includes proximity and access to parks and green spaces, associated with more positive mental and physical health outcomes.
Critical Facilities	Adaptive Capacity	Assesses proximity of critical facilities – or facilities that provide important community services.
Race & Social Equity Index	Adaptive Capacity	Assesses race and social equity considerations based on a variety of variables.

Community Wellbeing: Other Considered Indicators

Indicator	Vulnerability Element	Relevance & Considerations
People who are houseless	Sensitivity	No high-quality spatial data available
Cultural and community centers	Adaptive Capacity	Limited data available
Social cohesion	Adaptive Capacity	Limited data available
Environmental Health Disparities	Sensitivity	Included City's Race & Social Equity Index as proxy
Risk of displacement	Sensitivity	Data still being developed; to be added in future iterations

What other caveats and considerations are there?

Please add sticky notes

I hope that part of this work will include policy pressure to require informing the general public about vulnerability and practical considerations on financial decisions. 1/2

eg Practical economic considerations for Duwamish Valley residents given predicted sea level rise. 2/2

Geographic effects beyond city borders, for instance, effect of displacement from Seattle on food systems and forests

Affect of displacement on social cohesion and thus on climate vulnerability