



Seattle Hazard Identification and Vulnerability Analysis (SHIVA)

May 2026



Seattle Office of
Emergency Management

MESSAGE FROM THE DIRECTOR

When disasters strike, Seattle needs to be ready — and readiness starts with understanding what to expect. Disasters thankfully don't occur every day, but that also makes it harder to anticipate their impacts. That's where the Seattle Hazard Identification and Vulnerability Analysis (SHIVA) comes in. SHIVA brings together scientific research, historical records, engineering insights, and community knowledge to assess the causes and consequences of the disasters that could affect our city. Research has shown that awareness of hazards and their consequences empowers people to make better decisions during disasters.

SHIVA is the foundation of Seattle's entire emergency management program. It identifies the hazards the City of Seattle, its partners, and the community should prepare for. Developed through more than a year of research, engagement with city and regional partners, and hazard experts, it provides a baseline view of Seattle's demographics, built environment, and economy before analyzing how 19 identified hazards could impact the city and its residents. This information guides the development of policies, plans, and programs to reduce risk across all hazards.



Curry Mayer, Director,
City of Seattle, Office of Emergency Management

EXECUTIVE SUMMARY

The 2026 Seattle Hazard Identification and Vulnerability Analysis (SHIVA) revision offers the public, elected leaders, and City staff a comprehensive assessment of how hazards cause disasters and how they affect Seattle. It is the only resource that examines all of Seattle’s hazards in one place—linking the latest scientific research on hazard intensity with the real implications for our community. Since the federal government is proposing significant reductions to funding to support local disaster preparedness, targeted strategic investments to reduce disaster impacts is more critical than ever.

The analysis identified 19 primary hazards that drive Seattle’s disaster risk:

Biological Hazards	Built Environmental Failures	Cyber Disruptions
Earthquakes	Extreme Heat	Flooding
Hazardous Materials Incidents	Landslides	Power Outages
Severe Winter Weather	Social Unrest	Structure Fires
Terrorism and Targeted Violence	Transportation Incidents	Tsunamis and Seiches
Volcano Hazards	Water Shortages	Wildfire and Smoke
Wind		

In addition to individual hazard chapters, the SHIVA contains four supporting chapters: Climate Change, Community Profiles, Exposure Analysis, and Hazard Scenarios. These four chapters provide further context and detail about the social, economic, and physical environment and how hazards interact with these factors.

The [table](#) below and shown again in the Hazard Ranking chapter summarizes all 19 hazards on one page. It shows the potential severity of impacts each hazard causes, roughly how frequently the hazard occurs, and its likelihood of triggering secondary disaster consequences. City staff and subject matter experts evaluated these metrics to score each hazard, with the results forming a ranking showing overall risk. The priority was identifying hazards that can cause sudden, acute, and complex threats to life, property, and the environment and their potential consequences. Because disasters are rare events, this process involves uncertainty. Any of the hazards in this study could bring immense hardship to Seattle.

Key Findings

- Seattle communities do not bear the consequences of disasters equally. Neighborhoods with higher proportions of people of color, low-income residents, and historically marginalized populations have a greater exposure to most hazards, including but not limited to earthquakes, extreme heat, flooding, tsunamis, and volcano hazards.
- [Earthquakes](#) are Seattle’s most significant hazard. There is an estimated 87% probability that the city will experience an earthquake within the next 50 years at least as powerful as the 2001 Nisqually event. Seattle is also at risk from stronger, more damaging earthquakes originating from the offshore Cascadia Subduction Zone and from the Seattle Fault, which runs east-west through the center of the City.
- A new chapter has been added on [Wildfires](#). There is a growing understanding of the threat posed by wildfires on the west side of the Cascades. Recent research identifies the history of megafires in the Western Cascades. Such fires are infrequent but would be highly impactful. If one were to occur in the Skagit, Cedar, or Tolt watersheds, it could have severe consequences for Seattle’s drinking water and power supply. The Pend Oreille watershed in northeastern

Washington is also vulnerable to fire and could affect Seattle’s Boundary Dam. Additionally, wildfire smoke can cause significant health impacts.

- Seattle faces disaster risk from both rare, extreme events such as major earthquakes and from more frequent events like fires, urban flooding, power outages, and extreme weather. The frequent events are less individually harmful but have a cumulative impact that increases the risk they pose to Seattle. Our emergency management system must prepare for both types of hazards. The increasing frequency of many climate related hazards suggests a need for expanded collaboration between emergency managers, day-to-day business operations, and policy makers mitigating the effects of long-term chronic hazards.
- Hazards that impact neighborhoods are generally more manageable than city-wide hazards like extreme weather because fewer people and properties are affected and because it is easier to apply resources. Nevertheless, these smaller incidents challenge response because they draw significant resources away from normal City business operations creating dilemmas for City policy makers.
- [Extreme heat](#) is a deadly hazard in the second least air-conditioned city in the US, particularly for the elderly, those with chronic illnesses, and those experiencing homelessness. The 2021 Heat Dome highlighted this risk. Its impacts were mitigated by the event’s relatively short duration. The longer extreme temperatures persist, the more severe and dangerous the health consequences become. Had the 2021 heat lasted several days longer, severe health consequences would have risen dramatically.
- [Wind](#) and [power outages](#) emerged as priority hazards, driven by serious widespread impacts that occur with relative frequency. Seattle last experienced a major windstorm in 2006 when thousands lost power during very cold weather. With future power demand projected to rise significantly, Seattle will become more dependent on sources outside City Light’s generating capacity. This in turn makes Seattle more vulnerable to disruptions in the regional power network which suffers from underinvestment in maintenance.
- [Drones are an emerging terrorist threat](#). There have not been any successful attacks in the US, but the decreasing cost, increasing ease of use, technical advances, and the techniques developed on the battlefield in Ukraine are making drone attacks more likely. South America is experiencing a spike in drone attacks by extremist groups and criminal organizations that have sent members to train on the battlefield in Ukraine.
- Increasing political polarization has brought more attention to the hazards of [social unrest](#) and targeted violence, both in Seattle and nationwide.
- COVID revealed how [disease outbreaks](#) can create prolonged and widespread social impacts beyond the direct effects of the disease itself. Disease outbreaks have been given more weight in the hazard ranking process due to the impact on youth, the economy, and social cohesion.
- [Cybersecurity](#) is a continuous threat to city operations. The cyber ransomware attack on Seattle Public Libraries in 2024 underscored the increasing consequences for critical service provision by the City of Seattle and its partners.
- The December 2022 South Park [flood](#) revealed the increasing vulnerability of low-lying areas to compound flooding, in which flooding is caused by multiple drivers such as sea level rise, barometric pressure, high intensity precipitation, tides, and stream flows. The United States Geological Survey [released a series of compound flood estimates for King County](#) in December

2025 showing a large part of Seattle coastal areas and the Duwamish Valley are vulnerable to compound flooding.

Hazard Ranking

The table below summarizes the SHIVA. It ranks hazards based on two scenarios: one that is representative of events with an annual likelihood (or frequency) of 1% or greater and another scenario that is representative of extreme events that have an annual likelihood (or frequency) of 0.1% or less per year. The ranking represents the Seattle emergency management community's relative level of concern for our hazards.

How the model works

Hazards are ranked using the **Combined Ranking** column. It captures a Most Likely Scenario (the more common events) and a Credible Worst-Case Scenario (the rare extreme events). Both scenarios are evaluated using ten parameters that capture community impacts. Each parameter is assigned a score from 1 through 5 that are averaged to get a **Base Score**. Definitions for all parameters are given in [Table 2](#).

Two additional parameters, *Frequency* and *Cascading Effects*, function as multipliers. They are assigned a score of 1 to 5 then added together to yield a **Combined Multiplier**.

The **Base Score** is multiplied by the **Combined Multiplier** to get a Scenario Score. The scores for both scenarios are added together. Finally, to reflect long term trends, a *Future Emphasis* score (also 1 to 5), is added to the total to get a **Hazard Score**.

Scenario Score = *Average* (10 Parameters) * *Sum* (2 Multipliers)

Hazard Score = (Most Likely Scenario Score) + (Credible Worst-Case Scenario Score) + *Future Emphasis*

Scoring was done by Office of Emergency Management staff and the Strategic Working Group of the Seattle Disaster Management Committee.

It is important to look beyond the Combined Score. Many of the scores are very close. The breakdown of the scores reveals how impacts differ across hazards. For example, some hazards impact people directly much more than infrastructure while others are reversed.

Hazard Ranking

	Most Likely Scenario														Credible Worst-Case Scenario																		
	Geographic Scope	Duration	Health Effects	Displacement	Economy	Environment	Built Environment	Transportation	Critical Services	Confidence in Govt	Base Score	Frequency (F)	Cascading Effects (CE)	Multiplier (F + CE)	Base x Multiplier	Geographic Scope	Duration	Health Effects	Displacement	Economy	Environment	Built Environment	Transportation	Critical Services	Confidence in Govt	Base Score	Frequency (F)	Cascading Effects (CE)	Multiplier (F + CE)	Base x Multiplier	Future Emphasis	Combined Ranking	
Earthquakes	5	2	2	2	2	2	3	2	2	1	2.3	4	4	8	18.4	5	5	5	5	5	5	5	5	5	5	5	5.0	1	5	6	30.0	3	51.4
Wind	5	2	2	2	2	2	2	2	2	1	2.2	5	3	8	17.6	5	2	2	3	3	2	3	3	3	4	3	3.0	3	3	6	18.0	3	38.6
Power Outages	5	2	2	2	2	2	2	3	2	1	2.3	5	2	7	16.1	5	4	2	4	3	1	2	3	3	5	3.2	3	3	6	19.2	3	38.3	
Severe Winter Weather	5	4	2	2	2	1	2	2	2	1	2.3	5	2	7	16.1	5	4	2	4	3	2	3	4	3	3	3.3	2	3	5	16.5	5	37.6	
Wildfire and Smoke	5	3	2	2	1	2	1	2	1	1	2.0	5	1	6	12.0	5	5	2	4	4	5	1	1	4	3	3.4	3	3	7	20.4	5	37.4	
Infectious Disease and Biological Hazards	5	5	4	3	3	1	1	1	1	3	2.7	4	1	5	13.5	5	5	5	5	4	1	1	3	3	3	3.5	3	2	5	17.5	5	36.0	
Tsunamis and Seiches	3	2	2	3	3	2	3	2	3	1	2.2	3	2	7	11.0	4	2	4	5	4	4	3	4	3	3	3.6	2	4	5	21.6	3	35.6	
Cyber Disruptions	5	4	1	2	2	1	1	2	1	3	2.2	4	1	6	11.0	5	4	2	5	4	3	1	4	4	5	3.5	1	4	5	18.5	5	34.5	
Landslides	4	3	2	2	1	2	2	3	1	1	2.1	5	1	6	12.6	4	3	3	3	3	3	3	4	2	3	3.1	2	4	6	18.6	3	34.2	
Flooding	4	3	1	2	2	2	2	2	1	1	2.0	5	1	6	12.0	5	4	2	4	3	3	3	4	3	3	3.4	2	3	5	17.0	5	34.0	
Extreme Heat	5	3	3	2	2	2	1	2	1	1	2.2	4	1	5	11.0	5	5	4	4	3	2	1	3	3	3	3.3	3	2	5	16.5	5	32.5	
Transportation Incidents	2	1	3	1	2	1	2	3	1	1	1.7	3	1	4	6.8	3	4	4	4	3	3	2	4	3	5	3.5	2	4	5	21.0	3	30.8	
Social Unrest	3	1	2	2	3	1	2	2	2	3	2.1	5	2	7	14.7	5	3	3	5	3	1	3	2	2	5	3.2	2	2	4	12.8	3	30.5	
Water Shortages	1	4	1	2	2	2	2	2	3	3	2.2	5	2	7	15.4	5	5	1	3	3	3	2	1	3	3	2.9	2	2	4	11.6	3	30.0	
Hazardous Materials Incidents	3	2	2	3	2	3	1	2	2	3	2.3	4	1	5	11.5	3	4	4	4	3	2	1	4	2	3	3.0	2	3	5	15.0	3	29.5	
Structure Fires	1	2	3	3	2	2	2	2	2	3	2.2	4	1	5	11.0	4	4	3	4	4	1	3	4	3	5	3.7	1	3	4	14.0	3	28.0	
Built Environment Failures	2	2	2	2	2	1	1	3	1	1	1.7	5	1	6	10.2	5	4	3	3	4	3	4	4	3	3	3.6	1	3	4	14.4	3	27.6	
Volcano Hazards	3	5	1	4	3	2	3	2	3	1	2.7	2	2	4	10.8	5	5	3	4	3	2	4	5	1	1	3.4	1	3	4	13.6	3	27.4	
Terrorism & Targeted Violence	1	1	2	2	2	2	2	2	1	3	1.8	5	2	7	12.6	4	4	4	3	2	1	2	2	3	3	2.7	1	2	3	8.4	5	26.0	

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ACKNOWLEDGEMENTS

This document would not be possible without the help of many people within the City of Seattle and amongst the wider community. They helped us find data, suggested means of analysis, lent us their expertise, reviewed chapters, and evaluated scenarios. Standing out for special thanks is our management team at the Seattle Office of Emergency Management (OEM): Curry Mayer, Director; Andrew Stevens, Deputy Director; and Kate Hutton, Planning Program Manager. This was an incredibly long project that many jurisdictions would not undertake, especially in-house. We are grateful for the support you all have shown us during the whole process. TJ wants to thank all of his OEM colleagues, but especially Meg Hamele, who stepped in to lead revisions on six chapters and the Exposure Analysis as well as writing a new chapter, Wildfire and Smoke, while he was battling personal health challenges. While many hands contributed this document, any errors remain with the authors.

Cascade Volcano Observatory

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INTRODUCTION

In January 2020, the first laboratory-confirmed case of COVID-19 was reported in Washington State. The global pandemic that followed led to thousands of lives lost in Seattle. Thousands more had their lives upended. In the middle of the COVID-19 crisis, outrage at the murder of George Floyd sparked social unrest that became violent. These are just the latest disasters that stretch all the way from today to the Great Seattle Fire of 1889. They include many more events like severe winter weather, landslides, flooding, and power outages that have disrupted the life of the city. Despite the seriousness of these events, Seattle has not experienced a true catastrophe, but it remains a possibility. The most likely cause would be a major earthquake, but there are other hazards that could produce a disaster of a magnitude not yet known in Seattle.

Disasters overwhelm communities and the resources used to respond to them, but countermeasures are effective in mitigating impacts. Building codes, infrastructure improvements, firefighting, emergency management, flood control projects, and landslide stabilization efforts are just some of the investments that have significantly reduced loss of life, property destruction, community disruption, and environmental degradation. However, these measures come with costs, and it is impossible to guard against every bad thing. Therefore, it is critical to understand which hazards pose the greatest dangers to our city. That's where this document comes in. It analyzes hazards that cause disasters in Seattle and their effects so that the City of Seattle, partner organizations, and the public can make the smartest investments to lessen hazard impacts.

Washington State understands the importance of hazard analysis. The Washington Administrative Code requires political subdivisions have comprehensive emergency management plans that are “based on a hazard analysis or equivalent” ([WAC 118.30.060](#)). Additionally, Seattle’s emergency management program is accredited by the [Emergency Management Accreditation Program \(EMAP\)](#) which requires accredited programs to meet its standards for hazard identification as specified in standard 4.1 of the 2022 edition of the Emergency Management Standard, [EMAP EMS 5-2022](#). This document fulfills both these requirements. It also serves as the hazard analysis in support of Seattle’s [All-Hazards Mitigation Plan](#). Finally, it complements the [Threat Hazard Identification and Risk Assessment](#) (THIRA), a FEMA defined methodology focused on comparing threats against defined ‘core capabilities’. This document is broader than the THIRA and enables the City of Seattle, partner agencies, and the public to better prepare for, respond to, recover from, and mitigate the effects of disasters on our community. In doing so, it forms the foundation for the City of Seattle’s emergency management program.

Defining Hazards

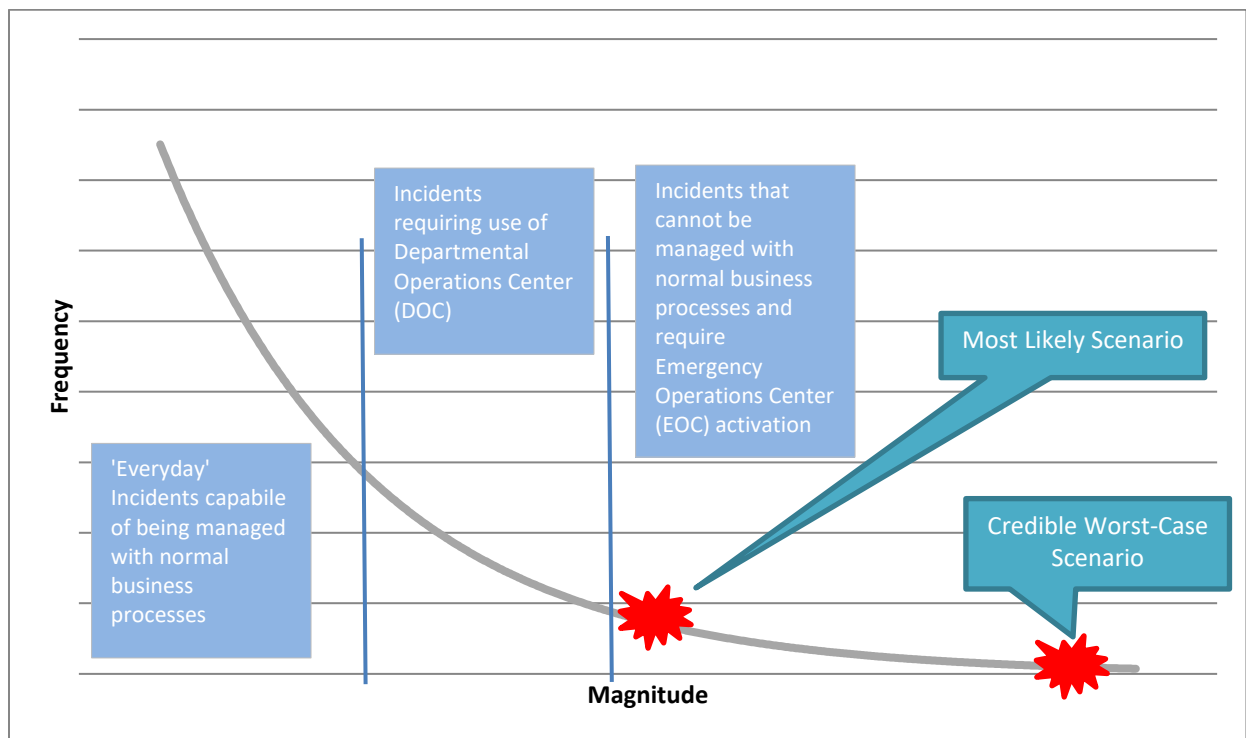
Most of this analysis consists of chapters covering specific hazards, but before considering them, it is important to back up and precisely define what hazards are and their relationship to disasters.

For the purposes of this analysis, a hazard is defined as “a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.”¹ A hazard is a *phenomenon* that *may* cause harm. Depending on the situation, a hazard may create an incident that can be managed by individual or small groups of agencies with normal resources. A hazard can manifest as a disaster, defined by the UN as “a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts.”² These later events require immediate community responses that are made more challenging because they also increase the demand for critical resources, cause logistical difficulties and communications bottlenecks, and often create unique situations that require rapid policy making. They are the subject of this analysis.

Hazards are measured by their *frequency* and *magnitude*. Frequency measures how often the hazard creates incidents. Magnitude measures incident consequences. The relationship between frequency and magnitude is non-linear as shown in [Figure 1](#). There are many more small incidents than large incidents. For example, landslides are a regular occurrence in Seattle. They happen every winter, but most are small, have limited impacts, and can be managed by individual departments or personnel from several departments working together in the field. Larger landslides or multiple landslides happening over a short length of time may require involvement of senior leadership from one or more responding departments. Leadership gathers in departmental operations center (DOC) to manage the incident. If the landslides have extraordinary impact, a citywide response is necessary. The City of Seattle Emergency Operations Center (EOC) will be activated. Personnel from across city government will respond along with non-city agencies with a role to play. Once the incident is stabilized, city government will partner with community-based organizations to begin community recovery. [Figure 1](#) shows the division of the different levels of response. The focus of this analysis is on incidents that cause an EOC activation.

Hazards are ranked by the frequency and magnitude of a Most Likely Scenario and a Credible Worst-Case Scenario as shown below. These scenarios and the ranking methodology are explained in detail in the next chapter, Hazard Ranking and Methodology.

Figure 1. Incident Frequency vs Magnitude



The analysis groups threats into 19 specific hazards that can trigger disasters. It defines the hazards, specific physical and social vulnerabilities to them, examines their consequences, estimates the hazard outlook over the next five years, and provides key contextual information. Earthquakes are Seattle’s top hazard, but each hazard has the potential to cause a disaster of historic magnitude. Finally, actual disasters rarely involve just one hazard. For example, earthquakes can trigger tsunamis, landslides, fires, hazardous materials incidents, and other secondary hazards.

Recovery from the worst of these incidents could take years. This potential was most recently seen with COVID-19. Thousands of people in Seattle were directly affected by illness. Thousands more were

affected by disruptions to schools, businesses, and social activities. Some places like Seattle’s downtown are still recovering five years after the pandemic’s emergence.

Defining Vulnerability

Hazard risks are not evenly distributed across the city geographically or demographically. Some places, for example, the Duwamish Valley, coastal areas, and areas near steep slopes have higher physical exposure. Likewise, some people, such as those with lower incomes, renters, minorities, and the elderly, are more susceptible to harm and therefore more vulnerable.

Vulnerability explains why hazard risks are not evenly distributed. It is defined as the susceptibility to harm and includes two overlapping ideas: 1) exposure to a hazard and 2) sensitivity to harm once exposed. For example, coastal areas are more vulnerable to coast flooding simply because they are on the coast and exposed to high tides, storm surge, and other coastal hazards. [Appendix A](#) identifies people, critical facilities, and property exposed to hazards we can map. Now consider two coastal areas. One is highly populated, and the other is undeveloped. The highly developed area is more vulnerable because more people are exposed to hazards. Finally, consider two highly populated coastal areas. In the first, residents live in elevated structures made of concrete. In the other, residents live in flimsy structures close to sea level. The second area is more vulnerable because its structures are more sensitive to damage. Places are more vulnerable if they have more people and assets exposed. Finally, vulnerable people, things, and places incur more harm when exposed to the same physical event. Many disaster scholars consider all forms of vulnerability to roll up into social vulnerability because the same factors that define social vulnerability also determine where people live and work.

Social Vulnerability

The concept of social vulnerability extends the basic idea of vulnerability by noting that different demographic groups experience different levels of harm during the same incident. Social inequality affects those who suffer the most during disasters. The Center for Disease Control has developed a model of social vulnerability that can be mapped. The result is included in the [Community Profile](#) in [Figure 9](#). The factors found to influence social vulnerability include:

- Being below 150% poverty
- Being unemployed
- Being housing cost burdened
- Having no high school diploma
- Having no health insurance
- Being age 65 or older
- Being age 17 or younger
- Having a disability
- Living in a single-parent household
- Lacking English proficiency
- Being a racial minority
- Living in a multi-unit structure
- Living in a mobile home
- Living in crowded housing units
- Lacking access to a vehicle
- Living in group quarters (e.g., dorms, prisons, shelters)

These factors have a cumulative effect. People in multiple categories are more vulnerable than people in one category. Many people falling into these categories lack sufficient reserves to deal with a sudden loss of residence or income. Others may face discrimination during disaster recovery.

Some of these factors make keeping oneself safe more difficult. They underscore the need for the community and local government to support its most vulnerable community members. Three critical areas are communications, self-care, and mobility.

Communications. If someone lacks the ability to receive, understand, and act upon emergency-related messages and public information, they may miss life-saving information. Roughly one in five Seattle residents speak a language other than English. The City of Seattle requires departments to have language access plans, includes language access in its [emergency plans](#) (PDF), and has built pre-scripted messages in AlertSeattle, its emergency alert system. See the City of Seattle [Language Access Program](#) for more information. Despite these efforts, providing quick, incident-specific information in all of the City of Seattle's 15 priority languages will be a challenge.

Self-Care. People who have limited ability to take care of themselves without assistance will face more challenges if critical lifelines like power, water, or communications fail, especially if they are socially isolated. Seattle has one of the lowest household sizes in the United States, and many people live alone. Developing neighbor to neighbor support programs is a critical step to mitigating this social vulnerability. [Seattle Emergency Hubs](#) is a volunteer group that facilitates this work.

Mobility. People who have a mobility disability or lack access to a means of transportation face dangers if they need to evacuate or access resources during disaster recovery. Mobility vulnerabilities are mitigated in urban areas where resources are closer than rural areas and where public transport systems are stronger. Neighborhood and community-based organizations are helpful for reducing mobility vulnerabilities.

Locational Vulnerability

Locational vulnerability includes characteristics of systems that allow system failures to cascade. The sociologist Charles Perrow identified two dimensions to systems that make them more prone to failures: complexity and tight coupling between system components. In Perrow's schema a university is a complex but loosely coupled system whereas a nuclear power plant is a complex, tightly coupled system.³ It also includes physical factors like weaknesses in the built environment, lack of redundancies in critical facilities, and proximity to hazardous areas. Because many of these vulnerabilities depend on specific hazards, they are covered in the hazard chapters.

Complexity

Cities are complex systems comprised of many components. How these components interact is not always understood. Normally, failures are contained, but when a system is tightly coupled, failures can cascade and cause system failure. Moreover, components in complex systems often interact in unanticipated ways because their connections are poorly understood. For example, Seattle hospitals had to curtail service during a 2006 windstorm and power outage because a laundry service that supplied them with clean linens lost power. The effects of a power outage miles from Seattle's hospitals cascaded through the urban fabric to the health care system.

Tight Coupling

The faster the pace of change in a system, the faster failures propagate, and problems escalate. Critical infrastructure is becoming highly automated. While automation is leading to efficiency gains, it also means that things can go wrong quickly. For example, during Hurricane Katrina, hospital patients became critical within hours of power failure. The lengthening of supply chains and reductions in inventories held by many businesses is another example of tight coupling.

Concentration

Besides complexity and tight coupling, the concentration of people and assets creates vulnerability because more harm can come from damage in a single location. Seattle has the densest concentration of people and resources between San Francisco and Vancouver, BC. Within Seattle, certain assets like hospitals and lifelines are even more concentrated. Most of Seattle's hospital beds are located near the city center. Many lifelines (power, water, gas, fuel, sewer, and transportation) run through narrow corridors, especially just south of the city. One unfortunately located incident could take out the greater part of a critical resource. Concentration is not solely a liability; dense population centers like Seattle have more resources to respond than surrounding rural or suburban areas. If they survive intact, these resources become valuable assets during a response and recovery.

Economic Conditions

As an area's economy and population grows and shrinks, the distribution of wealth changes where vulnerable populations are located. Infrastructure gets built and then starts to decay; hazardous areas are redeveloped or abandoned. These changes cause a city's vulnerability to fluctuate and its most sensitive spots to shift geographically. Disasters can exaggerate a city's growth or decline. A city in recession can decline quickly after a disaster, while growth in a booming city can accelerate if new capital enters the city during reconstruction. The amount of outside assistance is also a determinant.⁴

State of Knowledge

The ability to accurately predict the occurrence of a hazard has the potential to greatly reduce vulnerability to it. It is the ability to act on a prediction, though, that reduces vulnerability. The state of knowledge varies widely from hazard to hazard. The ability to predict ranges from:

Deterministic. The hazard's location, magnitude, and time of occurrence are all reliably known within narrow limits in advance. Pure deterministic examples of hazard prediction are rare.

Forecast. Some of the features of an impending incident can be predicted, usually based on the observation of a precursory signal. The prediction is based on probabilities. The precise magnitude, time, and location might not be known but there is some physical connection above the level of chance between the observation of a precursor and the subsequent event. Forecasting includes a precise probability statement. Volcanic eruptions and weather forecasts fall into this category.

Time independent. This principle assumes that hazards occur randomly within a block of time and uses past hazard locations to constrain the future long-term hazard. An example is an earthquake with an estimated 500-year recurrence rate. A future earthquake could happen at any time in this 500-year span. Locations are estimated based on known faults and past events.

Time/Location dependent. The hazard varies with time. Seasonality is a good example. Major storms tend to occur in the late fall and winter. Seismic hazards are greater along known faults.

Community Resilience

Community resilience is the ability of a community to minimize the consequences of disruptive incidents, recover quickly, and adapt to an altered post-incident environment. It emphasizes the role of social networks within a community. These networks can be informal based on personal connections formed through friendships, community events, hobbies, and social gatherings, or they can be formal networks in which organizations act as neighborhood cornerstones. Social networks establish social capital, the trust and respect that grows slowly within a community over time. During emergencies, these networks become anchor points for community self-help.

Social capital falls into three types: bonding, bridging, and linking. The following descriptions are drawn from the influential paper *Social Capital and Community Resilience* by Daniel P. Aldrich and Michelle A. Meyer.⁵

Bonding social capital exists between people who are emotionally close like friends and family. It is usually shared by people who share similar demographic traits. Bonding social capital is especially important in the immediate aftermath of a disaster when people depend on each other to share information and resources. A study of the 1995 Chicago heat wave found that communities with less bonding social capital suffered more deaths than those with stronger bonding social capital.

Bridging social capital connects people across social groups such as class or race. This kind of social capital is more likely to involve formal organizations like non-profits. Another example is a friendship between individuals who are of different classes, but both belong to the same religious community. Bridging social capital is important for long-term recovery in accessing outside resources. A comparative study of two communities in New Orleans found that the community with stronger bridging social capital received more outside support after Hurricane Katrina. [Puget Sound Resilience Hubs](#) is a community-driven program to build centers to develop and focus bridging social capital in Western Washington.

Linking social capital involves connections across individuals or groups with different resources levels. It allows people to access institutions with more power or resources. For example, if a non-profit has a relationship with elected officials, it has linking social capital.

Community resilience underscores the need to involve the whole community in emergency management. Connections within neighborhoods, participation in civic groups, and a healthy system of community-based organizations are essential for reducing harm from hazards. FEMA recognizes the importance of community resilience and includes it in the National Risk Index. It uses a methodology developed by Cutter, Ash, and Emrich that maps community resilience to the county level.⁶ King County was determined to have Relatively High community resilience. Unlike social vulnerability, which can be mapped to the census tract level, community resilience cannot be mapped at areas smaller than the county.

Summary of Document Updates

The previous revision to this document was completed in 2019. This revision incorporates new research for all 19 hazards, takes stock of recent events like COVID-19, social unrest, and the extreme heat event of 2021. The Community Profile was updated with new demographic, infrastructure, and planning information. A new Wildfire and Smoke chapter was added to emphasize dangers posed to Seattle's watersheds and dams outside city limits and the smoke hazard in Seattle. The SHIVA follows the City of Seattle Emergency Management Planning Policy and follows the development and maintenance process for external plans described therein.

How to Use This Document

The SHIVA is for anyone who wants to decrease the threat disasters pose to the Seattle community. Residents, employees, visitors, volunteers, government workers, academics, business owners, service providers, and infrastructure managers can all benefit from the SHIVA.

Hazard researchers have done tremendous work in the Seattle area. The SHIVA summarizes the best available Seattle-area hazard research and combines it with information about Seattle's social and physical environment to show how hazards affect our city. These effects have been evaluated with a set of metrics and scored. The results are given in [Table 1](#). Use it as a starting place.

Structure

Most of the SHIVA consists of chapters on individual hazards. These chapters are preceded by a hazard ranking, community profile, and a chapter on climate change with a bibliography and endnotes at the back. We assume that most readers are interested in specific hazards. Breaking out individual hazards allows readers to jump into specific concerns without having to read the entire document. Despite the emphasis on individual hazards, we hope readers will familiarize themselves with the more general chapters. They provide important foundational knowledge about hazards, vulnerability, and resilience.

Hazard Ranking

This section is the dashboard. It condenses key findings into one matrix and contains supporting material to explain the metrics the matrix uses and how the scores were derived. It also has a table that shows how different hazards are related because most disasters involve multiple hazards.

Community Profile

Community characteristics shape what happens when hazards manifest. To understand hazard impacts, one needs to understand the community. The Community Profile outlines how Seattle is put together as a physical and social space with an emphasis on traits that affect hazard impacts. The Community Profile subsections are:

- Physical Geography
- Population and Economy
- Land Use
- Transportation
- Utilities
- Media
- Emergency Services
- Healthcare and Human Services
- History

This is a data-heavy chapter. A lot of this data shows that Seattle is still feeling the effects of COVID-19, including high vacancy rates downtown, decreased transit ridership, and decreased enrollment in public schools. [Table 4](#) compares key Seattle demographics with 7 ‘reference cities’ across the United States, 2 cities in Western Washington (Bellevue and Tacoma), and King County. It enables readers to understand how Seattle differs from similar sized cities in the U.S. and with other communities in our region.

Climate Change

This chapter outlines how climate change affects our hazards. This analysis does not treat climate change as a stand-alone hazard, but as a process that manifests as an intensifier of hazards. Climate change is projected to affect air temperatures, sea level rise, precipitation, mountain snowpack, stream flow, and air quality for the Puget Sound area. The hazards expected to be most influenced by climate change are landslides, disease outbreaks, infrastructure failures, power outages, wildfire and smoke, extreme heat events, flooding, and water shortages.

Hazard Profile Chapters

Most of this document consists of 19 chapters on individual hazards. They can be read independently. Each chapter has the same structure allowing the SHIVA to be used as a reference. Despite this division boundaries between hazards are fuzzy. Emergencies often involve multiple hazards. Each chapter is summarized below.

Appendix A: Exposure Analysis

The City of Seattle has identified areas of heightened exposure for six hazards: earthquakes, landslides, volcanoes, tsunamis and seiches, flooding, and explosive hazardous materials. For each of these hazards, we have analyzed population, land use, structure number and type, critical facilities, social vulnerability by census tracts, and wildlife areas in areas with heightened risk.

Appendix B: Hazard Scenarios

This appendix details the scenarios used to score the hazards. There are two scenarios for each hazard, a Most Likely Scenario and a Credible Worst-Case scenario. The purpose is to develop scenarios that are representative of what kinds of disasters a hazard could produce based on the best available research. Any real event will differ from these scenarios, but the goal is to capture the scope and magnitude generally.

Bibliography

The SHIVA rests on research. To keep the SHIVA as concise as possible, much of the research was heavily summarized. The sources in the bibliography provide papers, books, and websites that cover topics much more fully than the SHIVA. It offers a wealth of knowledge. Readers are encouraged to use the sources to broaden their understanding.

Endnotes

The SHIVA uses endnotes to make the text flow more smoothly, but the Office of Emergency Management hopes that readers will use the endnotes to understand what sources were used and to then consult these works themselves. They are an easy way to approach the bibliography.

Hazard Chapter Format

Each of the hazard-specific chapters follows the same format. The common format enables the same key aspects of each hazard to be considered and allows readers to compare the same sections across hazards. This format causes some repetition but makes the SHIVA easier to use as a reference document.

Each chapter begins with a general section that explains why the hazard is a cause for concern. It provides enough fundamental science, research, and terminology to enable readers to understand subsequent sections without having to consult additional material. When relevant, it outlines disasters from outside the Northwest to illustrate why a hazard has been identified as being a risk to Seattle. These examples are especially important for newer hazards that do not have a long history in the Northwest.

Key Points

This section consists of bullet points that summarize the most important points about the hazard for a quick overview.

History

This section details the hazard's presence in Seattle. Most of it is a list of events in Seattle that had severe consequences. Occasionally, events from the Puget Sound region outside Seattle are included when they illustrate similar dangers here or have direct consequences here. Some events, especially the oldest ones, occurred when circumstances were very different than today. For example, Seattle's deadliest disasters are transportation accidents, but safety standards dramatically improved since these accidents and have dramatically reduced accident frequency. They are included for completeness and perspective.

Vulnerability

These sections apply vulnerability concepts to specific hazards. Vulnerability is a property of people, social systems, structures, or locations that make them suffer more harm than others for hazards of the same magnitude. For instance, wood structures are more likely to burn than brick structures when exposed to fire. Social vulnerability, the likelihood of some people suffering more harm when exposed to hazards of the same magnitude, is an equity issue. FEMA defines equity as the “the consistent and systematic fair, just, and impartial treatment of all individuals, including individuals who belong to underserved communities of color, persons who belong to communities that may face discrimination based on sex, sexual orientation, and gender identity (including members of the LGBTQ+ community); persons with disabilities, persons who may face discrimination based on their religion, national origin and persons with Limited English Proficiency, and persons who live in rural areas that have been systematically denied a full opportunity to participate in aspects of economic, social, and civic life.”⁷ Some social groups are disproportionately harmed by hazards and threats. Their vulnerability to disproportionate harm by hazards and threats is rooted in the social inequities that these communities endure. Examples of these social inequities include but are not limited to racism, ableism, sexism, and nativism.

Consequences

This section ties the previous sections together to draw out the likely outcomes if the hazard were to manifest. Because consequences vary with hazard magnitude and because smaller incidents happen more often than larger ones the SHIVA uses a “Most Likely” and “Credible Worst-Case” scenario to illustrate hazard consequences. The “Most Likely” scenario is often the upper range of the historical magnitude of past occurrences, and the “Credible Worst-Case” scenario is one that represents the biggest incident that has a reasonable chance of occurring.

Outlook

This section assesses the chance a hazard will cause a disaster in Seattle within five years of the SHIVA’s publication. It does not make predictions, because no disaster can be predicted, especially years ahead of time, but science and engineering have improved our ability to make good bets. If experts feel confident enough to give a numeric probability it is included in the section, but often it is not possible to do so. For climate related hazards, it is important to look beyond the five-year life span of this document for general trends. Longer time frames are included where relevant.

Conclusion

The conclusion is a brief summation of the major points of the text in a paragraph or two to help the reader remember the hazard.

Hazard Chapters

The bulk of this document consists of chapters detailing specific hazards. This section provides brief summaries of each hazard.

Earthquakes

Earthquakes are Seattle’s most threatening hazard. No other hazard has the combination of likelihood and potential destructiveness. The major consequences are building collapse, lateral spread (where the ground permanently shifts under buildings), landslides, fires, liquefaction (where the ground turns liquid under buildings), and potentially a tsunami. Casualties could exceed 1,000 people and economic damage could easily run into billions of dollars. Seattle has been preparing for earthquakes for many years by enhancing building standards, retrofitting infrastructure and facilities, and educating the public.

Seattle is at risk from three kinds of earthquakes. Each one has different consequences so understanding them is important. The first are deep earthquakes like those that struck in 1949, 1965 and 2001. They have been some of the worst disasters Seattle has faced but are the least dangerous of the three kinds of earthquakes. The second are shallow earthquakes. They happen when surface faults running through the Puget Sound region rupture. The most dangerous for Seattle is the Seattle Fault which runs through the middle of Seattle. It ruptured during the winter of 923-4 AD causing a magnitude 7.5 to 7.8 earthquake, massive landslides, and a tsunami. There is a lot of uncertainty about how often this fault ruptures. The South Whidbey Island Fault runs close to North Seattle and is the second biggest shallow earthquake risk for Seattle. The third kind of earthquake is a subduction zone earthquake. A massive fault system runs off the North American coast from Vancouver Island to Northern California. If the entire fault ruptured it would cause one of the world's biggest earthquakes and would devastate the Pacific Northwest. Earthquakes of this size are estimated to happen every 300 to 800 years. The last earthquake on this fault happened in 1700. For Seattle, a powerful Seattle Fault earthquake would probably be worse than a Cascadia Subduction Zone earthquake because it would happen in the middle of the city. For the region, the Cascadia Subduction Zone would be the worst scenario.

Landslides

Landslides are a common Seattle hazard, especially when ground water is saturated in the winter. Landslides can always be deadly but more commonly they destroy buildings, block roads, and sever lifelines. The greatest risk is when a storm or earthquake triggers a swarm of landslides throughout the city within several days. The biggest swarm was in 1997 when 300 landslides happened in less than four weeks. Landslides can also be triggered by earthquakes. A Seattle Fault earthquake could cause massive landslides. The last one in 923 AD caused whole forested hillsides to slide into Lake Washington. The City of Seattle addresses its landslide hazard by mapping its landslide prone areas and through its building codes. The U.S. Geological Survey (USGS) has created a [gauge](#) to show when Seattle has a heightened risk of landslides and Seattle Public Utilities creates weekly landslide forecasts during the winter.

Tsunamis and Seiches

Tsunamis and seiches are two water wave hazards. Tsunamis are caused when water is rapidly displaced, most often by an earthquake or landslide. Large tsunamis are some of the most destructive natural hazards. Huge volumes of water can move quickly onshore and push far inland. Tsunamis are a rare but potentially catastrophic hazard in Seattle. The most dangerous tsunamis are generated locally. A Seattle Fault earthquake presents the greatest potential for a tsunami in Seattle. A large landslide could also trigger a tsunami, which happened in the Tacoma Narrows in 1949. A Cascadia Subduction Zone earthquake would generate a tsunami that would endanger Seattle but would likely not be as harmful as one created by the Seattle Fault. Planning for locally generated tsunamis is challenging because waves could arrive minutes after a precipitating event. In 2025, the City of Seattle began tsunami planning and public education.

A seiche is a standing wave produced by the sloshing of an enclosed water body like a lake, bay, reservoir, or river. The cause can be either earthquake shaking or storms. They are rare occurrences in this area. An 1891 earthquake produced an eight-foot seiche on Lake Washington and the 1964 Alaskan quake generated seiche that damaged property on Lake Union. In 2002 another seiche occurred in Lake Union due to an earthquake in Alaska. Seiches do not move as far onshore as tsunamis making them primarily threats to shipping and overwater structures.

Volcanoes

With five volcanoes in the state and more in surrounding states and Canada, volcanic hazards are a highly visible hazard for Seattle. The biggest volcano threat to Seattle is debris from Mt. Rainer washing

down the Duwamish River into Elliott Bay following a massive debris flow called a lahar. Lahars are a mixture of water and rock fragments that flow down the slopes of a volcano like rivers of concrete. A lahar would likely stop south of Seattle, but debris could form a dam posing a flood risk and debris will wash down the Duwamish River for months or even years after the event, impeding use of the river and threatening properties along its banks. This could affect transportation routes and infrastructure lines such as water, natural gas, and power running into Seattle.

Severe ashfall is unlikely in Seattle but would cause major transportation and health impacts if it occurred. Seattle's prevailing winds blow from west to east and will probably move ash away from Seattle, but it is possible that rare easterly winds could occur during an eruption producing ashfall in Seattle.

Volcanic emergencies will probably impact neighboring communities more than Seattle. We will need to support more heavily impacted neighbors, cope with transportation closures, and help displaced people after an eruption or lahar.

Biological Hazards

This chapter includes disease outbreaks, like the COVID-19 pandemic, and bioterrorism. Biological hazards have the potential deadliest hazards Seattle experiences. A disease that killed at the rate of the 1918 pandemic flu would cause many more deaths in King County than COVID-19. New and highly infectious diseases like influenza and corona viruses are the most likely risk. Because human beings lack immunity to new diseases, non-pharmaceutical interventions like social distancing, school and business closures, and masking are necessary to slow disease spread until vaccines and effective treatments can be developed. These interventions save life and slow disease spread but have social costs and can become politicized.

Bioterrorism is the use of a biological agent as a weapon to cause fear, illness, or death. In 2001 packages containing anthrax, a deadly bacterium, were mailed to multiple locations in the Eastern U.S. The emergency caused a spike in reported 'white powder' incidents in Seattle that consumed Seattle Fire Department resources. Bioterrorism has the potential to be very deadly because it involves the use of biological agents that have been created specifically to harm human beings. Thankfully, the number of bioterrorism incidents is very small.

[Public Health – Seattle & King County](#) (PHSKC) is the lead agency for biological hazards in King County. It directs response to public health emergencies. The City of Seattle supports PHSKC and mitigates the effects of non-pharmaceutical interventions.

Social Unrest

Social unrest includes riots, civil disorders, strikes, and mass civil disobedience. They can cause deaths, injuries, and property destruction. Unlike other hazards which usually bring the community together, social unrest pulls it apart and jeopardizes long-term recovery. The 2020 rioting in Minneapolis saw 164 arsons, over 1500 properties damaged, and over \$500 million in damage. This incident and the 1992 LA riots that killed more than 50 people are examples of the worst-case social unrest. The largest recent social unrest in Seattle was the [1999 WTO protest](#) that resulted in numerous injuries and community disruption.

Seattle is the central stage for political and social activity in the Puget Sound region and the hub of its social and political activities. Demonstrations, rallies, and marches are frequent. Nearly all of them occur with people expressing themselves freely and peacefully. Occasionally, people engage in acts of civil disobedience like occupying intersections or the freeway. These acts are not lawful and can be dangerous to the public and to those committing them. Blocking traffic increases the chances of accidents and impedes emergency vehicles. On other occasions, violent individuals infiltrate peaceful

crowds to attack property and law enforcement. Since the WTO protests, May Day has been an occasion for these kinds of activities with hundreds to thousands of people participating. As the country has become more politically polarized, more confrontations between far-left and far-right groups have happened with law enforcement caught between them. These confrontations have the potential to become particularly dangerous as tempers flare and firearms become more common.

Strikes are included here as organized, mass actions. Nearly all are legal, protected, activities whose impacts are limited to the parties involved and do not involve emergency management. Some strikes, like teachers strikes are legal, but have widespread impacts whose effects need to be mitigated by leveraging the City of Seattle emergency management system to stand up drop-in childcare during strikes. Most public sector strikes are not permitted by contract and would be unlawful, but that does not mean they are not possible. They have affected transit, sanitation, power, mail, and public safety. In 2024, 50,000 Washington State workers [walked off the job](#) for one day. In 1975, Seattle City Light electricians went on strike for 98 days.

Terrorism and Targeted Mass Violence

The United States has experienced devastating terrorist attacks, including the 9/11 attacks and the Oklahoma City bombing. These attacks were political. It has also experienced many non-political acts of violence like the 1999 Columbine shooting. Recently, however, the personal and political have often merged, making the distinction between terrorism and non-political violence blurry. As susceptible individuals self-radicalize on the Internet, private and political grievances combine. Ideologies are becoming less clear with actors sometimes combining ideas usually considered far-left and far-right. The Internet allows hateful content to spread worldwide making the distinction between domestic and international terrorism another blurry boundary.

Most attacks are now committed by individuals. They are harder to detect. Despite being lone actors, these attacks can be extremely deadly. In 2011, a lone terrorist killed 77 people in Norway and in 2019 a shooter in New Zealand killed 51 people. Firearms are commonly used, but recently vehicle attacks have been used more frequently.

Guarding against lone actor attacks is challenging. Many people make threats online without committing acts of violence. Identifying which threats are serious is nearly impossible. Individuals who are planning violence often do not post their intentions online. Because attacks are planned outside organized groups, law enforcement lacks tools used in the past like inside informants. Adding to the challenge is an expanded choice of targets. During the 1980's and 1990's targets were often government buildings or officials. As these places became hardened in response, attackers shifted to open, soft targets.

The Seattle Police Department works with the [Washington State Fusion Center](#) to promote counterterrorism. In 2025, the Seattle Police Department launched the Immediate Violent Crime Prevention & Enforcement Plan. It is targeted at all kinds of violence, but its emphasis on heightened patrols and gun trafficking will benefit efforts to decrease targeted mass violence and terrorism.

Cyber Incidents and Disruption

Seattle is highly dependent on digital systems and the internet. Disruptions to cyber infrastructure can include internet outages, release or deletion of sensitive data and information, compromised infrastructure or services, or physical destruction. Digital systems can face intentional attacks from small scale hackers to sophisticated nation-state actors. Cyber disruption can also occur from human errors or from another hazard (e.g. earthquake). Seattle's utility infrastructure uses Supervisory Control and Data Acquisition (SCADA) Systems to run and maintain basic functions. Many critical systems are physically separated from the Internet, making them much harder to hack. In some of the more serious cases,

attackers target support systems like billing systems because these systems are connected to the Internet. Bringing these systems down can make critical systems difficult to operate in practice.

The likelihood of attack and disruption is increasing as more products and services connect to the internet. The Seattle Public Library experienced a significant cyber ransom event in the summer of 2024, severely impacting their regularly offered services for nearly four months. The worst-case scenario is a sophisticated and coordinated attack on multiple critical lifelines like power, transportation, communications, utilities, and healthcare. If such an attack were successful, it would endanger lives, reduce economic activity, and degrade quality of life. The Ukraine War shows that it is possible to defend against serious cyberattacks. Ukraine experienced cyberattacks with some serious consequences such as taking down cell phone networks, but it has not suffered collapse of its critical services.

Transportation Incidents

This chapter covers accidents involving vehicles on the land, air, and sea. In the early part of the 20th century, accidents were common and occasionally killed dozens of people in individual incidents. Improved safety standards and better engineering greatly reduced the risks, but people in transit are inherently vulnerable. In 2015, 6 people died and many more were injured when a ‘duck’ tourist vehicle collided with a bus on the State Route 99 bridge.

With a confluence of transportation systems, Seattle is exposed to aircraft, maritime, rail, and roadway accidents. The most vulnerable areas are near transportation hubs like King County International Airport, the Port of Seattle, railyards, and ferry terminal, as well as along transportation corridors such as I-5, bridges, tunnels, rail lines, flight corridors, and shipping lanes. Transportation accidents are single site incidents but can have impacts far beyond their immediate location especially if they damage critical infrastructure or release hazardous materials. They have the potential to cause high casualties. The worst-case transportation accident would involve a large vehicle like a passenger aircraft or large maritime vessel like a ferry or cruise ship and critical infrastructure like a bridge or tunnel. The collapse of the Francis Scott Key Bridge in Baltimore illustrates the long-term impact of a transportation accident. The collapse caused six deaths, shut down Baltimore’s port, and will cost billions to replace.

Structure Fires

This chapter covers fires involving buildings and marine vessels. Vehicle fires are covered in Transportation Accidents. Wildfires are covered in their own chapter. The development of modern fire codes and the improvement of firefighting have dramatically reduced the number of fires, but recent data show a reversal of the trend. Some of this reversal may be due to COVID countermeasures that caused people to spend more time in their residences. Despite the decrease in the number of fires, the number of deaths is increasing. 77% of all fire deaths are due to structure fires.⁸ The 2003 Station nightclub fire in Rhode Island killed 100 people. This incident highlights the continuing dangers posed by structure fires, especially in crowded spaces, despite overall improvements in fire protection.

Some of the worst-case fires could involve fires in high-rise buildings, hotels, entertainment venues, ships, and industrial sites. These structures require complex responses with high numbers of lives at risk. Some involve dangers like hazardous materials incidents. Beginning in 2021, Seattle saw an increase in the number of vacant building fires. They endanger firefighters and neighboring structures. In 2024 the City of Seattle passed legislation to make the remediation and demolition of dangerous vacant buildings easier.

Hazardous Material Incidents

Industrial manufacturing, food processing, transportation routes, biological research, and medical radiology expose Seattle to hazardous materials. These dangers include chronic environmental risks and

acute releases. Chronic environmental risks include four EPA Superfund sites along the Duwamish Waterway and Elliott Bay. They contain contaminated sediments that could be reanimated and transported by hazards like flooding, landslides, and earthquakes. Acute releases include respiratory hazards like ammonia used in food processing and cold storage and explosive hazards from natural gas and crude oil. Seattle's central section (downtown, First Hill, and Capitol Hill) have the most hazardous materials incidents followed by the University District.

Beginning in 2013, large amounts of crude oil began to be transported through Seattle by rail. It is the same type that exploded in Quebec killing 47 people. These trains travel through densely populated areas of the city including Seattle's two biggest sports stadiums. Seattle is a center for biotech and a regional medical center. These industries expose Seattle to biological and radiological hazards. In 2019, Cesium-137 from a medical device leaked at Harborview. The cleanup took years to complete. An oil train explosion is one of the worst-case hazardous materials incidents for Seattle, especially if one were to happen in the dense, central section of the city.

Built Environment Failures

This chapter includes collapse or failure of structures like buildings, dams, and bridges as well as infrastructure systems. The 2021 Surfside condo collapse, which killed 98 people, focused attention nationally on building collapse. Similarly, 2024 Francis Scott Key Bridge collapse highlighted the vulnerability of critical infrastructure and its widespread economic effects. Locally, Seattle has experienced significant failures including a tower crane collapse, a wastewater treatment plant failure, and the need to close the West Seattle bridge to avoid a potential collapse.

One of the most potentially serious kinds of failures are dam breaches. When they occur, they can rapidly release large volumes of water that pose extreme risk for downstream communities. Seattle has six structures considered high hazard dams (the Bitter Lake, Roosevelt, and Volunteer Park reservoirs, the SW Genesee St Detention Dam, the High Point Stormwater Dam, and the Ballard Locks). Despite the presence of these structures in the city, Seattle's biggest exposures are from the Mud Mountain and Howard Hanson Dams. In the worst-case scenario of a breach, occurring when the pool behind the dam is at maximum height, large parts of the Duwamish Valley could be flooded. Besides these direct risks to Seattle, the City of Seattle owns dams in the Cascades on the Skagit, Tolt, Pend Oreille, and Cedar Rivers. Communities along these rivers are exposed to hazards from these dams. Seattle Public Utilities and Seattle City Light work directly with the jurisdictions where these dams are located to mitigate risks. The City of Seattle has active programs to monitor and inspect its dams. Information about them can be found in the [National Inventory of Dams](#).

Seattle is a city surrounded and divided by water. Bridges are critical to Seattle's transportation and constitute another infrastructure hazard exposure. The West Seattle bridge has been closed twice due to structural problems. The old I-90 bridge sank in 1990. The interruptions these incidents caused highlight the city's dependence on bridges.

Power Outages

Power outages are a type of built environment failure but are treated as a separate hazard their consequences have a unique profile compared to other built environment failures. The 2003 Northeast Blackout highlighted the fragility of the U.S. power system. Seattle experienced a widespread, week-long power outage from a winter storm in December 2006. Since that outage, Seattle City Light (SCL) has acquired a power management system that allows it to isolate outages and respond faster. It has also improved fire suppression in its underground electrical system. In the 1980's and 1990's several fires in the underground system caused extended outages in major parts of downtown. About half of Seattle's power is purchased from the Bonneville Power Administration (BPA), making the city vulnerable to

disruptions in other areas of the Northwest. Other events that may cause power outages include wildfire events in the Cascades near city-owned dams and transmission lines, and terrorist attacks targeting power infrastructure.

Demand for electricity in the region is growing faster than previously expected, coming from the adoption of electric vehicles, population growth, data centers, and the shift towards electrifying buildings for heating and cooling. In addition, climate change is projected to decrease hydropower generation in the summer by mid-century. This increased demand will require adding wind, solar, geothermal, and battery storage in the coming years to meet energy needs to avoid operating with less reserve capacity.

Extreme Heat

Extreme heat events (EHEs) are some of the deadliest disasters Seattle can face. More than 400 excess deaths were reported in Washington State during the 2021 Heat Dome event. Because Seattle has a generally mild climate, most people are not acclimatized when EHEs do occur. The temperature itself is just one factor driving the consequences of EHEs. The other important factors are the season, difference between the pre-event and event temperatures, the event duration, nighttime cooling, wind and humidity. Meteorologists can accurately forecast the development of an EHE and the severity of its associated conditions with several days of lead time. The National Weather Service (NWS) has developed a Heat Health Watch/Warning System that tailors extreme heat guidance to specific regions in the country. EHEs are projected to become more intense in the future due to climate change. The most vulnerable people in EHEs are people with diabetes, the elderly, infants, people experiencing homelessness, and people who are socially isolated.

Flooding

Seattle is susceptible to several flood types: coastal flooding (including king tides), riverine, urban, and compound flooding. A major cause of Pacific Northwest flooding is the class of storms called atmospheric rivers which happen when the Jet Stream brings moist air from the tropics into the Northwest. They can cause extended periods of heavy rain that can cause riverine and urban flooding. Recent weather patterns have produced very high intensity rain cells, sometimes over narrow geographic storm-tracks.⁹ These storms release larger amounts of rain, in short periods of time, which the drainage systems cannot always handle adequately.

- Coastal flooding happens during storms and especially high tides (called ‘king tides’). When the two coincide, the consequences are more severe. Sea level rise will make coastal flooding worse.
- Riverine flooding happens mostly along Seattle’s creeks and along the Duwamish River.
- Urban flooding occurs when heavy rain overwhelms the drainage system. Seattle’s drainage systems were designed and originally built for longer duration and lower intensity rainstorms. The city has developed mitigation measures like detention ponds to decrease the consequences of urban flooding, but it remains a risk.
- Compound flooding happens when two or more flooding sources occur simultaneously or within a short period of time. Seattle’s South Park neighborhood experienced severe compound flooding in December of 2022 from a low-pressure event coinciding with King Tides, causing the Duwamish River to overtop while the drainage system backed up causing urban flooding.

Some parts of the city are also vulnerable to flooding from dam failure from dams outside of city limits. The greatest risks are the Howard Hanson and Mud Mountain Dams, which discharge into the Green

River and the Duwamish. However, the likelihood of flooding in Lower Duwamish Valley due to a dam failure is low.

Severe Winter Weather

Seattle's winter weather is generally mild. When Seattle does receive snow, accumulations can be large. The consequences are especially severe if the snow lingers for more than several days or triggers secondary hazards such as power outages. Seattle has heightened vulnerability to snow and ice storms because of its hilly topography. The city prioritizes clearing major roads. Due to the logistical challenges of Seattle's narrow road widths in many areas and parking being allowed on both sides of most streets, Seattle does not plow residential streets. If snow is deep enough and persists for more than several days on residential streets, people may face a situation where arterials are clear but lack the ability to reach them in their vehicles. After a 2008 snowstorm, Seattle began treating roads with salt and deicer more aggressively which has improved arterial accessibility during snow events. Excessive cold furthermore exacerbates risks to human health and safety when electric heating sources are inoperable. During the 2008 snowstorm, several people died in King County due to carbon monoxide poisoning when they used charcoal grills indoors to heat their homes.

Water Shortages

Seattle can experience water shortages during the summers that follow winters with low snowpack, because nearly all of Seattle's water comes from watersheds in the Cascades that accumulate their supply from melting snow. Snowpack is projected to decline in future years due to climate change. The main shortage impacts are reduced stream flows for salmon, usage restrictions, and economic hardship for businesses that require large amounts of water. In 2019, Seattle Public Utilities (SPU) updated and adopted the 2019 Water System Plan and an accompanying Water Shortage Contingency Plan to respond to and mitigate water supply problems.¹⁰

Seattle City Light (SCL) faces challenges during water shortages because most power in the Northwest is generated by hydroelectric dams. During water shortages not as much water is available to turn generators to make electricity. To meet demand, SCL must buy more expensive power from outside the region. In addition to climate-related vulnerabilities, water shortages can be caused by main breaks. These shortages due to infrastructure failures are usually localized and short but could be longer if they are caused by another hazard like an earthquake.

Wildfire and Smoke

Wildfires are a natural part of ecosystems here in the Pacific Northwest, but climate change is altering seasonal fire trends. Fire season is predicted to increase in duration and fire activity is anticipated to increase in severity as the century progresses. This is due to changes in temperature, precipitation patterns, and snowpack, as well as other ecosystem changes such as invasive species and historic burn practices. While Seattle itself only has very limited direct wildfire risk, the Seattle City Light and Seattle Public Utilities own many assets in the Cascade Mountain that are susceptible to wildfire that are critical in providing our power and water supply. A major fire in one of Seattle's watersheds would have severe and long-lasting effects on Seattle's drinking water supply.

One of the largest risks wildfire poses to Seattleites is the smoke it produces, which can cause and exacerbate a variety of health issues. Smoke is particularly dangerous for youth, the elderly, those with preexisting health conditions, those who work outdoors, and people experiencing homelessness.

Wind

Windstorms with wind speeds equaling those of category one hurricanes can strike Seattle. Sustained winds of 69 miles per hour were recorded in the Seattle area in 2006. Seattle's most damaging storm was the 1962 Columbus Day Storm. Windstorms cause power outages, structural damage, transportation blockages, and coastal flooding. Fall and winter are the most common seasons for windstorms, but occasional out-of-season storms can be dangerous as well. Falling trees account for most damage and pose large safety risks for people and infrastructure. Windstorms often accompany other weather hazards such as landslides, urban flooding, snow and extreme cold and can produce complex emergencies. Seattle's new building code requires new structures to withstand 85 mph gusts. The City of Seattle has programs for vegetation management that serve to mitigate damage to electrical systems during windstorms. This tree trimming program intensified after the 2006 storm that caused lengthy power outages.

HAZARD RANKING

This chapter provides a ranking of all 19 hazards included in this document along with an explanation for how we arrived at the ranking. It expands on the [definition of a hazard](#) given in the Introduction, how we identified potential hazards, how we chose which of them to include, and finally how they compare to each other. The City of Seattle has limited resources to mitigate, plan, and prepare for them. The City of Seattle ranks hazards to prioritize where it will expend effort and resources. The rankings are not a precise prediction of hazard frequency or severity. The ranking is a simplification of highly complex phenomena. It represents our best evaluation of the overall threat posed, but a low ranking does not mean that the hazard is not dangerous. Any of the hazards identified could cause a horrible disaster.

Hazard Identification Methodology

This analysis uses multiple criteria to identify hazards based on best practices. Two key touchstones are the [FEMA Comprehensive Preparedness Guide \(CPG\) 201](#) and the [Emergency Management Accreditation Program \(EMAP\) standard 4.1](#).

The City of Seattle Emergency Management Strategic Plan, “the City’s emergency management program is intended to improve the City’s ability to prevent, mitigate, prepare for, respond to, and recover from natural and human-caused disasters “. Disasters are defined in the Introduction. We used these definitions as a lens to scope what to include in this analysis. It led us to look for phenomenon that threaten public safety, property and the environment, require immediate action and cannot be managed through day-to-day programs.

Using these definitions, CPG 201, and the EMAP standards, we employed the following techniques to identify specific hazards:

- Reviewing media archives, mainly old newspapers, for hazards occurring in Seattle
- Reviewing plans and reports written by the City of Seattle and key stakeholders
- Conducting a literature review focusing on local environmental and social issues and the built environment
- Consulting with subject matter experts (e.g., seismologists, cyber-security specialists)
- Meeting with emergency management partners and community stakeholders
- Researching emergencies or disasters from other areas that have not occurred locally but have a credible chance of doing so.

In the end we found over 80 descriptors for hazards in our research. Some were synonyms like ‘tremblor’ and ‘earthquake’. Some were special cases of a general hazard such as a blizzard (snow and wind) being a type of snowstorm. Others were related hazards like active shooter incidents, bombings, and terrorism. choose 19 hazards that pushed us to develop the broadest set of capabilities that will be useful no matter what Seattle experiences.

Climate change is treated as a broad phenomenon that affects hazards rather than a separate, distinct hazard. It has its own chapter where its effects are examined.

Ranking Model Structure

Each hazard has been evaluated using its Most Likely and Maximum Credible scenarios. Both scenarios are evaluated using twelve parameters developed from EMAP and FEMA standards. Ten of these twelve parameters are “base parameters” that directly affect the community, e.g., health effects. Each of these ten base parameters was assigned a score from one through five. The ten base parameters were averaged for a “Base Score” for each of the two scenarios.

The remaining two parameters, “Frequency” and “Cascading Effects,” function as multipliers. These two parameters were also assigned a score of one through five. The two scores were added to get a “Combined Multiplier.”

The “Base Score” was then multiplied by the “Combined Multiplier” to get a scenario score. Finally, the scores for the two scenarios were summed and added to the “Future Emphasis” parameter to get a hazard score. The equation is written below.

*Scenario Score = Average (Base Parameters) * Sum (Multipliers)*

Hazard Score = (Most Likely Score) + (Credible Worst-Case Score) + Future Emphasis

Draft scores were assigned by Office of Emergency Management staff and the Office of Emergency Management’s Strategic Working Group.

Comparing Hazards

Ranking and comparing hazards is a subjective but useful exercise to stimulate discussion and develop priorities. Standard metrics are applied throughout and provide a basis for comparison. Each metric is ranked from one to five with one being low and five being high. A bigger number indicates bigger consequences.

All Hazards Can Have Serious Consequences

For some people, a minor snowfall is an excuse to stay home from work and play, but for others, even a few inches of snow can be life threatening. Even hazards that don’t directly affect the general population can have ripple effects. Understanding our hazards, our vulnerabilities and their consequences is one of the components necessary to build a resilient community.

Hazard Ranking, Summary of Hazard Metrics, and Relationships Between Hazards

[Table 1](#) shows the hazard rankings. [Table 2](#) defines the SHIVA metrics. Many organizations are now using categories given by the Emergency Management Accreditation Program standard 4.3.2. We have cross reference our categories with EMAP. The corresponding EMAP category is noted in [Table 2](#) in the first column. Finally, some hazards induce secondary, tertiary or more hazards as shown in [Table 3](#).

Table 1. Hazard Ranking

	Most Likely Scenario														Credible Worst-Case Scenario																		
	Geographic Scope	Duration	Health Effects	Displacement	Economy	Environment	Built Environment	Transportation	Critical Services	Confidence in Govt	Base Score	Frequency (F)	Cascading Effects (CE)	Multiplier (F + CE)	Base x Multiplier	Geographic Scope	Duration	Health Effects	Displacement	Economy	Environment	Built Environment	Transportation	Critical Services	Confidence in Govt	Base Score	Frequency (F)	Cascading Effects (CE)	Multiplier (F + CE)	Base x Multiplier	Future Emphasis	Combined Ranking	
Earthquakes	5	2	2	2	2	2	3	2	2	1	2.3	4	4	8	18.4	5	5	5	5	5	5	5	5	5	5	5	5.0	1	5	6	30.0	3	51.4
Wind	5	2	2	2	2	2	2	2	2	1	2.2	5	3	8	17.6	5	2	2	3	3	2	3	3	4	3	3.0	3	3	6	18.0	3	38.6	
Power Outages	5	2	2	2	2	2	2	3	2	1	2.3	5	2	7	16.1	5	4	2	4	3	1	2	3	3	5	3.2	3	3	6	19.2	3	38.3	
Severe Winter Weather	5	4	2	2	2	1	2	2	2	1	2.3	5	2	7	16.1	5	4	2	4	3	2	3	4	3	3	3.3	2	3	5	16.5	5	37.6	
Wildfire and Smoke	5	3	2	2	1	2	1	2	1	1	2.0	5	1	6	12.0	5	5	2	4	4	5	1	1	4	3	3.4	3	3	7	20.4	5	37.4	
Infectious Disease and Biological Hazards	5	5	4	3	3	1	1	1	1	3	2.7	4	1	5	13.5	5	5	5	5	4	1	1	3	3	3	3.5	3	2	5	17.5	5	36.0	
Tsunamis and Seiches	3	2	2	3	3	2	3	2	3	1	2.2	3	2	7	11.0	4	2	4	5	4	4	3	4	3	3	3.6	2	4	5	21.6	3	35.6	
Cyber Disruptions	5	4	1	2	2	1	1	2	1	3	2.2	4	1	6	11.0	5	4	2	5	4	3	1	4	4	5	3.5	1	4	5	18.5	5	34.5	
Landslides	4	3	2	2	1	2	2	3	1	1	2.1	5	1	6	12.6	4	3	3	3	3	3	3	4	2	3	3.1	2	4	6	18.6	3	34.2	
Flooding	4	3	1	2	2	2	2	2	1	1	2.0	5	1	6	12.0	5	4	2	4	3	3	3	4	3	3	3.4	2	3	5	17.0	5	34.0	
Extreme Heat	5	3	3	2	2	2	1	2	1	1	2.2	4	1	5	11.0	5	5	4	4	3	2	1	3	3	3	3.3	3	2	5	16.5	5	32.5	
Transportation Incidents	2	1	3	1	2	1	2	3	1	1	1.7	3	1	4	6.8	3	4	4	4	3	3	2	4	3	5	3.5	2	4	5	21.0	3	30.8	
Social Unrest	3	1	2	2	3	1	2	2	2	3	2.1	5	2	7	14.7	5	3	3	5	3	1	3	2	2	5	3.2	2	2	4	12.8	3	30.5	
Water Shortages	1	4	1	2	2	2	2	2	3	3	2.2	5	2	7	15.4	5	5	1	3	3	3	2	1	3	3	2.9	2	2	4	11.6	3	30.0	
Hazardous Materials Incidents	3	2	2	3	2	3	1	2	2	3	2.3	4	1	5	11.5	3	4	4	4	3	2	1	4	2	3	3.0	2	3	5	15.0	3	29.5	
Structure Fires	1	2	3	3	2	2	2	2	2	3	2.2	4	1	5	11.0	4	4	3	4	4	1	3	4	3	5	3.7	1	3	4	14.0	3	28.0	
Built Environment Failures	2	2	2	2	2	1	1	3	1	1	1.7	5	1	6	10.2	5	4	3	3	4	3	4	4	3	3	3.6	1	3	4	14.4	3	27.6	
Volcano Hazards	3	5	1	4	3	2	3	2	3	1	2.7	2	2	4	10.8	5	5	3	4	3	2	4	5	1	1	3.4	1	3	4	13.6	3	27.4	
Terrorism & Targeted Violence	1	1	2	2	2	2	2	2	1	3	1.8	5	2	7	12.6	4	4	4	3	2	1	2	2	3	3	2.7	1	2	3	8.4	5	26.0	

Table 2. Hazard Metric Definitions

Consequence Category	Definition	One	Two	Three	Four	Five
Frequency	How often has the hazard occurred in the past?	Unprecedented or less than 1 in 2500 chance per year	1 in 2500 to 1 in 1000 chance per year	1 in 1000 to 1 in 100 chance per year	1 in 100 to 1 in 50 chance per year	Greater than 1 in 50 chance per year
Geographic Scope	Size of the affected area. Includes areas not damaged but strongly affected by the incidents. For example, areas backed up by a transportation accident.	Single site. One or two blocks.	Single Site - Multiple blocks	Community (i.e., all of Downtown	Citywide or regional events that affect only specific areas within the region.	Regional.
Duration	How long does response and initial short-term recovery last?	Less than 24 hours	1 -3 days	4 - 7 days	7 - 30 days	30 + days
Health Effects, Deaths and Injuries [EMAP - Public]	How dangerous is the hazard to human health and safety?	No deaths or injuries	1 - 10 deaths and/or 1- 100 injuries	11-50 deaths and/or 101 - 500 injuries	51 - 500 deaths and/or 501 - 1500 injuries	Over 501 deaths and/or 1501 over injuries
Displacement and Suffering [EMAP - Public]	How likely is the hazard to negatively impact the exposed population in terms of displacement, personal property loss and increased indebtedness?	No displaced people / minor inconveniences	1-100 displaced people long-term. Hundreds short-term displaced. Vulnerable populations begin to have problems with food, water, and access to services	101 - 250 displaced long-term. Thousands short-term displaced. Vulnerable populations have serious difficulties. General population is starting to have problems	251-1000 people displaced long-term. Tens of thousands short-term displaced. Up to 30% of population experiencing difficulties.	1001+ displaced people long-term. More than 100,000 short-term displaced. More than 30% of population facing acute shortages of basic supplies and access to services.
Economy [EMAP - Economy]	How does the hazard affect the local economy?	No measurable impacts.	No impacts to overall economy, but isolated businesses experience hardships	Entire sectors experiencing loss of revenue and capital.	Core sectors of Seattle's economic base are affected and unable to generate revenue. Capital losses between 1 and 10% of assessed value.	Physical losses equal to 10% of assessed value. Loss of ability to generate revenue.
Environment [EMAP - Environment]	How damaging is the disaster for the natural environment?	No damage / temporary minor damage	Degradation of ecosystem that will repair itself	Degradation of ecosystem that requires intervention	Functional loss of an ecosystem, but restoration possible.	Long-term loss of an ecosystem

Consequence Category	Definition	One	Two	Three	Four	Five
Structures [EMAP - Property, Facilities, and Infrastructure]	How does the hazard affect buildings and physical infrastructure? This includes utilities.	No effects.	1 - 10 structures red tagged. Up to 25% loss of one utility	11 - 250 structures red tagged. Multiple utilities affected up to 25%	251 - 1000 structures red tagged. Multiple utilities affected 25 - 50%	1000+ structures red tagged. At least two major utilities degraded at least 50%
Transportation [EMAP - Property, Facilities, and Infrastructure]	How does the hazard affect the ability of residents and workers to access the resources they need? Watch the combination of high mobility and duration impacts.	No effects on mobility	All essential services accessible, but delays reaching work or non-essential services	One critical service inaccessible. Degradation of at least one mode. Major corridors open, but minor streets degraded or impassible	Many critical services inaccessible. One major mode inoperable. One major corridor inoperable	Most critical services inaccessible. Multiple modes inoperable. Most high-volume corridors impassible.
Critical Services (EMAP - Continuity of Operations and Responders]	How likely is the hazard to reduce the community's ability to provide critical services: public safety, social, utilities, financial, food distribution, and medical. This includes the loss of responders due to death or injury.	No impairment of critical services	Temporary degradation of 1 critical service	Temporary degradation of multiple critical services. Long-term degradation of 1 critical service	Temporary degradation of most critical services. Long-term degradation of multiple services.	Unable to deliver Most critical services
Confidence in Government [EMAP - Confidence in Government]	Would public's confidence in government be shaken	No	(not used)	Somewhat	(not used)	Yes

Consequence Category	Definition	One	Two	Three	Four	Five
Cascading Effects	How severe and complex will the secondary effects be?	Hazard extremely unlikely to cause secondary hazards and if they occur are minor.	Secondary hazards may occur, but are likely to be minor compared to primary hazard	Secondary hazards occur that extend the impact of the disaster and hamper response but are not disasters in their own right.	Secondary effects generated that significantly increase the magnitude of the disaster. Secondary impacts would likely be considered disasters if they occurred by themselves.	Secondary effects generated and rival or exceed primary hazard. Secondary impacts would definitely be disasters in their own right. Example: train derailment leading to massive chlorine spill.
Future emphasis	How much is the level of emphasis in mitigating, planning for, and preparing for this hazard changed based on trends, increasing understanding of the hazard, and changing underlying conditions that give rise to the hazard.	Decreasing emphasis	(not used)	Emphasis unchanged	(not used)	Increasing emphasis

Table 3. Hazard Relationships

		Secondary Hazards																		
		Earthquakes	Landslides	Volcanoes	Tsunami and Seiches	Biological Hazards	Social Unrest	Terrorism and Targeted Violence	Cyber Disruption	Transportation Incidents	Structure Fires	Hazardous Materials Incidents	Built Environment Failures	Power Outages	Extreme Heat	Flooding	Severe Winter Weather	Water Shortages	Wildfire and Smoke	Wind
Primary Hazard	Earthquakes																			
	Landslides																			
	Volcanoes																			
	Tsunamis and Seiches																			
	Biological Hazards																			
	Social Unrest																			
	Terrorism and Targeted Violence																			
	Cyber Disruption																			
	Transportation Incidents																			
	Structure Fires																			
	Hazardous Materials Incidents																			
	Built Environment Failures																			
	Power Outages																			
	Extreme Heat																			
	Flooding																			
	Severe Winter Weather																			
	Water Shortages																			
	Wildfire and Smoke																			
	Wind																			

This table shows the relationships between primary hazards and secondary hazards (i.e., cascading effects). A secondary hazard is one that can be triggered by the primary hazard. A triggered hazard has its own secondary hazards. These are tertiary hazards. For example, a snowstorm occurs. This is the primary hazard. Then it rapidly melts triggering urban flooding and landslides. These are the secondary hazards. The landslides knock out the supports of a bridge that also carries power, water and gas lines. These outages are the tertiary hazards. These cascading effects can have a huge multiplier effect and make the effects of hazards hard to predict. They are one of the major reasons it is a mistake to equate hazard vulnerability with disaster vulnerability.

COMMUNITY PROFILE

With an estimated 816,600 residents¹¹ (2025) and 632,813 jobs (2024)¹², Seattle is the largest municipality in the U.S. Pacific Northwest. It is the region's diverse center of cultural and economic activity. Built on a hilly isthmus between Puget Sound and Lake Washington, Seattle is famous for rainy weather, proximity to nature, coffee, software, and airplanes, but as is often the case with things a place is famous for the truth is more complex and interesting.

To understand how hazards impact Seattle, one must first understand Seattle. This chapter provides an overview of Seattle that gives a context for all the hazard chapters. This community profile does three things: explains what is at stake, broadly demonstrates the community's "defenses" against hazards, and provide basic facts about Seattle demographics, natural environment, and built environment. A major theme running through the data in this chapter is Seattle's continuing recovery from the pandemic.

Seattle is strong economically. Two of the five largest companies in the world by market capitalization (Microsoft and Amazon) are headquartered in the greater Seattle area.¹³ It is home to some of the wealthiest neighborhoods in King County and some of its poorest.¹⁴ Paradoxically, Seattle is both a city of neighborhoods that looks inward but is highly dependent on international trade with over \$36 billion exported out of the metropolitan region in 2023.¹⁵ Housing supply has not kept up with Seattle's job growth resulting in a housing crisis. Median home prices now exceed six times median annual household income and nearly half of Seattle's renters are rent burdened, defined as spending more than 30% of income on rent and utilities.¹⁶

The Seattle community extends beyond the city limits. The City of Seattle owns important resources outside the city limits. They include dams in the North Cascades (Ross and Diablo Dams), Pend Oreille County (Boundary Dam), the Tolt River Watershed, and the Cedar River Watershed. These resources are owned by Seattle City Light and Seattle Public Utilities. Water and power transmission lines connect these resources to the city. Identifying the hazards that threaten these resources is important to gain a comprehensive picture of Seattle's vulnerability. In turn, these assets pose hazards to the communities where they are located. They are addressed in this analysis.

Physical Geography

For most of Seattle's hazards geography plays a major role. It is a good place to start looking at Seattle from a hazard perspective. See [Figure 2](#) for a look at Seattle's topography.

Location

Seattle is one of a string of cities running from Vancouver, Canada to Portland, Oregon. It is the northernmost major American city in the lower 48 states. Fargo, North Dakota, and the northern border of Maine are south of Seattle. Its position in the upper left part of a map of the Lower 48 can make it feel far from the rest of the U.S., but close to Alaska and Asia. As the closest major U.S. city to Alaska, Seattle has deep ties to that state starting with the Alaska-Yukon Gold Rush in 1897. Seattle is also one of the closest U.S. ports to Asia. This proximity has led to strong trade and immigration relationships with Asia. Overall, Seattle's location gives it an outward orientation. It looks as much to the north and west as it does to the east.

Western Washington's Puget Sound region is a large, north-south oriented basin bordered by the Olympic Mountains on the west and the Cascade Mountains on the east. Puget Sound itself is a narrow extension of the Pacific Ocean that runs down the middle of the basin. Seattle sits along Puget Sound's eastern shore.

City of Seattle Assets Outside the City Limits

The City of Seattle owns watersheds, dams, and power and water transmission lines in the Cascades and Eastern Washington. City Light owns five dams. The biggest, the Boundary Dam is in Northeast Washington in Pend Oreille County along the Pend Oreille River 110 miles north of Spokane. Three more, the Ross Gorge, and Diablo dams, are close together along US Highway 20 in North Cascades National Park. The last is on the Cedar River. Seattle Public Utilities owns the Tolt and Cedar watersheds on the western front of the Central Cascades about 40 miles east of Seattle.

Location Effects on Vulnerability

Seattle is relatively isolated with few surface routes running east-west through the Cascades (I-90 and SR 2) and those running north-south confined to the narrow space between Puget Sound and the Cascades.

Another effect of waterways and steep hills: hospitals concentrated on First Hills could be hard to reach if bridges are impassable.

Flooding, landslides, bridge collapses, and other hazards can block these routes and isolate Seattle. The watersheds, dams, and transmission lines outside the city limits make Seattle a wider target geographically. These areas are vulnerable to wind, wildfires, landslides, earthquakes, and other incidents that do not affect Seattle directly.

The effects of rivers and steep hills meant the 2020-2 West Seattle Bridge closure increased Fire Department response times. They were mitigated by adding a ladder and medic unit to West Seattle.

Landforms

Seattle is an isthmus sitting on the 84 square miles between Puget Sound to the west and Lake Washington to the east. Elliott Bay extends into Seattle's middle section giving Seattle an hourglass shape. Downtown is in this narrow section, causing many major transportation routes and services to bottleneck.

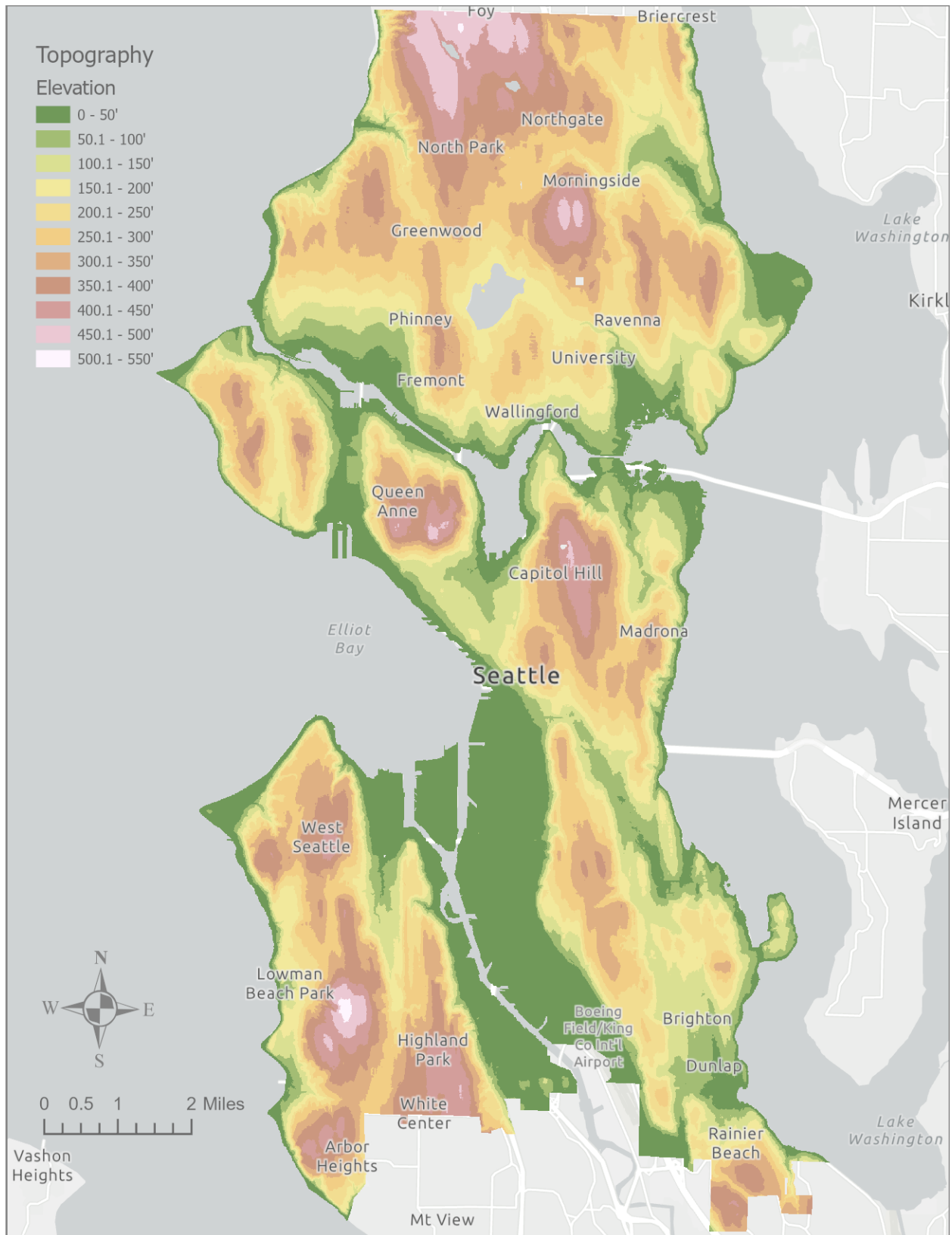
Two waterways—the Duwamish River and the Washington Ship Canal—divide the city into clearly defined sections. The Duwamish River runs north-south through the city's center and divides the southern third of the city into east-west halves as it runs from the southern border into Elliott Bay. The Lake Washington Ship Canal, which connects Puget Sound to Lake Washington through a series of cuts and locks, separates the northern third of Seattle from the rest of the city.

Seattle is very hilly. During the Pleistocene epoch (2,580,000 to 11,700 years ago) the Cordilleran ice sheet pushed down from the north over the area that is now Seattle. Ice 3,000 feet thick scoured the land and left north/south trending ridges and troughs. The troughs filled with water to become Puget Sound and Lake Washington. These ridges form our hills with their steep eastern and western sides. The highest hills reach over 500 feet. Like the water barriers, the hills have guided Seattle's development. Roads are forced to jog around obstructions or dead end suddenly.

Landform Effects on Vulnerability

The importance of these water and slope barriers on emergency response cannot be overstated. The arrangement of hills and water has dictated where transportation routes and large facilities can be located. The resulting patterns create a relationship between the natural and built environments that are fundamental to Seattle's hazard vulnerability. Key transportation routes and utilities are

Figure 2. Topography



City of Seattle, King County, WA State Parks GIS, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA

concentrated by the topography making it possible for a single incident to affect multiple types of infrastructure. Many critical facilities like hospitals, specialty public safety units, and utility resources can be isolated if key transportation routes are impeded. In 2020 dangerous cracking in the West Seattle bridge forced it out of service. Access to and from West Seattle became much more difficult. Response times for the Seattle Fire Department ladder and medic units increased. An extra ladder and medic unit were funded for West Seattle to mitigate this increase.

Most of Seattle's hospital beds are on First Hill, including Harborview, the only Level 1 Trauma Center for Washington, Wyoming, Alaska, Montana, and Idaho (WWAMI region). There are four hospitals located north of the Ship Canal Bridge, one of which includes nearly all the pediatric hospital capacity in King County. The Veterans Administration hospital is on Beacon Hill and there is a psychiatric hospital in West Seattle that houses most of the involuntarily committed patients in King County, including those who pose a threat to public safety. The locations of hospitals provide broad geographic coverage across Seattle yet impacts to transportation infrastructure during disasters can isolate these facilities and render them only capable of providing medical services to their immediate communities.

The Fire Department's hazardous materials team is housed in Pioneer Square. Normally, this centralization of a limited resource is the most efficient distribution of resources, but during an emergency some neighborhoods could be cut off from these downtown services. West Seattle and Magnolia depend on just three bridges each for their direct connections with the rest of the city. In a major crisis, casualties would have to be transported downtown because there are no hospitals in those areas. If the bridges were down, there would be no way to get medical treatment to the neighborhood quickly. Even after the immediate crisis, isolation could remain an issue. San Francisco Bay commuters were confronted with long-term delays after the Cypress Freeway collapse in the 1989 earthquake. Seattle's dependence on bridges could easily lead to similar transportation problems.

Geology

Tectonic activity, glaciation and human activity give Seattle its geology. The Puget Sound Basin is being compressed by the movement of the Pacific and Juan de Fuca plates. The strain is relieved by earthquakes on a series of faults running through the Puget Sound Basin. These faults move vertically. The areas north of the faults sink after earthquakes and subsequently fill with sedimentary material. Seattle has one of these basins under its downtown.

Glaciation is an important shaper of Seattle's geology. At least seven times the Cordilleran Ice Sheet moved down from British Columbia to cover the Puget Sound Basin in ice up to 3000 feet thick. As the ice advanced and retreated it deposited layers of sand, clay, and till (as a mix of different material). The only exposed bedrock in Seattle is Seward Park and near the south end of King County International Airport.

Human activity changed Seattle's geology. Nearly 20% of the surface of Seattle is covered with fill produced by filling in the tide flats in the Duwamish Valley and other low-lying areas.¹⁷ Regrading projects removed Denny Hill in what is now Belltown. Cuts were made in Beacon Hill to allow rail transport from Lake Washington to Puget Sound.

How Geology Effects Vulnerability

Seattle's geology affects which areas of the city are exposed to or have heightened risk from earthquakes, landslides, and urban flooding. The sedimentary basins amplify seismic waves to produce stronger ground shaking during earthquakes.

The glaciated soils affect where landslides happen. Water percolates through sand and till until it encounters clay. It then moves sideways until it empties out onto a hillside. These contacts between

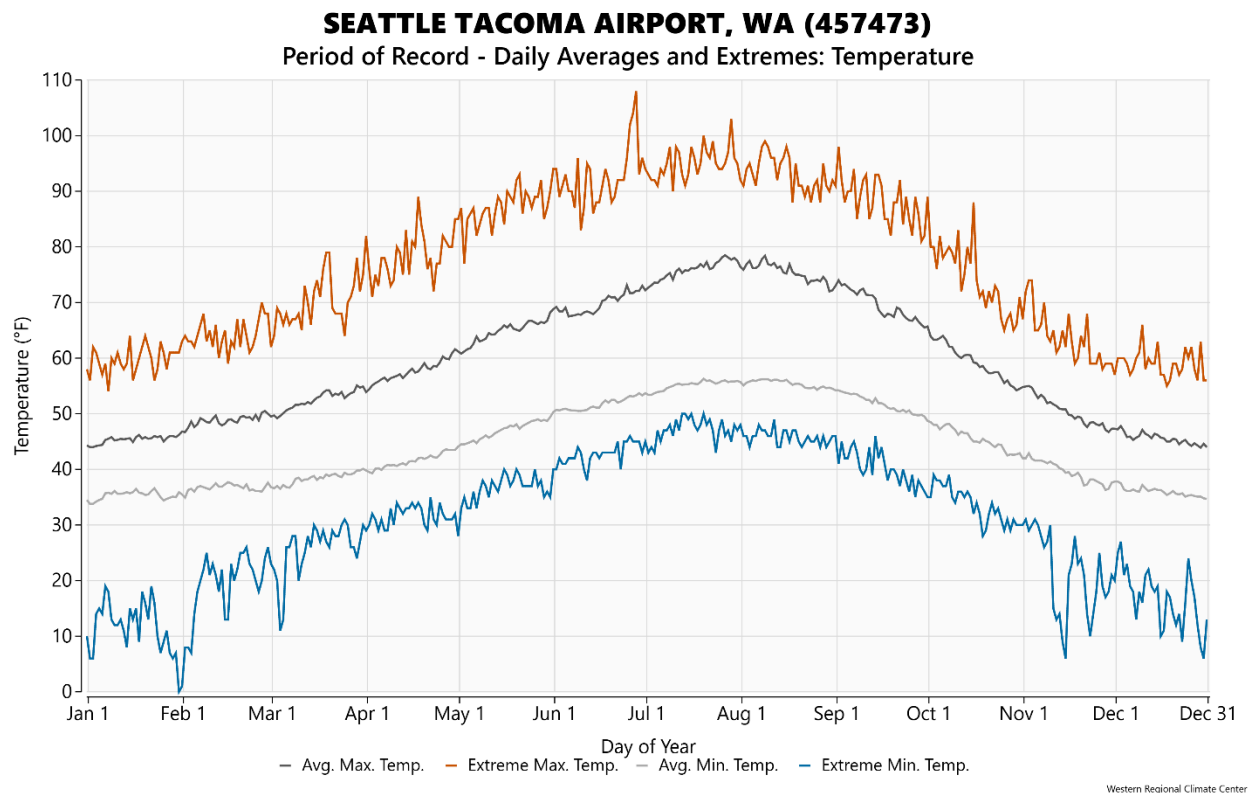
sand, till, and clay are at heightened risk of landslides, especially because as till and sand become saturated they become heavier and less cohesive.¹⁸ In many areas human activity has destabilized slopes. In analyzing a century's worth of reports, the engineering firm Shannon and Wilson calculated that 84% of all landslides had some degree of human influence.¹⁹

Climate and Weather

Climate change is affecting Seattle and is covered in its own chapter. Seattle has a temperate climate with wet winters and dry summers. Seattle receives less total precipitation than Boston but has 149 days with some amount of rain. Its temperature is moderated by the Pacific Ocean, keeping the lows generally above freezing and the highs generally below 80 degrees. Humidity is very low and wind speeds average less than 6 mph.

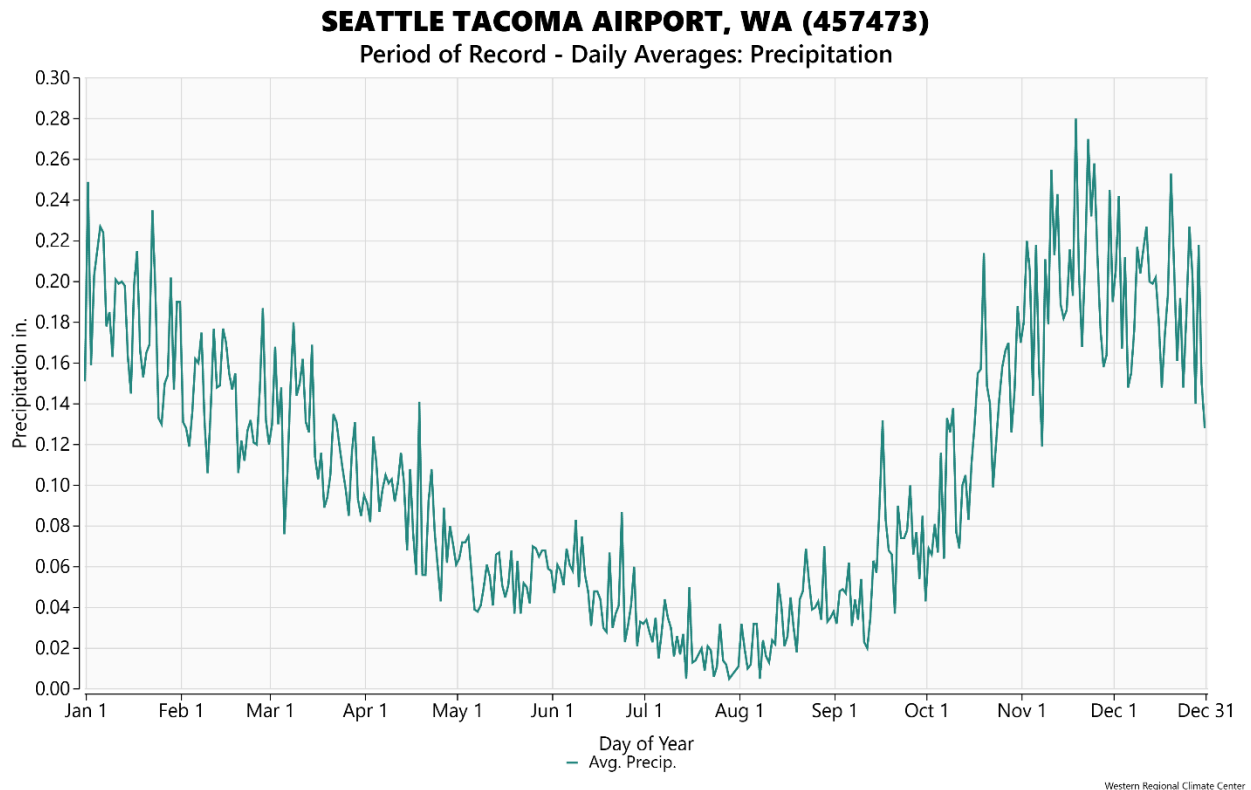
Despite having generally mild weather, Seattle experiences periodic weather extremes. It periodically receives hurricane force winds and even an occasional tornado. To understand these complexities, one must first understand how the Pacific Ocean and Western Washington's mountain ranges influence Seattle's weather.

Figure 3. Daily Average and Extreme Temperature Summary (SeaTac) 1/1/1945 – 2/4/2025²⁰



Prevailing winds bring the city's weather from the west over the Pacific Ocean. Because air temperature over water does not vary as much as it does over land, the air that reaches Seattle does not vary widely in temperature giving Seattle cool summers and temperate winters. On average each year since 1945 there have been 3.3 days over 90 degrees. The number jumps to 4.3 days per year since 1995. On average there have been 2.4 days where the temperature remains below 32 degrees since 1945 but drops to 1.5 days since 1995.²¹

Figure 4. Seattle Daily Average Precipitation Summary (SeaTac) 1/1/1945 – 2/4/2025²²



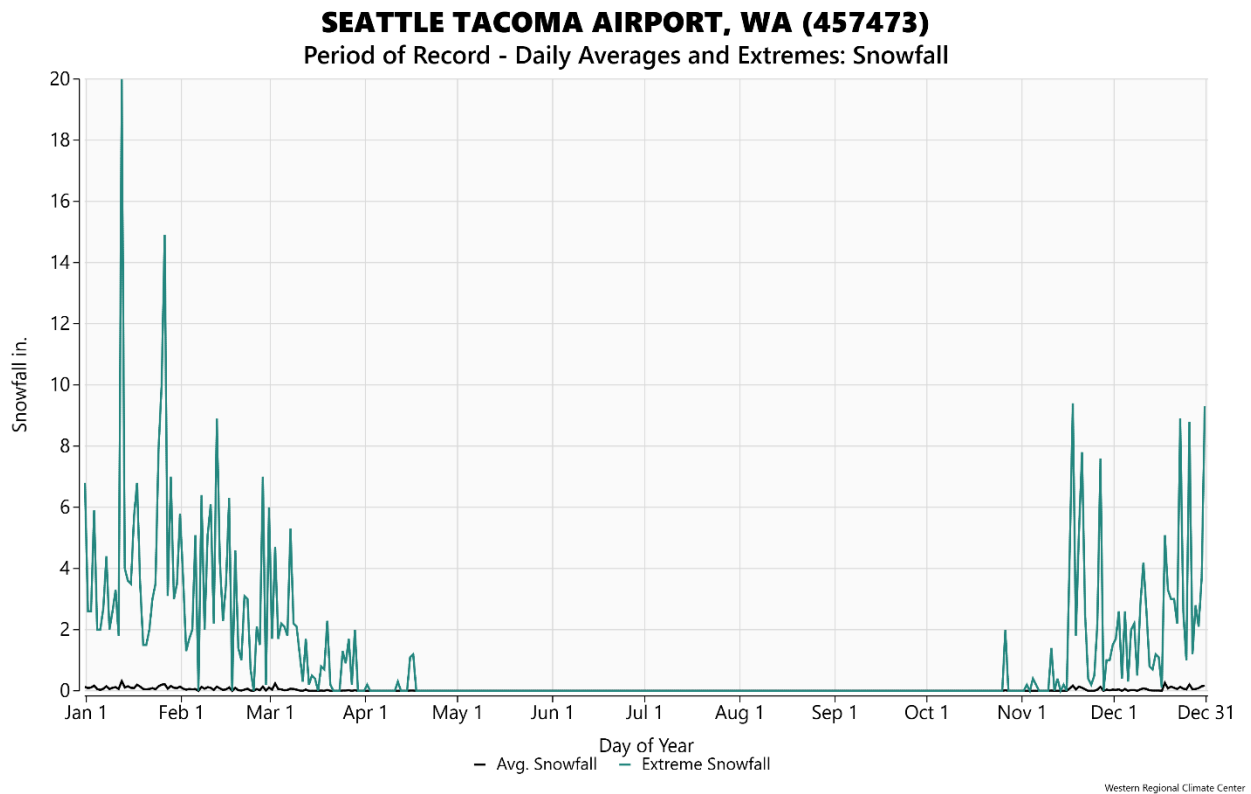
The Pacific Ocean also accounts for the seasonality of our precipitation. Weather systems tend to follow the jet stream, a narrow band of high, strong winds. During the winter the jet stream frequently passes over Seattle, bringing wet, stormy weather. As temperatures rise over the Pacific in the summer, the jet stream is pushed north, taking the clouds and rain with it. Over 75% of Seattle’s precipitation falls between October 1st and March 31st, just under half falls between November 1st and the end of February.

Olympic and Cascade Mountain Ranges

The Cascades are a barrier that keeps dry continental air out of the region and moist Pacific air trapped in it. Continental air is hot in the summer and cold in the winter. With continental air blocked, temperate marine air is the main influence on Seattle’s temperatures. This marine air carries a lot of moisture, especially in the winter. It is blocked by the Cascades as it moves east and must rise to get over them. As it does so it cools and condenses, creating clouds and moderate rain. As a result, Seattle has rainy and overcast days but less total rain per year than many cities.

The snowiest places on earth are less than 100 miles from Seattle. Mt. Baker had 1,147 inches (nearly 100 feet) of snow during the winter of 1998-9 breaking a record set at Mt. Rainier of 1,122 inches. During the same winter, Seattle got only a few inches of snow. On average, Seattle gets 12 inches of snow per year. That is almost twice what Portland and Vancouver receive, but nowhere near Boston’s 42 inches, Minneapolis’s 56 inches, or Denver’s 58 inches. Occasionally, however, Seattle seems transported into the snowy Cascades. Seattle’s one day record of 22.5” beats Minneapolis’s 18.5” by 3 inches. Seattle record snowfalls far exceed average snowfalls. Most snowfalls happen when cold continental air pushes through the mountains and collides with an incoming Pacific storm. The reasons for the occasional heavy snow are covered in the chapter on severe winter weather.

Figure 5. Average and Extreme Snowfall (SeaTac) 1/1/1945 – 2/4/2025²³



Climate Effect on Vulnerability

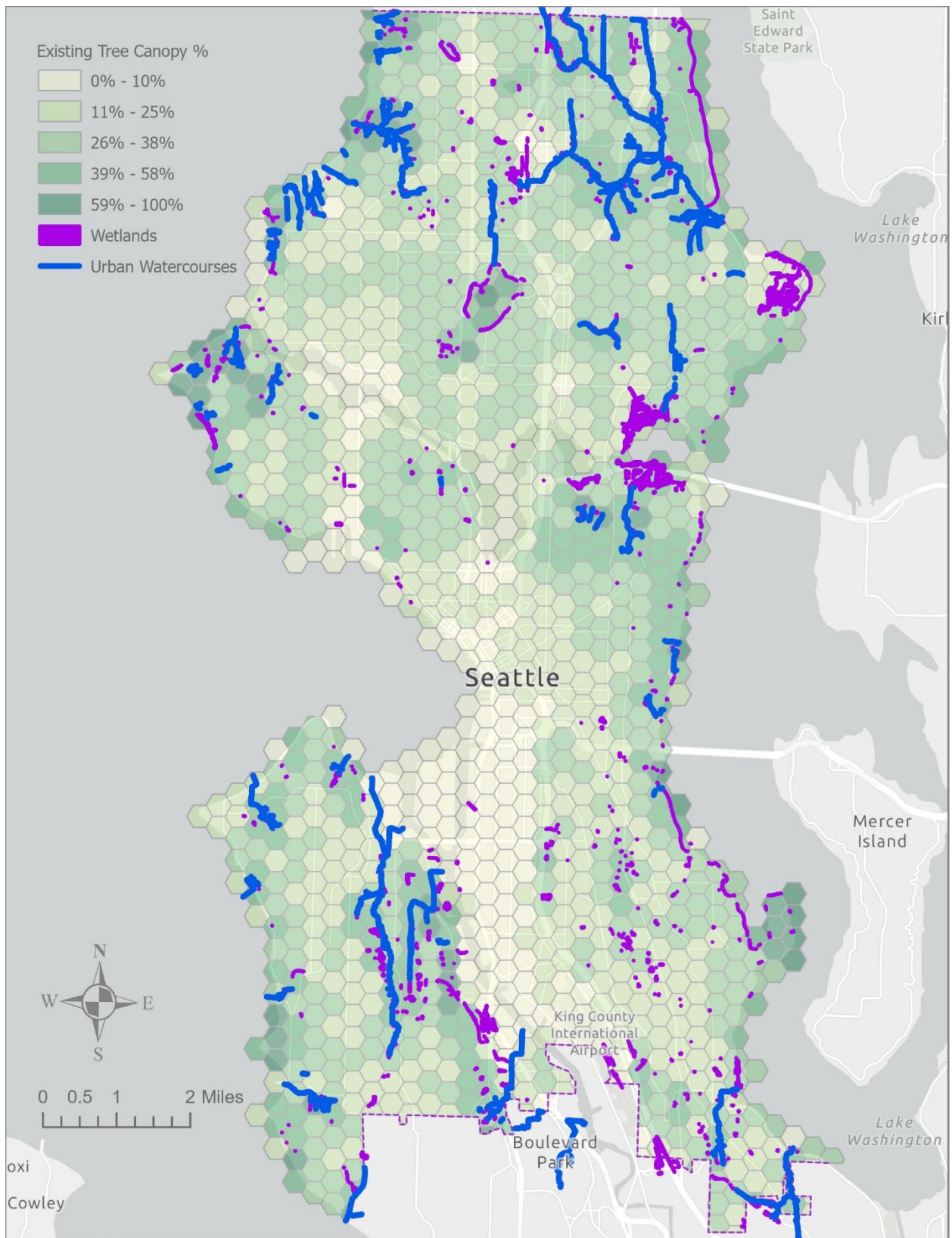
Seattle's generally mild climate leads to some dilemmas because acute events can be far outside averages. The snowfall totals reveal the dilemma most starkly: Seattle is neither a low snow city like Atlanta or San Francisco nor a heavy snow city like Denver. Stuck in the middle, the government, businesses, and residents face difficult choices about how much preparation to undertake. Adding to the complexities is Seattle's hilly topography that multiplies the effects of heavy rain, mud, and snow.

Weather can challenge emergency response. If a disaster were to strike while snow was on the ground, it would greatly complicate the critical tasks. Transporting the injured to hospitals, many of which are located on hills, would be difficult and the fire department could be delayed in responding to emergencies. Even rain can be an unforeseen complication. After the Northridge Earthquake in 1994, many people moved out of their damaged houses and into local parks. The good weather allowed them to do this. In Seattle, they might not be so fortunate.

Natural Environment and Environmentally Critical Areas

Although Seattle is the most urbanized part of the Pacific Northwest it retains parts of its pre-urban ecosystems. These areas are essential to the wellbeing of residents, workers, and visitors. The City of Seattle protects its natural environments with plans and regulations. Two critical tools are the Urban Forest Plan and the Environmentally Critical Areas Ordinance. Developed areas are ecosystems too and can contribute to Seattle's biodiversity.

Figure 6 Seattle’s Tree Canopy, Watercourses, and Wetlands



WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Urban Forest

Trees are a vital part of Seattle's ecosystem, especially our large native conifers. Seattle was originally heavily forested. (For a [reconstructed map](#) (PDF) of Seattle before European arrival, visit the [Burke Museum's Waterlines Project](#)). In 1972, 40% of the city was covered by trees. From 1972 to 1996 Seattle lost over 46% of areas with heavy tree cover and 67% of areas with medium tree cover.²⁴ By 2007 Seattle's tree canopy was at 23%. To correct this loss, the City of Seattle adopted the Urban Forest Management Plan in 2007, which created a goal of 30% canopy cover by 2037. In 2016 a tree canopy assessment showed 28.6% tree cover in Seattle. In 2021, despite the 30% goal, a new assessment revealed that Seattle's tree canopy has shrunk by 1.7% or 255 acres, roughly the size of Green Lake, to a new total cover of 28.1%.²⁵

The decline is being led by native species on public property. Seattle's Parks and greenways have the highest percentage of these species which is why these areas have seen the biggest declines (-5.2% from 2016 to 2021). These areas are dominated by red alder and big leaf maple. They are pioneer species that populated areas that were logged. The trees are nearing the end of their natural lives, but our increasingly dry and hot summers are increasing pests and exacerbating mortality. Normally, alders and maples would be succeeded by Douglas fir, western hemlock, and red cedar, but because these trees were logged, there are far fewer seedlings available to replace them. In 1999, less than 293 acres of Seattle were covered with the native conifer forests that once dominated Seattle's 54,379 acres and this number is decreasing.²⁶

Urban Forest Effects on Vulnerability

Trees, especially our mature ones reduce vulnerability to many hazards and stressors. Areas with high tree cover show more economic vitality and correlate with better health. They mitigate heat, improve air quality, and reduce flooding. The City of Seattle estimates that tree canopy loss from 1972 to 1996 costs Seattle \$1.3 million per year by causing an extra 7.5 million cubic feet in stormwater runoff – a factor in urban flooding.²⁷ Trees also improve urban air quality by removing thousands of pounds of pollutants from the atmosphere. The estimated benefits from carbon storage amount to \$10.9 million in savings.²⁸

Despite their many benefits, trees also pose some risks due to wind and snow when they can damage houses, power and telephone lines and their roots pull up underground pipes. A 2016 [LIDAR](#) (a type of remote sensing) analysis shows that most of Seattle's trees are located in residential areas and in the right-of-way, representing 72% and 22% of the canopy cover, respectively.²⁹ The areas with the densest tree cover in the city, Northeast and West Seattle, have the greatest amount of debris, fallen trees, and associated service disruptions during storms. The potential damage caused by falling trees can be mitigated by trimming the weak limbs and removing weakened trees near buildings and infrastructure.

Wetland and Riparian Corridors

Wetlands are some of the most valuable and complex ecosystems on earth. They mitigate flooding, improve water quality, recharge groundwater, stabilize the shoreline, and offer habitat to many fish and wildlife species. Seattle has 547 acres of wetlands or just under one square mile.³⁰ Many wetlands are narrow, fragmented bands along Seattle's 45 small streams. The biggest concentrations are located along streams, Union Bay, the Arboretum, and Sand Point. See [Figure 6](#).

Riparian corridors are the transitional areas between terrestrial and aquatic environments. They are the areas along Seattle's streams and often overlap with wetland ecosystems. They maintain stream and waterbody quality by removing sediment, pollutants, and woody debris while maintaining water temperatures. They promote healthy salmon and wildlife habitat.

Aquatic Environments

Seattle has a complex variety of aquatic environments that include streams, a river, lakes, estuaries, and nearshore marine habitats. Salmon are a vital part of Seattle’s heritage and each of these environments is important in their lifecycle. Nearly all of Seattle marine and freshwater shoreline has been heavily modified by urban development including the lowering of Lake Washington by 9 feet with the construction of the Lake Washington Ship Canal and the re-routing of the Cedar River from the Green River into Lake Washington.

- *Rivers and Streams.* Seattle has 45 streams. Many are confined in pipes, but the largest Thornton, Piper’s, Taylor, Longfellow, and Fauntleroy flow openly and support salmon population. Salmon also migrate along the Duwamish River, five miles of which was designated as an Environmental Protection Agency (EPA) Superfund site in 2001. In December 2024, clean-up began and is expected to take a decade and reduce PCB contamination by 90%. The mouth of the Duwamish has two other Superfund sites: the Harbor Island and Lockheed West Seattle Superfund sites.³¹
- *Lakes.* Lake Washington borders Seattle’s eastern side. It provides habitat for seven types of salmon and trout and many bird species including eagles and ospreys. Its connection to Puget Sound through the Ship Canal allows salmon and trout to use it as a migratory path. Three small lakes, Green, Haller, and Bitter also support wildlife, but are cut off from Puget Sound because they no longer have natural drainage systems.
- *Estuaries.* Estuaries are the transition zones between streams and marine waters. All of Seattle’s estuaries are highly modified. Natural estuaries are very important habitat for young salmon. Restoring Seattle’s estuaries to a more natural state would benefit salmon recovery.
- *Nearshore marine.* Seattle has about 33 miles of shoreline along Puget Sound. Only 10% is unaltered.³² Natural nearshore environments support complex ecosystems. They depend on processes that erode and transport terrestrial soils to shallow water. Bulkheads, seawalls, and shoreline armoring interferes with these processes and degrades the nearshore environment. The most environmentally productive habitats in Seattle are some of these unaltered shoreline areas: Seward Park, Union Bay, West Point, and Magnolia Bluffs and Lincoln Park to Fauntleroy Cove.

Many of Seattle’s shorelines are bordered by bluffs. In non-urbanized environments Puget Sound bluffs provide material for beach and shoreline environments below them. Wave action can steepen bluffs making them more susceptible to groundwater induced failure.³³ In Seattle, much of the shoreline has been armored to prevent beach erosion and landslides. Ironically, armoring can cause some bluffs to recede faster by depriving their bases of sediment. During the 1996-97 landslides many landslides occurred on slopes where a bulkhead had protected the base of the bluff for decades.

Prior to urban development, Seattle contained numerous peat bogs. These areas are prone to settle when cut off from water recharge damaging buildings and streets. The Greenwood area has been especially affected by peat settlement. The City of Seattle has identified 39 peat settlement areas and regulates them. A [map](#) of these areas is available on the City’s GeoData portal.

History

History has a significant, but hard to quantify effect on hazard consequences. It drives development patterns and culture that in turn affect hazard vulnerability. This brief section outlines broad themes that affect our hazard outcomes.

People have been living in the area we know as Seattle for 13,000 years. Eleven inhabited sites have been located within the current city limits. The [Burke's Museum's Waterlines Project map](#) (PDF) identifies these sites and more around Lake Washington. The oldest known settlement, 4,000 years old, is located at West Point in Magnolia. As the time of European settlement, the Duwamish River was well populated.³⁴ These people experienced the most recent and extremely powerful Seattle Fault earthquake in the winter of 923-4.

Non-indigenous settlement began in 1851. The 1855 Point Elliott Treaty forced Puget Sound's indigenous people on to reservations. Seattle's major growth started in the 1880s. Even its older buildings seldom date back beyond the 1890's. Despite its youth, Seattle's history has a direct impact on the location of the most vulnerable structures and generates collective institutional memories of past disasters that shape perceptions of all the hazards the city faces.

Seattle grew out from its Pioneer Square location. Many of the oldest buildings in the city are there and in the surrounding First Hill, Queen Anne, and Capitol Hill areas. As the city grew, it spawned several towns that became the roots of several Seattle neighborhoods, notably Ballard, Columbia City, and Georgetown. Due to the influence of these satellite areas and the area's hilly topography, Seattle developed strong neighborhoods. Consequently, older and more vulnerable structures are scattered throughout the city, especially in the old cores like Ballard and Columbia City. This development suggests a need for a decentralized emergency response to cope with damage to these older structures in the outlying areas.

Past disasters have created a filter through which residents and city leaders perceive the area's hazards. Two moderate magnitude 5 earthquakes of the mid-1990s jolted the city into an awareness of the risk that a major earthquake poses for it. As a result, it began preparing for earthquakes with a program called Project Impact before the much larger 2001 Nisqually Earthquake. These collective memories can produce ironic results. After the great fire of 1889, building codes changed to require brick construction. Soon, brick construction became a norm. This new construction introduced a vulnerability to the at-the-time unnoticed risk of earthquakes.

Socio-Economic Environment

Fueled by a strong technology sector, Seattle has been one of the fastest growing cities in the United States, but this growth has come with a steep cost of rising wealth inequality, housing costs, and racial inequity. In 2023, the technology sector experienced a slowdown, but it is too early to know if it will have implications for the larger economy. In 2024, the Seattle Metropolitan Statistical Area (MSA) had a gross domestic product of \$567 billion dollars, a 29% increase from 2020.³⁵

Seattle's population grew from 608,660 in the 2010 census to 737,015 in the 2020 census or 21%. That is more than double the rate from 1990 to 2010. More of the Seattle metro's population is concentrating in the city of Seattle. In 2012 Seattle reversed a 102-year-old trend and grew at a faster rate than its suburbs. From 2012 to 2020 Seattle's population grew by 20% while the rest of King County grew by 14%.³⁶

The COVID-19 pandemic disrupted Seattle's rapid growth. Evidence can be seen in different growth estimates of the US Census and the Washington State's Office of Financial Management (OFM). In 2021 US Census estimates showed a slight decrease to 734,000 while OFM's showed an increase to 742,400. The difference is only 8,400. Both numbers are samples. It would be strange for them to be the same, but it is rare for these two estimates to point in different directions. It is possible the Census data may reflect people moving out of Seattle during the COVID pandemic.³⁷ By 2023 both estimates showed renewed growth, but the gap in the estimated population has grown. The US Census estimated Seattle's population at 755,078 while OFM estimated 779,200 for a difference of over 24,000.³⁸

Seattle's rapid growth has led to a housing crisis with demand far outstripping supply. Many people who could not afford price increases have likely been forced out of Seattle. Seattle is increasingly becoming a city of the wealthy. In 2024 the Seattle metro area median housing price was 6.6 times the median household income. Renters now represent over half of Seattle's households. Over half of renters are rent burdened, meaning over 30% of their income goes to rent. The National Low Income Housing Coalition estimates it takes an income of \$90,760 to afford a fair market one-bedroom apartment in Seattle. The only good news is that rent increases have been slowing.³⁹

The affordability gap is increasing Seattle's vulnerability because many frontline staff who keep Seattle running cannot afford to live in the city where they work. Whenever an event strikes that impedes transportation, many frontline staff cannot make it into work, causing reductions in services that many vulnerable people rely on. For example, during snow events, staff at some libraries have been unable to commute to work. Due to minimum staffing requirements some branches have had to close or reduce hours. Libraries are not shelters, but they are public spaces where people without options can go to warm up during the day. The reduced hours mean more people out in the cold.

Seattle is one of the most expensive cities in the US. Several government agencies and companies have developed models for measuring the cost of living. Most put Seattle between the 5th and 7th spots. There are signs that Seattle, like Manhattan and San Francisco, is losing its middle class and becoming less diverse than its suburbs. Seattle's median income is rising, but pockets of poverty remain.

Population and Demographics

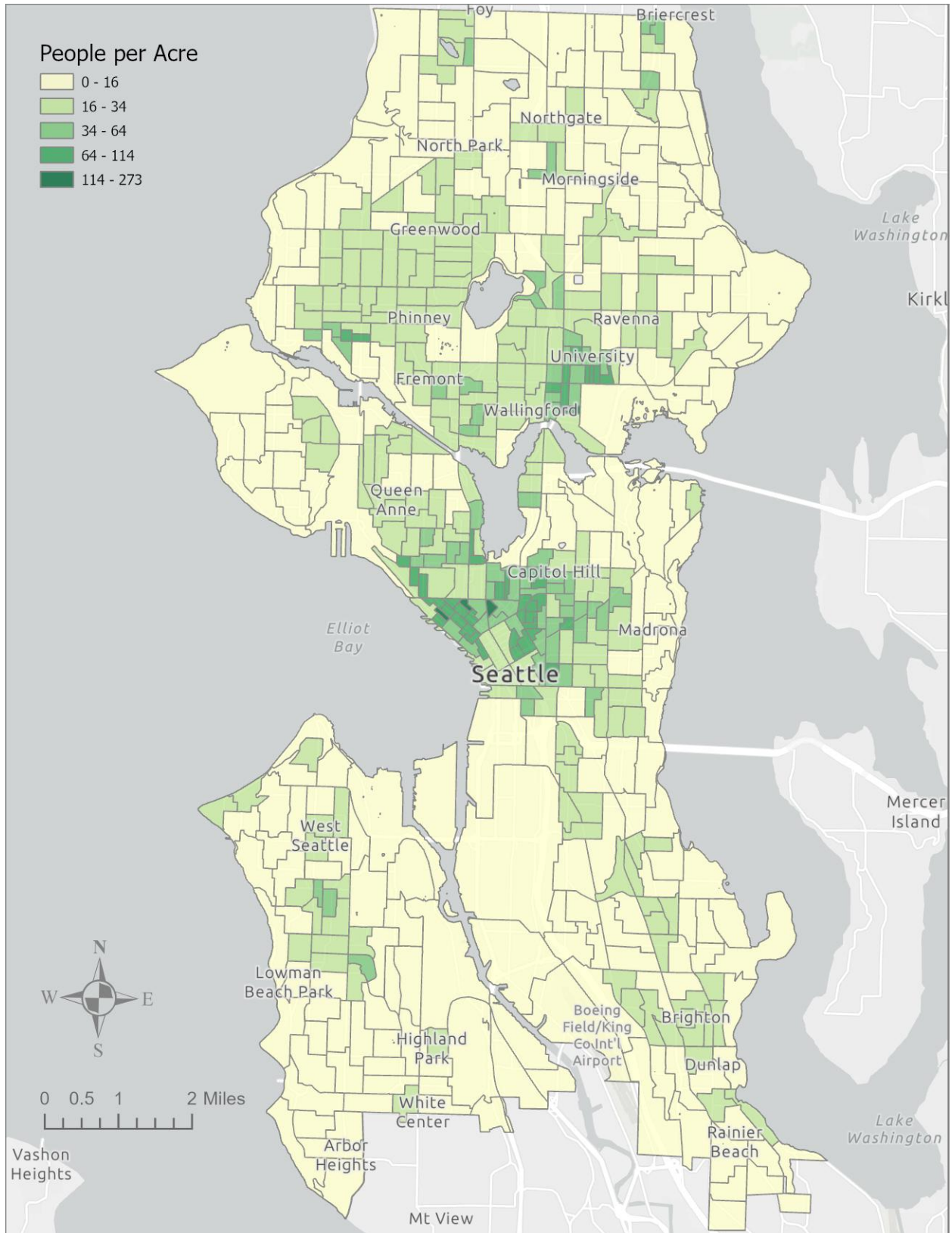
Seattle is a dynamic city with a high percentage of immigrants, especially from Asia. It attracts many young, college-educated people starting their careers. About half of the population is between the ages of 25-55 and the majority live alone or with one other person. The percentage of children is very low. In the 2020 census, Seattle has the 3rd lowest percentage of kids among US cities with a population of 100,000 or greater.⁴⁰ Nearly 1 in 5 Seattle residents were born in a foreign country with nearly 60% of these immigrants coming from Asia. It includes highly dense areas near the downtown core and University District ([Figure 7](#)). [Table 4](#) shows key social and demographic for Seattle data along with 9 other cities for comparison.

The 2023 American Community Survey shows that that:

- 28.5% of Seattle's residents worked from home.⁴¹
- Seattle has an average household size of 2. Almost 43% of Seattleites live alone.⁴²
- 70% of residents 25 and over have at least a bachelor's degree.⁴³
- 14.4% of Seattle residents are under 18.⁴⁴
- 20% of Seattle households have a car available to them.⁴⁵
- 19% of Seattle residents are foreign-born.⁴⁶

In 2023 the median household income in Seattle was \$120,608, up from \$91,164 in 2013 (inflation adjusted 2023 dollars) or a 32% increase.⁴⁷ In 2023, Seattle's poverty rate was 9.9% which is low compared to most other US cities. It has decreased from 14.7% in 2010.⁴⁸ Hidden in this good news is the likelihood that many lower income people may have been priced out of Seattle while pockets of extreme poverty remain. The GINI index is a summary measure of income equality based on the difference between observed income distribution and a perfectly equal income distribution. Values range from 0 to 1 where 0 is perfect equality (everyone receives an equal share of income) and 1, perfect inequality (one person or group receives all income). US cities with some of the highest GINI scores are Atlanta (.5653) and New Orleans (.5635). Seattle has a value of .4899 which is slightly higher than the U.S. (.4828). Cities with low GINI scores include Arlington, Texas (.4461) and Mesa, Arizona (.4201).⁴⁹ High GINI scores often indicate the presence of a highly wealthy group as well as lower income

Figure 7. Population Density 2020



City of Seattle, King County, WA State Parks GIS, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA

Table 4. Demographic Summary of Seattle and Similar Cities⁵⁰

	Comparison Cities										Regional Comparison			Nation
	Seattle	Portland	Denver	San Francisco	Minneapolis	Boston	Oklahoma City	Atlanta	Tacoma	Bellevue	King County	U.S.		
Estimated Population	755,081	630,395	716,577	808,988	425,142	652,442	702,654	510,826	222,932	151,579	2,271,380	334,914,896		
Pop 25 yrs+: Bachelor's or higher*	67.60%	53.50%	55.70%	60.20%	54.40%	54.10%	36.60%	58.40%	33.60%	71.40%	55.90%	34.00%		
Average household size	2.00	2.09	2.05	2.09	2.04	2.10	2.43	1.92	2.24	2.39	2.35	2.49		
With a Disability	10.4%	13.7%	10.9%	12.2%	12.0%	13.2%	14.8%	12.9%	15.3%	7.7%	10.5%	13.6%		
Speak language other than English	21.8%	17.5%	22.7%	43.9%	19.4%	34.2%	21.5%	11.4%	19.6%	50.0%	30.8%	22.5%		
(Foreign Born* and **	19.5%	12.6%	13.8%	35.4%	14.2%	28.0%	11.8%	8.4%	12.0%	41.9%	25.8%	14.3%		
FB - Asia	11.2%	5.6%	2.6%	22.6%	3.2%	8.3%	3.5%	3.0%	5.5%	30.7%	14.9%	4.4%		
FB - Latin America	2.5%	3.0%	7.6%	6.4%	3.8%	13.1%	6.9%	2.7%	3.1%	1.1%	4.4%	7.3%		
Hispanic or Latino (of any race)	8.7%	12.2%	27.9%	16.4%	10.2%	19.4%	22.7%	6.5%	14.8%	5.9%	11.1%	19.4%		
Race														
White	60.1%	67.7%	59.5%	39.0%	61.3%	46.1%	54.1%	38.9%	59.4%	41.5%	54.0%	60.5%		
Black or African American	6.5%	6.0%	8.3%	4.8%	17.3%	20.3%	12.7%	46.4%	9.4%	0.9%	6.7%	12.1%		
American Indian and Alaska Native	0.6%	0.7%	1.2%	0.9%	1.0%	0.2%	2.9%	0.1%	0.9%	0.5%	0.6%	1.0%		
Asian	17.2%	7.2%	3.8%	35.9%	5.9%	10.5%	4.6%	4.9%	9.3%	45.9%	20.9%	6.0%		
Native Hawaiian / Pacific Islander	0.3%	0.6%	0.2%	0.3%	0.1%	0.1%	0.3%	0.0%	0.7%	0.1%	0.8%	0.2%		
Some other race	3.0%	3.0%	7.6%	7.6%	4.6%	8.6%	7.0%	2.3%	4.9%	2.8%	4.7%	7.4%		
Multiracial	12.0%	14.8%	19.2%	11.4%	9.8%	14.2%	18.5%	7.7%	17.5%	8.4%	12.2%	12.8%		
Means of Transport to Work														
Mean Travel to Work Time (minutes)	25.5	24.2	25.7	30.9	21.0	30.2	22.1	25.7	28.4	25.4	27.6	26.8		
Car, truck or van - drove alone	38.7%	53.0%	56.5%	29.7%	54.4%	33.9%	75.3%	55.4%	66.4%	53.6%	53.2%	69.2%		
Public transportation	14.2%	6.2%	3.8%	11.3%	7.0%	25.1%	0.3%	5.5%	3.5%	7.3%	8.0%	3.5%		
Walked	8.5%	5.1%	3.6%	6.7%	3.2%	13.9%	1.3%	5.2%	2.2%	4.5%	4.5%	2.4%		
Worked at home	28.5%	25.7%	26.0%	45.6%	23.0%	17.7%	10.5%	25.5%	14.2%	26.0%	24.0%	13.8%		
Mobility (Lived last year in another state / country)	7.5%	5.3%	5.3%	2.6%	6.2%	6.2%	3.7%	5.7%	3.7%	3.7%	5.2%	3.0%		
Income														
Median Household Income	\$ 120,608	\$ 86,057	\$ 94,157	\$ 126,730	\$ 81,001	\$ 96,931	\$ 67,015	\$ 85,880	\$ 89,107	\$ 158,253	\$ 120,824	\$ 77,719		
Mean Household Income	\$ 169,292	\$ 119,449	\$ 136,323	\$ 193,467	\$ 112,784	\$ 142,120	\$ 90,584	\$ 139,184	\$ 114,948	\$ 222,228	\$ 170,348	\$ 109,160		
Families below poverty	4.1%	7.8%	6.5%	7.5%	8.4%	10.2%	11.3%	13.4%	9.2%	5.9%	5.1%	8.8%		
Individuals below poverty	9.9%	13.4%	10.0%	12.0%	15.3%	15.6%	15.6%	18.1%	12.6%	8.3%	8.8%	12.5%		
GINI income inequality measure	0.49	0.48	0.49	0.54	0.49	0.53	0.47	0.57	0.46	0.47	0.48	0.48		
Housing														
Total housing units	400,166	308,338	366,952	418,143	215,327	313,752	308,571	270,820	102,705	68,171	1,021,711	145,333,462		
Percent Vacant	9.4%	6.3%	5.9%	6.2%	7.4%	5.3%	8.2%	14.0%	5.9%	10.9%	7.5%	6.3%		
Owner-occupied	43.7%	50.8%	47.1%	37.1%	45.8%	35.9%	57.0%	48.3%	54.8%	54.9%	55.6%	65.2%		
Renter-occupied	56.3%	49.2%	52.9%	62.9%	54.2%	64.1%	43.0%	51.7%	45.2%	45.1%	44.4%	34.8%		
Median owner occupied value	\$ 898,600	\$ 570,300	\$ 626,500	\$ 1,348,000	\$ 355,600	\$ 703,600	\$ 248,100	\$ 443,300	\$ 474,100	\$ 1,349,200	\$ 848,300	\$ 340,200		
Percent paying >35% income for rent	35.4%	43.4%	38.0%	34.0%	37.0%	41.5%	41.6%	45.5%	39.0%	32.8%	38.4%	42.5%		
Age														
Under 18	14.5%	16.1%	17.7%	13.6%	18.6%	14.4%	25.4%	17.5%	18.7%	20.0%	19.1%	21.7%		
Over 65	12.9%	14.9%	12.9%	18.5%	11.6%	13.4%	13.6%	12.2%	14.7%	14.8%	14.5%	17.7%		

Sources: U.S. Census Bureau, American Community Survey 1-year Estimates 2023 except * U.S. Census Bureau, American Community Survey 5-year Estimates 2023. ** King County and the United States use ACS 1-year Estimates 2023. Accessed 4/8/2025

groups. If a city's population is growing, a high GINI score suggests wealthier people moving into the city leading to displacement pressure on lower income people. Seattle's moderate GINI score indicates some displacement pressure. Racial, ethnic, and gender disparities contribute greatly to inequality in the U.S. and Seattle. The median black household income in Seattle is 59% of overall median. It is 71% for Hispanic households and 61% for female headed households with children.⁵¹ Census estimates show the number of children in Seattle peaked in 2017 after a growth trend in the 2000's. Seattle Schools experienced growing enrollment until the COVID-19 pandemic when total enrollment dropped from a high of 53,627 in 2019 to 49,226 in 2023.⁵² It remains to be seen whether the number and percentage of children will increase as Seattle recovers from the pandemic.

Income gaps, systemic racism, and high housing costs create disaster vulnerability. Often the least expensive housing is in areas that are the most prone to hazards. When a community is impacted, it is often difficult to find alternate housing in the neighborhood, making it challenging to keep communities intact. When the low-income South Park neighborhood flooded in late 2022, emergency responders helping the community found no low-income housing close to the affected properties. Khmer and Hispanic residents were especially impacted.⁵³

Seattle has historically been less racially diverse than many other large US cities, but a large in-migration from Asia is increasing Seattle's diversity. In 2023, 17% of Seattle residents were of Asian descent. Additionally, in 2023, nearly 1 in 5 Seattle residents is foreign born. Most of the foreign-born population immigrated from Asia. This is much higher than the rest of the US but not compared to suburbs like Bellevue where 42% of the population is foreign born. Seattle has a relatively small Hispanic (7.4%) and Black (6.3%) populations compared to the rest of the US.

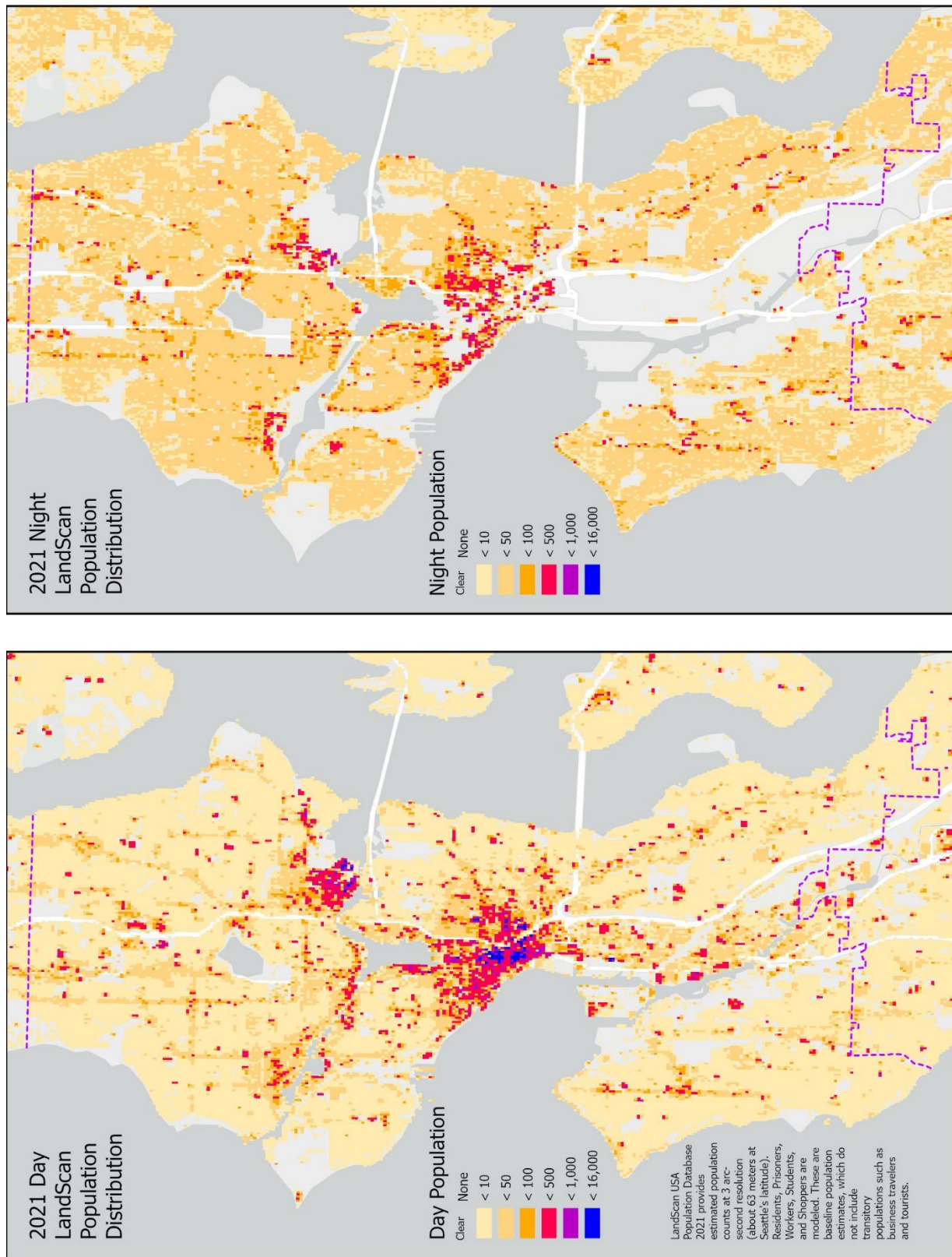
Several local and national studies link respondent demographic characteristics to personal preparedness. Combining a region's demographic profile with these studies can hint at the level of preparedness in a community and possible vulnerabilities. The 2023 FEMA National Household Survey on Disaster Preparedness correlated demographic profiles to levels of preparedness, barriers to preparedness, and perception of risk. The findings represent the nation and may not reflect local Seattle's population. All demographic groups self-reported roughly similar assessments of their disaster preparedness. The percentage saying they were prepared ranged mostly between 51% and 54%. The lowest were Native Americans at 44%, Native Hawaiians or Pacific Islanders at 47%, people with faith-based beliefs at 47%, and African Americans at 49%. The Black population reported the highest belief in the efficacy of disaster preparedness followed by the white population; the lowest reported was the among the Asian population. Those over 60 also had less belief in the efficacy of planning. The over-60 demographic reported lower rates of having a personal plan (41% for the general population vs 28% for over-60). Low-income people engaged at low, or no cost preparedness actions (like making a plan) at the same levels as higher income people but had lower rates of action for higher cost actions like assembling supplies or documenting insured property.⁵⁴

Demographics usually refer to the residential population, but disasters don't always happen when people are at home. [Figure 8](#) uses the [LandScan](#) system developed by Oak Ridge National Laboratory to show the distribution of Seattle's daytime and nighttime population distribution in 2021. Seattle has a higher daytime population than its nighttime population. In 2019, pre-COVID, the Puget Sound Regional Council estimated that on a typical day, Seattle's daytime population was 864,000, but the actual number can vary greatly by season, day of the week, weather, and on-going events.

Social Vulnerability

Hazards do not affect the population equally. Some people suffer more than others. These people are 'socially vulnerable.' The Centers for Disease Control developed an index based on 16 demographic characteristics known to correlate to disaster vulnerability. FEMA uses this index in its

Figure 8. 2021 Day / Night Population Distribution



[National Risk Index](#). [Figure 9](#) shows the distribution for Seattle. Seattle’s most socially vulnerable people tend to be clustered around Seattle’s edges, in Rainier Valley, Beacon Hill, south downtown, and North Seattle (chiefly around Northgate and Lake City Way). Social vulnerability affects harm from all hazards. One of the most effective ways to reduce a community’s overall vulnerability is to target social vulnerability.

Seattle’s elderly population has an increased risk of social isolation, of having a disability that prevents them from leaving their home, and of facing barriers to obtaining information.⁵⁵ All of these concerns are exacerbated during a hazard event. In 2016, Seattle joined the Age-Friendly City initiative to address environmental, economic, and social factors influencing the health and well-being of older adults. This includes efforts to reduce social isolation among aging adults and to educate the elderly about emergency preparedness.⁵⁶

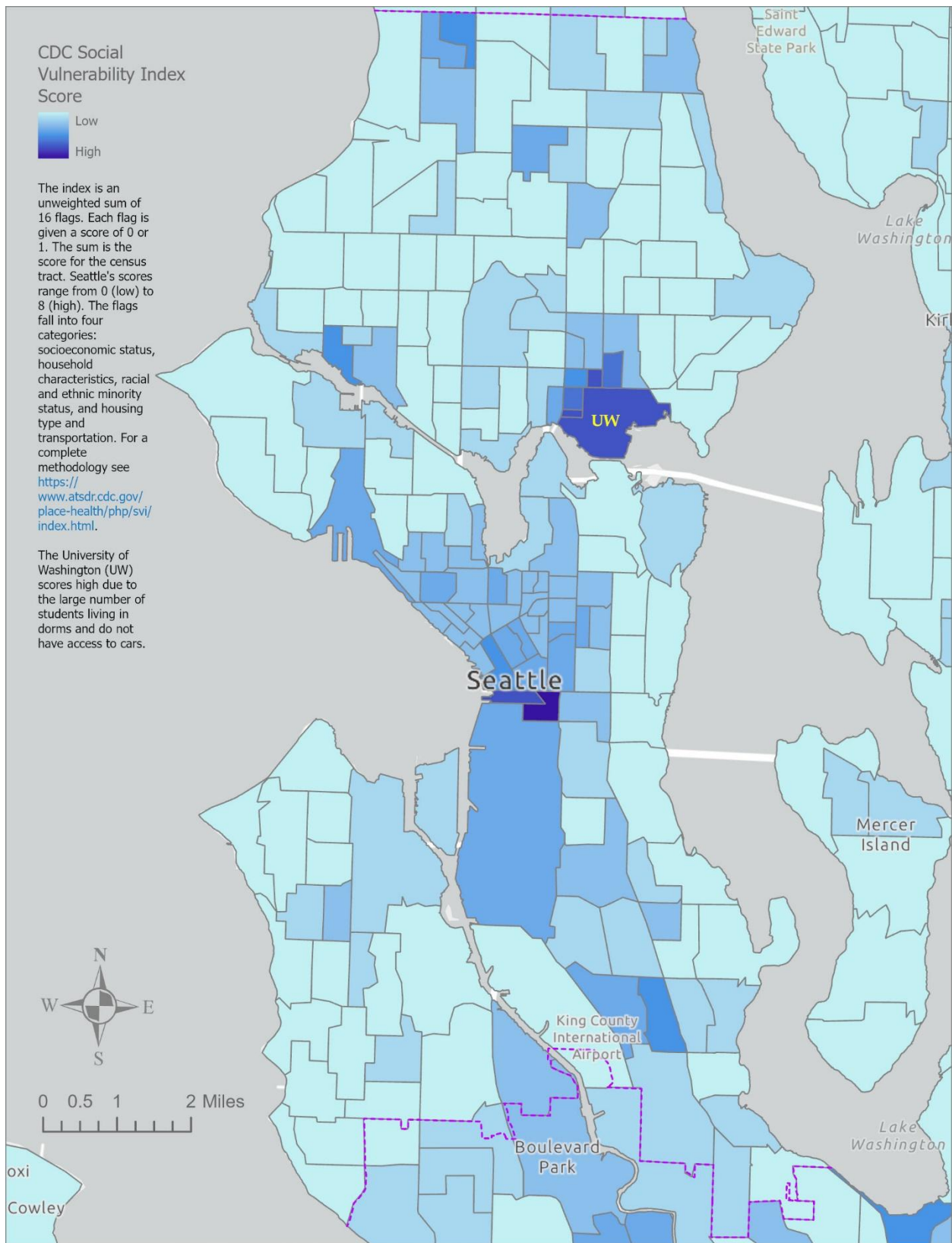
Being homeless makes people highly vulnerable to hazards. The Seattle area has seen a rise in the number of people experiencing homelessness. Measuring the number of people experiencing homelessness is difficult. The most common measure is the US Department of Housing and Urban Development’s Point-In-Time count, but it is largely held to be an under count. It shows an increase in individuals in King County experiencing homelessness from 13,368 in 2022 to 16,385 in 2024 or a 22% increase. The County found that 60% of people experiencing homelessness were unsheltered while 40% were sheltered.⁵⁷

To address potential undercounts in the Point-in-Time Count, the King County Regional Homelessness Authority also measures homelessness by measuring the number of households receiving services. On June 30, 2023, 10,622 were homeless. 71% of these households consisted of adults. Not all people experiencing homelessness are unsheltered. In the King County survey, 54% of households had some form of shelter (e.g., emergency shelter, hotel, couch surfing).⁵⁸ Because people move in and out of homelessness, King County estimates over 40,000 people experience homelessness in King County over the course of 2020.⁵⁹

Those experiencing homelessness are particularly vulnerable to hazards as they may face greater barriers to obtaining information and resources. Additionally, the unsheltered population is likely to face disproportionate affects from weather-related hazards such as winter storms, extreme heat events, or flooding depending on where they are located. Almost a quarter of homeless youth in Seattle identify as LGBTQ,⁶⁰ a population that has historically faced discrimination that may compound the stress felt in a disaster situation.⁶¹ Due to this extreme vulnerability, many Seattle emergency operations center (EOC) activations (most commonly winter storms, heat, and smoke) now emphasize providing emergency services to people experiencing homelessness.

To mitigate demographic vulnerability, the Seattle Office of Emergency Management has taken steps to address equity and social vulnerability by implementing the Community Safety Ambassador (CSA) program that provides emergency preparedness education and skill-building opportunities to Seattle communities that can be disproportionately impacted by hazards and threats, especially non-English speaking communities. CSAs are native speakers in many of the most commonly spoken languages in Seattle other than English and are trusted community members. In 2020, the Office of Emergency Management conducted a mitigation study with a focus group comprised of members of the CSA. The central aim of this study was to identify the top services that are of fundamental importance to local BIPOC, immigrant, and refugee communities in the Seattle area. The focus group included representatives from Chinese, East African, Latinx, and Southeast Asian communities. Among these communities, access to affordable housing, homelessness and emergency services, as well as health and mental services were the top issues identified as priorities to address in order to mitigate the disproportionate impact of emergencies and threats.

Figure 9. CDC Social Vulnerability Index



WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

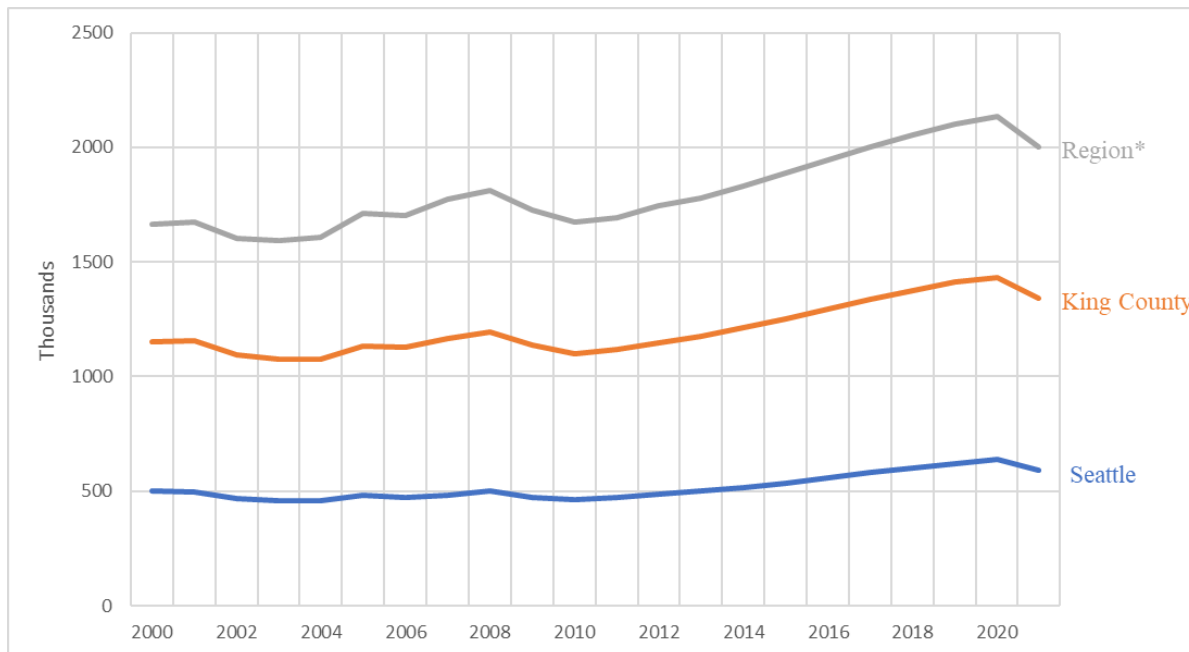
Economy

Both the overall economic strength and the wealth distribution affect an area’s vulnerability to hazards and its recovery from disaster. Disasters usually accelerate pre-existing trends. Places with a growing economy see an influx of capital for rebuilding after a disaster and recover quickly while those with weak economies see business move out, resulting in a loss of tax base, and triggering a prolonged decline. Economic structure matters as much as overall trends. Places like Seattle with an overall robust economy can have structural problems with pockets of poverty and poor economic health. Disasters make these problems worse by increasing wealth inequality and indebtedness. Junia Howell and James Elliot conducted a longitudinal study that found the more FEMA aid an area receives, the more wealth inequality grows in the years after a disaster. If a household has more initial wealth than others before the disaster, especially if the wealth has less depreciation, it receives more assistance in the form of grants and low interest loans than lower income households.⁶²

Seattle has had a strong economy in the 21st century. The Seattle metro area is one of the leading technology hubs in the US. Nearly 1 in 10 jobs in Washington are in tech and 80% of them are in the Seattle metro. It accounts for 30% of the metro’s economy. Complementing the tech sector are healthcare, biotechnology, communications, tourism, and transportation industries.

Data from the Puget Sound Regional Council shows nearly a quarter of Seattle’s jobs are in information technology and professional services (22.6%), followed by healthcare at 11.7%. Government and education combine for 13.4%. Manufacturing and construction account for 7.4%.⁶³ These percentages reflect national trends away from manufacturing and into the service sector.

Table 5. Local and Regional Estimated Employment⁶⁴



Much of Seattle’s recent growth was driven by Amazon’s expansion. Amazon is Seattle’s major employer. Its market capitalization grew from \$123 billion in 2013 to \$2.475 trillion in 2025 with a huge surge during the pandemic.⁶⁵ Until 2026 it was the largest leaser of office space in Seattle employed 55,000 people, but layoff, development of office space outside Seattle, and remote work have started to shrink its footprint. As of 2026 its employee count dipped to under 50,000, leaving UW as Seattle’s biggest employer.⁶⁶ Amazon’s growth has driven up median household incomes in Seattle to the 3rd highest among the 25 largest metro areas.⁶⁷ The increase is being driven by wealthier households moving into the city and poorer households moving out.⁶⁸

COVID related employment shifts have had a huge impact on high density employment areas including downtown and South Lake Union. Many businesses catering to office workers have closed. Visitors and shoppers have rebounded, but the number of office workers remains below pre-pandemic levels. The Downtown Seattle Association reports average weekday worker foot traffic in 2024 at 56% of 2019, pre-pandemic baseline. While the numbers are still low, they are an improvement since a low of 24% in 2021. With vacancy rates still high at 21.5% and substantial numbers of workers partially remote, challenges remain to return worker foot traffic to pre-pandemic levels.

The aerospace industry led Seattle's post-war growth. While it still spends billions in the Seattle area, it has dramatically cut employment in Seattle proper, with most jobs located in Renton and Everett. The aerospace industry is very cyclical. The swings of Seattle's economy have been very dramatic. With the reduction in Boeing's presence and the development of other sectors, Seattle's up and down economy has become more stable.

Most of Seattle's manufacturing sector remains centered along the Duwamish River and in parts of Ballard. Seattle has a much lower concentration of manufacturing than the rest of King County and Washington State, but some manufacturing subsectors have high concentrations in Seattle. These include construction, freight, printing, seafood processing, food and beverage, metal fabrication and stone products. The geographic concentration of Seattle's manufacturing poses a risk, given that most of its industry sits in a liquefaction zone on top of the Seattle Fault. Businesses in the South Park neighborhood face increasing flood exposure with sea level rise. Many of these companies are small businesses that may not be able to survive prolonged downtime.

Seattle's healthcare industry has seen steady growth over the past two decades. In 2023, there were 78,099 healthcare and social assistance jobs, accounting for about 11.7% of the job market.⁶⁹ This number does not reflect the growing number of jobs in biotech and medical research, which have become prominent industries in Seattle with organizations like the Fred Hutchinson Cancer Research Center and the Allen Brain Institute. The healthcare and health research sectors are concentrated in First Hill (hospitals), South Lake Union (medical research and biotech firms) and the U-District (University of Washington).

The Port of Seattle is an important component of the city's economy. Seattle's shipping industry remains strong. Terminal expansions such as the opening of Terminal 30 are increasing the scope of operations, much of which involve intermodal operations. This industry centers around the mouth of the Duwamish River.

Seattle has become a major tourist destination. The number of visitors has steadily grown after a collapse during the COVID-19 pandemic. In 2023, Seattle and King County had 37.8 million visitors, up 9% from the previous year reaching 90.2% of 2019 levels.⁷⁰ The arts, music, and sports are major contributors to the local economy generating revenues in the billions and employing thousands. Seattle tourists spent \$8.2 billion in 2023, generating over \$787 million in state and local taxes.⁷¹ The Washington State Convention Center completed a major expansion in 2023, increasing Seattle's convention business.

Besides its direct contribution, the cultural sector combines with the outdoor and coffee industries to contribute to Seattle's reputation as an attractive place to live and work. Although it is hard to quantify, this attractiveness is cited as a major reason that businesses locate in Seattle.

Seattle's overall economy is strong, but a slow downtown pandemic recovery remains a drag. Like the rest of the country, inflation climbed rapidly in 2022 to 10.1% locally in June 2022 before dropping back to 2.7% in December 2024.⁷² The Seattle metro area's gross domestic product grew by 32% from the beginning of 2019 to the beginning of 2023 to \$567 billion.⁷³ Seattle supported an estimated 638,290 jobs in 2023. This number represents jobs covered by unemployment insurance, about 85-90% of total jobs.⁷⁴ During the COVID pandemic, Seattle lost 48,120 jobs by 2021.⁷⁵ After a peak in March and April

2020, unemployment rate for the Seattle metro area dropped to 6.3% in December 2020 and then to 4.5% in June 2025.⁷⁶

Land Use

Seattle is a mature city at the core of the Puget Sound metropolitan region. It is approximately 53,500 acres or 84 square miles in size, making it nearly twice as large physically as Boston, San Francisco, or Vancouver BC but quite a bit smaller than Portland or Denver. Like other core cities, it has little undeveloped land and a large share of the region's major institutions, government, business, and industry. Even so, many areas of the city are covered with smaller single-family homes built in the 1920s, 30s, and 40s, that give much of Seattle the atmosphere of an older suburb. This atmosphere is changing, however, as Seattle's density increases under the State's Growth Management Act.

Single family lots take up nearly 50% of Seattle's land area excluding right-of-way. Multi-family uses where half Seattle's population lives, occupies 8%. The lack of land available for multi-family has led to an increase in housing prices in Seattle. The major employment uses (commercial, industrial, and major institutions) cover 24% of the city's area. Parks and open space use 13%.

Land use drives population shifts on all time scales, from daily commutes to weekly recreation to long-term residential patterns. The Seattle Police Department estimated that Seattle's 2017 daytime population grew by 18% every weekday to approximately 842,000 people, however the percentage has likely decreased since the COVID-19 pandemic.⁷⁷

Seattle is home to the region's biggest sports and entertainment venues as well as cruise ship terminals. In 2017, the Port of Seattle reported that over 1 million passengers came to Seattle by cruise ship, generating over \$500 million in business revenue. The activities located on this land use contribute thousands of people to Seattle's waterfront, tourist, entertainment, and stadium areas at all times of day. With about 9,000 people per square mile, Seattle seems to be in transition from a lower density city like Atlanta, Portland, or Denver, dominated by single family neighborhoods, to a higher density city like Vancouver BC, San Francisco, and Boston. The former cities have between 3,500 and 4,800 people per square mile; the latter cities have between 14,000 and 18,000. The highest population densities occur in Seattle's Belltown, Capitol Hill, First Hill, and University District neighborhoods, with over 114 people per acre in some census block groups.⁷⁸

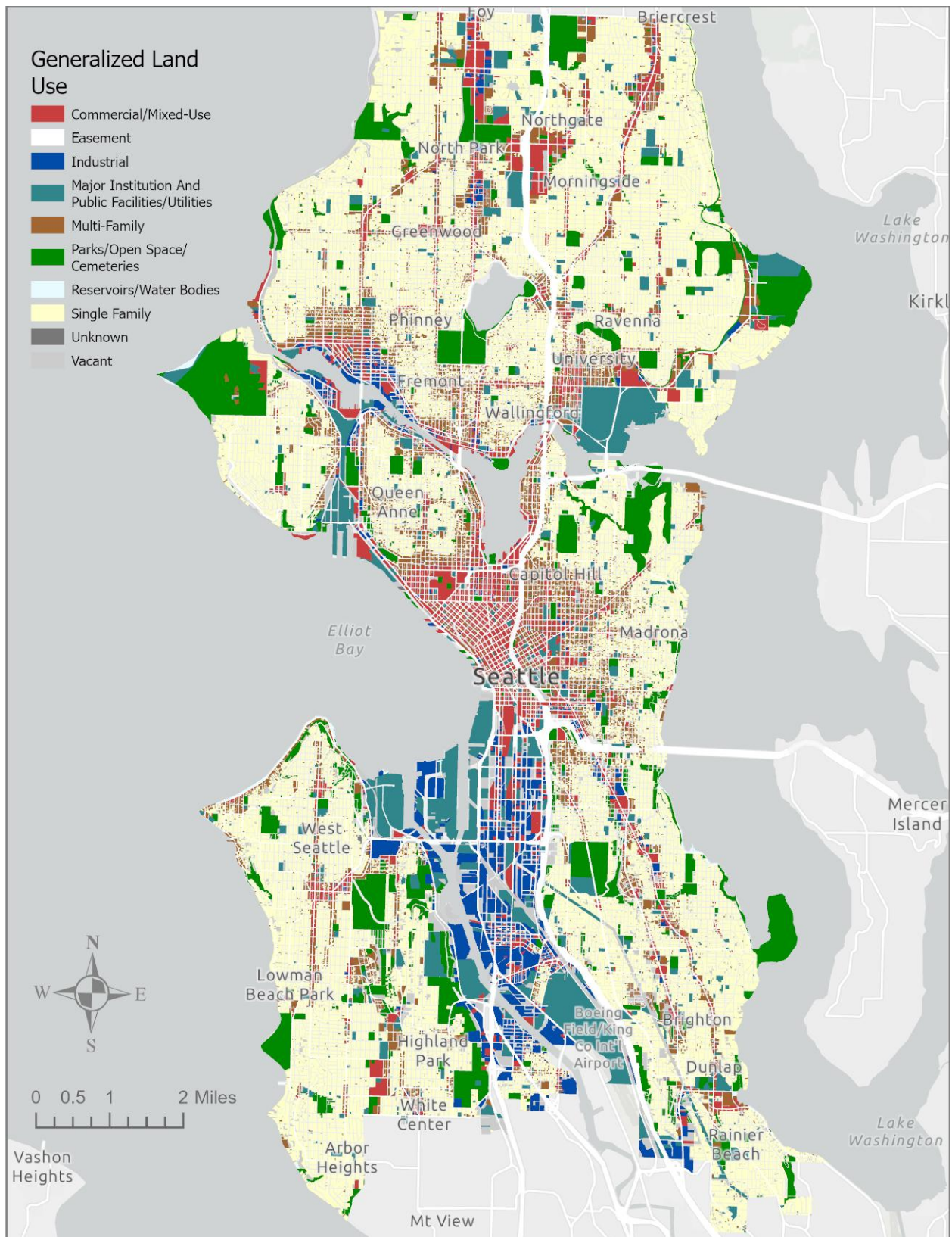
Comparing Seattle's multi-family areas with those of Boston and San Francisco reveals different development patterns. More people living in multi-family residences in Seattle live in big complexes than in Boston and San Francisco, which have whole neighborhoods of smaller, 3 and 4-unit buildings. This development gives Seattle a steep density gradient from multi-family to single-family areas. The implication for emergency management is that the number of residents who may be affected by a disaster can vary more over short distances.

Washington State's Growth Management ACT (GMA) has guided development plans for Seattle. The GMA stresses putting growth in already developed areas to prevent urban sprawl. Seattle has responded to the GMA with a Comprehensive Plan in 1994. In 2025 a final draft plan, the [Mayor's Final Recommended One Seattle Plan](#) was released. It includes changes to Seattle's zoning code designed to enable more housing options. A major goal is to locate housing, jobs, and stores near each other to reduce the necessity of car use. Tables in [Appendix A](#) show what percentage of these areas fall within mapped hazard areas (e.g., landslide prone).

Transportation

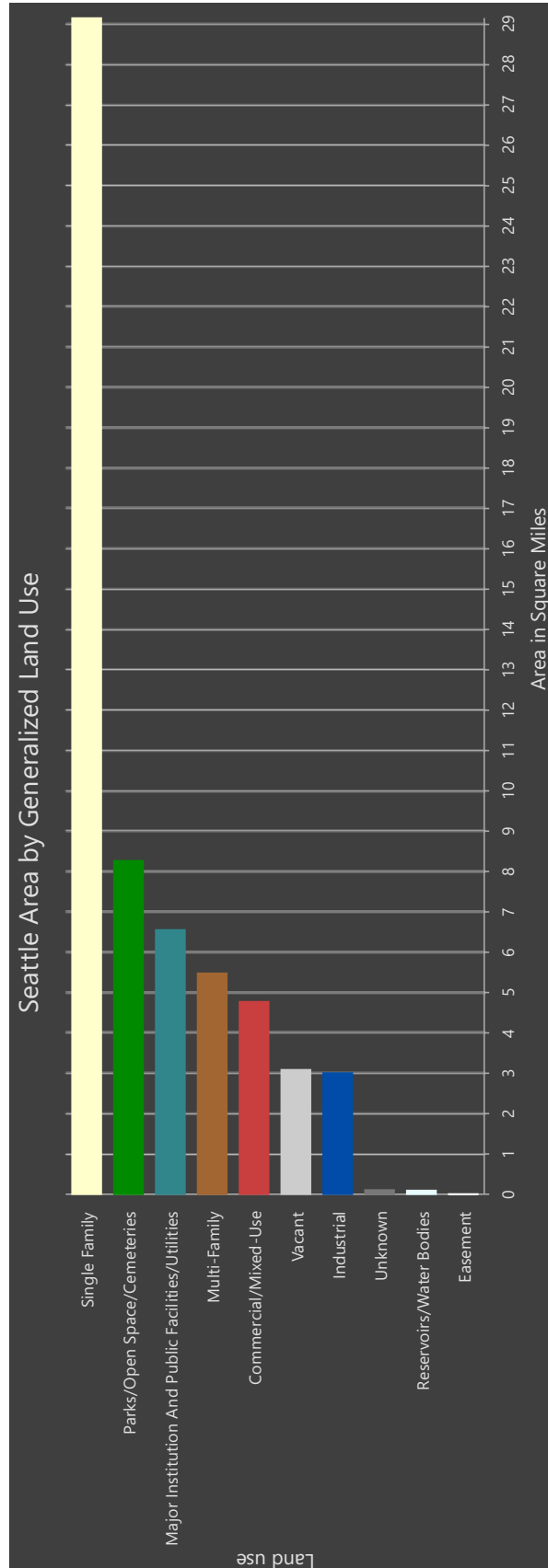
Seattle is Western Washington's transportation hub. The region's most important routes connect within it. Seattle's system is a complex system of surface, air, and marine modes that moves people and freight inside the region as well as in and out of it. This system must balance the needs of many different user

Figure 10. Land Use



City of Seattle, King County, WA State Parks GIS, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA

Figure 11. 2023 Land Use Summary⁷⁹



groups. Contention between passenger and freight transport (e.g., freight trains crossing busy streets) and between passenger transport modes (e.g., between car and bicycle) is one of the major challenges facing Seattle today. The [Seattle Transportation Plan](#) guides the development of Seattle’s transportation system. It contains more data and project details than contained here.

A healthy transportation system is essential to a healthy city and effective disaster response and recovery. Without transportation, emergency crews can’t reach people in need, stores can’t be resupplied, and workers can get to their jobs. Transportation has become even more critical for emergency response because more and more essential workers are living outside of Seattle due to rising housing costs in the city. During recent snowstorms, staffing for critical has been a major challenge because support staff live far from their jobs.

The transportation system directly affects the ability to move critical resources (including people) the first few hours after a major disaster strikes. A significant number of employees face long commutes or must cross vulnerable bridges. In major disasters, state and federal assistance is important, but it may be difficult to bring in outside help if the transportation system is heavily damaged.

The COVID-19 pandemic led to massive changes in transportation with the rise of remote work, the growth of delivery services, and a decline in non-essential travel. The recovery from COVID-19 is still ongoing and it is too early to tell what shifts will be permanent, and which will be temporary. In 2023, 28.5% of Seattle’s workers worked from home. In 2019 the percentage was 8%.⁸⁰

Passenger Transport

Passenger transport is the movement of people for all purposes like commuting, personal business, and leisure. Having transportation options is good for disaster resilience because it provides redundancy. Nearly all local trips in Seattle rely on its right-of-way, which occupies 26% of Seattle. Whether people drive, walk, or take the bus, they are using the right-of-way. Ensuring it stays accessible is essential for resilience. Nationally, 45% of trips are for shopping or errands, 27% are social, and 15% are commuting.

The US Census Bureau collects commuting data. The following table and charts from the US Census Bureau American Community Survey compare commute trips in 2019, pre-pandemic with 2023. They compare results for Seattle residents with the Seattle metropolitan area and the whole US. The results are shown in [Table 6](#). It shows shifts away from public transportation and towards telecommuting.

The Puget Sound Region Council conducts a Household Travel Surveys every two years. They are smaller, but more comprehensive than the US Census Bureau’s commuting surveys. The [most recent survey](#) (PDF) is from 2023. It shows that in the greater Seattle area the percentage of trips made by car vary from 61% among the lowest income households (under \$25,000) to high of 89% for middle income households (\$75,000 to \$99,000).⁸¹

Table 6 US Census Commute to Work by Mode.⁸²

Mode	Seattle city only		King County		United States	
	2019	2023	2019	2023	2019	2023
<i>Worked from home</i>	7.9%	28.5%	5.2%	24.0%	5.7%	13.8%
<i>Public transportation</i>	25.1%	14.2%	14.9%	8.0%	5.0%	3.5%
<i>Drove alone</i>	44.5%	38.7%	60.2%	53.2%	75.9%	69.2%
<i>Carpooled</i>	6.8%	6.0%	9.6%	7.7%	8.9%	9.0%
<i>Walked</i>	10.7%	8.5%	5.2%	4.5%	2.6%	2.4%
<i>Bicycle</i>	3.7%	2.7%	1.7%	1.2%	0.5%	0.5%
<i>Taxicab, motorcycle, or other means</i>	1.3%	1.4%	1.1%	1.3%	1.4%	1.5%

Personal Vehicles

Personal vehicles dominate Seattle’s surface transportation, but 20% of Seattle households do not have access to a car.⁸³ Before the pandemic nearly half of Seattle residents drove alone to work. For the whole metropolitan area that total climbs to nearly 70%. Most non-commute trips are also taken by car. Reducing car dependency has been a major public policy goal. There is no consensus measure for car dependency. A car insurance industry analysis used Federal Highway Administration and Census Bureau data to rank US metropolitan areas on car dependence based on 4 metrics. Because Seattle has lower annual miles driven per driver and vehicle, Seattle was ranked the least dependent metro area in the US but remains car dependent.⁸⁴ Running counter to this finding is a Seattle Times analysis showing that Seattle has more cars per capita than any other major US city except Long Beach.⁸⁵ The [Walk Score](#) service that ranks areas according to the ability to accomplish errands without a car. Seattle’s overall score of 74 is “Very Walkable” which is very good but ranks below denser cities like Boston and San Francisco.⁸⁶

The number of electric vehicles in King County is growing. In January 2025, King County had 113,169 EVs registered. While better for the environment, EVs pose some challenges during emergencies. During power outages, they can’t be charged, reducing mobility. After some disasters people have relied on car radios for news. If the EV isn’t charged, owners lose that resource. EVs are less likely than gas powered cars to catch fire, but if they do, water runoff used to fight the fire can be highly acidic.⁸⁷

Transit

Seattle has a robust transit system but the COVID-19 pandemic reduced ridership dramatically. In 2019 26% of Seattle residents commuted by transit. In 2021 it was only 6%. King County Metro’s average weekday boardings dropped 75% from February 2020 to April 2020. It is slowly recovering as of 2023. Metro’s February average weekday boardings in 2023 are 42% of those in February 2020. Sound Transit is faring better. It has about 70% of its pre-COVID-19 ridership. [Commute Seattle’s 2022 survey](#) shows that the decline in transit use is mostly due to people shifting to remote work. As companies bring more workers back into the office overall ridership for all Seattle metro area transit providers has been increasing but in 2023 it was still just 61% of 2019’s ridership.⁸⁸

Several organizations offer models that measure and rank transit systems. They are somewhat subjective but offer insight into systems beyond simple ridership numbers. Walk Score ranks Seattle transit at ‘Good’ while AllTransit places it 12th based on system connectivity, access to jobs, and frequency of service.⁸⁹ Redfin places Seattle 7th between Chicago and Baltimore in cities over 300,000.⁹⁰

Transit modes in Seattle are a mix of bus, vanpool, rail, and ferry systems. Buses have the largest ridership. The two biggest fleets are run by King County’s Metro system (operating within King County) and Sound Transit (operating between Pierce, King, and Snohomish Counties). Together the two systems averaged 365,000 boardings on an average weekday.

Paratransit (mostly vanpools and vanshares) is also popular in the Seattle area, with a combined yearly ridership of about 3.5 million. Microsoft runs its own bus fleet, the Connector, to bring employees to its Redmond campus.

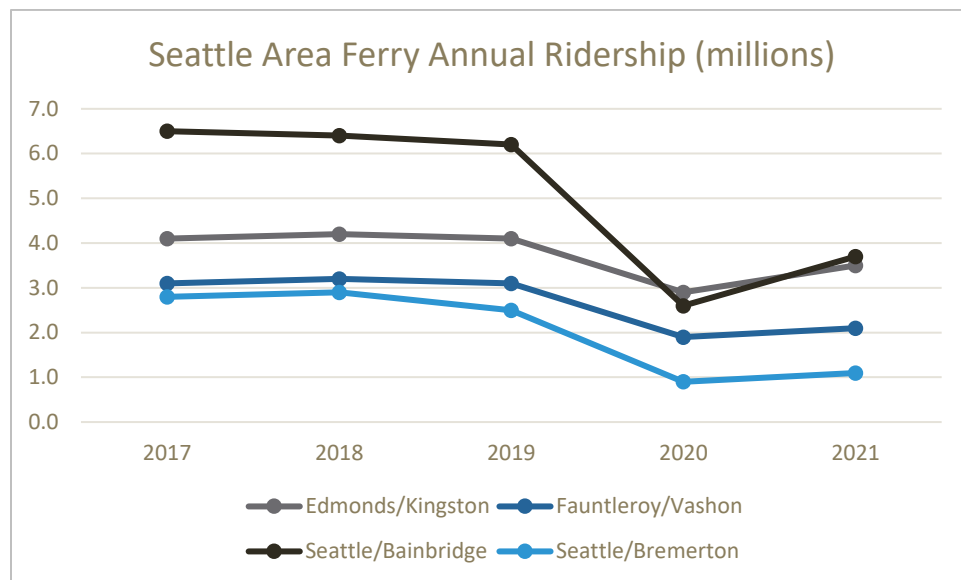
The Seattle Department of Transportation (SDOT) also operates two streetcar lines in Seattle. One in the South Lake Union area and the other in First Hill. The two combined have a weekday average ridership of 4595 persons.⁹¹

Marine

Ferries play an important role in Seattle’s passenger transportation. Washington State has the largest ferry system in the United States. As a system had an annual ridership of nearly 25 million in 2018 with the biggest share in the routes in the Seattle area. COVID-19 reduced the total down to 14 million in 2020, or 57% of the 2018 peak. Ridership is recovering but is not back to pre-COVID-19 levels.

Excluding passenger only ferries, which have a smaller ridership, four routes dock in the Seattle area. Two docks in downtown (Seattle-Bainbridge, Seattle-Bremerton) and one docks in West Seattle (Fauntleroy-Vashon). The Edmonds – Kingston ferry, while outside the city, also serves Seattle residents and workers. The biggest COVID-19 ridership declines were those docking in Seattle.

Table 7 Seattle Area Ferry Annual Ridership



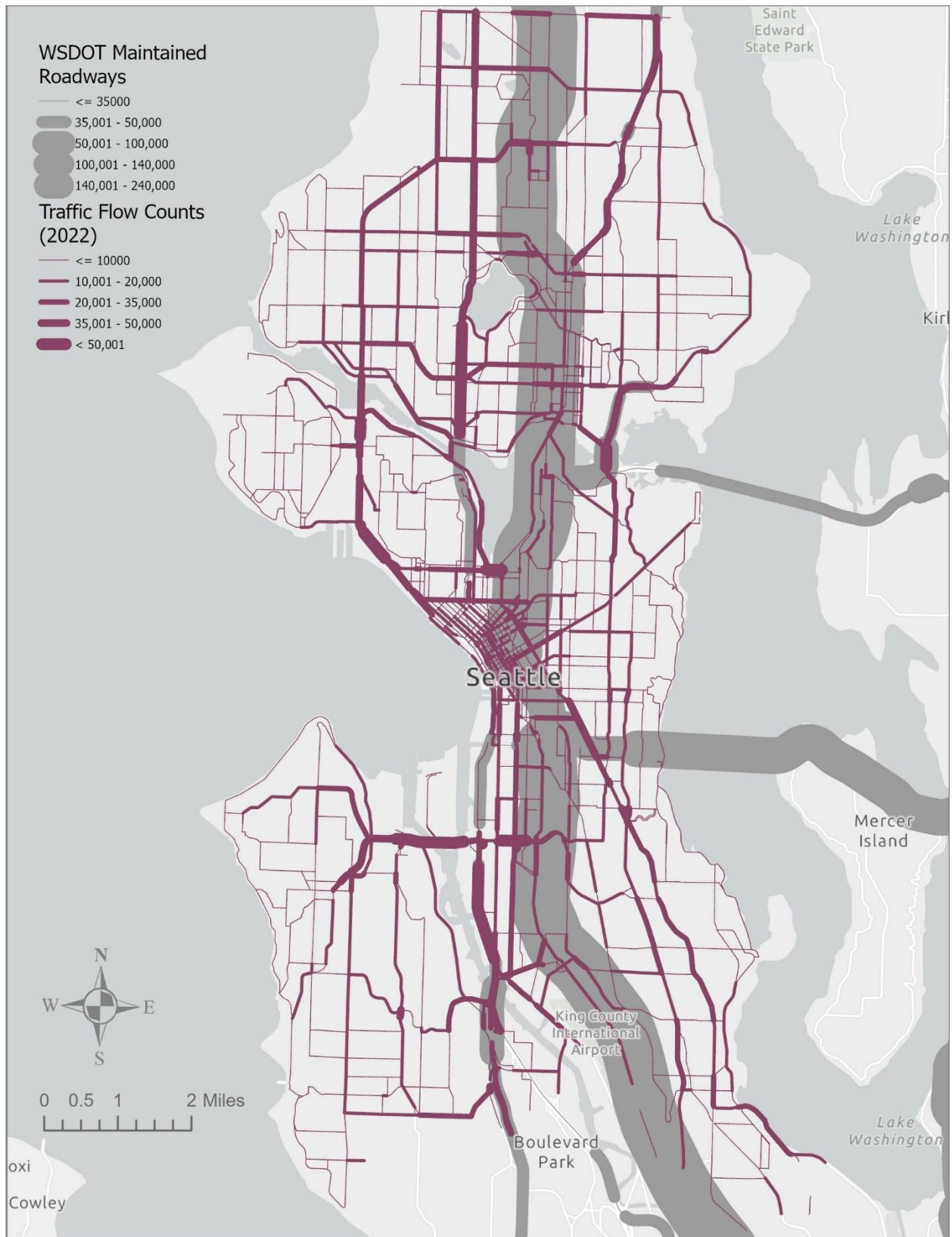
Air

Seattle is served by four airports:

- Seattle-Tacoma International Airport
- King County International Airport
- Renton Municipal Airport
- Paine Field

Most commercial passenger air transport is through Seattle Tacoma International Airport (SeaTac) located south of Seattle. It ranks as the 11th busiest airport in the U.S.⁹² In 2024 SeaTac set a record with 52.6 million passengers with a forecast for further growth in 2025.⁹³ SeaTac is a vital link for residents of Western Washington who lack another major commercial hub nearby. The next closest hubs are Portland and Vancouver, BC. King County International Airport (Boeing Field), located just outside the city limits handles a smaller number of passengers from small carriers, charters, and general aviation. Paine Field, about 25 miles north of the city, began commercial flights in 2017 but the number of flights is far smaller than SeaTac. The region has two other airports that can handle large aircraft (important during large emergencies). They are Renton Municipal Airport and Joint Base Lewis-McChord.

Figure 12. 2022 Traffic Flows



WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Rail

Passengers use Amtrak for long-distance travel and Sound Transit commuter rail for short trips. Sound Transit is covered in the Transit section. Amtrak operates three routes in Seattle out of King Street Station. Most significant is the route serving the corridor between Vancouver, BC. and Eugene, OR. The other two are Seattle / Chicago and Seattle / Los Angeles. In 2022, Seattle's King Street Station saw 397,692 passengers, more than double 2021's total. This is still a 41% decrease from 2019.⁹⁴

Freight Transport

Freight is essential for Seattle to support the economy and to supply goods for residents. The COVID-19 showed the importance of supply chain. Many of the supply chain problems were caused by transportation problems. While many of these occurred outside Seattle, our local freight network can keep goods off shelves and exports and imports from driving the local economy. In 2016, the City of Seattle adopted a [Freight Master Plan](#) which is an excellent resource for in depth information on the current state of freight mobility and its future.

Among metropolitan Seattle-Tacoma-Bellevue metropolitan area itself was 10th among U.S. metro areas foreign trade with the transportation equipment accounting for the bulk.⁹⁵ Large quantities of goods move through Seattle daily and the freight system reflects these movements. Freight systems require complex intermodal integration (e.g., ship to truck to rail to air). The look of this integration, in turn, depends on the type of commodity being transported (e.g., aircraft parts vs. grain). Seattle has built intermodal networks around the container, bulk cargo, and grain terminals of the Port of Seattle's Marine Division and around the two airports serving Seattle, SeaTac, and Boeing Field

Seattle's marine cargo terminals and rail yards are located close to downtown. They must contend with completing land uses and passenger transportation. A series of docks, terminals, inter-modal rail yards and many designated truck streets serve the marine business. Trains must go slowly through the many areas of the city where rail lines cross streets and vehicles must wait for them to pass. Similar contention problems face trucks on crowded city streets. Slow speeds may be a challenge for commerce, but they improve public safety by enforcing low speeds on vehicles carrying hazardous materials like the large number of crude oil trains passing through Seattle.

Marine

Seattle is home to a diverse port that supports container traffic, bulk cargo, a major grain terminal, and a large fishing fleet. The Ports of Seattle and Tacoma operate as a partnership that together is the fourth largest container gateway in North America. In 2024, it handled 25.6 million metric tons which was down from 30 million metric tons in 2019. Despite the overall decrease, the 2024 amount is an improvement over 2023.⁹⁶ Most incoming goods are loaded onto trains and shipped to Chicago. Capacity is an emerging issue for many ports. In many cases the ground and intermodal transportation infrastructure surrounding the port is the biggest capacity issue. Seattle's port facilities are exposed to many hazards: earthquake induced liquefaction, tsunami, and post-lahar sedimentation (a volcanic hazard).

Air

Air cargo is important during disaster recovery operations to bring critical supplies into an impacted area quickly. It operates differently than marine shipments because of greater time constraints. The type of goods shipped via air differ from those shipped via marine systems. This business depends on timely ground access to the air terminals for trucks hauling cargo to and from the airports. Together SeaTac and King County International Airport handle 85% on the region's air cargo.⁹⁷ SeaTac's air cargo operations have increased significantly in the past decade. In 2022, SeaTac handled 456,289 metric tons of cargo, up from 290,653 metric tons in 2007. The value of this cargo was \$24.5 billion. These numbers

are far below major air cargo hubs like Memphis, Anchorage, and Louisville which handle five to ten times the tonnage as Seattle. A 2021 study of regional aviation stated that both SeaTac and King County International Airport are becoming capacity constrained and will need additional buildings and land for air cargo.⁹⁸

The biggest constraints on air cargo capacity are access to ground transportation and facilities to park aircraft. Port businesses are very sensitive to disruption because traffic can easily be routed through competing ports.

Rail

Two major freight carriers operate in Seattle, BNSF and Union Pacific. Rail is a big component of intermodal freight transport. BNSF and Union Pacific operate intermodal rail yards to support transshipment of goods through the Port of Seattle. Intermodal freight makes up most about 75% of Seattle's commodities freight with bulk grain shipped through Seattle's grain terminal on Elliott Bay a distant second. BNSF operates a maintenance facility in Interbay.

Tracks run along Puget Sound north of Lake Washington Ship Canal where they are exposed to landslides and storms. South of Seattle the tracks head inland until they pass Tacoma where they rejoin Puget Sound. All the yards are in liquefaction zones. Two lines cross the Cascades. One crosses under Stevens Pass through a long tunnel and the other goes over Stampede Pass south of I-90.

Pipelines

Pipelines are part of the transportation system. Seattle has one significant pipeline: the Seattle lateral of the British Petroleum (BP) line running from Ferndale to Portland. The Seattle lateral runs from Renton north to Harbor Island along the Seattle City Light right of way. This pipeline transports gasoline and diesel fuel to a regional distribution center on Harbor Island. About 9 million gallons of fuel are transported annually through the pipeline. In 1999, the pipeline exploded in Bellingham, killing three children.

Infrastructure

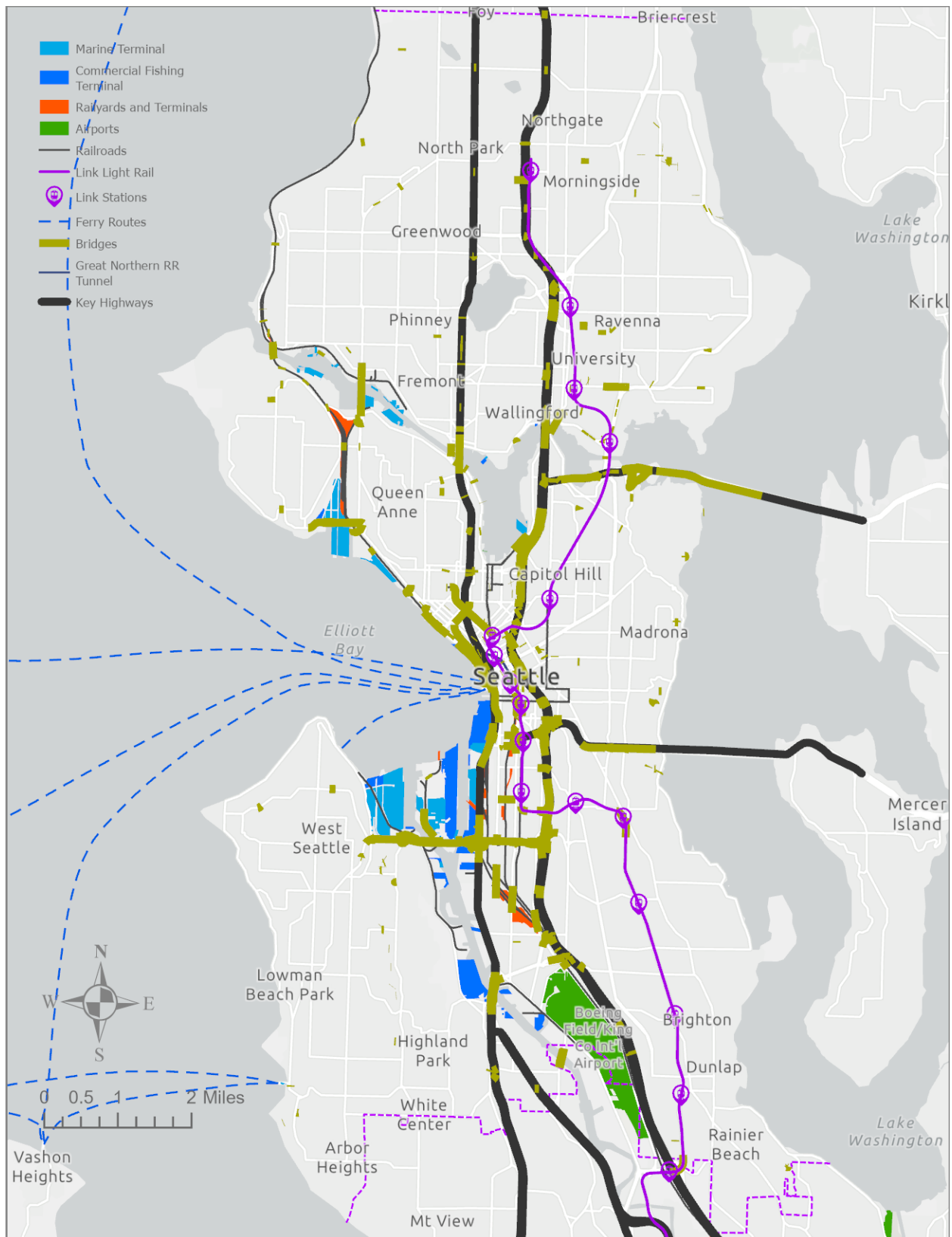
Streets and Highways

Streets are the backbone of Seattle ground transportation system. The public right of way accounts for over one quarter of Seattle's land area. Because Seattle is a built-out city, very little land is available for the construction of new roadways. Streets for vehicles occupy most of the right of way, it also serves as passageways for pedestrians and bicycles, housing a major part of Seattle's urban forest, and acting as a protective 'skin' for power, gas, water, drainage, and telecommunications lines. Streets and the rest of the public right of way are where a lot of a community's public life occurs. Urban designer Allan B. Jacobs asserts that great streets make great communities.⁹⁹

Seattle has 3,944 lane miles of street pavement excluding alleys. Arterials, the busiest streets, account for 39% of the total.¹⁰⁰ The rest are residential and industrial. These streets are prioritized for service during snowstorms depending on traffic volume and transit priority. In 2018, 35% of arterial pavements were rated 'poor' or worse by the Seattle Department of Transportation (SDOT) due to a maintenance backlog. That is an increase from 26% in 2010. It has no funding to assess the condition of non-arterial streets.

Seattle's streets are laid out in a grid pattern or, more accurately, many grid patterns. Due to historical circumstances, hilly terrain, and an irregular shoreline, early designers laid out grids independently of one another. Streets jog where these grids meet. Steep terrain causes streets to meander around obstacles. Other streets follow old paths (Madison St) or natural features (Lake Washington Blvd) as part of Seattle's Olmstead-designed Park system.

Figure 13. Major Transportation Infrastructure



City of Seattle, King County, WA State Parks GIS, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA

Seattle uses several classification systems for its streets. The most fundamental is the designation of a roadway as an Interstate Freeway, arterial or residential street. The system is designed to funnel vehicular traffic from low-volume access streets through progressively bigger arterials (collector, minor and principal) and finally to the Interstate Freeways.

The backbone of motorized transport is the two Interstate Freeways (I-5 and I-90) and three principal arterials (SR-99, SR-520, and the West Seattle Freeway) that have large, limited access portions. These five roadways handle the highest traffic volumes. I-5 and SR-99 run north-south and move much of the traffic within the city. SR-520, I-90, and the West Seattle Freeway run east-west. They feed into SR-99 and I-5 and serve to move vehicles into and out of the city and West Seattle. The area with the highest daily traffic volume is on I-5, just south of the I-90 junction, with an annual average daily traffic of 244,973 vehicles in 2023.¹⁰¹

Despite ranking high for transit usability and walkability, Seattle's traffic is congested. Depending on the study, Seattle ranked 11th in the nation in 2024 for traffic congestion based on the [TomTom traffic index](#).¹⁰² Another ranking by [INRIX](#) places Seattle 10th worst in 2024.¹⁰³ Seattle possesses little reserve capacity. The prolonged closure of a major roadway shifts traffic onto already overloaded infrastructure. The closure of the West Seattle Bridge, which reopened in September 2022 after a two-and-a-half-year closure, revealed the lack of reserve capacity.

Bridges

Bridges are essential for transportation in Seattle. It is bordered by Puget Sound to the west and Lake Washington to the east. Transportation across Puget Sound depends solely on ferries. Crossing Lake Washington relies on two floating bridges, SR5-20 and I-90. Seattle is divided north-south by the Lake Washington Ship Canal and West Seattle is separated from the rest of the city by the Duwamish Waterway.

I-90 bridge handled 137,087 vehicles on an average day in 2023, while SR520 handled 57,913.¹⁰⁴ Washington State began replacing the SR-520 bridge in 2012, due to concerns around hollow support columns that are vulnerable to damage in earthquakes.¹⁰⁵ The new bridge opened to traffic in April 2016 and currently handles 70,000 vehicles per weekday down from its peak of 96,000 in 2010. The new bridge was constructed to withstand wind speeds up to 89 mph.

The Ship Canal is spanned by seven bridges (six roadways and one rail). The most important is the I-5 Ship Canal Bridge, which handled an annual average of 197,092 vehicles in 2023.¹⁰⁶ It would be catastrophic for transportation if this bridge went out of service for an extended period. The next busiest, the Aurora Bridge, handles just a fraction at an annualized average of 30,630 vehicles per day in 2023.¹⁰⁷ The four remaining bridges are bascule (draw) bridges that were built between 1914 and 1919.

The Duwamish is crossed by two bridges inside the city limits and two more just outside the city limits. The two inside the city limits combined handle over 225,000 vehicles per day. I-5 and East Marginal Way both cross the Duwamish just south of the city.

Utilities

Utilities provide a public service: power (gas and electricity), water, communications, solid waste management, and sewer. Seattle has a mix of publicly and privately owned utilities. Utilities make urban life possible, but they come with hazards that must be managed. Utility hazards include downed electrical lines, water main breaks and gas, and steam pipe explosions. Often these hazards can lead to long duration outages and endanger lives in extreme cases. These hazards are covered in the [Built Environment Failures](#) chapter later in this document.

Electricity

Electricity in Seattle is supplied by Seattle City Light (SCL), a publicly owned utility that is part of the City of Seattle. Unlike many other municipal electric utilities, Seattle City Light has its own generation facilities and transmission system. It produces about half of its own power and purchases the rest. The largest outside provider is the Bonneville Power Administration (BPA). Over 88% of SCL's generated power comes from hydroelectric dams on the Skagit River (North Cascades) and the Pend Oreille River (northeast Washington).¹⁰⁸ In 2023, they provided electricity to 419,601 residential and 50,779 commercial customers in a service area that includes all the City of Seattle, the cities of Shoreline, Lake Forest Park, Burien, Normandy Park, SeaTac, Tukwila, and Renton and two areas of incorporated King County south of the Seattle city limits.

It owns 2,330.9 miles of distribution lines, some of which carry power from hydroelectric dams to Seattle. These lines are exposed to hazards like wildfires, landslides, avalanches, and other hazards that do not affect the City of Seattle itself. These hazards are covered in the Power Outage chapter along with links to sources that cover these outside Seattle hazards with more depth than can be provided here.

Seattle's heaviest electrical loads occur in the winter. Many buildings, including 62% of Seattle's housing units, have electric heat.¹⁰⁹ Because of the heavier use of purchased power in the winter, Seattle is more vulnerable to regional power outages, such as one in BPA's system, in the winter.

Seattle's mild summer climate reduces the demand for air conditioning, allowing SCL to sell surplus power. Seattle's summer temperatures are projected to rise with climate change and with it the number of units using HVAC. From 2013 to 2023 the number of housing units with air conditioning has risen from 32% to 63%.¹¹⁰ This rise creates financial risks for SCL because it will have to buy more power on the open market without a guarantee that it can increase rates to pay for it.

Seattle's use of hydroelectric power makes the city dependent on the snowpack in Washington's mountains. During years of low snowpack SCL must purchase more power from BPA and other providers. Climate change may be reducing the Cascade snowpack. This trend is a major concern for SCL.

Natural Gas

Natural gas is provided to 150,000 customers in Seattle by Puget Sound Energy (PSE), a private, regulated utility. Because natural gas contributes to climate change, in 2021 the City of Seattle banned the use of natural gas for heating in most new construction. The US Census surveys households about their main source of fuel. The number of households heated by gas increased from 112,514 in 2011 to 122,352 in 2021 but measured as a *percentage* it was a *decline* from 40% to 35%.¹¹¹

No natural gas is extracted in Washington State. It is imported in about equal amounts from Canada and the Rocky Mountains through the Williams Northwest Pipeline running through the eastern edge of the Puget lowlands. Spur lines take gas through Renton and Lynwood to a distribution system feeding Seattle from both the south and north. There are no transmission lines through Seattle. Most of the distribution system is buried and was built after the 1950s. Original pipes were cast iron; they have all been replaced by more flexible steel or plastic pipes that perform better in earthquakes.

Water

Seattle's drinking water is provided by Seattle Public Utilities (SPU), a City of Seattle department. SPU controls supply, transmission, and distribution of water within the City of Seattle and wholesales water to water districts in King County. SPU provides water to 1.6 million people in the region.¹¹² Nearly all of Seattle's water comes from two watersheds in the Cascade Mountains east of Seattle. Having two watersheds gives Seattle's water supply resilience. About two-thirds of the supply comes from the Cedar River and one-third comes from the Tolt River. Wells provide less than one percent of Seattle's water.

The total yield from the combined system is 147.3 million gallons per day which is down 1% from 2021.¹¹³ Like electric power, Seattle's water supply is dependent on snowpack in the surrounding mountains. Unlike electricity, it is more difficult to obtain water from distant sources. Most of the system is gravity fed which means most customers can use water when the power is out.

Per capita water consumption has been dropping. Total consumption peaked in the late 1980s near 170 million gallons per day. Now SPU's customers use 120 million gallons per day despite the population increasing by over 1 million people. The main causes of the decrease were the 1992 drought that led to higher water rates, a revised plumbing code, and improved conservation. Demand for water is highest in the summer with peak day consumption averaging around 200 million gallons per day.¹¹⁴ The drop in demand is being threatened by more frequent high summer heat. The last few years produced an uptick in the number of gallons consumed per day.

Drainage and Wastewater

Seattle Public Utilities (SPU) manages wastewater and drainage systems in Seattle. Seattle has three types of systems to move, or convey, stormwater and wastewater: a combined sewer system, a separated sewer system, and a partially separated system, each covering about one-third of the city. In a combined sewer system, wastewater and stormwater travel in the same pipes to treatment plants. In a separated sewer system, wastewater and stormwater travel in separate pipes. Wastewater is conveyed from homes and businesses to treatment plants. Stormwater is conveyed through a separate drainage system to drainage outlets. In a partially separated system, wastewater from inside homes and businesses, and stormwater from roof gutters and downspouts are conveyed in the same pipes to treatment plants, while stormwater from streets is conveyed through a separate drainage system to drainage outlets.

The King County Wastewater Treatment Division (WTD) operates the West Point treatment plant—one of the County's three regional wastewater treatment plants—in addition to four combined sewer overflow (CSO) treatment facilities within the city of Seattle and the wastewater trunkline system that serves Seattle. The majority of wastewater collected from within Seattle is treated at the West Point plant.

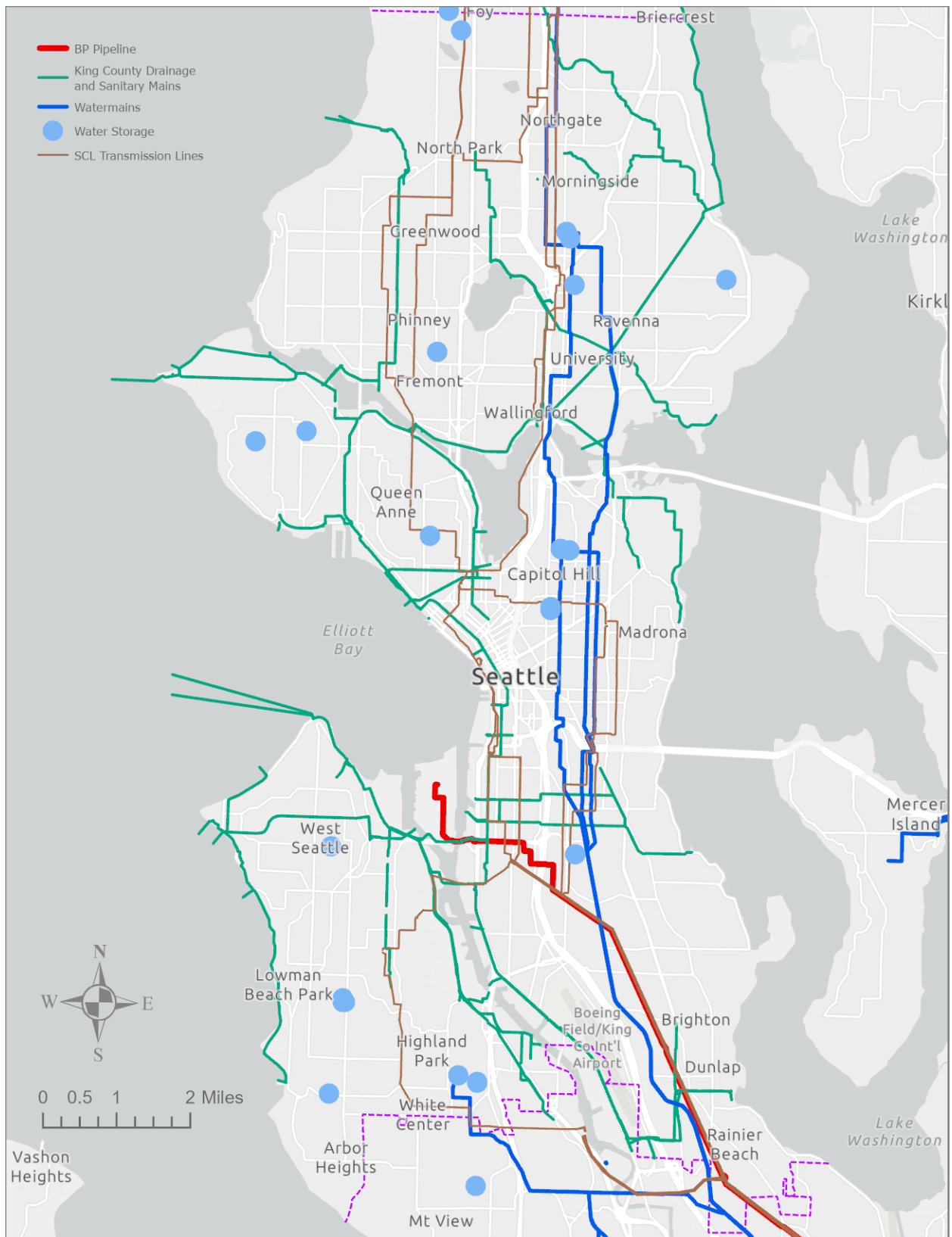
During heavy wet weather conditions, the combined sewer system can be overwhelmed with stormwater. When the system is overwhelmed, the untreated mixture of sewage and stormwater overflows at designated relief points called outfalls; these events are known as combined sewer overflows (CSO). While this helps to keep combined sewage from overflowing in streets or backing up into homes and businesses, it contributes pollution to Seattle's waterbodies.

In the late 20th century, City-led and County-led infrastructure programs worked to address CSO problems in Seattle. Despite this work, combined sewer overflows remained a significant source of pollution to local waters in this century. In 2013, the City of Seattle, U.S. Environmental Protection Agency, U.S. Department of Justice, and the Washington Department of Ecology signed a wastewater consent decree that detailed specific actions for the City to take to reduce combined sewer overflows. King County Wastewater treatment division also signed a wastewater consent decree to address their combined sewer overflows.

SPU has invested almost \$1 billion in Seattle's sewer system to reduce combined sewer overflows since 2008. From 2010-2024, Seattle significantly reduced CSOs when measured by both frequency and volume. From 2010 through 2017, SPU built four large storage tanks along Lake Washington. In 2019, we began construction on the Ship Canal Water Quality Project in partnership with King County Wastewater Treatment Division.

During heavy wet weather conditions, the drainage system can also be overwhelmed with stormwater. When high intensity storms occur, the drainage system can also reach capacity causing urban flooding. Seattle had 166 CSO events in 2023.¹¹⁵ A [live map of CSO status](#) is available from King County. Sewer

Figure 14. Major Utility Infrastructure



City of Seattle, King County, WA State Parks GIS, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA

systems must be engineered to prevent the buildup of explosive gases like methane. Sewer gas explosions are very rare but can occur if gas leaks into them. In 1981, illegal dumping in Louisville caused a major explosion that injured four people and caused millions of dollars in damage.¹¹⁶

Steam / District Energy

District energy systems produce steam, hot water or chilled water at a central plant and then pipe the water or steam to buildings in a district for heating, hot water and air conditioning. [Centrio Seattle](#) heats approximately 166 buildings in downtown Seattle and First Hill, including many hospitals.¹¹⁷ The University of Washington also runs a steam system for many of its buildings. Three major Seattle hospitals use steam to sterilize equipment and provide humidification. Loss of steam to hospitals can create an infection control emergency and could compromise patient safety if the outage is lengthy. Centrio Seattle generates its steam in power plants on Western Avenue. One is near Pike Place Market, and the other is near Yesler Way. In 2009, they built a new boiler that burns wood waste and reduces carbon emissions. While district energy systems have many benefits and high reliability, they must be managed well to prevent accidents like the 2007 New York steam pipe explosion. The plant near Yesler Avenue is vulnerable in earthquakes because it is on soil that can liquefy in an earthquake.

Telecommunications and Internet Access

Seattle's telecommunications infrastructure mirrors national infrastructure. Access to information and telecommunications is largely over the Internet. This dependence makes our community highly sensitive to Internet outages. Even 10 years ago, a large percentage of the population had multiple ways to get information and contact friends and family. Now nearly all communication travels through the Internet and Internet outages cause information blackouts.

The leading cell providers are AT&T Mobility, Verizon, and T-Mobile. The latter is headquartered in Bellevue, making Seattle its home ground. Cable franchises are split between CenturyLink, Comcast/Xfinity, and Astound. Local governments, including the City of Seattle, can issue wireless emergency alerts (WEA) which are brief messages about imminent dangers to cell phones in targeted areas. The City of Seattle also has [AlertSeattle](#), an opt-in mass alert system to compliment the WEA system.

Over 95% of Seattle households have a broadband Internet connection available to them and over 98% have a computer. These overall data conceal disparities. Only 82% for the households making under \$20,000 per year have access to the Internet. 96% of Seattle residents have a smartphone and 91% have a cellular data plan.¹¹⁸

The number of households with landline phones has been decreasing. The Center for Disease Control estimates that only 19% of households nationally have access to landlines. They do not have data for Seattle specifically but given that Seattle has a higher rate of smartphone adoption than the rest of the U.S., it is probable that even fewer than 19% of households in Seattle have landlines.¹¹⁹

More and more people are opting to end their traditional cable service and instead consume television through internet streaming services such as Netflix and Hulu. The two largest cable providers are Comcast with 98,000 subscribers and Astound with 5,000. Nationally, only about 10% of the population digital antennas to watch television.¹²⁰

Traditional broadcast systems remain important, especially in emergencies. Broadcast radio is the oldest of the telecommunications services. It is also one of the most important because it requires only a transmitter and receivers.

Media

Media plays an essential role in reducing hazard impacts whether it is traditional media or social media. Most Americans use multiple devices to check news, and they check throughout the day. Over half of Americans, 58%, prefer get news from digital devices and third, 32%, prefer get news from television. Radio and print trail with 6% and 4%. The percentage of Americans who consume news “Sometimes” or “Often” has declined since 2020 across all platforms. The rise of social media as a news source was one of the big changes during the 2010s along with the spread of misinformation. 25% of Americans ‘often’ get news from social media.¹²¹

Text Based Print/Online

Most of Seattle’s newspapers have evolved into a combination of print and online or online only. These sources often have detailed reporting on hazard related issues at the local level. They range from the Seattle Times, the only remaining Seattle major daily general circulation paper to neighborhood and ethnic newspapers. Ethnic newspapers and newsletters are critically important for reaching vulnerable communities who may lack access to mainstream media. The vital role played by ethnic publications was emphasized after a family of five Vietnamese-speaking people died heating their home with a charcoal burner. Many of these publications are highly trusted by the communities they serve. Seattle now standardly contacts ethnic media to put out public safety information during emergencies. One limitation is that many publications do not come out daily, so response can be slow after emergencies.

Blogs has become a popular two-way communication tool at the community level and within affiliation groups (e.g., trade groups). Examples include www.myballard.com and westseattleblog.com. These blogs are both current and relevant at the neighborhood level. Most of these blogs offer Twitter feeds for mobile users.

Radio

Seattle is the 11th largest broadcast radio market in the U.S.¹²² In emergencies, live radio call-in shows often become one of the best ways to create a community forum and disseminate information after a disaster. For example, after Hurricane Katrina local radio stations hosted call-in shows to allow members of the community to question officials, businesses, and one another about the best ways to cope with the emergency at hand. As more stations become automated and play only nationally syndicated content, this vital community resource shrinks.

The Emergency Alert System (EAS) is a national warning system based in broadcast radio (although it now reaches other media, too). National, state, local, and weather alerts can be issued. It is used most commonly for weather emergencies. The Washington State plan can be found [on the Washington State EAS Plan website](#). KIRO radio 710 AM is the federally designated station in the Seattle area. Alerts would start with these stations and propagate to other radio and television stations.

Television

Seattle is the 12th largest television market in the United States.¹²³ Fourteen local television stations broadcast here, including affiliates of all major U.S. networks. These stations are all available via broadcast, cable, and streaming. A smaller percentage of Seattle customers use satellite receivers. More and more people are ending their cable television contracts as most television and news is now available on the internet either as a stream or in clips. EAS messages propagate to television.

Emergency Services

Emergency Services encompass law enforcement, fire protection, and emergency medical services. The City of Seattle covers most emergency services with the Seattle Police and Fire Departments. Seattle Fire handles emergency medical services as well as fire protection. Other organizations located in Seattle like

the Port of Seattle and the University of Washington support some emergency services. American Medical Response, a private company, contracts with the City of Seattle for non-life-threatening emergency transport services.

Both the Seattle Police and Fire Departments are facing staffing shortfalls. Both departments have plans to boost staffing. The understaffing is a vulnerability for Seattle in responding to disasters.

Law Enforcement

The Seattle Police Department (SPD) is the primary law enforcement agency operating within the City of Seattle. In 2024 SPD had 1,054 total officers and 933 deployable officers.¹²⁴ SPD is the largest law enforcement agency in the State. Between 150 and 180 officers are on duty at the same time depending on circumstances.

Other agencies with limited jurisdiction inside Seattle are King County Sheriff (public transit), Washington State Patrol (state transportation routes), the University of Washington Police (UW property), the Port of Seattle Police (port property) and railroad police (Amtrak, BNSF).

SPD uses five precincts as its basis for operations. There is a police station in each precinct. SPD also maintains specialty units that operate citywide. They include Special Weapons and Tactics (SWAT), Harbor Patrol, Canine Unit, Mounted Patrol and a Traffic Unit.

Dialing 911 in Seattle first connects a caller with the Community Safety Communications Center. Trained employees transfer calls concerning fire or medical issues to the Fire Alarm Center; they evaluate calls concerning law enforcement issues and send them to dispatch, as necessary. The Community Safety Communications Center handled around 505707 calls in 2024.¹²⁵

Crime in Seattle has increased 25% from 36,621 offenses in 2008 to 45,753 in 2024 but is down from a high of 50,199 in 2022. Seattle's population has also grown so converting these numbers into rates is important. Dividing the number of crimes by Seattle's population of 797,700 (2024) as estimated by the Washington Office of Financial Management yields a rate of 5,735 per 100,000 in 2024. The rate in 2022 was 6572 per 100,000 or a 12.7% decrease, however the rate of violent crime has only decreased 1.2% for 741 per 100,000 to 671 per 100,000.¹²⁶

SPD is the lead agency for responding to civil disorder and terrorism investigation. The 2020 George Floyd unrest was a painful and pivotal experience for Seattle Police which included efforts to defund the department. From 2019 to 2022, the department lost 327 officers. In 2023 it has a net loss of 6. A new Recruitment and Retention Plan was launched to increase officer numbers. These declines come as Seattle's population continues to rise. Many big events require officers to work overtime with negative effects on officer health and performance.¹²⁷

The King County Department of Adult and Juvenile Detention (DAJD) maintains two adult detention facilities and one youth facility. The King County Correctional Facility is the primary detention facility in Seattle while the Kent Regional Justice Center is primary for south King County. The DAJD handled 15,520 bookings in 2022. The average daily secure population from January 2021 to July 2023 varied between 1,227 and 1,559. Staffing shortages are also a challenge at DAJD. DAJD now maintains a [metrics dashboard](#). Detention facilities are vulnerable spaces in disasters.

In Washington State, county superior courts are the court of general jurisdiction. Several other courts have been established with limited, concurrent jurisdiction. The most important court for Seattle is the Seattle Municipal Court, the largest limited-jurisdiction court in the State of Washington.

Fire

The Seattle Fire Department (SFD) provides fire suppression services in the City of Seattle and is the lead agency for most incidents that involve rescue operations. Seattle Fire achieved Fire Protection Class One, a measure used for fire insurance ratings. It is the highest rating awarded in Washington State in

100 years and puts Seattle Fire in the top 1% of services in the US. This success is valuable because Seattle Fire is experiencing staffing shortages. In August 2022 it had 1,026 uniformed staff which is 57 positions below the full complement of 1,083. It makes up the difference with overtime.¹²⁸ SFD has between 216 and 220 on duty at any given time.

These personnel are divided among 33 fire stations, 19 of which house one engine company with the remaindered housing an engine company plus additional resources. SFD also operates specialized apparatuses. A summary of Seattle Fire’s resources is listed below.

In 2022, the number of dispatched responses moved over 100,000 for the first time to 106,453. It was a 12.3% jump from 2021. The increase is being driven by the opioid epidemic. Most calls (74%) are for basic or advanced life support. 25% of these calls were for fire. Fire calls have seen a 50% increase in two years.

Table 8. Fire Department Resources

Number	Resource
33	Fire Stations
32	Engines
12	Ladder Trucks
5	Aid Units
2	Peak Time Aid Units
8	Medic Units
3	Health One Units
2	Air Trucks
2	Hose Wagons
4	Fire Boats
1	Shared Training Facility

Table 9. Fire Department Responses

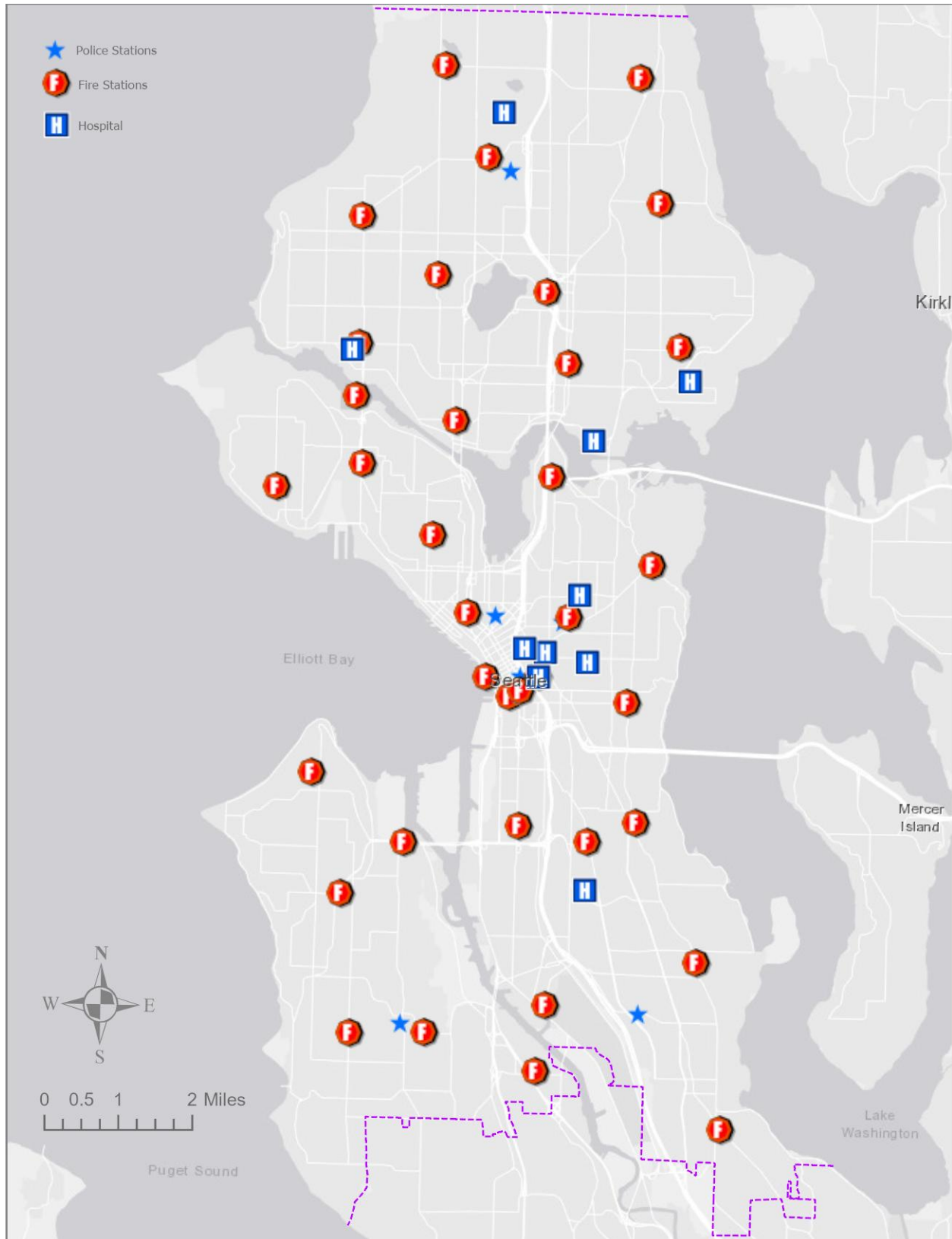
Type	2020	2021	2022	2023	Change 2020 to 2023
Total Responses	80,316	93,233	106,453	111,319	38%
Basic Life Support	50,900	56,208	64,127	66,336	30%
Advanced Life Support	10,817	12,356	14,681	16,407	50%
Fire	18,094	24,255	27,180	28,107	55%
Special Operations	Not given	361	407	385	6%
Mutual Aid	505	53	58	84	N/A

Emergency Medical Services (EMS)

SFD is Seattle’s primary provider of emergency medical services other than healthcare facilities. All Seattle fire fighters are certified EMTs or paramedics, as well 56 police officers in 2023.¹²⁹ To provide Basic Life Support (BLS), SFD maintains five basic life support aid units and contracts with a private provider, American Medical Response (AMR). AMR normally operates seven more BLS aid units.

To provide Advanced Life Support (ALS) in life-threatening situations, SFD partners with the University of Washington and Harborview Medical Center to operate the successful internationally recognized Medic One program. Medic One’s initial focus was cardiac care. Compared to other large cities, cardiac arrest

Figure 15. Public Safety Facilities



City of Seattle, Bureau of Land Management, Esri, HERE, Garmin, USGS, EPA, NPS, Esri, HERE, NPS

victims in Seattle are 2-3 times more likely to survive. Seattle's survival rate after cardiac arrest outside of a hospital is 19.9%.¹³⁰ Medic One has 78 paramedics and 7 medic units in Seattle.¹³¹ The Medic One system consists of an additional 171 paramedics in neighboring cities and in King County.¹³²

Due to a growing number of people experiencing homelessness and the increasing use of opioids, SFD has seen an increase in EMS responses. Health One is a new program launched in 2019 that pairs firefighters with Seattle Human Services Department case managers to help people in crisis.

Public Safety Communications Systems

In 2023, the city completed a multi-year project to replace its old 800 MHz radio system with the Puget Sound Emergency Radio Network (PSERN).¹³³ Construction and updates of radio towers and new equipment at radio sites and for users of the system has improved overall coverage and connectivity. Some City departments, such as Transportation and Seattle City Light operate their own radio networks to use during a disaster event.

The City also relies on short-wave radio communications for some functions that require high-capacity connections, such as parks, libraries, and some fire stations. The City's main network nodes are linked by a fiber optic ring to provide redundancy to the communications system.¹³⁴ If a fiber cable along this ring is cut in one spot, calls can be rerouted the opposite direction and still delivered.

Seattle has an active and robust amateur radio capability led by the [Auxiliary Communications Services \(ACS\)](#). Started in 1993, it consists of over 150 trained volunteers with Washington State Emergency Worker certification. ACS volunteers respond to community based [Seattle Emergency Hub](#) sites to provide communications support to connect Seattle's neighborhoods to its Emergency Operations Center in the event primary communications systems fail. For an overview of radio support at hub sites see this [short video](#) by the Seattle Channel.

Health Care and Human Services

Seattle's health care and human services systems are tightly intertwined. A public-private network provides services ranging from the basic social safety net to advanced medical treatment.

Health Care

Seattle has the largest concentration of medical facilities and personnel in the Pacific Northwest with ten hospitals, 267 emergency department (ER) beds, a public health department shared by the City of Seattle and King County, as well as integral supporting businesses and services like medical laboratories, research institutions, training centers, and medical suppliers.¹³⁵ The rest of King County has an additional five hospitals. The core of Seattle's healthcare system is direct patient services, and its ten hospitals dominate. Many of the hospitals manage ancillary healthcare services across Seattle such as ambulatory care centers, long-term care facilities, home health care and other services. Seattle's healthcare facilities serve many patients from outside the city.

Due to the concentration of many healthcare services within the city limits, Seattle has a very high number of healthcare workers within its residential population. In a regional catastrophic event, Seattle would have large numbers of general medical personnel available, especially during business hours when outpatient clinics are operating.

Public Health – Seattle & King County is the 9th largest metropolitan health department in the United States. It is a primary provider of local public health services and collaborates with many different partners through an integrated system of healthcare and public health services.

Public Health – Seattle & King County focuses on three major functions:

- Health Protection – Tracking and preventing disease and other threats; regulating dangerous environmental and workplace exposures; and ensuring the safety of water, air and food.
- Health Promotion – Leading efforts to promote health and prevent chronic conditions and injuries.
- Health Provision – Helping ensure access to high quality health care for all populations.

In Washington State, the Local Health Officer of Public Health – Seattle & King County has wide-ranging authority to control public health emergencies. Powers include the ability to quarantine people, close schools and other public institutions and take other measures to control health risks. This considerable authority has been used with discretion. The Washington State Secretary of Health can act in lieu of local health officer under limited circumstances.

The regional healthcare system is coordinated by the [Northwest Healthcare Response Network](#) (NWHRM). They are responsible for coordinating patient tracking, resource sharing, and operations. They play a key role as a neutral party ensuring that multiple health care networks which are competitors during normal times, can operate as a unified whole during emergencies.

The healthcare system is strained post COVID-19. Typically, 90% of all ICU beds are occupied with some facilities consistently at 100% occupancy. The two leading causes are chronic staffing shortages and the difficulty in discharging patients who do not have a safe place to go.¹³⁶

Human Services

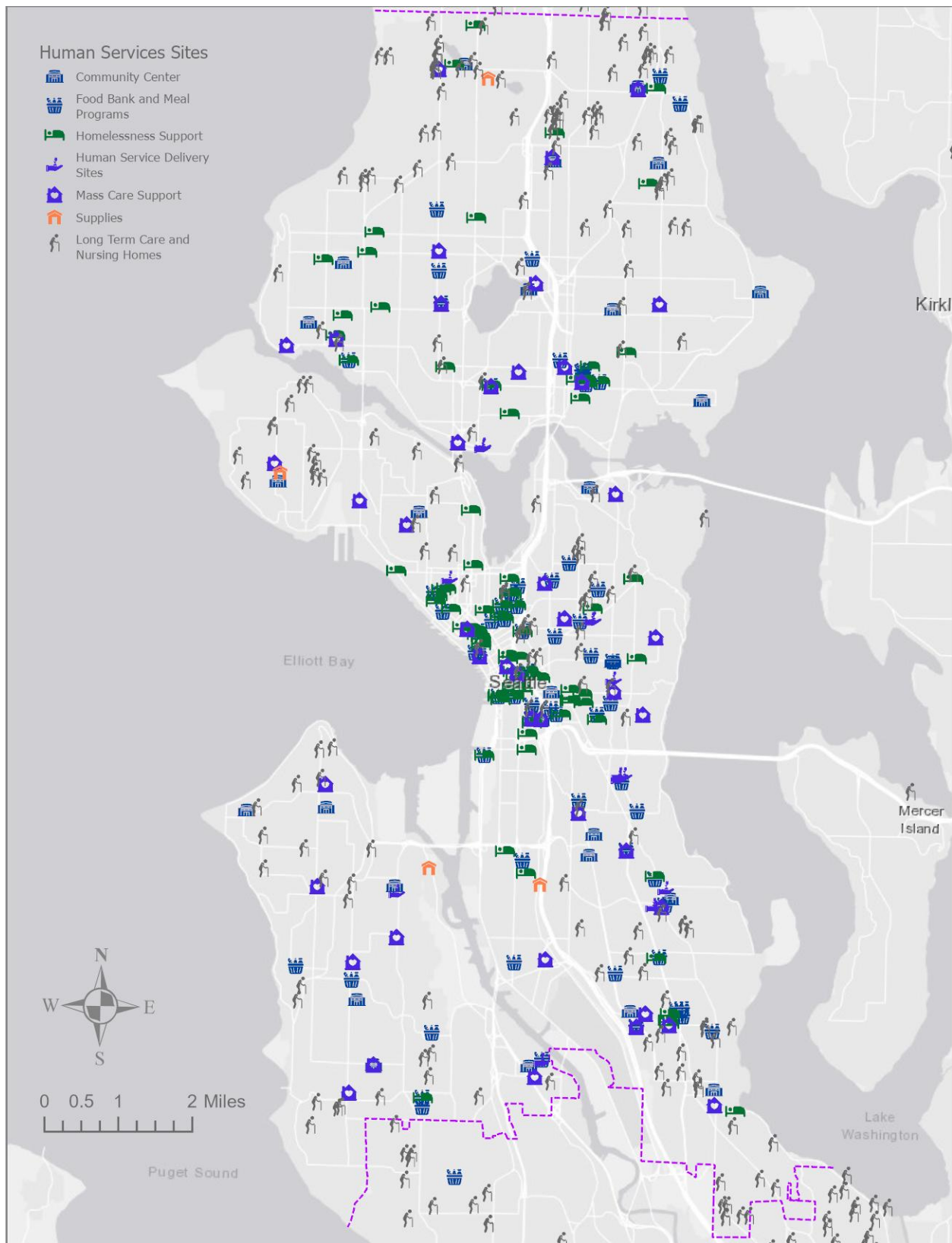
Seattle’s human service sector addresses the basic needs of the most vulnerable members of the community. It is a network of government agencies, non-profits, and philanthropies. Seattle’s Human Services leads this coordination for the City of Seattle. It partners with and invests in many (but not all) of the city’s local nonprofit and community programs. These programs fall into six areas: preparing youth for success, supporting affordability and livability, addressing homelessness, promoting public health, responding to gender-based violence, and promoting healthy aging. The department reaches many people with over 2 million community meals and 326,728 medical/dental visits served to low income and vulnerable populations, 36,145 people enrolled in the Utility Discount Program, and 7,294 survivors received domestic violence, sexual assault, and/or gender-based violence services.¹³⁷

The range of services provided by Seattle’s human services organizations varies widely. Roughly stated, the issues concerning the sector cluster around providing the following for all members of the community:

- Food
- Shelter
- Personal safety
- Access to healthcare
- Access to training and education to learn job skills
- A supportive community environment
- Access to culturally competent services

Seattle’s human services sector is comprised of hundreds of public, quasi-public (e.g., Seattle Housing Authority) and private organizations. These differ so greatly in size, resources, scope, and capacity that it is impossible to make general statements about a “typical” organization. A relatively small number stand out due to their size and scope of operations. They include the Human Services Departments of Seattle, King County, and Washington State, the Seattle Housing Authority, and large nonprofits such as American Red Cross, Salvation Army, and Catholic Community Services. Seattle is also home to many

Figure 16. Human Service Facilities



City of Seattle, Bureau of Land Management, Esri, HERE, Garmin, USGS, EPA, NPS, Esri, HERE, NPS

foundations that do not offer direct services but supply funding to providers. In general, government agencies do not provide direct services and rely instead on a network of nonprofit organizations. Funding for these organizations is provided by government grants and contracts as well as donations from individuals, corporations, and foundations.

The effectiveness of human service delivery after a disaster depends on strong linkages between the community and the organizations supplying the services. Often it is the smaller organizations that have the strongest ties to the community, but many of them are not prepared for major disasters and often lack viable continuity of operations plans that allow them to remain in business after a disaster. [Figure 16](#) shows the distribution of human services facilities.

Following a December 2006 Windstorm, the United Way convened a task force to examine the response of nonprofit human service agencies in King County. It reported that “The Task Force concludes that the region is not prepared to deal with the impact on vulnerable and special populations in a major disaster event.”¹³⁸ The local United Way report and many national studies question the ability of nonprofits to lead human service response after a major event. The human service delivery system is so fragmented that sharing information is difficult under normal conditions and impossible given the stress of a disaster. The reports concluded that nonprofits work best in a complimentary role to government. The City of Seattle and United Way King County began a program to help non-profits build more resilient, it is not clear whether it has led to permanent change as of 2023.

During many disasters, members of the public spontaneously organize themselves to provide help to themselves and those in need. These emergent groups often begin operating before official organizations. Tension can arise between these two groups, especially when government attempts to shut down or control these groups. The most successful responses make good use of emergent groups.

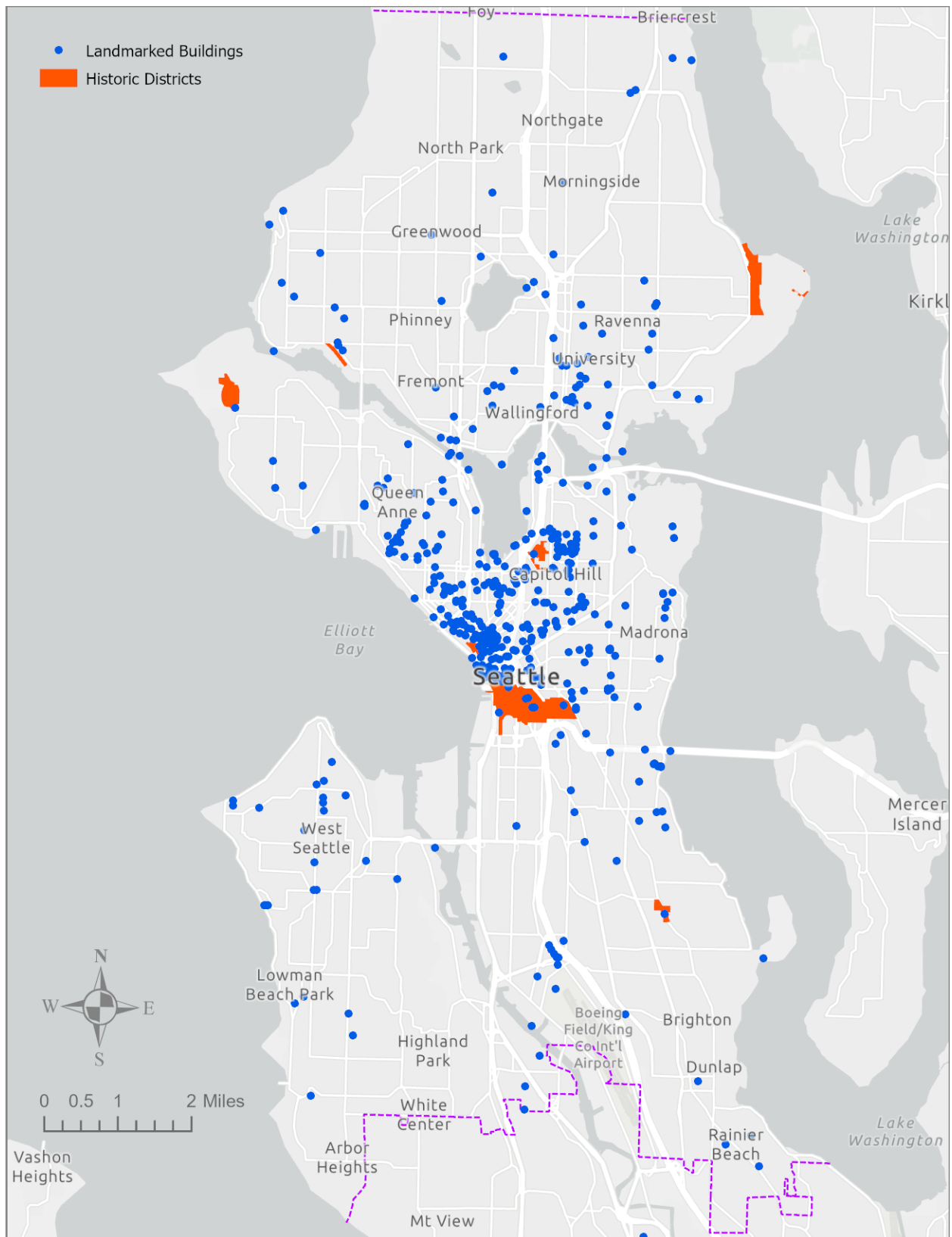
People living unsheltered are the most vulnerable to disasters. Much of the City of Seattle’s response to ‘routine’ large emergencies like extreme weather events, consists of planning and coordinating emergency sheltering and outreach operations for homeless people. The King County Regional Homelessness Authority (KCHRA) is the lead agency for these operations but partners with the Seattle Human Services Department and many non-profits and faith-based organizations to provide services.

The COVID pandemic was a huge challenge for the human services sector, but also one that led to growth and flexibility. Many new creative strategies were developed, but resources remain a challenge.

Table 10. Age Distribution of Housing Stock Reported by U.S Census (2023)¹³⁹

Total housing units	400,166	
Built 2020 or later	14,922	3.7%
Built 2010 to 2019	71,731	17.9%
Built 2000 to 2009	48,235	12.1%
Built 1990 to 1999	22,738	5.7%
Built 1980 to 1989	28,328	7.1%
Built 1970 to 1979	24,858	6.2%
Built 1960 to 1969	30,848	7.7%
Built 1950 to 1959	33,863	8.5%
Built 1940 to 1949	93,538	7.8%
Built 1939 or earlier	88,134	23.4%

Figure 17. Historic Districts and Landmarks



City of Seattle, King County, WA State Parks GIS, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA

Buildings

Many hazards threaten buildings. Understanding them helps understand risks to the people who depend on them. About one third of Seattle’s housing units were built prior to the 1949 building codes that introduced seismic standards and nearly two thirds prior the city’s 1992 upgrade of its seismic codes. The table below shows the age distribution of Seattle’s housing stock.

Most of Seattle’s housing is wood frame construction, which generally performs well in earthquakes. The City of Seattle, the Port of Seattle, and Seattle Public Schools have surveyed their facilities for seismic safety. The City of Seattle has identified over 1,100 unreinforced masonry structures, that are prone to collapse in an earthquake. Other forces like wind and landslides are accounted for in the building code. Historic buildings help define the soul of a city. [Figure 17](#) shows the distribution of these structures and districts in Seattle. Many, especially those that have not been substantially renovated, are vulnerable to earthquakes and other hazards. Seattle’s largest historic district, Pioneer Square, is located in a liquefaction prone area making it especially vulnerable to earthquakes.

Summary

Cities have a different hazard exposure profile than rural areas, suburbs, or small towns. The concentration of people, economic power, services, political institutions, and cultural life give cities the vitality to overcome many setbacks. Their complex network of infrastructure, services and economic relationships all tied into a geographic node creates an inherent vulnerability, but also a vibrancy that creates a countervailing resilience.

Seattle’s public is well educated and resourceful, but like any urban population it relies on functioning infrastructure. For example, as more people live in high-rises, they become dependent on power to pump water to their apartments and transport them in elevators. Following the 2011 Japanese earthquake and 2012’s Superstorm Sandy, many urban residents had to temporarily move out of their dwellings for this reason because they could not contend with long flights of stairs.

Often cities have the capacity to quickly rebound after small and medium sized shocks but suffer when an event takes out resources for an extended period. Modern urban life depends on a complex, interdependent web of services. Loss of a couple of services for more than several days can bring normal city life to a halt. How long can cities function without power and roads? If the services are out for weeks or months, the result can be an irreversible decline, especially if a city’s fortunes were declining prior to a disaster.

CLIMATE CHANGE

Climate change is the biggest environmental threat our planet faces, and it is occurring rapidly.¹⁴⁰ This document focuses on extreme events which constitute a major climate change threat. Climate change presents Seattle with many challenges: flooding, summer heat and drought, rising sea levels, heightened wildfire risk, and declining snowpack. Seattle will also experience indirect impacts. These could include higher commodity prices, increased migration and increased economic and political instability across the globe. Climate change is a factor that may intensify and/or increase the likelihood of certain hazards. Of the 19 hazards considered in this analysis, eight are directly affected by climate change and four are indirectly affected. Together they represent nearly two-thirds of Seattle's hazards.

The City of Seattle completed a [Climate Vulnerability Assessment](#) in 2023. It provides a comprehensive look at how climate change will affect Seattle. It goes beyond the scope of this document to consider chronic problems over a decadal time scale. Complimenting this work is the [Fourth National Climate Assessment's chapter on the Northwest](#) which sets our region's experience in the national context.

The physics of climate change have been [understood for over 100 years and the first evidence was recorded in 1938](#). Climate change is caused by the build-up of greenhouse gases (GHG) in the atmosphere. GHGs are measured by their warming potential equivalent to carbon dioxide (CO₂). As measured by air trapped in Antarctic ice, CO₂ concentrations were less than 300 parts per million (ppm) over the last 800,000 years. In 1880, CO₂ was at 290 ppm. Today CO₂ stands at 405 ppm, a 40% increase. Unfortunately, even if the world stopped burning fossil fuels tomorrow, existing levels of atmospheric GHGs would continue to contribute to warming global temperatures.

While reducing CO₂ emissions is a global project, cities, such as Seattle, play an important role. In 2020, Seattle emitted 3,012,800 tons of CO₂ equivalent gases ('equivalent' means other GHGs like methane are converted into their equivalent CO₂ amounts). 61% of the city's GHG emissions come from road transportation, 37% comes from commercial and residential buildings, and 2% from waste management.¹⁴¹ (Note: The 2020 totals show a large drop from 2018 due to the COVID19 pandemic-related reduction in transportation emissions.) The most prominent GHGs in the Seattle region are carbon dioxide (CO₂), fluorinated gases (e.g. hydrofluorocarbons), methane (CH₄), and nitrous oxide (N₂O).¹⁴²

Key Points

- ❖ 4.2°F - 5.5°F increase in average annual temperature in the Pacific Northwest by the 2050s.
- ❖ 4 – 56 inch increase in sea level rise by 2100 (dependent on land movement). Rising sea levels lead to an increased risk of coastal flooding and landslides.
- ❖ Drier summers, with more severe precipitation events in other seasons leading to an increased risk of urban flooding and landslides.
- ❖ 42-55% decline in mountain snowpack by 2070 creates water management challenges.
- ❖ Seattle's watersheds will become more reliant on variable rainfall than snowmelt.
- ❖ 63 additional deaths on average per year linked to extreme heat and air pollution.
- ❖ Increased risk of wildland fire for both sides of the mountain and degraded salmon habitat.

In 2013, the City of Seattle adopted a [Climate Action Plan](#). It set a goal for Seattle to reduce total 'core' carbon emissions by 58% from a 2008 baseline by 2030, which include those of combined transportation, building, and waste, and seeks to become carbon neutral by 2050.¹⁴³ The most recent [2022 Greenhouse Gas Emissions Inventory](#) shows a 12% decrease in emissions from 2008 to 2022.¹⁴⁴ Further, the Seattle City Council passed a resolution in 2017 stating the city's commitment to uphold the Paris Agreement, meaning Seattle will take steps to ensure that future warming is limited to 1.5°C.¹⁴⁵ In 2025, Seattle issued an audit of the 2013 and began a [revision](#) of the Climate Action Plan.

Direct Effects

Climate change will not affect the Pacific Northwest uniformly. This section outlines what the primary changes are expected to be for the Puget Sound region. These projected changes use emissions scenarios developed by the [Intergovernmental Panel on Climate Change](#) (IPCC), specifically ‘RCP 8.5’ the ‘high’ emission scenario that represents ‘business-as-usual’. If global emissions are curtailed significantly, the effects will be reduced. The [Climate Impact Group](#) (CIG) used the IPCCs scenarios to develop local projections. The CIG is an interdisciplinary research group at the University of Washington. They provide the most rigorous and comprehensive climate change information for the Pacific Northwest. Readers are encouraged to visit CIG’s [Climate Mapping for A Resilient Washington](#) application to explore the data beyond what can be summarized here.

Temperature

The Office of the Washington State Climatologist has [an app](#) to show historical changes in temperature over time in the Pacific Northwest. The average annual temperature for the Pacific Northwest has increased near 2°F since 1900.¹⁴⁶ This warming is statistically significant in all seasons except for spring. The Pacific Northwest climate has a high degree of variability, resulting in short-term cooling or warming trends that may stray from the long-term average temperature increase. For example, there were cooling trends from 2000 to 2011 despite overall long-term warming.¹⁴⁷ In addition, almost all temperature monitoring stations show warming, but the rate of warming has not been consistent across the region.

Temperature increases are accelerating. The Puget Sound region is projected to warm between 4.2°F and 5.5°F on average by the 2050s when compared to averages from 1970 – 1999.¹⁴⁸ The range reflects the difference between low and high future greenhouse gas (GHG) scenarios. The IPCC’s low GHG scenario (4.2°F of warming) represents GHG emissions continuing at the current rate until mid-century and then decreasing dramatically thereafter due to intentional global reductions in emissions. The high GHG scenario (5.5°F of warming) represents steady increases in GHG emissions until 2100. Much higher warming is possible in the second half of the century, but the magnitude of warming is dependent on GHG emissions.¹⁴⁹

Historical data show that the *global* climate has also been warming and trends are measurably accelerating.¹⁵⁰ Average global surface temperatures rose 1.5°F from 1880 to 2012.¹⁵¹ There is likely to be regional variation in the rate of global warming.

Sea Level Rise

Sea level rise is occurring now. Global sea level has risen 8 inches from 1900 to 2009. Since the mid-1800s, the rate of sea level rise has surpassed the previous two millennia, indicating an accelerating trend.¹⁵² [Vertical land movement affects sea level rise](#) and creates inconsistencies across the Puget Sound region. In Seattle, where the land is subsiding (gradual sinking) at the rate of about -0.5 inches per decade, the Seattle tide gauge reveals 8.6 inches of sea level rise from 1900 to 2008, averaging 0.8 inches per decade.¹⁵³

As with temperatures, the rate of sea level rise is expected to vary over time due to seasonal and decadal climate variability. Factoring in uncertainties in global sea level rise, vertical land movement, and regional wind and ocean circulation patterns, the projected range of sea level rise for Seattle is as low as 4 inches, and as high as 56 inches by 2100.¹⁵⁴

Sea level rise worsens seasonal tidal flooding, causes coastal erosion, especially along bluffs, and can inundate low lying structures and infrastructure. At a global scale, it has been linked to worsening storm surge, but the CIG did not find clear evidence of increased storm surge in Puget Sound. Storm surge needs high winds and high waves to occur. CIG found that observed trends were ambiguous.

Seattle has begun adapting to the future effects of sea level rise. For example, in designing its new sea wall, the City of Seattle evaluated its plans against the highest sea level estimates and found that the top of the sea wall would still be 3 feet above the new mean water level projected in 2100.¹⁵⁵

Water Cycle

How and when precipitation occurs in the Puget Sound region has profound effects for our communities. Seattle's water supply and power system are dependent on Cascade Mountain snowpack stored up over the winter and released as melting water in the late spring and summer during our drier months. With warmer temperatures, more precipitation will fall as rain and immediately run off instead of being stored as snow. The CIG projected that the Puget Sound region will experience a decrease in snowpack. Peak snow accumulation and snowmelt-derived streamflow across the West have shifted earlier with more precipitation falling as rain.¹⁵⁶ Snowpack in the Washington Cascades has declined by 25% since the mid-1900s, and the state's last remaining glaciers are melting rapidly.^{157,158} Average spring snowpack in the Puget Sound is projected to decline by -42% to -55% by 2070 to 2099 (relative to 1970 - 1999, for both low and high GHG scenarios).¹⁵⁹

Due to the decreased snowpack and earlier spring melting, streams that rely on snowmelt are projected to experience peak streamflow earlier in the year, and for some rivers, dry years are becoming drier. Seattle's watersheds will become more reliant on rain than on snowpack. Winter streamflow is projected to increase by 28% to 34% by 2080, while summer streamflow is projected to decrease by 24% to 31% by 2080.¹⁶⁰ The increase in winter streamflow increases the risk of flooding in low lying areas along the Duwamish, especially the South Park neighborhood.

Overall, heavy rainfall events are expected to become more severe for Washington State, but it is likely that the average annual precipitation will continue to be determined by yearly variations. The number of days with more than one inch of rain is estimated to increase 6% to 20% by the 2050s (relative to 1971 – 2000).¹⁶¹ The estimated changes in annual precipitation are smaller, between -4% to 14% by the 2050s (relative to 1950 – 1999).¹⁶² While projections of seasonal precipitation are mixed, most models point towards drier summers. Water demand in Seattle is only expected to increase 5% by 2075, likely offsetting some impacts, but the effects of heavier rainfall on stormwater management could be costlier.¹⁶³

Air Quality

While some progress has been made in reducing emissions in Seattle, air quality is expected to decline due to increasing air temperatures, longer periods of heat, and drier summers. These factors have the potential to increase ground-level ozone and fine particulate matter accumulation. Summer deaths in the Greater Seattle area attributed to ozone are projected to increase to 132 per year by 2050, up from 69 per year from 1997 to 2006.¹⁶⁴ Since 2017 Seattle has experienced an increase in the frequency of wildfire smoke. Nationally, climate change is projected to intensify wildfires and with them, smoke.

Hazard Effects

Climate change will intensify many of Seattle's hazards: landslides, disease outbreaks, infrastructure failures, power outages, extreme heat events, weather-related hazards, and wildfires.

Biological Hazards

Climate change brings with it a host of negative health impacts from increased heatstroke, dehydration, pollen allergies, and cancer risk. Many of them will be chronic problems that won't trigger activation of Seattle's emergency management system but will need to be addressed with enhancements to our everyday health system. See the City of Seattle [Climate Vulnerability Analysis](#) (PDF) for more on chronic hazards.

Climate change will bring complex, acute crises that will need a collaborative emergency management approach. Warmer temperatures will bring more mosquitoes, ticks, and fleas into the Seattle area and with them Lyme disease and West Nile virus. Fungal diseases like *Cryptococcus gatti* and Valley Fever (coccidioidomycosis) that were previously limited to the tropics are now found in the Pacific Northwest.¹⁶⁵ The Oregon Health Authority recorded spikes in *Salmonella* and *E. coli* cases during extreme heat in 2015. Increasing water temperatures will lead to increased harmful algal blooms that contaminate shellfish. A 2022 study of 375 human pathogenic diseases found that over half, 58%, were made worse by climatic hazards while 16% improved.¹⁶⁶

Extreme Heat

Average temperatures in the Seattle area have increased by 1.5°F from 1950 to 2020.¹⁶⁷ By the 2050s, UW Climate Impacts Group projects that temperatures on the hottest days in the Puget Sound area will increase by 6.5°F on average.¹⁶⁸ Of special importance for emergency management are the number of extreme heat days and the duration of heat events like 2021's Heat Dome. Currently, King County has a median of 9.5 days over 90°F. Under the high emissions scenario (RCP8.5) that number is projected to more than double to 20.1 between 2040 and 2059. With extreme heat, duration matters as much as intensity. Three days is a key inflection point. After three days, people without access to cooling begin to experience ill effects at an increasing rate. The First Street Foundation predicts the chance of three days over 86°F will go from the current 67% to 86%.¹⁶⁹

Seattle's heat waves will get both hotter and longer. To compound the problem, nighttime temperatures are increasing faster than daytime temperatures, reducing the relief of nighttime cooling that many Seattle residents are accustomed to.¹⁷⁰ Extreme heat events are a particularly dangerous hazard for Seattle, where the generally mild climate makes it difficult for the community to acclimate to extreme heat when it occurs, and buildings have historically not been constructed to insulate from high outdoor temperatures.

Heat is not evenly distributed in Seattle. Areas with few trees and high impervious surface area retain heat more than greener parts of Seattle. Often these are areas where poorer and marginalized residents live.

Flooding

Climate change will worsen flooding events. Seattle experiences three kinds of flooding: urban, in which the drainage system is overwhelmed by sudden, intense precipitation; coastal flooding, in which low pressure and high wind drive ocean or lake water onto shore; and riverine, in which a stream or river overtops its banks. Climate change will not change Seattle's annual precipitation, but it will concentrate it in the winter. Many flooding events are triggered by atmospheric rivers which are predicted to intensify with climate change.¹⁷¹ Higher sea levels can extend the reach and impact of storm surge.¹⁷² Low-lying areas fronting Puget Sound could be subject to flooding, especially when winter storms coincide with high tides.

Infrastructure Failures

Climate change intensifies extreme events that damage infrastructure directly as with heat that damages bridges and road surfaces or overwhelms them as with the case of wastewater and drainage systems unable to cope with runoff beyond their design capacity. Sea level rise will have direct consequences for coastal and low-lying infrastructure: wastewater treatment, power distribution, port facilities, railways, fiber optic cables, and roadways.

Landslides

The occurrence of sudden water loading on already saturated slopes is the defining indicator for landslide likelihood in Seattle. Climate change will increase the number of atmospheric rivers and precipitation intensity both of which will contribute to triggering landslides.¹⁷³

Power Outages

Seattle's electrical system is highly exposed to climate change risks. Precipitation changes will challenge power generation. Summer power demand for cooling will increase. The other hazards mentioned here will threaten electrical power transmission and distribution from the flooding of substations, to heat sagging power lines, to landslides undermining transmission towers. Each of these hazards increases the likelihood of power outages. The consequences of a prolonged power outage during an extreme heat event is especially dangerous.

Water Shortages

Seattle Public Utilities (SPU) states that existing water resources will be sufficient to meet forecasted demand until 2060.¹⁷⁴ The primary impact on SPU's water system is projected to arise from more frequent temperature-driven droughts due to low snowpack and/or early snowmelt that leads to an extended summer dry season.

Hydropower generation in the Columbia River Basin is projected to increase by 5% in winter and decrease by 12% to 15% in summer by the 2040s (relative to 1970-1999). The same seasonal pattern of change is expected to occur in the Skagit watershed. In the long term, Seattle City Light (SCL) will look at the potential need to modify operations of its hydroelectric projects. To be consistent with National Energy Reliability Council requirements, SCL has already adopted a more conservative planning standard for its Integrated Resource Plan, effectively reducing the amount of generation the utility can count on from its hydro resources in the future.

Wind

How climate change affects the frequency and intensity of windstorm events in the Pacific Northwest is unclear. CIG partnered with Seattle City Light (SCL) to project changes in extreme wind events and lightning risk for the future period of 2040 to 2070. The model simulations showed no significant change in the frequency of extreme wind events.¹⁷⁵ Small increases in frequency were found in mountain locations but were minor compared to natural variability. Additional research is needed to understand the projected effects of climate change on extreme wind events in the Puget Sound region.

Wildfire

Wildfires will likely increase in number and size due to climate change. Fire season itself is expected to lengthen in duration due to higher average temperatures and predicted diminished snowpack. This will lead to drier soils and vegetation, enabling fire spread and growth. Climate change is furthermore predicted to alter the historic range and spread of insects and pests, such as the mountain pine beetle, that can weaken trees and plants, making them more vulnerable to burning. High temperatures and increased wildfires across the country may limit and/or exhaust local fire suppression capabilities, leading to weakened response and further fire spread.

Resources

Climate change has received wide attention in the Pacific Northwest. The University of Washington's [Climate Impact Group](#) (CIG) is the leading source for regional specific climate research. It is a frequent partner for the City of Seattle which has a number of initiatives to address climate change and are outlined at <https://www.seattle.gov/environment/climate-change>.

[Seattle Climate Vulnerability Assessment](#). Citywide perspective on Seattle’s climate vulnerability. This chapter cites this resource often.

[Seattle Climate Data Portal](#). Brings together multiple datasets covering Seattle emissions and combines them with socio-economic data to show impacts. The site explains Seattle’s plans to decarbonize transportation, buildings, and waste streams.

[Climate Trend Analysis Tool](#). From the Office of the Washington State Climatologist. Shows changes in temperature, precipitation, and snow.

[Building Greenhouse Gas Emissions Map for Seattle’s Non-Residential and Multi-Family Buildings](#). Shows buildings rated by Energy Use Intensity (EUI), a measure of energy use per square foot.

[Climate Mapping for A Reliant Washington](#). Shows changes in frequency and intensity for multiple climate related hazards in Washington.

1. EARTHQUAKES

Earthquakes are Seattle's most potentially damaging hazard. Seattle is subject to infrequent but potentially devastating large earthquakes from local surface faults and the huge Cascadia Subduction zone. A large earthquake from one of these sources could be one of the worst natural disasters in US history. Seattle is also subject to frequent earthquakes originating deep below the surface. Deep earthquakes happened in 1949, 1965, and 2001, with the 2001 Nisqually earthquake causing an estimated \$2-4 billion in damage. The Seattle area has an 84% chance of experiencing another earthquake like these in the next 50 years.

What Causes Our Earthquakes?

Most earthquakes are caused by fault-slips in the Earth's crust. These are driven by convection in the Earth's mantle, the layer of hot, dense rock between the Earth's crust and core. On geological scales it acts like a viscous liquid, and convection causes movement in the earth's crust. Just as hot air rises and cool air sinks, hot mantle material rises, cooling as it nears the surface. The cooler material then begins to slowly sink, which creates a convection cell. Hot, rising rock pushes plates across the surface of the earth. When plates collide, the thinner, denser ocean plate is usually forced under the thicker, lighter rock of the continent. ([Figure 18](#) shows the process)

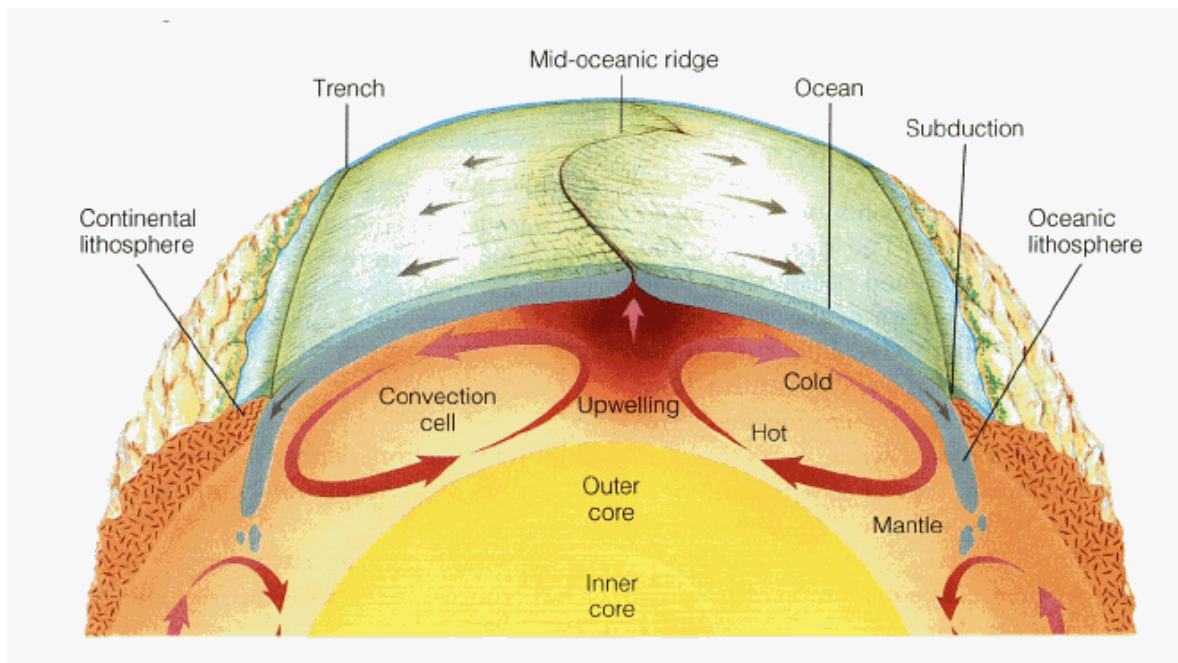
As the plates collide and scrape past each other, strain builds. Earthquakes happen when the strain accumulating in rock becomes greater than the strength of the rock or the pressure keeping it from slipping.

In the Pacific Northwest, the Pacific Plate is moving northwest and is pushing the smaller Juan de Fuca plate clockwise under the North American Plate. This process is known as subduction. The motion of the plates is not smooth. Friction and pressure along the interface of the plates prevents the ocean plate from moving under the continent, locking them together for decades or centuries. Strain builds up until the fault breaks, and a few meters of the Juan de Fuca plate slips under the North America Plate, causing a megathrust earthquake.

Key Points

- ❖ *Lead agency – Seattle Fire Department*
- ❖ *Seattle has three types of earthquakes:*
 - *Shallow (0-30km depth)*
 - *Deep (30-70km depth)*
 - *Subduction (shallow, but offshore)*
- ❖ *Seattle's worst-case scenario is a strong shallow earthquake on the Seattle Fault. It would cause many deaths and injuries, widespread, lengthy utility outages, and 10s of billions in damage.*
- ❖ *The Pacific Northwest region's worst-case scenario is a major subduction earthquake on the Cascadia Subduction Zone. It would affect an area from Northern California to British Columbia. These happen every ~300-800 years, with the last one occurring in 1700.*
- ❖ *The most common large earthquakes are the deep variety, like the 2001 Nisqually earthquake, and happen every ~30-50 years.*
- ❖ *Large subduction zone earthquakes happen every 300-800 years with an average of 450-500 years.*
- ❖ *We don't know how often the Seattle Fault is active. It produced a magnitude 7.5 to 7.8 earthquake in 923 AD or 924 AD.*
- ❖ *Earthquakes can cause many cascading impacts including tsunamis, landslides, fires, power outages, broken infrastructure, and hazardous materials incidents.*
- ❖ *Recent modelling suggests that subduction zone earthquakes cause strong shaking at certain frequencies that exceed the design standards for many new concrete core high rise buildings.*

Figure 18. Convection in the Earth's Crust



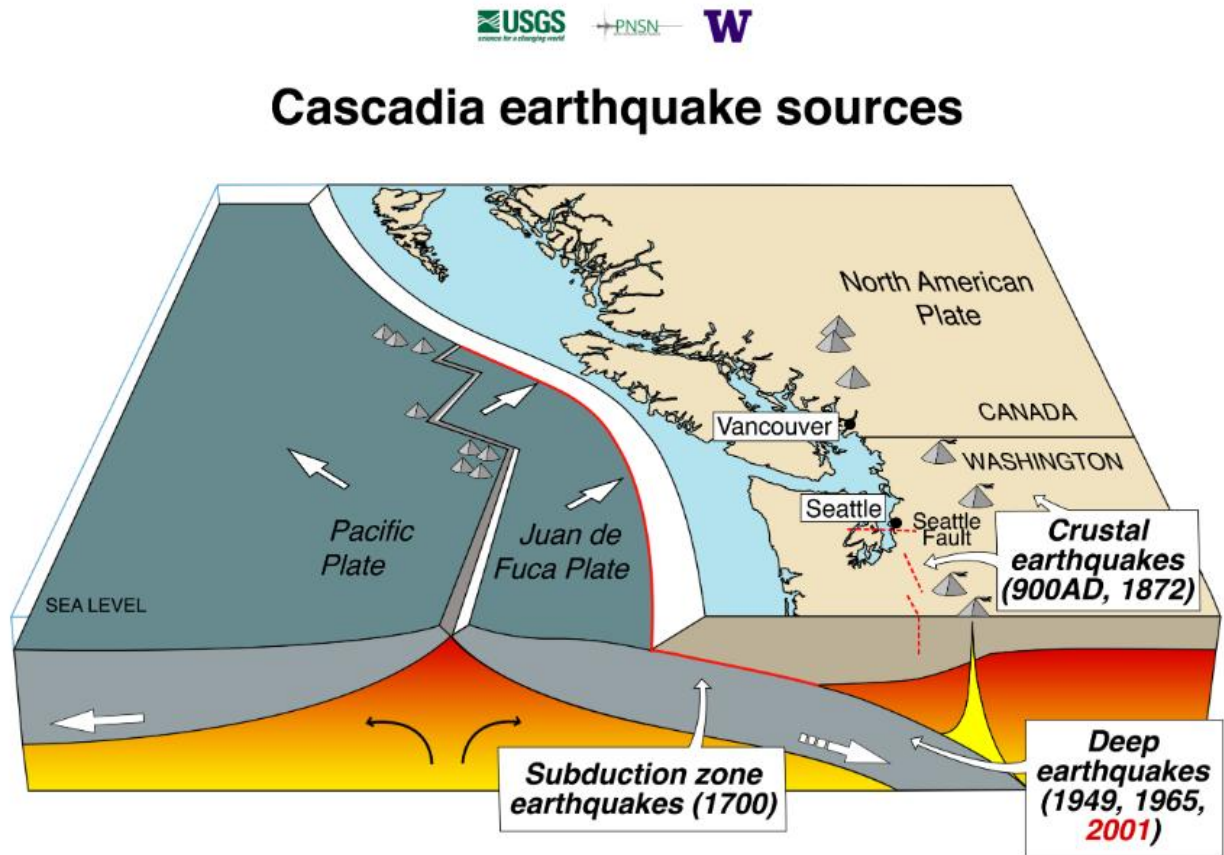
Source: <http://clarkscience8.weebly.com/forces-inside-earth.html>.

Types of Earthquakes in the Puget Sound Region

The Puget Sound region experiences three types of earthquakes:

1. **Shallow earthquakes** (also called “crustal”) occur in the North American Plate as it adjusts to the build-up of strain along the interface between the North American and Juan de Fuca Plates. Depths vary from 0 to 30km (about 21 miles). They are usually felt intensely near their epicenter, but their effects diminish relatively quickly with distance compared to other types of earthquakes. There are active shallow fault systems running throughout the Puget Sound region including Seattle.
2. **Subduction earthquakes** (also called “megathrust”) happen when pressure at the interface between the Juan de Fuca plate and North American plate unlocks along a sloped plane where the plates meet off the Washington coast. This fault is over 1,000 km (620 miles) long. Megathrust earthquakes are the largest type of quake, with magnitudes from M 8 to over M 9. M 9 earthquakes have occurred at roughly 450-500-year intervals along the Pacific Coast.¹⁷⁶ (See [Earthquake Magnitude](#) below for an explanation of magnitude).
3. **Deep earthquakes** (also called “intraplate earthquakes”) occur at depths between 35 and 70km (about 21 - 43 miles). Because they are centered farther from the surface, they are not felt as intensely but affect wider areas than crustal quakes. They are the most common type of large earthquake in our region. Western Washington has experienced three since 1949, including the 2001 Nisqually earthquake.

Figure 19. Earthquake Sources



Measures

Earthquake Magnitude (M)

Moment magnitude measures the amount of slip on a fault multiplied by the area of the fault that slips. The rigidity of the slipping material also plays a role. The moment magnitude is proportional to the total energy released by an earthquake. Earthquakes of magnitude M5 are considered “moderate;” above M8, they are considered “great.”

Moment magnitude is a different measure from the Richter scale, which was designed in 1935 for small to medium earthquakes in California, within 600 km of the recording seismograph. Because of these shortcomings, Moment magnitude is the most common scale used by the United States Geological Survey (USGS).

Modified Mercalli Intensity (MMI) Scale

The Modified Mercalli Intensity (MMI) Scale is a subjective measurement of earthquake effects and damage (see [Table 11](#)). The MMI scale grades earthquakes using twelve steps based on damage and human behavior. Maps drawn from reports of what people felt are useful in determining areas of damage concentration. Because effects differ in and across areas, an earthquake can have multiple intensities.

Table 11. Modified Mercalli Intensity (MMI) Scale

I. Not Felt	Not felt by many people unless in favorable conditions.
II. Weak	Felt only by a few people at best, especially on the upper floors of buildings. Delicately suspended objects may swing.
III. Weak	Felt quite noticeably by people indoors, especially on the upper floors of buildings. Many do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
IV. Light	Felt indoors by many people, outdoors by few people during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rock noticeably. Dishes and windows rattle alarmingly.
V. Moderate	Felt outside by most, may not be felt by some outside in non-favorable conditions. Dishes and windows may break and large bells will ring. Vibrations like large train passing close to house.
VI. Strong	Felt by all; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight.
VII. Very Strong	Difficult to stand; furniture broken; damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by people driving motor cars.
VIII. Severe	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture moved.
IX. Violent	General panic; damage considerable in specially designed structures, well designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X. Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundation. Rails bent.
XI. Very Disastrous	Few, if any masonry structures remain standing. Bridges destroyed. Rails bent greatly.
XII. Catastrophic	Total damage - Almost everything is destroyed. Lines of sight and level distorted. Objects thrown into the air. The ground moves in waves or ripples. Large amounts of rock may move position.

Acceleration

Acceleration is the rate of change in velocity for a unit of time. During an earthquake, the ground experiences acceleration. Engineers and seismologists use several acceleration measures. *Peak ground acceleration* measures the largest velocity experienced by particles on the ground. *Spectral acceleration* measures the velocity a building experiences at its base during an earthquake.

Typically, the higher the acceleration, the more stress on a building. Peak ground acceleration can be a good measure for smaller buildings (below 7 stories), while spectral acceleration can be a good measure for larger buildings when also taking building design into account. Seismic acceleration is divided into horizontal (east-west and north-south) and vertical components. The distinction can be critical as some structures are designed to withstand motion in some directions better than others. Acceleration varies with distance from the epicenter and local conditions, like soil type.

In 2007, the USGS developed a series of maps that estimated the maximum acceleration Seattle neighborhoods would face in the next 50 years. See [Figure 24](#) for maps of these ground motions.

Period relates to acceleration. All structures have a “natural period,” or the rate at which they move back and forth from horizontal force.¹⁷⁷ For example, 10-20 story buildings typically have a natural period of 1 to 2 seconds. If the wavelength of seismic waves is close to the natural period of the

structure movement, resonance occurs. Resonance effects can increase acceleration that a building experiences up to 5 to 6 times.

Duration is also used as a measure. The longer shaking lasts, the greater the likelihood of damage, especially in soft soils. Duration is most concerning in a megathrust earthquake, where shaking can last several minutes.

Geology

The upper level of soil greatly modifies seismic waves that travel through it. The amplification and directionality of seismic waves depend on soil type, soil stiffness, soil thickness, and soil geometry (see [Figure 20](#)). Soft soils, especially those that overlay hard rock, amplify seismic waves. The amplification causes more vulnerable soil farther from the epicenter to shake more intensely than less vulnerable soils closer to the epicenter. The SODO area and the Duwamish Valley immediately south of it are areas of poorly consolidated soil (see [Figure 23](#)), and experience more intense shaking than the surrounding hills even though they are the same distance from the epicenter.

Local geology contributes to secondary incidents such as liquefaction and landslides. Liquefaction is a special type of ground settlement that occurs in water-saturated sands, silts, and gravels. In an earthquake, loose soils compact, displacing and pressurizing the water. The “solid ground” then liquefies. Whole buildings have overturned when the underlying soils lose the tensile strength required to support the structure. More commonly, only part of a building sinks, causing uneven settling. If liquefaction occurs on a slope, even if it is gentle, the muddy soil can flow laterally and cause severe structural damage. Earthquakes can trigger landslides by shaking unstable or steep slopes. Wet conditions can exacerbate landslide potential because waterlogged soils are less able to resist shear stress in slopes. More information about landslides can be found in the chapter on them below.

History

The Puget Sound region is a seismically active area in Washington. Nineteen moderate and large earthquakes have occurred in western Washington since 1880. Twelve of these nineteen were centered in the Puget Sound region. The list below includes the most significant earthquakes to have affected the Seattle area.

Because the historic record is so short, geologic evidence is essential to understanding the complete history of a region’s seismic risk. Learning the history of one of Seattle’s major seismic risks, the Seattle Fault, has been challenging because the glaciers that covered Seattle 15,000 years ago eliminated traces of older earthquakes. A 2023 study used [lidar](#) to look for ancient landslides deposits. Earthquakes often trigger widespread landslides so many occurring in the same region at the same time are a sign of an earthquake. This line of evidence suggests that the Seattle Fault was active four times between 4,600 and 2,000 years ago.¹⁷⁸

Winter 923/924. 7.5 Seattle Fault earthquake or 7.8 composite earthquake. It has been known for several decades that the Seattle Fault ruptured about 1,100 years ago, but new research has pinpointed the year to the winter of 923/4 with an estimated magnitude of 7.5. New tree ring evidence shows that this earthquake triggered the Saddle Mountain fault on the southeast Olympic Peninsula. The compound event was either a single 7.8 or a 7.5 followed by a 7.3 event.¹⁷⁹ It caused massive landslides and a tsunami. Whole hillsides slid into Lake Washington and Puget Sound. A tsunami with waves up to 13 meters or 44ft flooded much of the low-lying area around the mouth of the Duwamish River.

Jan. 1700. 9.0 megathrust earthquake along the Pacific Northwest Coast. Coastal areas dropped as much as 1.5 meters as the Cascadia Subduction Zone ruptured along its 1000 km length. It generated a tsunami that struck Japan.

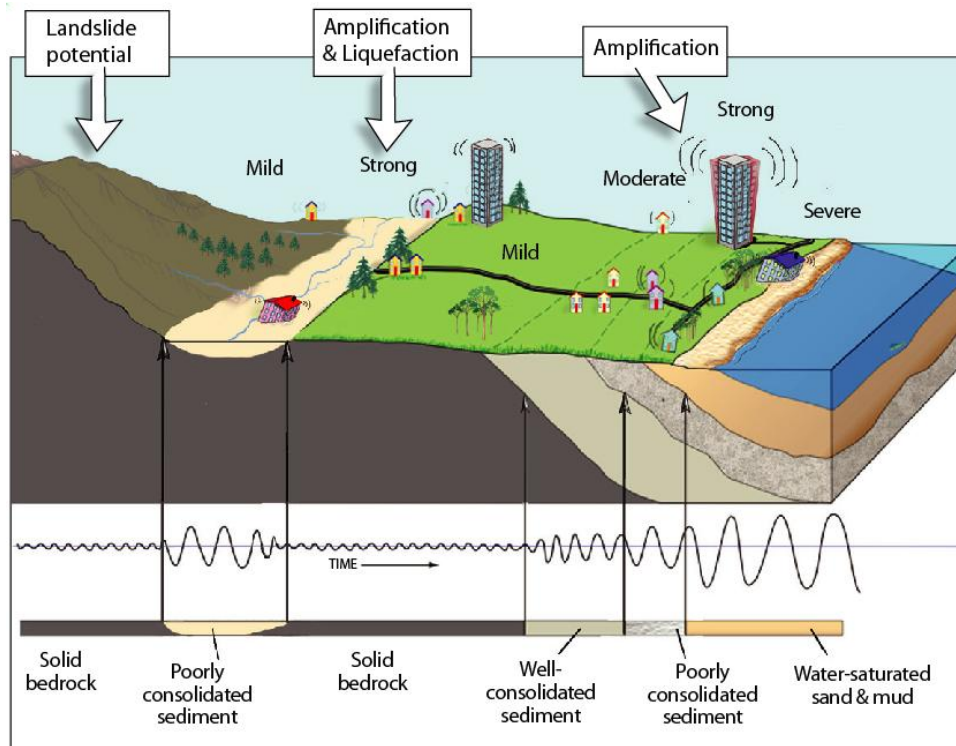
1833. New evidence suggests a possible earthquake on the Seattle Fault in 1833, but further analysis is needed. As of now, there is no estimate of its potential magnitude.¹⁸⁰

Dec. 1872. 6.8 shallow earthquake shook the North Cascades. It triggered a landslide that temporarily blocked the Columbia River.

Jan. 1909. 6.0 deep earthquake centered in the San Juan Islands.

Nov. 1939. 5.75 deep earthquake centered near Olympia. Chimney and building façade damage near the epicenter. No damage was reported in Seattle.

Figure 20. Soil Amplification, Liquefaction, and Landslide Hazards from Earthquake Ground Shaking



Apr. 1945. 5.5 (no data on depth) earthquake centered under North Bend. Chimney and building façade damage near the epicenter. A boy was hit by falling brick in Cle Elum. No damage reported in Seattle.

Feb. 1946. 6.3 deep earthquake centered under mid-Puget Sound. Damage in Seattle was mainly limited to the Duwamish Valley and structures built on pilings.

Apr. 1949. 7.1 deep earthquake centered near Olympia. The earthquake had a peak acceleration of .3g and produced type VIII MMI damage at its highest intensity. Eight people were killed, mostly from falling brick and the region suffered \$463 million in damage (2025 dollars). In Seattle, the earthquake's effects were felt mainly in the northern section of West Seattle and at the mouth of the Duwamish River.

Apr. 1965. 6.5 deep earthquake with the epicenter closer to the city than the 1949 quake. The earthquake's acceleration was lower, .2g. While it did cause type VIII MMI damage, most of its effects were limited to type VII MMI. As in 1949, many ground failures occurred in the Alki and Harbor Island areas, but they were not as concentrated as in the 1949 quake. Six people were killed, mostly by falling debris. Damage was \$155 million (2025 dollars). Based on these records, one report estimates that M 6.5 events have a repeat rate of roughly 30 years with an 84% chance of an M 6.5 or greater in the next 50 years.¹⁸¹

Jan. 1995. 5.0 shallow quake, with a depth of 11 miles. Centered under Robinson Point on Bainbridge Island. No damage reported.

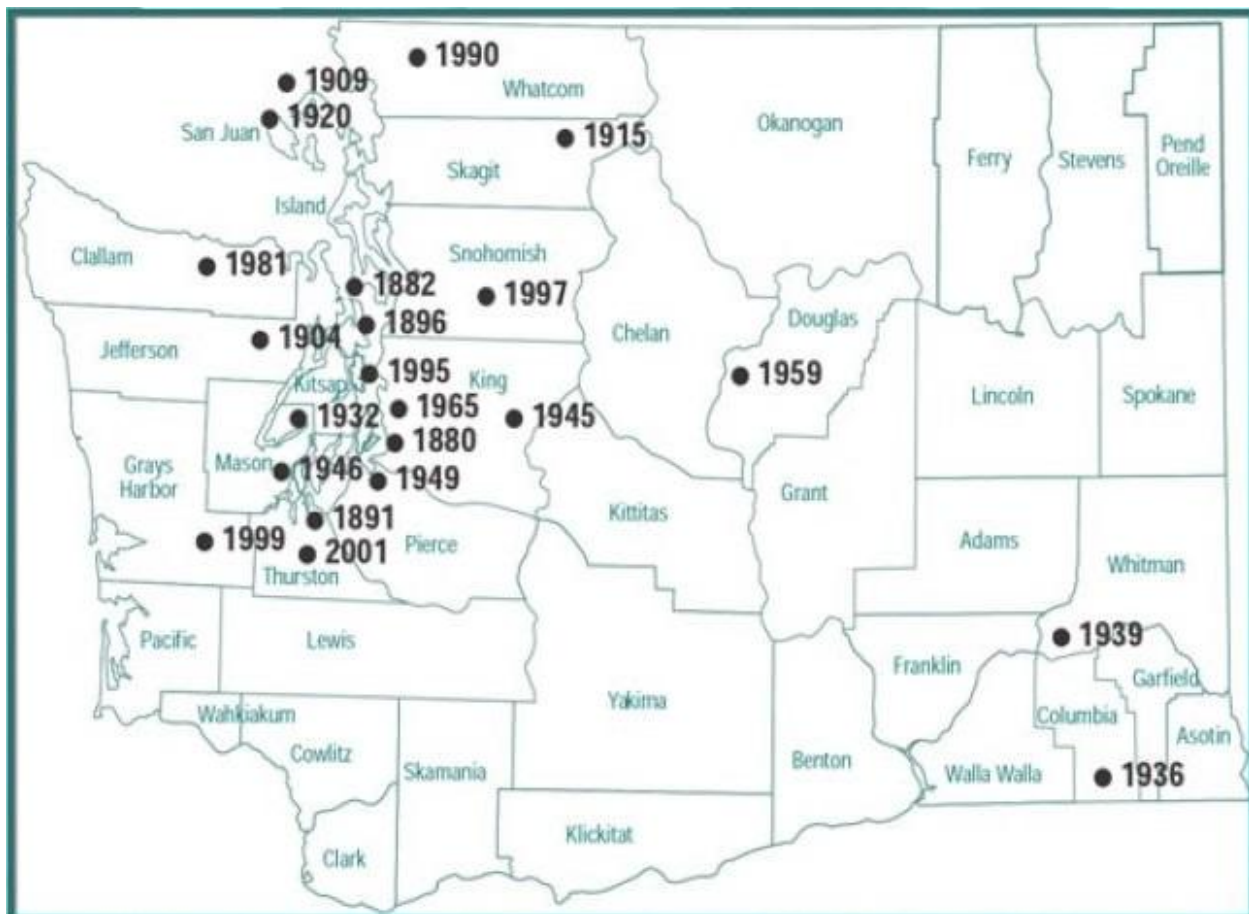
May 1996. 5.3. A shallow quake centered under Duvall. Some light damage was reported, mainly objects falling from shelves. No damage reported in Seattle.

Jun. 1997. 4.9. Another shallow quake centered under Bremerton. No damage reported in Seattle.

Feb. 2001. 6.8. Large deep quake under South Puget Sound, the “Nisqually Earthquake.” One death was attributed to a stress-related heart attack during the earthquake. 400 people were injured, but only 4 were serious injuries.¹⁸²

Significant public and private damage occurred from the Nisqually Earthquake. Four residential homes were destroyed, 46 suffered major damage and 120 suffered minor damage.¹⁸³ 217,000 people lost power. The City of Seattle incurred over \$36 million in response costs and repairs to city-owned facilities and systems, and costs from damage to arterial roads and bridges. Eighteen bridges were damaged in the Seattle.¹⁸⁴ Total damage in Seattle was estimated to be over \$200 million.¹⁸⁵ Total damage in Washington State was estimated to be \$2-4 billion.¹⁸⁶

Figure 21. Major earthquakes in Washington since 1880

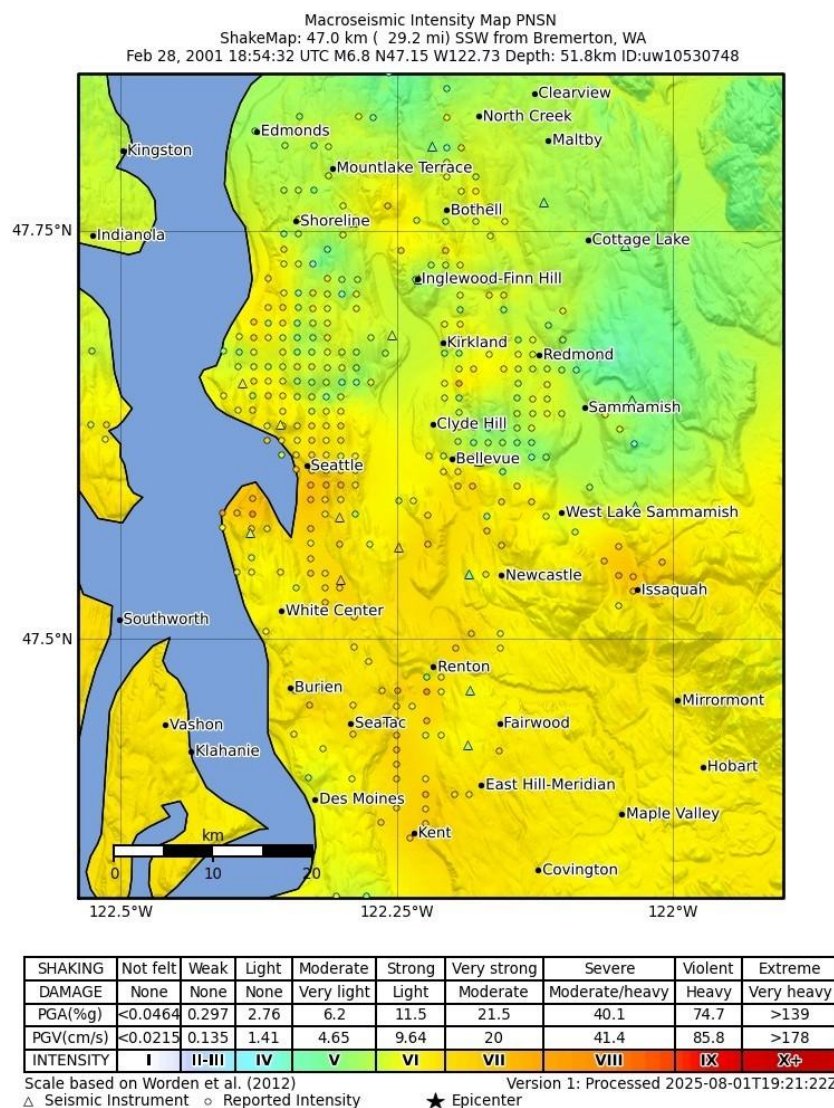


The quake’s damage to structures serving vulnerable populations raised concerns. Seattle’s Office of Housing (OH) did an unofficial survey of 45 non-profit assisted housing properties serving low-income residents post-Nisqually. Most faced minor structural or plaster damage. One men’s homeless shelter, the Compass Center, was red tagged and its 75 male residents were forced to vacate. The building was repaired and seismically upgraded in 2005.¹⁸⁷ The Seattle Housing Authority (SHA) also faced damage to

its buildings, some of which housed low-income and elderly people. The two buildings that suffered the most damage were older brick structures that were sold after being repaired. In total, the earthquake cost SHA over \$200,000, mostly to repair elevators (most of this cost was reimbursed by the U.S. Department of Housing and Urban Development and FEMA).¹⁸⁸

The earthquake had both direct and indirect impacts on many businesses. The northern end of the Boeing Field runway was closed for two weeks after the earthquake. Results from a survey of 832 small businesses (those with less than 500 employees) in the Puget Sound area revealed that 20% incurred direct physical losses from the earthquake. Of these, 6.5% suffered losses over \$1,000 and 2% suffered losses over \$10,000. Overall, average losses amounted to 1.3% of annual revenue. The three areas with the most identifiable, concentrated small business damage were Downtown Olympia, Seattle's Pioneer Square, and Seattle's Harbor Island.¹⁸⁹

Figure 22. Nisqually Intensity Measured by Modified Mercalli Intensity Scale



The largely industrial Harbor Island experienced the highest level of shaking in Seattle, similar to areas that experienced heavy damage in the 1994 Northridge, California earthquake. Nearly 40% of Harbor

Island firms had direct losses exceeding \$20,000. They also suffered high rates of indirect losses from disruptions to operations.¹⁹⁰

Vulnerability

Seattle's most vulnerable areas are where populations, buildings, and geology susceptible to harm or damage share the same space. To understand where these areas are, the Office of Emergency Management used earthquake modelling software to identify them. The models show that Seattle's most serious earthquake hazards affect low income and minority residents disproportionately. Representative scenarios were chosen for each of Seattle's three earthquakes sources from [Washington State's list of seismic scenarios](#): 1) deep sources, like the 2001 Nisqually Earthquake, 2) Cascadia Subduction Zone, and 3) shallow faults like the Seattle Fault. They estimate ground shaking for each of the scenarios. The software used the ground motion estimates to predict building damage at the block level. The Building Damage Index (BDI) measures the ratio of damaged to undamaged buildings in a block. The Building Damage Index is explained in [Table 12](#) and maps of damage by BDI are shown in [Figure 25](#).

Finally, the software platform from startup One Concern combines the damage model with demographics summarized at the census block level. The models, when completed in 2020, predict that lower-income and minority communities will be disproportionately affected by stronger earthquakes. [Table 13](#) shows whether a demographic group is over or underrepresented on heavily damaged blocks (BDI 3+). Underrepresented groups are shown with a negative percentage. Overrepresented groups are shown with a positive percentage and will suffer higher proportional impacts than underrepresented groups.

Vulnerable geology is a major factor influencing the damage patterns modelled above. Seattle's center sits on top of the Seattle Basin, a deep geologic basin filled with glacial deposits, sediments, and sedimentary rock, roughly 7 km deep (see [Figure 26](#)). The loose ground material within the basin amplifies ground shaking in an earthquake and prolongs its duration. The USGS modeled basin effects for a M6.5 Seattle Fault earthquake and estimated that ground motions would last about 25 seconds.¹⁹¹ Additional modeling was done by the University of Washington's M9 group to understand the effects of the Seattle Basin on ground motion in a megathrust earthquake.

Surface geology, the first 30 meters below the surface, creates variability in shaking for different parts of the city. The 2007 USGS seismic hazard maps shown in [Figure 24](#) reveal that Seattle's neighborhoods experience dramatically different levels of shaking. Seattle's liquefaction and landslide-prone areas experience more severe ground motion than other areas. Southeast Seattle is likely to experience serious but comparatively less shaking than the rest of the city because a large part of it is composed of stiff bedrock.¹⁹²

Liquefaction

Loose soils are prone to a process called liquefaction. When these soils shake, they can turn from a solid soil to a watery, soupy material that loses its load bearing capacity. Liquefaction prone soils are present in Seattle's Duwamish area, including Harbor Island, the east side of West Seattle, the Interbay area, the University Village area, and along Puget Sound. Many are areas with artificial fill. Ground failures caused by previous earthquakes in Seattle have primarily been in these areas of artificial fill ([Figure 23](#)). The tables and figures in [Appendix A](#) summarize land use in liquefaction prone areas. It is heavily weighted toward economic uses. 43% of the land in liquefaction prone areas is for commercial use, industrial use, or for major institutions (e.g., universities, colleges, hospitals, utilities, federal facilities, etc.).

Figure 23. Seattle Fault Zone, Liquefaction Areas, and Ground Failures

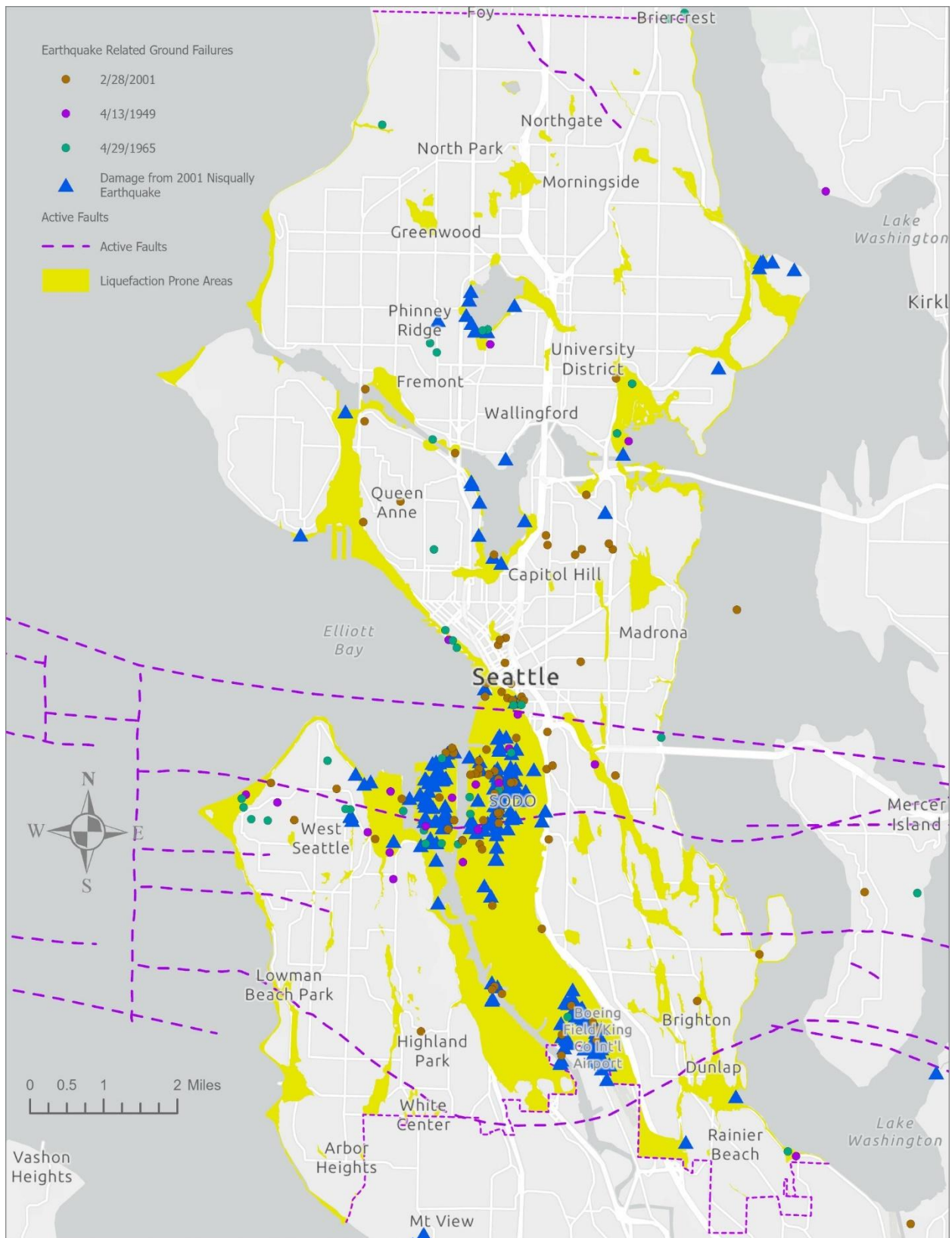
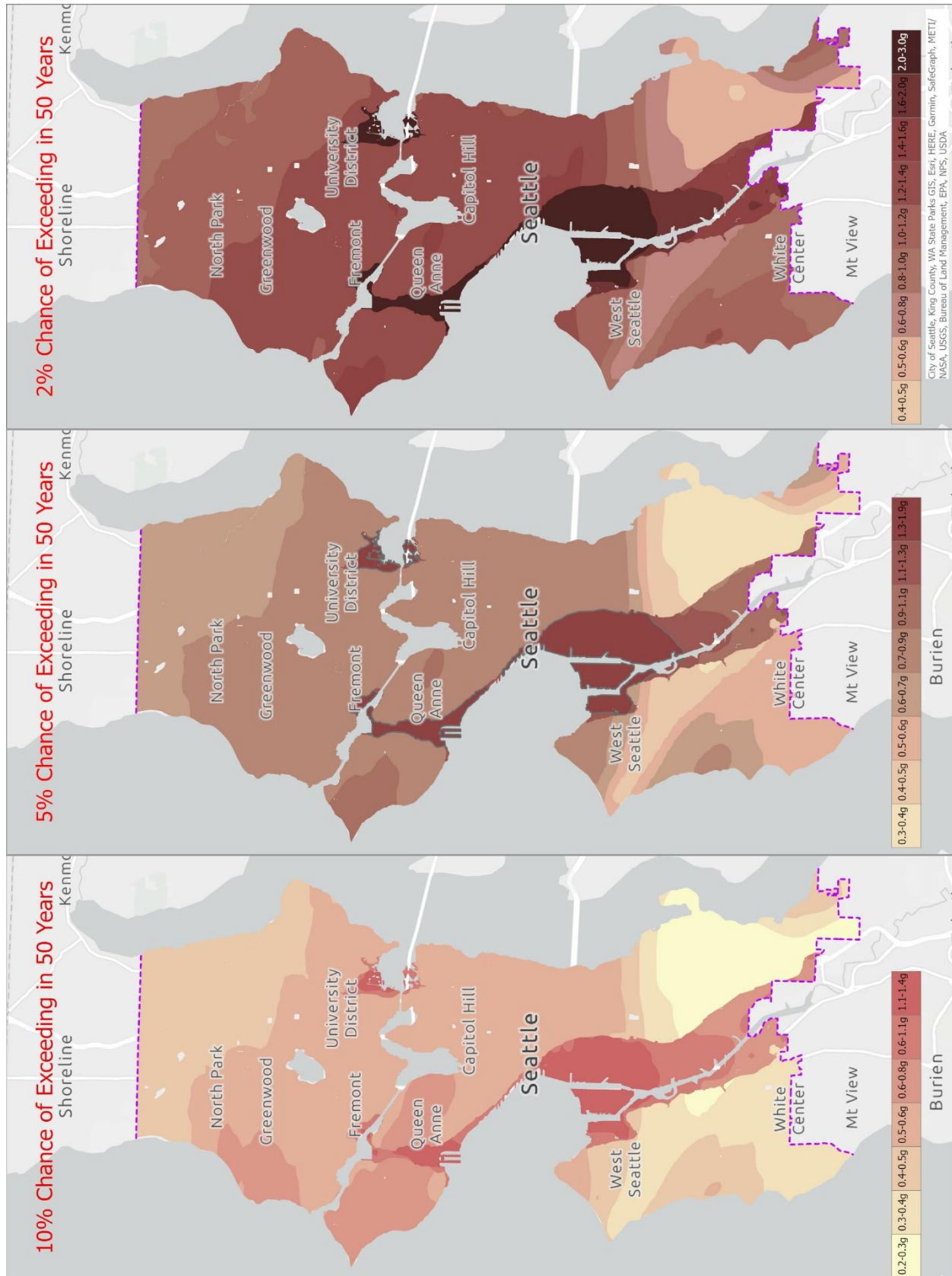


Figure 24. Probabilistic Ground Motions



Structures and Earthquake Vulnerability

How a building is constructed can significantly affect its vulnerability earthquake damage. Certain construction types are particularly susceptible to damage, especially older buildings that predate modern seismic codes and standards.

The most vulnerable building types include:

Unreinforced Masonry (URM) Typically, older brick buildings constructed before 1945. Usually identified by exposed brick on interior walls, header courses, and arched windows. (See [Figure 27](#)) These buildings lack steel reinforcement and are highly prone to collapse during earthquakes.



Non-Ductile Concrete Older concrete buildings, usually built before 1980 that lack adequate steel reinforcement. They are difficult to identify visually, as the structural elements are usually concealed. Evaluating their seismic vulnerability requires potentially invasive investigation.



Tilt-Up Construction Involves concrete wall panels poured horizontally and then tilted into place. Commonly used in warehouses and light industrial buildings. Prone to failure at connections between the walls and roof during a seismic event.



Credit: CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=126766393>

Soft-Story Buildings Characterized by a weak or open first story, typically due to ground-floor parking or open retail spaces. These structures lack sufficient lateral resistance and are vulnerable to collapse.



Some common construction types in Seattle and their general performance:

Unreinforced Masonry (URM) Buildings: URM Buildings are considered the most dangerous building type in seismic events. Seattle has identified around 1,100 URM buildings.¹⁹³ They are primarily located in Capitol Hill, Pioneer Square, Duwamish/SODO, Queen Anne, and the University District. Most URM

Figure 25. One Concern Models for Three Scenarios. See following page for legend key

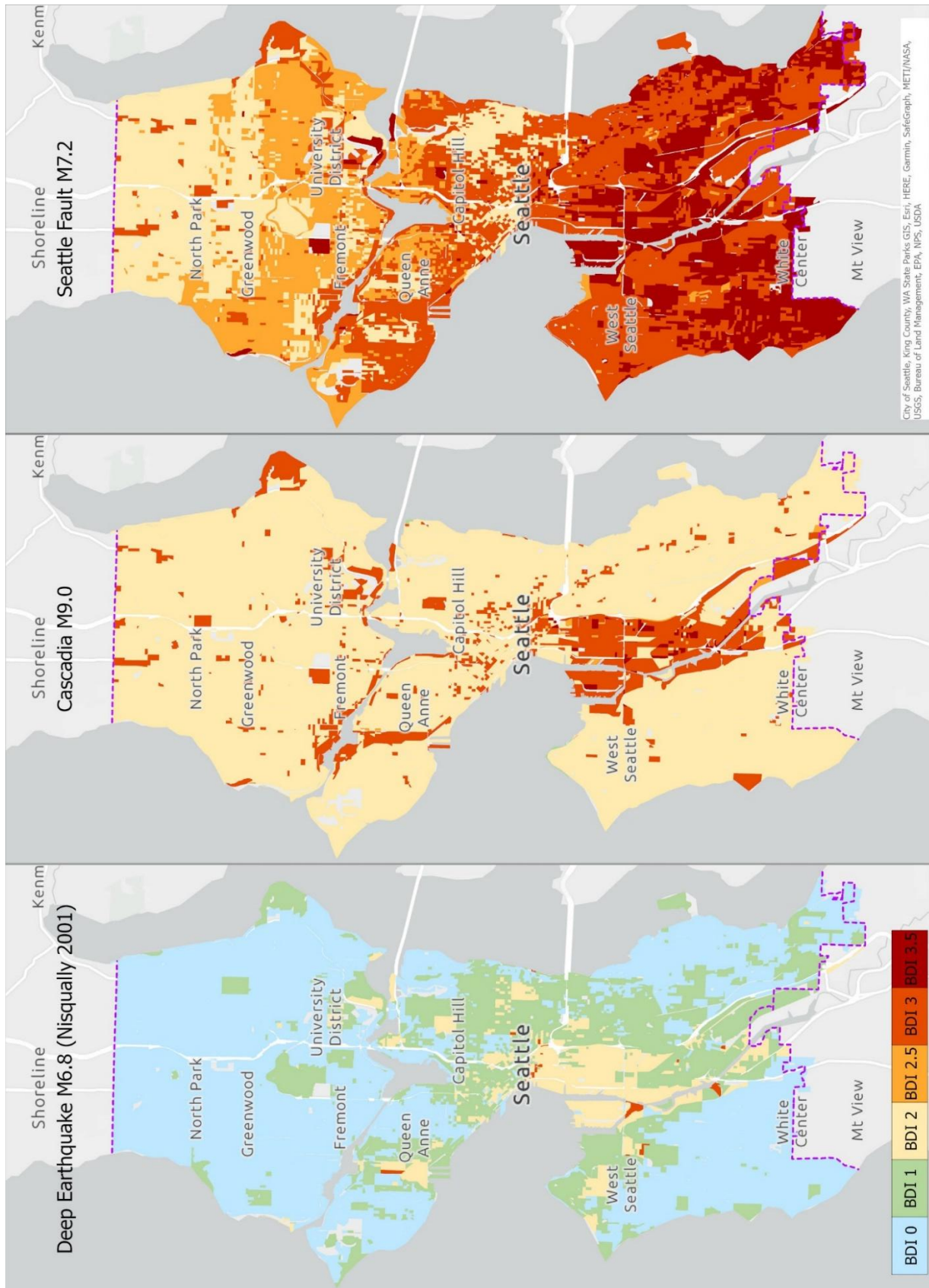


Table 12. One Concern Model key

Building Damage Index	Definition	Major non-structural Damage / Structural Damage / Collapse			
		Undamaged	Light Damage	Major non-structural Damage	Structural Damage / Collapse
0	No damage to limited light damage. A maximum of 10% of buildings sustain some aesthetic or non-structural damage. It is possible that isolated buildings sustain heavier damage. All buildings except isolated exceptions are safe to enter.	90 - 100%	0 to 10%	Isolated	Isolated
1	Light damage. More than 10% of buildings sustain aesthetic or non-structural damage. The remaining buildings are likely to be undamaged. It is possible that isolated buildings sustain heavier damage. All buildings except isolated exceptions are safe to enter.	90 - 100%	10 - 100%	Isolated	Isolated
2	Moderate damage. 10 to 50% of buildings sustain major non-structural damage like collapse of non-load bearing building components. An addition 0 to 10% of buildings have loss of load bearing components. The remaining buildings remain undamaged or sustain light damage. Buildings with major non-structural damage have conditions for entry with range from minor (e.g., do not use damaged part of building) to severe (e.g., no overnight occupancy). Buildings with structural damage cannot be occupied.	50 - 90%		10 - 50%	Isolated to 10%
2.5	Moderate to heavy damage. More than 50% of buildings sustain major non-structural damage like collapse of non-load bearing building components. An addition 0 to 10% of buildings have loss of load bearing components. The remaining buildings remain undamaged or sustain light damage. Buildings with major non-structural damage have conditions for entry which range from minor (e.g., do not use damaged part of building) to severe (e.g., no overnight occupancy). Buildings with structural damage cannot be occupied.	0 - 50%		50 - 100%	Isolated to 10%
3	Heavy damage. Between 10 and 50% of buildings have lost load bearing capacity. These buildings have collapsed by the engineering definition and cannot be occupied. The remaining buildings suffer a range of lesser damage. Buildings with major non-structural damage have conditions for entry with range from minor (e.g., do not use damaged part of building) to severe (e.g., no overnight occupancy).	0 - 50%		50 - 90%	10 - 50%
3.5	Heavy to severe damage. More than 50% of buildings have lost load bearing capacity. These buildings have collapsed according to the engineering definition and cannot be occupied. The remaining buildings suffer a range of lesser damage. Buildings with major non-structural damage have conditions for entry which range from minor (e.g., do not use damaged part of building) to severe (e.g., no overnight occupancy).	0 - 50%		0 - 50%	50 - 100%

Table 13. Demographic exposure to three earthquake scenarios based on 2020 modeling

	Deep Earthquake (2001 M6.8 Nisqually). About every 30 to 50 years.	Cascadia Subduction Zone (M9.0). About every 300 - 500 years	Seattle Fault (M7.2) Every 5000 - 15,000 years
Black	-21%	+27%	+53%
Asian	-34%	+39%	+36%
White	+13%	-14%	-17%
Hispanic	-31%	+15%	+25%
Low income	-29%	+81%	+7%
Children	+18%	-56%	+5%
Seniors	-6%	-4%	+5%

How to read: The percentage is the degree the demographic group is over (+) or underrepresented (-) in severely damaged areas (BDI 3 and 3.5). For example, in the Cascadia scenario, people who are low income are 81% more exposed to severe damage than the rest of the population.

Figure 26. Sediment Thickness in the Seattle Basin

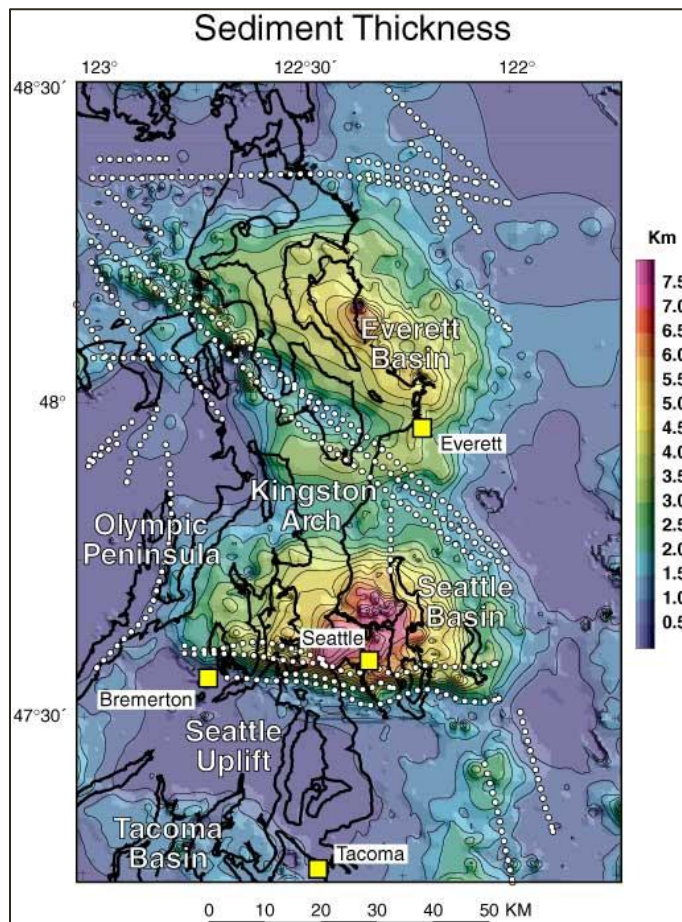
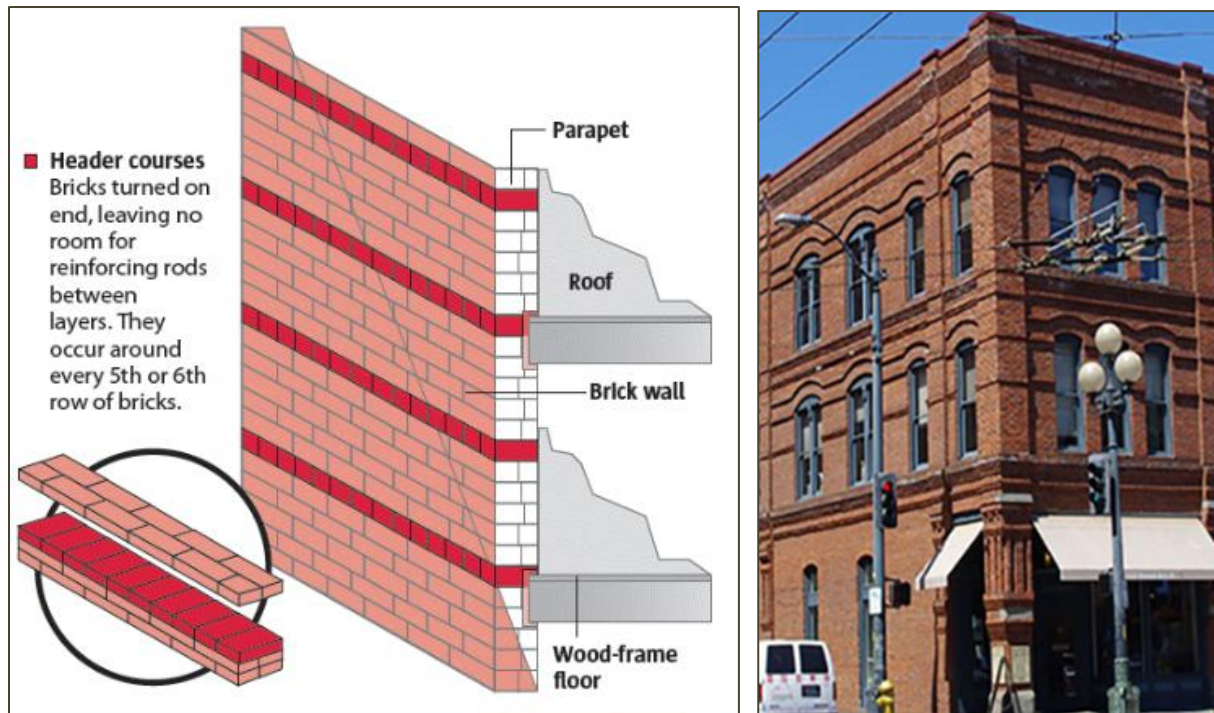


Figure 27. Unreinforced Masonry Construction



Source: The Seattle Times

serve commercial, residential, or public assembly purposes. During the 2001 Nisqually Earthquake, URMs accounted for approximately two-thirds of red-tagged buildings (deemed unsafe for occupancy), with damage totaling around \$8 million.¹⁹⁴ Parapets on these buildings frequently detach and fall into the right-of-way during seismic shaking. The City of Seattle is currently developing [an ordinance](#) to require retrofitting of URM buildings to reduce this hazard.¹⁹⁵

Non-Ductile Concrete and Tilt-Up Structures: Many buildings built before 1980 do not have adequate steel reinforcement to withstand strong ground motion from a crustal or megathrust earthquake.¹⁹⁶ The prevalence of these construction types in the Pacific Northwest is not fully understood, but they are common in commercial and industrial settings. Tilt-up buildings, commonly used for warehouses or strip malls, are particularly vulnerable due to weak roof-to-wall connections, which can lead to catastrophic roof collapse.

Soft-Story Multifamily Buildings: Seattle's multi-family housing stock includes many buildings from the late 1950s and early 1960s with soft-story construction. These buildings often feature open ground floors used for parking, supported by columns or posts that lack lateral strength. These buildings are concentrated in Belltown, First Hill, Capitol Hill, Queen Anne, University District, and Ballard. Even when structural collapse does not occur, utility and elevator damage can displace residents and workers, as seen in New York City following Hurricane Sandy, where 65 buildings in lower Manhattan experienced long-term utility disruptions.¹⁹⁷

Single-Family Wood-Frame Homes: Most of Seattle's single-family homes are wood-frame construction, which generally perform better during an earthquake relative to other types of construction due to their flexible frame. However, more than half were built prior to the introduction of seismic codes in 1949. Many have short cripple walls (also called "pony walls") between the foundation and floor joists, which are prone to failure and can cause the structure to shift off its foundation, resulting in severe damage to

utility connections. Fortunately, these homes can be retrofitted relatively inexpensively, typically by bolting the home to its foundation. The City of Seattle has sponsored a program since the mid-1990's to promote these retrofits. About half of the housing units in Seattle are single-family residential units.

Figure 28. Home Damage Due to Soft Story



Photograph by John K. Nakata. Source: Nakata, J. K., Meyer, C. E., Wilshire, H. G., Tinsley, J. C., Updegrave, W. S., Peterson, D. M., Ellen, S. D., Haugerud, R. A., McLaughlin, R. J., Fisher, G. R., & Diggles, M. F. (1999) The October 17, 1989, Loma Prieta, California, Earthquake – Selected Photographs, U.S. Geological Survey. Retrieved July 24, 2018, from <https://pubs.usgs.gov/dds/dds-29/>

Regional Studies

Lessons from Portland: The Oregon Department of Geology and Mineral Industries (DOGAMI) conducted a study on earthquake damage to structures in an M9.0 Cascadia scenario for a three-county region in Northwest Oregon, including Portland. While the results cannot be directly related to Seattle's vulnerability, it provides a general idea of the amount of destruction we could expect in an urban area from a megathrust earthquake. For Multnomah County (including Portland), the estimated building damage in dry conditions:

- 3,536 buildings (1% of building stock) with complete damage (i.e., critical structural elements have failed)
- 302 collapses.

In wet conditions, where the risk of liquefaction and landslides are higher, estimates increase to:

- 13,039 buildings (5% of building stock) with complete damaged
- 677 collapses.¹⁹⁸

Wood-frame single-family structures perform best while many industrial and commercial buildings perform more poorly (it should be noted that Portland has around 50% more URMs than Seattle¹⁹⁹). Studies also projected injuries and fatalities assuming of an M9.0 megathrust earthquake in Portland:

- Daytime megathrust event: 10,404 injuries, most of which would be minor, and 604 fatalities.²⁰⁰
- Nighttime megathrust event: 2,491 injuries and 119 fatalities considering that most people will be in single-family wood-frame structures.²⁰¹

Seismic Risk in High-Rise Buildings and Basin Effects: Recent research from the University of Washington studied the impact of sedimentary basin amplification on modern high-rise buildings, specifically those using reinforced concrete core walls as their lateral systems. Simulated ground motions for magnitude 9.0 Cascadia Subduction Zone (CSZ) earthquakes showed that the ground motion amplification within the Seattle Basin significantly increases the probability of collapse compared to current design targets of 10% collapse probability for a 1-in-2475-yr event). Collapse means the building has lost structural integrity and ability to sustain loads.

- Buildings under 240 feet (about 24 stories), built to code minimum standards. These buildings have an average 27% collapse probability.
- Buildings over 240 feet are generally subjected to additional analysis and design requirements through a peer review process, lowers collapse probability to 14%.
- The annual probability of a CSZ event (.2%) is much higher than the rare-event basis of current seismic design standards.

These findings strongly suggest that basin effects need to be accounted for in Seattle’s building codes.²⁰²

Figure 29. Reinforced concrete core building under construction.



Comparative Basin Studies and Structural Behavior: A related study analyzed data from earthquakes that occurred in deep basins in Japan that share similar geologic features with the Seattle Basin. Findings include:

- Reinforced concrete moment frame buildings (i.e., those where the structure is a system of concrete beams and columns) are more likely to collapse when located in a sedimentary basin versus a non-basin site, under same ground shaking conditions.
- A second study by Marafi examined the sway of buildings in an earthquake from 4 to 40 stories tall. It concluded that buildings within the Seattle Basin sway three times more than those outside of it, increasing the likelihood of structural and non-structural damage.²⁰³

Another study used past ground motion data to quantify the effects of megathrust earthquakes on 24 older and modern buildings in Seattle and Portland. The authors concluded that megathrust CSZ earthquakes are more likely to cause building collapse than crustal earthquakes and attributed this consequence to the longer duration of shaking expected in a megathrust earthquake.²⁰⁴

Transportation Vulnerability

The surface, marine, and air elements of Seattle’s transportation system are exposed to earthquake hazards. Liquefaction is a common element to this exposure. Most of the Duwamish Valley is a liquefaction zone. Both of Seattle’s major north-south corridors, I-5 and SR99/SR509 run through this zone, as well as key bridges and elevated structures, including the West Seattle Bridge, the First Avenue South Bridge, and the approaches to the western terminal of I-90. The King County International Airport (Boeing Field) is completely in a liquefaction zone as are most of the city’s rail and marine terminals. During a Seattle Fault earthquake uplift will occur. Depending on the amount, and whether the surface is ruptured, transportation routes and utilities will be severely damaged.

Seattle is highly dependent on bridges making Seattle neighborhoods vulnerable to isolation if they fail. The City of Seattle owns 134 bridges. 16 bridges have been identified as a priority for seismic retrofits of which 7 have been completed, 8 are in construction and 1 has been awarded as of 2024.²⁰⁵ The improvements should save these bridges from catastrophic collapse, but many will not be functional after a strong Seattle Fault or megathrust earthquake.

The Washington State Department of Transportation (WSDOT) owns many of the most heavily trafficked bridges in Seattle including critical bridges like the Aurora Bridge and the I-5 Ship Canal Bridge. Large portions of I-5 and I-90 rest on columns and run near slopes prone to failure. The WSDOT owns 83 bridges in Seattle. Through their own seismic retrofit program, they have completed seismic retrofits on 55 and partial retrofits on the remaining 28.²⁰⁶ The bridge constructed near the south portal of the new SR 99 tunnel uses both flexible rebar and concrete. Not only should these new materials avoid a collapse, but they should also minimize damage, so the road is still usable after an earthquake.²⁰⁷ It is the world’s first “flexible” bridge.

Seattle faces a unique transportation vulnerability due to the presence of [areaways](#) — hollow spaces beneath sidewalks — primarily found in the Pioneer Square neighborhood. These structures are a distinctive and historic feature of the city, originating during the reconstruction that followed the Great Fire of 1889. As part of the rebuilding effort, many streets in the area were elevated. In response, building owners began creating new entrances on their second floors and enclosed the space between the raised street level and their buildings, leaving voids beneath the sidewalks—now known as areaways. The retaining walls used to support the raised streets were typically made of brick or stacked boulders held together with mortar. Like unreinforced masonry buildings (URMs), these walls are highly susceptible to damage during seismic events. In the event of an earthquake, the sidewalks and supporting walls in Pioneer Square could fail, posing serious risks to pedestrians, motorists, and nearby structures. In response to visible signs of wall displacement and concerns about structural integrity, the City of Seattle conducted a structural analysis of the areaways in 2018. As a precautionary measure, load restrictions were placed on many curb lanes within Pioneer Square to reduce the risk of damage from heavy vehicles.

Breaks in the street and bridge network would impair the delivery of emergency services. The region's largest trauma center and most of the city's medical services are on First Hill and Capitol Hill. These medical centers would be difficult to reach if a major bridge or section of freeway collapsed. Police and fire stations are more decentralized, increasing the likelihood that at least some units could reach an emergency. However, moving police and fire vehicles from a lightly impacted area to a heavily impacted one could be very difficult if bridges fail.

Utility Vulnerability

Public utilities (water, electricity, natural gas, sewer, solid waste, and telecommunications) share many of the same exposures and vulnerabilities. Most are networked with key trunk alignments running through or across liquefaction and landslide prone zones and fault lines. A big risk in these areas is permanent ground displacement that can damage or sever lines. Additionally, support facilities and key network nodes are commonly placed in liquefaction zones because they are often easier to build on. Many of these systems were first constructed before the seismic hazard was completely understood. Utilities have inherent resilience as well. They now have control systems that allow them to route around damage to minimize outage sizes. Utility owners are playing catch up to retrofit their systems, and the work will take years or even possibly decades to complete.

Utility vulnerabilities can be inferred from past performance in Seattle and studies of earthquakes elsewhere. A Washington State report mentions that both the 1949 and 1965 quakes interrupted service in water, sewer, gas, and electric systems.²⁰⁸ The performance of these systems varies. Underground systems are more vulnerable to landslides, liquefaction, and surface faulting.

Damage to electrical systems has varied significantly in recent earthquakes. The 2014 M 6 Napa earthquake resulted in 70,000 customer outages, mostly lasting less than a day.²⁰⁹ In contrast, the M 6.3 2011 Christchurch, New Zealand earthquake resulted in many outages. It took 10 days to get 90% of customers restored.²¹⁰ The difference was due to the exposure of electrical systems to liquefaction and landslides, which was much more prevalent in the Christchurch earthquake.

Seattle City Light's South Service Center and two of its substations are in a liquefaction zone, but all sit on pilings which reduces the liquefaction risk. Seattle City Light uses an uncommon voltage in their system. If transformers are destroyed due to liquefaction or other earthquake hazards, they must be rebuilt from scratch. To protect them, Seattle City Light has the highest number of [base-isolated](#) transformers of any utility in the US.²¹¹ Base-isolation is a system that allows a structure to move independently from the ground.

The Bonneville Power Administration (BPA), located in Oregon, provides about half of Seattle's power. BPA seismic evaluations have revealed that transmission towers are especially vulnerable to seismically induced ground displacement, landslides, and liquefaction. A liquefaction hazards assessment by GRI found that transmission towers at four major Columbia and Willamette River Crossings were vulnerable to the shaking expected from a major Cascadia Subduction Zone earthquake. As a mitigation measure, BPA has positioned cables that could be installed underwater to replace damaged river crossings.²¹² Other vulnerable equipment includes substations and rigid bus connections. The BPA implemented some seismic hardening of their system but expressed the need for further seismic resilience work in 2016.

Liquefaction may threaten critical utility systems by damaging or isolating infrastructure. SPU's water transmission pipelines cross areas with liquefaction and landslide susceptibility and through the Seattle Fault and South Whidbey Island Fault Zones. The Olympic BP Pipeline and sewer main lines cross the Duwamish liquefaction zone. To increase resilience to liquefaction, Puget Sound Energy has replaced over 8,000 miles of its 12,000-mile network of gas mains with flexible plastic piping to provide more seismic resilience.²¹³ Surface faulting can also disrupt service. During the 2011 Tohoku earthquake in

Japan, at least six main submarine fiber optic cables connecting Japan's communication network to other countries were damaged due to fault movement.²¹⁴

Water systems have suffered significant damage in major earthquakes. Damage to treatment facilities, storage (tanks and reservoirs) facilities and pipelines has resulted in significant disruption to water utilities. Power outages and damage to transportation and communications facilities added to the complicated water service restoration. In the most catastrophic earthquakes, it has taken months to restore water to some customers.

Guided by a 1990 assessment, many SPU water facilities were seismically upgraded or replaced with more seismic-resistant facilities. Examples include the replacement/upgrade of the West Seattle, Myrtle, Beacon, and Maple Leaf intown reservoirs, replacement of the Queen Anne Standpipes, building upgrades to the Operations Control Center Warehouse and four pump stations, and upgrades to the Cedar River pipelines where they emerge from underground at Ginger Creek.²¹⁵

In 2018, SPU conducted another study which estimated that after a M9.0 Cascadia Subduction Zone or M7.0 Seattle Fault earthquake, most or all areas in SPU's direct service area could lose water system pressure within 12-24 hours of the earthquake. The study further estimated that it could take one month to restore customer service to 70% of direct service customers and two or more months before service has been restored to all customers.²¹⁶ In smaller, more frequently occurring deep earthquakes, such as the 1949, 1965, and 2001 Puget Sound earthquakes, significantly less damage will occur and little, if any, disruption to the SPU water system is expected.

Efforts in the future to increase seismic resiliency will likely focus on:

- Using isolation and control strategies to mitigate the earthquake effects on the water system.
- Improving emergency preparedness and response planning.
- Continuing to seismically upgrade existing critical facilities.
- Increasing the seismic reliability of the transmission pipeline system that conveys water into Seattle and to SPU's wholesale customers (most of King County).
- Using earthquake-resistant distribution pipes in those areas susceptible to permanent ground displacement.

Secondary Hazards

Secondary earthquake hazards can be just as bad, or worse, than the ground shaking. The most significant secondary hazards are tsunamis, fires, hazardous materials releases, and landslides. Each of these hazards is described more fully in its own chapter.

Fires

Of the 28,000 buildings destroyed in the 1906 San Francisco earthquake most were lost in the huge fire that followed it. Multiple ignitions combining into a conflagration is the most dangerous post-earthquake fire hazard. Earthquakes cause fires by damaging ignition sources, like natural gas lines, and generating sparks, while damaging the water systems that are used to suppress fires. Post earthquake fires can cause more damage than the earthquake that started them. Fires were the most common cause of death in the 1995 Kobe earthquake. People trapped in collapsed buildings died in fires that swept over damaged areas.

Khorasani and Garlock (2017) reviewed 20 historic earthquakes of M5.0 or greater that resulted in multiple fire ignitions. They identified key cause and response factors: wind was a key factor in how much the fire spread; gas pipes, electric wiring, and toppled furniture were the major sources of ignition; and availability of water after an earthquake is a key determinant in the ability to control a conflagration.²¹⁷ Scawthorn and colleagues developed an ignition rate based on the MMI scale. For an

earthquake with an MMI intensity of VII (“very strong”), one ignition per 18 million square feet of building floor area is expected. In an MMI X (“disastrous”) scenario, one ignition per 1.5 million square feet of building floor area is expected.²¹⁸

A 2021 study of Seattle’s downtown concluded that Pioneer Square, the waterfront, and older sections of Belltown are most at risk for fire following an earthquake. The researchers developed a model that predicted probability of ignition across three earthquake scenarios, where access would be impeded by debris, and where water pressure would be low due to pipe damage. The areas identified scored high in one or more of these three factors.²¹⁹

Compounding the fire following an earthquake hazard is the high likelihood that Seattle will not be able to rely on mutual aid from neighboring jurisdictions. If Seattle’s firefighting resources are spread thin, a conflagration becomes much more likely.

Hazardous Materials Incidents

Hazardous materials releases are a common, and sometimes deadly, secondary hazard after an earthquake. Many older structures contain asbestos. When these buildings collapse, asbestos can be released into the air. Most releases are small and contained within the structure, but they present a serious hazard to people in these buildings. Krausmann and Cruz collected data on 46 chemical facilities in Japan to review damage caused by the 2011 Tohoku earthquake. They found that 28 of these facilities had equipment damage with possible hazardous materials releases.²²⁰ A small number of releases could escape into the atmosphere creating a widespread hazard.

The possibility of catastrophic hazardous materials releases in Portland, Oregon, a city like Seattle, was raised in a 2023 study by the Portland State University Institute for Sustainable Solutions. It found that a Cascadia Subduction Zone earthquake could release between 65 and 194 million gallons of petrochemicals and threaten the health of 44,000 people. Most starkly, it estimated a worst-case scenario with 2,500 potential deaths. Seattle has not done a comparable analysis, and the extent of the risk is not as well understood, but some of the same risk factors are present. Seattle is a distribution hub for petrochemicals and the hub, Harbor Island, is in a liquefaction zone along the Seattle Fault.²²¹

Tsunami

The Seattle Fault creates Seattle’s most dangerous tsunami hazard. The last earthquake on this fault generated a tsunami that left deposits across Puget Sound. Recent models estimate that a repeat of this earthquake would produce waves up to 13 meters (44 feet) along Elliott Bay’s shoreline with inundation exceeding 6 meters (20 feet). The waves would arrive within two to five minutes after the earthquake making escape to high ground challenging, especially in Sodo and Duwamish Valley. Maps of the inundation area are shown in [Figure 41](#). Only one earthquake of this size is known to have occurred since the last glacial advance 15,000 years ago, but several M 6.5 earthquakes have occurred within the last 3,500 years. These smaller earthquakes would generate smaller, but still dangerous, tsunamis.²²²

Besides the Seattle Fault, the Cascadia Subduction Zone and other Puget Sound surface faults can generate tsunamis that could impact Seattle. A 2021 tsunami model for a magnitude 9 Cascadia Subduction Zone earthquake predicts a tsunami of 3 -7 feet arriving in Seattle 2 hours and 20 minutes after the earthquake.²²³ The Washington State Emergency Management Division conducted a study that estimated consequences along the King County shoreline. Seattle was not differentiated. It found that within the tsunami inundation area the ground shaking and tsunami would cause up to 25 deaths or injuries, damage 317 to 439 buildings, and cost \$505 to \$616 million in damage.²²⁴

The other major surface faults, the Southern Whidbey Island, Tacoma, and Devil’s Mountain faults, can generate tsunamis. Tsunamis from these faults have not been modelled for Seattle but are likely to be less severe than those from Seattle Fault and Cascadia Subduction Zone.

Landslides

Allstadt and colleagues examined the potential for shallow (less than 2.8 meters deep) landslides following a M7.0 Seattle Fault earthquake. They found such a quake could trigger 5,000 landslides in dry conditions and as many as 30,000 in extremely wet conditions. While the study models only a single scenario, and completely wet conditions are unlikely, it is a sobering look at the potential impact of landslides following a Seattle Fault earthquake. The study did not model deep-seated landslides, which can cause whole hillsides to fail. Landslide prone areas are spread throughout the city along hillsides. These areas are mostly zoned as open space or residential. North Seattle has less landslide-prone areas than the central and southern areas. In the middle and southern part of the city, Magnolia, Queen Anne, Madrona, West Seattle, and the northern end of Beacon Hill are the largest potential landslide areas.²²⁵ The major northern landslide area is Golden Gardens in Ballard and along Lake Washington north of Sand Point.

Consequences

Of all the hazards facing Seattle, earthquakes have the broadest range of consequences and potentially the biggest impacts. The consequences cut across all aspects of community life: public safety, housing, utilities, business, critical services, and cultural life. What happens after an earthquake depends on its magnitude, depth, and location. To compare different areas, FEMA estimates annualized earthquake losses based on probability and damage from all of a region's earthquake sources. Among metropolitan areas, FEMA ranked Seattle fifth, behind four metropolitan areas in California: Los Angeles, San Francisco, Riverside, and San Jose.²²⁶

Deep earthquakes, our most common type, will have consequences centering on vulnerable people, locations, and infrastructure like that found in older neighborhoods and the northern part of West Seattle. Widespread deaths and injuries are unlikely, unless a high occupancy building suffers a catastrophic collapse. Unreinforced masonry buildings will account for a high percentage of collapsed buildings. Dozens of these structures could be uninhabitable. Hundreds of buildings, including houses, will suffer significant non-structural damage that could limit overnight occupancy. Sheltering operations will be necessary to support those unable to find their own accommodation. Renters in heavily damaged buildings will be displaced. The transportation system will have significant but limited outages. Emergency responders will be able to reach those in need. Air, rail, and marine transport will have more impact because they are concentrated in liquefaction zones. Long utility outages will probably be limited to specific sites in vulnerable areas like liquefaction zones where infrastructure is damaged. Overall damage will probably be measured in 100s of millions of dollars. Seattle's economic base will likely not be threatened. If the regional economy is strong, the city will be able to recover quickly overall, but owners of damaged and underinsured buildings will face long term financial hardship.

A magnitude 9 megathrust earthquake will devastate the entire Pacific Northwest coast. Seattle will not be the most damaged community in Washington but would experience much more damage than the 2001 Nisqually Earthquake. Seattle's damage model predicts damage will be widespread throughout the whole city with concentrations in liquefaction zones in the Duwamish Valley, the Rainier Valley, and Interbay, and in older neighborhoods like Pioneer Square, Chinatown-International District, the University District, and Ballard. Hundreds of buildings will collapse with unreinforced masonry buildings taking a heavily disproportionate share. Mid-rise buildings and buildings under 200 feet will be more affected by this type of earthquake due to resonance effects with the longer period seismic waves megathrust earthquakes generate.²²⁷ Fatalities are impossible to predict accurately, but dozens to hundreds of fatalities and hundreds of injuries are possible. Seattle's damage model predicts that lower income people will be disproportionately impacted. Because of the effects on multi-story buildings, more apartment dwellers, who are more likely to be renters will be affected. Thousands will need long term shelter. The transportation and utility systems will be heavily damaged. Emergency crews will not be able to reach everyone in need, and they will not be able to field enough staff to respond to all sites.

Because of the widespread damage outside Seattle, help from outside will be very slow to arrive. The City's economy is likely to be severely impacted. Recovery will be challenging because of the regional damage and will be measured in years.

The Seattle Fault can generate earthquakes up to magnitude 7.5. One of that size is this city's worst case natural disaster scenario. In 2005, the Earthquake Engineering Research Institute (EERI) worked with the region's scientific and engineering community to model impacts of a 6.7 magnitude Seattle Fault earthquake. This scenario's damage estimates are probably low because in 2005 little was known about the deep basin effects. The EERI scenario predicts ground rupture of approximately 6 vertical feet from Harbor Island to Issaquah. Ground motions would be two to five times that of the Nisqually Earthquake. This type of rupture on the Seattle Fault zone would severely disrupt north-south lifeline systems, including utilities and transportation routes.²²⁸ Estimates are 1,600 fatalities regionally. With the highest population densities, the oldest building stock, and location right on the fault, Seattle would probably suffer most of those fatalities.

Mobility is the foundation for earthquake emergency response, but Seattle's transportation system would be severely impacted by either a megathrust or Seattle Fault earthquake. Due to its dependence on bridges, Seattle could face major difficulty in responding if damage to key structures render them unusable. It would be difficult to move emergency personnel and resources to where they are needed or to take the injured to hospitals.

If the region experiences a large shallow or megathrust quake, many utilities would be severely impacted in large parts of the city. If trunk lines break or critical substations and transformers are broken, power outages would occur over a wide area. If many lines are damaged, outages will persist for a longer time. Another deep quake would probably cause only minor interruptions, but these impacts could be severe if the epicenter were closer to Seattle than the Nisqually Earthquake.

Fire suppression is critical after earthquakes. It is highly probable that Seattle's water distribution system would be damaged in a shallow or megathrust quake, limiting the ability to fight post-earthquake fires.²²⁹ This danger can be mitigated by rerouting water in the distribution system around breakages, drawing water from open water sources (reservoirs, lakes, and Puget Sound), and using flexible overland piping.

The economic impact of a large earthquake would be enormous. In 2005, EERI estimated that losses for an M6.7 Seattle Fault earthquake would amount to \$33 billion (almost \$60 billion in 2025 dollars). It's likely that the number would be much higher now, considering the massive growth Seattle has experienced since 2005. A successful recovery would depend on local, regional, and national political and economic conditions. In a megathrust earthquake, Seattle will have to compete with more heavily damaged areas for recovery help. Recovery can be delayed for years if a community cannot achieve consensus about post-disaster goals. Any recovery would depend heavily on favorable economic conditions.

Seattle's URM's are likely to suffer significant structural damage or collapse during any significant earthquake. About half of the city's URM's are commercial, industrial, or office buildings, while the other half are residential, public assembly, government, and mixed-use spaces, and schools. The consequences of these facilities collapsing could include major economic losses to businesses, and potential injury or death to their inhabitants.

The larger Seattle business community will face challenges if the transportation and telecommunications networks are disrupted. If these systems remain inoperable for a long period of time, Seattle enterprises could face a permanent loss of business.

The 2005 Seattle Fault earthquake scenario estimated that 46,000 households in King County would be temporarily displaced. About half will need short-term shelter (less than 2 weeks) but the rest will need

housing for a few months. 15%, or 6,900 people, would be displaced for over six months. Some of these households would find shelter with family, others would find rentals, but the government would have to assist with locating shelter for a large percentage of these households.

Earthquakes are natural events, but they can cause severe environmental damage. The last Seattle Fault earthquake triggered numerous landslides that sent whole hillsides into Lake Washington and Puget Sound. The trees that grew on these hillsides slid into Lake Washington and became navigational hazards for boats. Earthquakes are also expected to trigger hazardous materials releases when structures that house them are damaged or contaminated sediment in the Duwamish Waterway Superfund site is re-suspended in the water column. When this happens, contaminants are more likely to come into contact with people and other parts of the environment.

The United States Geological Survey has developed an Earthquake Early Warning (EEW) system, called ShakeAlert, which has been operational since May 2021. This system saves lives by alerting the population through their cell phones about imminent ground shaking. The system can connect with automated systems like trains and elevators to add further protection.

Outlook

The USGS estimates that intraplate earthquakes of M6.0 or greater (like the Nisqually quake) occur about every 30 to 50 years. Crustal earthquakes with a magnitude of 5.5 to 6.5 occur about every 100 years. Megathrust earthquakes have a recurrence interval of 300 - 800 years with an average interval of 450 to 500 years.

Table 14. Earthquake Type and Estimated Recurrence Intervals.²³⁰

Type	Magnitude	Mean Recurrence	Probability in next 50 years
Deep Earthquakes like Nisqually	Greater than 6.5	~26 years	85%
Megathrust (CSZ) Earthquakes	Greater than 9.0	~500 years	10 to 15%
Any Puget Sound Crustal Fault	Greater than 6.5	~265 years	17%
Seattle Fault	Greater than 6.5	~890 years	5%

The last megathrust earthquake occurred on January 26, 1700. The last Seattle Fault earthquake was either late 923 or early 924. The USGS sees evidence that the Seattle Fault has been active 3 to 4 times in the past 3,000 years, with an earthquake of about M6.5 or greater occurring roughly every 890 years. The United States Geological Survey estimates the probability of a magnitude 6.5 or greater earthquake on the Seattle fault in the next 50 years as 5%.²³¹

In 2007, the USGS produced a series of [probabilistic earthquake hazard maps](#) for Seattle (reproduced in [Figure 24](#)). These maps illustrate the chance that delineated areas will exceed a certain level of shaking over a 50-year period. The maps were primarily developed to understand the effects of shaking on tall buildings (over 10 stories) and URM. They show the effects of underlying geology, such as areas with artificial fill and soft soils, which amplify ground shaking. Ground shaking is measured by acceleration as a percentage of the force of gravity. The measure is abbreviated 'g'. The full force of earth's gravity is 1g. It requires more than 1g to throw objects up in the air. In [Figure 24](#), areas in dark red have the potential

for the highest level of ground shaking, while areas in green are expected to experience less shaking due to the underlying geology.

Conclusions

Earthquakes are both high probability and high impact events in Western Washington, making them the most likely source of the most damaging disaster Seattle will face. A large earthquake could cause hundreds or thousands of deaths and lasting damage to the city's economic base. Secondary impacts could include hazardous materials spills, infrastructure failure, landslides, conflagrations, seiches, or even a tsunami. Each of these would cause additional damage and potential casualties. Response to and recovery from a large earthquake would be the largest challenge this community has confronted.

2. LANDSLIDES

On March 22, 2014, the hillside above the community of Oso, Washington collapsed, killing 43 people. This event solidified how hazardous landslides can be in Western Washington. It left many people wondering if Seattle could suffer a similar catastrophe. Nationally, landslides were estimated in 2006 to cause over 25-50 deaths and cost about \$6.3 billion per year in the United States (adjusted from 2001 dollars). Landslides are a common natural hazard in Seattle. Even small landslides can be deadly, and storms can cause hundreds of landslides within a few days.²³²

A landslide is the movement of a mass of soil, rock, or debris down a slope. Landslides occur when the weight of soil on a slope exceeds its strength causing a collapse. The amount of downslope force and slope material strength changes with a variety of factors including geology, precipitation, changes in water level, erosion, ground water, earthquakes, prior landslides, or human activity.²³³ Most landslides have multiple causes. The most frequent triggers of landslides in Seattle are human alteration of the slope, groundwater saturation, or a combination of both. For example, a person may cause a pipe to leak and saturate the ground, triggering a landslide. Earthquakes can be a powerful landslide trigger, especially if the soil is saturated.

While landslides do not always fit neatly into exclusive categories, most Seattle landslides fall into four general types characterized by Shannon and Wilson:²³⁴

- **Shallow Colluvial or ‘skin’ landslides.** These landslides usually involve only the first few feet of the loose, heterogeneous soils on a slope and happen when the soil becomes saturated with water. Over two-thirds (69%) of all landslides in Seattle are shallow.

They can attain speeds of up to 60 km per hour and can have debris runouts that exceed 50

Key Points

- ❖ *Lead Agency – Seattle Fire Department*
- ❖ *Seattle’s steep hills, wet winters, and geology make it prone to landslides, especially in the winter and early spring.*
- ❖ *Hundreds of landslides can occur over short periods of time causing widespread public safety hazards and property damage.*
- ❖ *8.4% of the city’s area is slide prone. 81% of the slide-prone area is zoned for open space, the right of way, or single-family residential areas.*
- ❖ *The most common landslides are shallow (less than 6 – 10 feet deep), fast moving (up to 60 km per hour) and occur on undeveloped slopes. Shallow slides can have runouts that exceed 50 feet.*
- ❖ *Rainfall is the major landslide trigger. Most landslides occur when soils are saturated then get an additional jolt of water from a rainstorm.*
- ❖ *Most homeowner’s insurance do not cover landslides.*
- ❖ *Rail lines run along landslide-prone slopes. Landslides have disrupted or cancelled passenger trains along the Puget Sound over 500 times from 2015 – 2018.*
- ❖ *Landslides can trigger secondary hazards like flooding and hazardous materials incidents.*
- ❖ *The City of Seattle has undertaken measures to mitigate vulnerability to landslides. They include mapping landslide prone areas, requirements to stabilize building sites during construction, public education, and slope stabilization projects.*

feet.²³⁵ They can incorporate water and transform into a rapidly moving slurry called a debris flow that runs out far from the bottom of the slope.

- **Deep-seated or rotational landslides.** These slides involve soil movement deeper than six feet. Normally the soil moves as a block on an arc-shaped failure surface. Often several blocks move started with the one lowest on the slope. These blocks often rotate as they move downhill. As with shallow landslides, water is a factor. Deep-seated landslides often happen repeatedly in the same location many years apart, making it important to recognize that a potential building site may also be the site of an old landslide, and account for 18-19% of all landslides in Seattle. The Oso event was a deep-seated landslide.
- **High Bluff Peeloff.** These landslides occur when blocks of soil fall from high bluffs, primarily along the Puget Sound. Between 3-4% of all slides in Seattle are high bluff peeloffs.
- **Groundwater Blowout.** This type of landslide happens when groundwater pressure builds up at the contact between overlaying pervious (sand) and underlaying impervious (clay) soil units, causing increasing groundwater pressure that may initiate a landslide starting as the contact point. Between 5-6% of all slides in Seattle are groundwater blowouts.

Deep-seated landslides are the most complex landslide covered here. Speed is a risk factor for landslides. Deep-seated landslides have a range of speeds. They usually occur more suddenly on slopes made of pervious soils, like sand. Slopes with more impervious material like silt and clay experience gradual movements over weeks to months. There can also be dormant landslides that go unrecognized until they begin to move again. It is believed that there had been smaller landslides at the same location of the 2014 Oso landslide, making the slope more unstable to begin with.²³⁶

Most landslides happen between late October and late March when we get the majority of our precipitation, but slides can be delayed beyond early spring.²³⁷ According to Tubbs, the probability of landslides rises after a wet, cold winter, especially if a freeze occurs in late winter and early spring.²³⁸ The ground becomes saturated over the winter, and then porous following a freeze, so a subsequent rain penetrates the surface while the high water table prevents the ground from absorbing it. The water increases the slope stress by adding weight and increasing pore pressure within the soil.

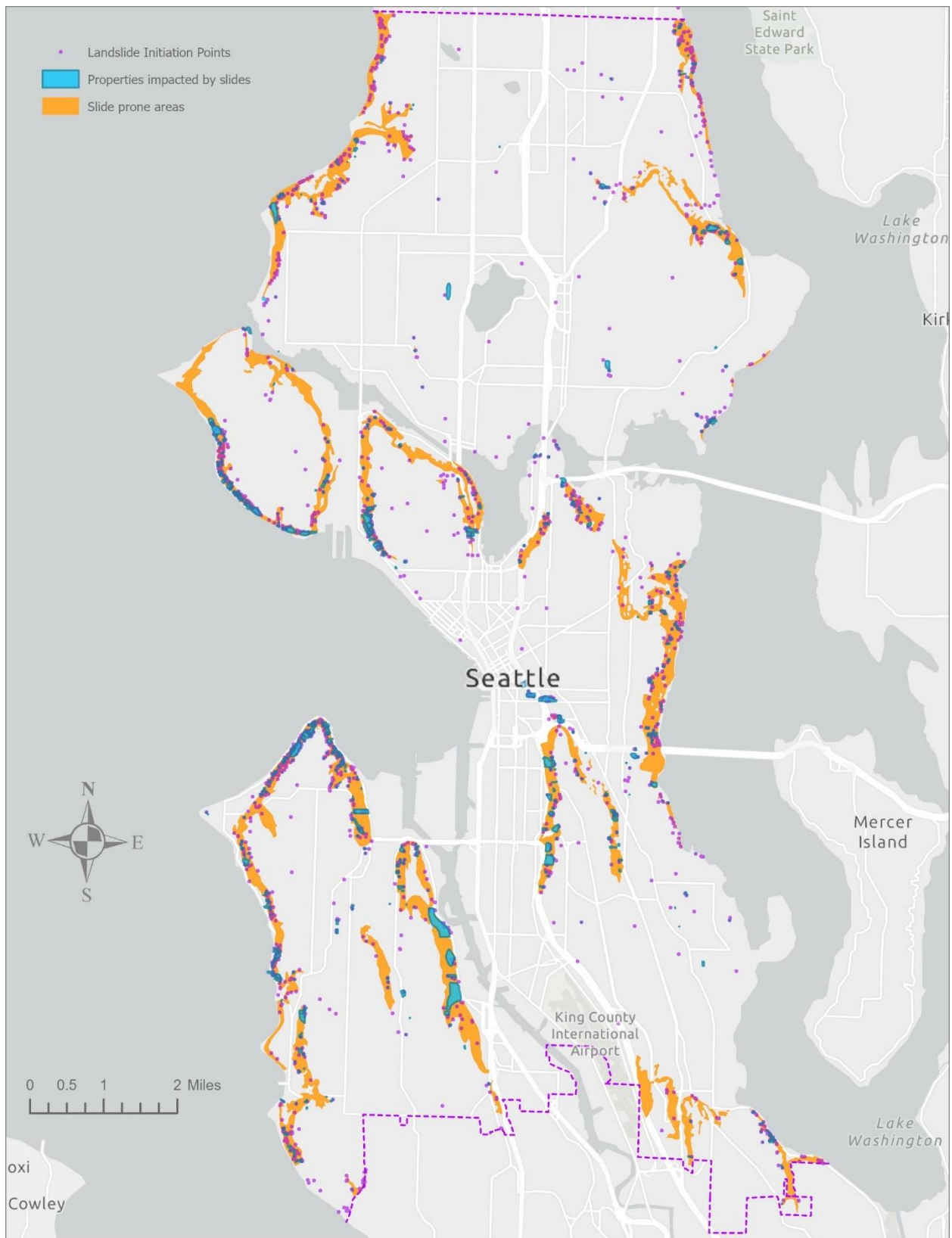
Landslide Monitoring

The U.S. Geological Survey (USGS) created a [tool](#) to help the Seattle public understand when the Seattle area is at heightened risk for landslides. It consists of graphs modeled on historic events and current national weather service data. The graphs show the 18-day cumulative precipitation forecast, the intensity of rainfall in the past 72 hours, a rainfall intensity and duration index for the past 14 days, and a water balance model that shows soil saturation. The tool shows real-time data from monitoring instruments located north of Seattle on slopes like those in the city. They include rainfall and soil water content. Most of the graphs have thresholds that can be monitored to see whether there is a heightened real-time or forecasted risk for landslides.

History

The Seattle Engineering Department (the forerunner of Seattle Public Utilities) began recording landslides in 1890. By 2000, when the engineering firm Shannon and Wilson was hired to investigate and analyze the database, the list had grown to 1,326 landslides. In 2021 the Shannon and Wilson database was combined with records from the Seattle Department of Transportation to identify 624 areas affected by historic landslides. In some cases, it was not possible to identify any affected properties. In these cases, the map shows a landslide initiation point without a related property. See [Figure 30](#) for a

Figure 30. Landslides and Landslide Prone Areas



City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

map of these initiation points. Additionally, each winter City of Seattle engineers track landslides. At the end of the winter, these new landslides are added to the landslide inventory.

Only the events that required significant city response are included in this section. Many of these significant landslides happened during winter storms. Often these storms involved multiple landslides in multiple locations throughout the city. Seattle's three worst years for landslides were 1933/34, 1985/86 and 1996/97.²³⁹ The records below were compiled from newspaper accounts.

1921. Six major slides occur on a single weekend.²⁴⁰

1933/34. More than 400 Seattleites battle slides in ten areas of the city. These slides prompted numerous repair projects.²⁴¹

1941. Several slides occur during December around Sand Point.²⁴²

1948. Multiple slide events in Magnolia and Yesler Terrace.²⁴³

1961. Slides occur in many areas of the city during the spring.²⁴⁴

1965. SR 520 threatened, one lane closed, Roanoke interchange closed.²⁴⁵

1966. A large slide closes Golden Gardens Drive NW to traffic in January. Shannon and Wilson's Landslide Study reports this as a heavy winter.

1969. Large slides occur on Magnolia Bluff.²⁴⁶

1971/72. Slides destroy homes in Madrona causing about \$1.8 million in damage. These slides were also probably connected with snowfall.²⁴⁷ Largest number of landslides since 1933/34.

1974. West Seattle experiences multiple slides in the winter. Golden Gardens Park was also damaged.²⁴⁸

1983. Queen Anne slide closes Aurora for a day. Mud travels as far as Lake Union.²⁴⁹

1985/86. Shannon and Wilson's Seattle Landslide Study reports this as a heavy winter.

1995/96. A large slump along Perkins Lane in Magnolia destroys five homes (January).

1996/97. Over 100 slides reported in the city (January). These slides and the accompanying snow caused approximately \$100 million in damage. More slides occurred in March.

2014. A deep landslide occurred the morning of March 22 near the community of Oso in Snohomish County. Three weeks of heavy rainfall preceded the event. It was the deadliest landslide in the history of the U.S. with 43 fatalities and several injured. Forty-nine homes and structures were destroyed,²⁵⁰ and State Route 530 was closed for more than two months. The state estimated capital losses of at least \$50 million.²⁵¹

A study of 50 landslides in Seattle found that hillside excavation for roadcuts and other construction activities contributed to 40% of Seattle's landslides.²⁵² During the construction of Interstate 5, newspaper accounts document numerous landslides along Beacon Hill and Capitol Hill.

Urban development can reduce risk but can also expose more people to the landslide consequences. When impervious materials like concrete are added to a slope, water is diverted, and soil is less likely to become saturated. Seattle's modern construction codes have specific engineering requirements in slide-prone areas to increase structural safety and reduce the amount of water that can penetrate the slope.²⁵³ A decrease in landslides in some areas, like the southwest side of Yesler Hill, is presumably a result of its transformation into a dense urban neighborhood. Additionally, some slopes such as the west side of Beacon Hill have benefited from large public works projects, such as construction on I-5 in the 1960s that added concrete reinforcements and drainage.²⁵⁴

Vulnerability

Eighty-eight percent of the documented landslides in Seattle have occurred either within a steep slope area or potential landslide area already mapped by the City of Seattle (see [Figure 30](#)).²⁵⁵ The map reflects slopes where landslides are prone to initiate, but it does not account for the potential runout of a slide, which can extend further than 50 feet.²⁵⁶ The runout hazard is important. The homes that were destroyed in the Oso landslide were not in landslide-prone areas but were reached by the massive debris flow coming from the slide. Because the 50-foot runout is a general rule, additional research is needed to understand potential runout lengths.

The areas that have had the greatest number of landslides in Seattle are along Alki Avenue in West Seattle and Perkins Lane North in Magnolia, with over 100 documented landslides each. Other areas with large numbers include Beach Drive Southwest, Pigeon Point, Madrona, Rainier Avenue S.E., Interlaken, Magnolia, and bluffs along the Puget Sound and adjoining parks in Northwest Seattle.²⁵⁷ Human alteration of the slope was at least a partial cause in 84% of landslides in Seattle in the 20th century.²⁵⁸

Landslides in certain parts of Seattle are increasing, most notably along the slopes along northwest and northeast Seattle, Perkins Lane, and the Duwamish Head. A few areas, such as the areas around southwest Yesler Hill and the slope along the west side of Beacon Hill, are having fewer landslides.

Deep-seated landslides have occurred in Southwest Magnolia, Northwest and Southwest Queen Anne, East Queen Anne, Alki, Admiral Way, West Beacon Hill, Interlaken, Madrona, and Pigeon Point.²⁵⁹

Nearly one third of the area designated as landslide prone is single family residential (33%). As the amount of vacant property dwindles in the city, more people are willing to build on landslide-prone slopes. Additionally, many of these areas are desirable for their proximity to the water and views. The City of Seattle cannot stop people from building homes in landslide-prone areas, but it does require more intensive geologic assessments and mitigation work to eliminate risks to homes and neighboring properties. Common mitigation measures can include special foundation designs and pipes that drain slopes. Nevertheless, there is always a risk when building on a slope. A home built underneath a bluff on Bainbridge Island was buried in a landslide in 1997, killing a family of four. It is unclear how many older properties conform to current standards. Furthermore, mitigation is usually designed to prevent loss of life and not property loss, which is typically uninsured for landslide hazards.

Transportation / Right of Way

Public right of way, such as roads, railways, and trails, accounts for 25% of the land within landslide prone areas. Landslides can either go over the right of way, undermine it, or both.

The most vulnerable right of way is parallel to a slope. Seattle has many such locations: the railroad tracks running along Puget Sound in north Seattle, I-5 along parts of Beacon Hill and Capitol Hill, and SR 99 Aurora along Queen Anne. It is estimated that landslides have disrupted or canceled passenger train service along Puget Sound over 540 times between 2015 and 2018.²⁶⁰ Since 2011, two trains have been derailed by landslides in the Seattle-Everett corridor. BNSF requires that passenger trains suspend service for 48 hours after a landslide, but this rule does not apply to freight trains. BNSF and the State of Washington funded a \$16 million project to mitigate landslides in this corridor. They built retaining walls, improved drainage systems, and conducted erosion control in six different areas.²⁶¹ They have also installed slide detection fences, which act like a trip wire and automatically send an indicator to train conductors when a slide occurs.

A landslide going over a right of way does not typically damage it, and the debris can be cleared in a matter of hours. Exceptions occur if crews are unavailable or complications like downed power lines are present. Landslides that undermine a right of way take longer to repair and cost more. Bridges and other roadway structures are especially vulnerable. In 1996, a landslide destroyed a support of the Magnolia

Bridge causing it to remain closed for months. The I-5/I-90 and I-5/Spokane Street Viaduct interchanges are on landslide prone slopes as are ends of the West Seattle Bridge, Ballard Bridge, and I-5 Ship Canal Bridge.

Utilities

Utilities, especially those underground, are vulnerable to landslides. Because drainage systems are close to slopes by necessity, they are most frequently damaged. About 8% of reported landslides have damaged the city's drainage infrastructure. Another 4% have been associated with water leaks, with the leak sometimes causing the landslide and not the reverse.

Seattle's water, power, and sewer lines all cross landslide prone areas. The sewer system is the most exposed to landslide hazards because it has main lines that run parallel along the base of many landslide prone hill sides, especially in West Seattle, the east side of Queen Anne Hill, and in Carkeek Park. Sewer mainlines cross landslide prone slopes in more than seven locations. Seattle water supply lines cross landslides prone areas in three locations: southeast Seattle, the north end of Beacon Hill, and the Interlaken area of Capitol Hill. Power transmission lines cross landslide prone areas in southeast Seattle.

Consequences

Landslides will continue to pose a threat to property and public safety. Property damage is the most common consequence of landslides, but the 2014 Oso landslide tragedy and the 1997 deaths on Bainbridge Island underscore risks to human life.

Property damage from the flurries of landslides in 1974 and 1997 was roughly shared equally by the public and private sectors. However, little can be drawn from two occurrences, and this distribution should be studied further. It may reveal trends in property damage patterns that could help prepare the city for future events.

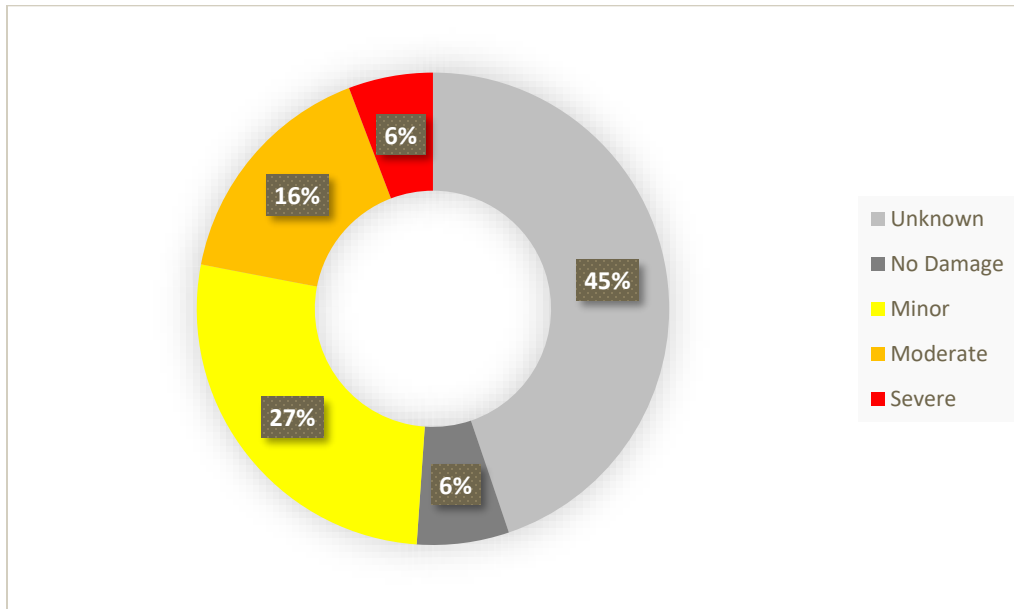
Most of the land in or immediately adjacent to the City's mapped landslide prone areas is residential so it is to be expected that most future property damage will be private residential. Historically, this has been the case. There is little information about severity (i.e., how many homes were destroyed and how many were only damaged). Newspaper articles making frequent reference to "destroyed homes" yield only anecdotal evidence.

Other significant impacts could include the interruption of lifeline services such as water, sewer, and transportation. The city's water, gas, sewer, and power lines all cross areas prone to landslides, particularly in Highline, the east side of Beacon Hill, and the east side of West Seattle. Of these areas, Highline is generally the most critical because many of the utility networks have trunks that run through the area. All the Cedar River water pipelines enter the city in this area as well.

Transportation corridors could very well be blocked by future slides. Both I-5 and I-90 run through a large landslide area around Beacon Hill. Aurora has been blocked by landslides along the east face of Queen Anne Hill several times. Since each one of these routes handles thousands of vehicles every day, landslides around them have the potential to disrupt large parts of the city.

Landslides often happen in groups over a period of days or even weeks. They usually have the biggest impact in residential areas where they can displace whole blocks of households. Less commonly, they threaten commercial buildings and facilities that host critical services. Their economic impact comes when they block transportation routes or force businesses to vacate their premises. By blocking roads and damaging lifelines they also inhibit the City's ability to deliver critical services to impacted neighborhoods.

Figure 31. Landslide Damage Severity Summary²⁶²



Landslides can cause secondary disasters. Landslides can cause flooding by blocking rivers, streams, and storm drains, and lead to releases of hazardous materials by destroying waste and storage sites, or derailling freight trains. These trains are increasingly carrying Bakken crude oil, a highly flammable oil that has been known to explode when impacted. Hazardous materials are housed or transported close to potential slide areas in West Seattle, Interbay, and along the Burlington Northern tracks running through the Golden Gardens area.

Future research should study the potential tsunami generative effects of submarine landslides in water bodies such as Lake Washington. Seattle can also be affected by landslides in other parts of the state. Landslides, rock fall, and avalanches have closed I-90, Washington’s main east-west corridor and SR20, which provides access to Seattle City Light facilities in the North Cascades.

Cumulative Hazard

Landslides are a hazard that can best be analyzed by looking at cumulative impacts. While most landslides are insignificant and would not constitute an emergency, their relatively high frequency and their tendency to occur in swarms can compound consequences over time.

Outlook

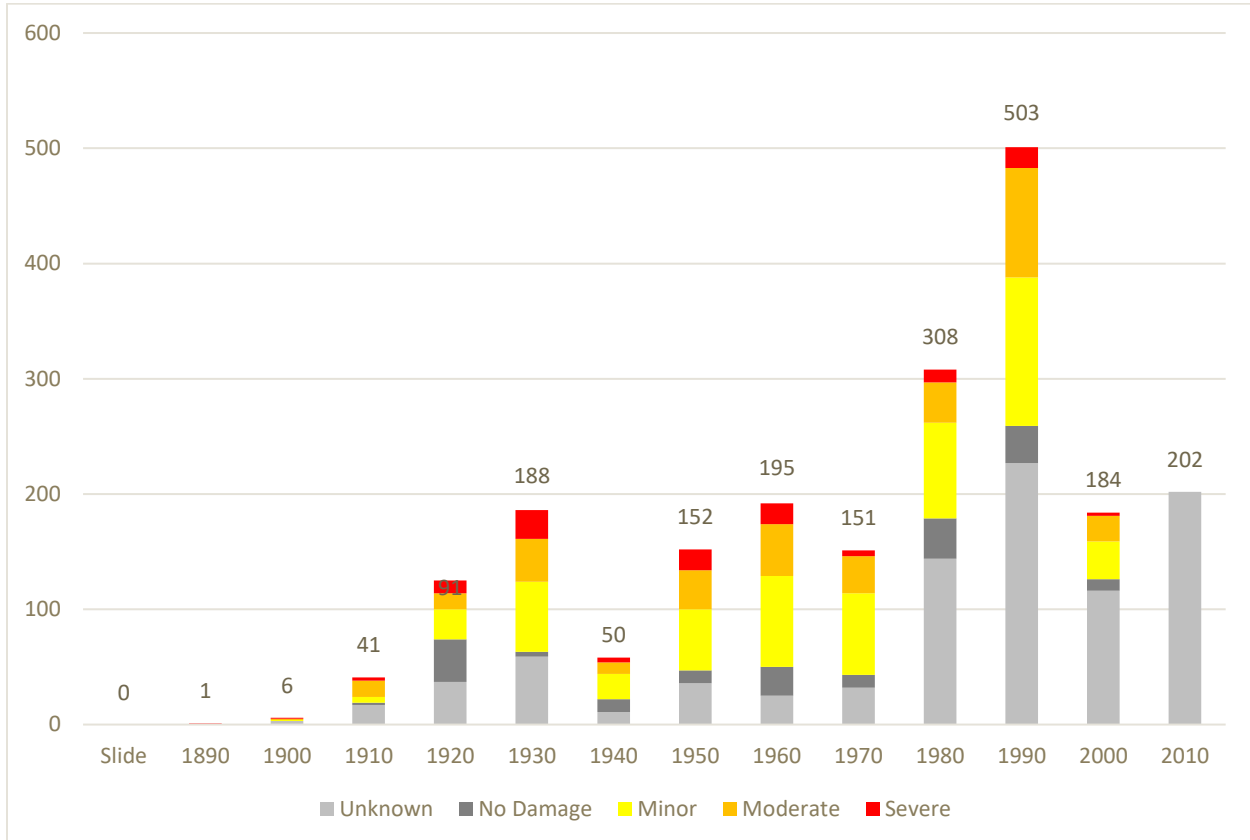
The outlook for landslides in the City of Seattle can be extrapolated from Seattle’s robust historical databases, climate change, global weather cycles, and development patterns as an educated guess. Given the predicted increase in extreme precipitation events, it seems likely that the chance for outbreaks of ‘swarms’ of landslides will increase. Development can reduce the chance of landslides if good engineering practices are followed but increased development in landslide prone areas and poor property maintenance can increase the chance of landslides.

The Shannon and Wilson database is a great source of information on landslides in the 20th century. The number of landslides recorded by the city increased dramatically from the mid-1900s to the end of the century ([Figure 32](#)). This increase likely reflects a combination of development on landslide prone-slopes and more frequent reporting. In the past, landslides on undeveloped property were underreported. Once developed, property owners in these areas probably reported slides to the city more frequently. The large spike in the 1990s also reflects the extreme number of slides that occurred during the winter

of 1996/97. Since the 1990s, the number of landslides recorded has decreased to about 190 slides per decade.

The number of landslides that have severely damaged property decreased between 1980 to 2000 (Figure 32). While it has not been formally studied, stricter building codes for properties in slide-prone areas could have contributed to the decrease in property damage. Shallow landslides made up a growing proportion of slides from 1950 onward, with deep seated landslides becoming less common with a big exception for the 1990s.

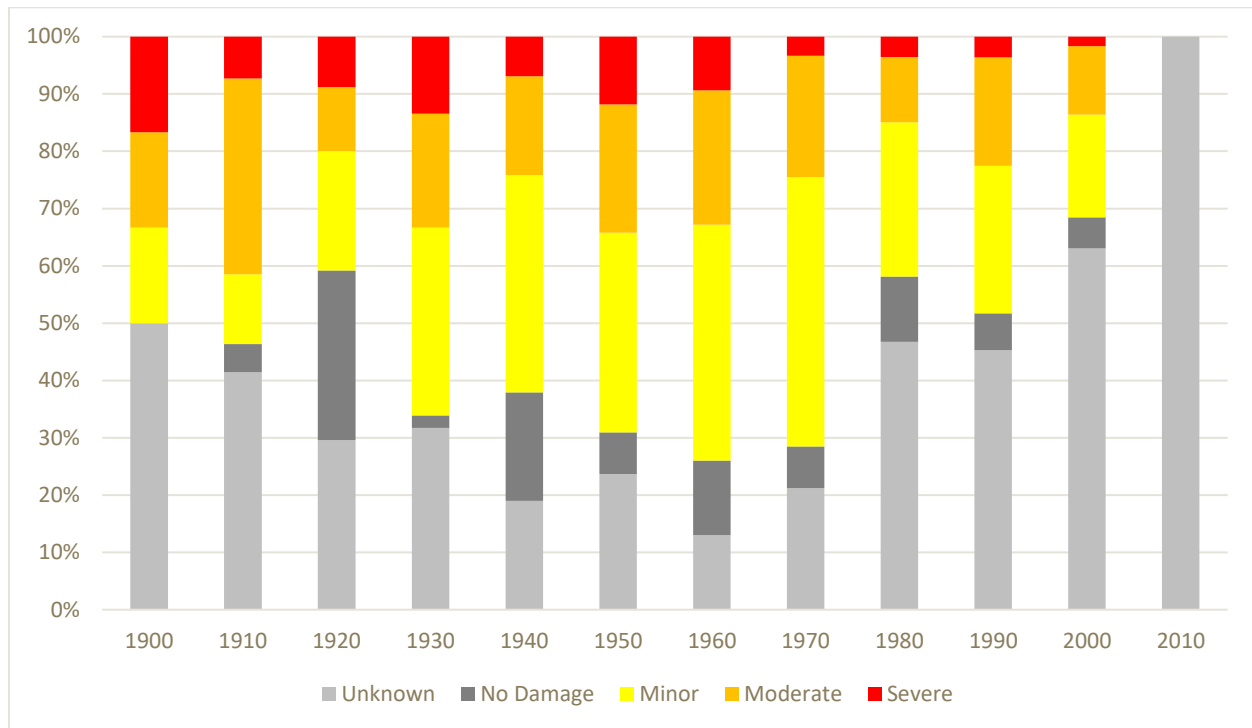
Figure 32. Landslides by Decade with Damage²⁶³



Note: Landslide damage data has not been collected since 2003

The tragic Oso landslide, in the North Fork Stillaguamish River (NFSR) Valley, about 60 miles north of Seattle, caused concerns that a similar massive landslide could occur in Seattle. The NFSR Valley has a steeper and taller topography and is much less developed than Seattle. A recent study analyzed and dated 25 deep-seated landslides, including the Oso landslide. The results revealed that deep-seated landslides from our current geologic age (roughly the past 12,000 years) have an average frequency of one slide every 140 to 500 years in the NFSR Valley.²⁶⁴ Seattle's hills are not as large as those in the Cascade foothills, but we have a lot more people and property in harm's way. Massive landslides have occurred in Seattle as a secondary hazard to earthquakes.

Figure 33. Distribution of Landslide Damage by Decade²⁶⁵



Note: Landslide damage data has not been collected since 2003

Conclusions

Landslides are a common, complex, and growing problem in Seattle. There is substantial evidence that landslide losses are growing as more property is developed in landslide prone areas. One bright spot is that safety measures seem to be working. Because landslides are often secondary to other hazards, such as earthquakes and storms, a normally simple response to these hazards can become more difficult. Following the major slides of 1996/97, the City of Seattle convened an Interdepartmental Landslide Team to address the problem. Since then, several structural and non-structural mitigation measures have been taken. In addition, USGS rainfall monitoring soil condition monitoring as well as the availability of new landslide susceptibility maps add greater accuracy to the city's predictive ability.

3. VOLCANOES

With five active volcanoes, including one that violently erupted within the past 50 years, Washington State faces one of the highest volcano hazards in the US. The biggest hazard for Seattle is Mt. Rainier. The mountain has a history of sending huge debris flows called lahars down its flanks into the Puget Lowlands. It is possible though unlikely that a lahar from Mt. Rainier would reach Seattle. What is more likely is that a lahar from Mt. Rainier would stop in the Kent Valley where it would deposit vast amounts of debris which would subsequently be transported down the Green and Duwamish Rivers into Elliott Bay over the course of months or years in a process known as post-lahar sedimentation. This debris would clog the waterway flood the Duwamish Valley. Underscoring this risk is the fact that Elliott Bay used to extend south to Auburn. A major reason the mouth of the Duwamish is in Seattle today is that the valley filled in with lahar deposits.²⁶⁶

Ashfall is another volcano risk for Seattle. Prevailing winds in Western Washington are mostly westerly. About 80% of the time ash from Cascade volcanoes has moved east.²⁶⁷ Because Seattle is west of the Cascade Range volcanoes, the probability of receiving significant ashfall is low.

Washington's volcanoes are the result of tectonic motion that also gives the Pacific Northwest its seismic activity. As the oceanic plate (Juan de Fuca) subducts (sinks) beneath the North American Plate along the Cascadia Subduction Zone, it heats up and releases water and gases that lower the melting point of the mantle to generate magma. Magma can rise through the crust and erupt onto the surface, or it may stall underground and never erupt (see [Figure 34](#)).

Washington's volcanoes have generated both explosive and effusive (meaning the primary hazard is lava flow, not an explosion) eruptions. The style of eruption depends in large part on magma's journey to the surface. Magma rises to the Earth's

surface, pressure decreases, and gases expand and separate from liquid. As magma rises, it also cools

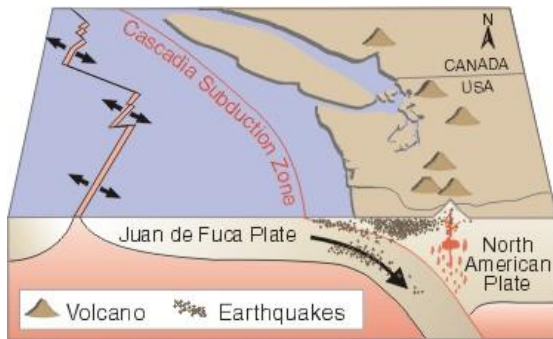
Key Points

- ❖ *Lead Agency – Seattle Fire Department*
- ❖ *The biggest volcano risk for Seattle is excessive sediment washing down rivers that originate on Mt. Rainier. Lahars or debris flow from Mt. Rainier could damage the Mud Mountain dam. If it were to fail, the Duwamish Valley could flood.*
- ❖ *Ash fall is possible, but the prevailing wind direction is likely to send ash to the east.*
- ❖ *Volcanoes cause damage from*
 - *Pyroclastic flows (heated material)*
 - *Lahars (debris flows)*
 - *Ash*
 - *Landslides*
 - *Lava flows*
 - *Excessive Sedimentation (loose volcanic debris washing downstream)*
- ❖ *Washington's volcanoes are too far from Seattle to cause pyroclastic damage.*
- ❖ *Excessive sedimentation from Mt. Rainier is the most likely effect in Seattle itself.*
- ❖ *Heavy sediment could wash down the Duwamish affecting port operations.*
- ❖ *Ashfall is unlikely in Seattle but could indirectly affect Seattle by impairing Seattle's water and power systems and by snarling regional transportation.*
- ❖ *Lahars are an extreme safety risk to people who live and work along rivers originating on volcano slopes but are not likely to reach Seattle. They could destroy infrastructure that Seattle depends on.*
- ❖ *Washington State has five active volcanoes. Mt. Rainier is the closest and most likely to affect Seattle.*

and crystallizes. A relatively slow ascent could result in magma becoming thicker and more viscous. If it traps gases, an eruption could be explosive. If gases can escape, magma may emerge from the vent to build a lava dome, with minimal explosive activity. A relatively rapid ascent of magma to the surface could result in lava flows.²⁶⁸

Violent, explosive eruptions can produce many hazards, including pyroclastic flows, landslides, gases, tephra (ejected ash and rock), and lahars (Figure 35). While the Hollywood image of a volcanic eruption may be fast flowing lava, the geologic history of Washington volcanoes indicates the more likely outcomes are short-traveled lava flows and lava domes forming at the vent, and potentially explosive eruptions. Of these hazards, the two most likely to affect Seattle are lahars and associated flooding as well as ashfalls. Post-lahar sedimentation is also a hazard likely to affect Seattle.

Figure 34. Subduction in the Pacific Northwest²⁶⁹



Lahars

The USGS defines lahars as mudflows and debris flows that originate from the slopes of a volcano. Lahars contain a significant concentration of sediment and sometimes woody debris. Most, but not all, are preceded by volcanic and seismic activity. During an eruption, they are triggered when hot pyroclastic flows melt snow and ice and also by landslides. Other triggers, during both eruptive and non-eruptive periods, include intense rainfall on loose volcanic rock deposits, breakout of a lake dammed by volcanic deposits, and glacier outburst floods.²⁷⁰ Lahars are especially hazardous in areas of Western Washington along rivers originating on the slopes of volcanoes. Lahars can look and behave much like flowing concrete. They can travel at speeds of a few tens of miles per hour along gently sloping valleys. Higher speeds of more than 60 miles per hour are possible on steep slopes closer to volcanoes. Though spontaneous lahars are possible (a “no-notice” lahar could occur during non-eruptive periods), most large lahars are preceded by volcanic and seismic activity. Lahars from Cascades volcanoes can travel many tens of miles from their source, making them extremely dangerous even to communities far from volcanoes. A lahar that occurred 5,600 years ago at Mount Rainier, called the Osceola Mudflow, covered roughly 212 square miles of the Puget Sound lowlands.²⁷¹

Tephra / Ash

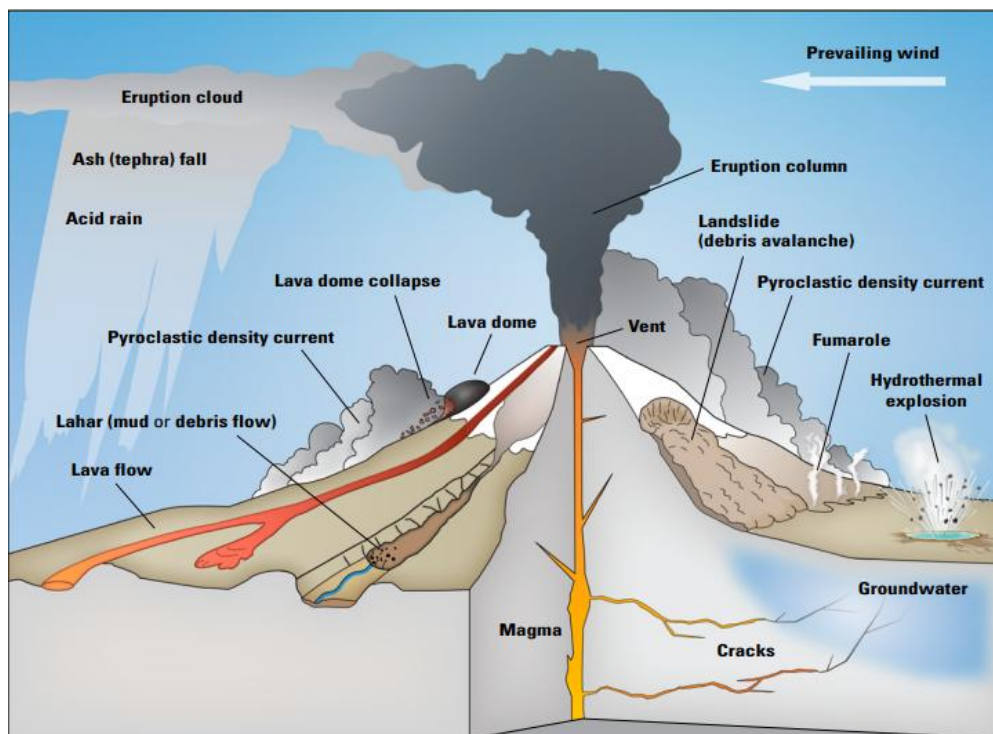
Tephra consists of shattered fragments of rock, minerals, and volcanic glass ejected during a volcanic eruption. The finest tephra (less than 2mm in size) is called volcanic ash. Large eruptions generate ash plumes that rise high into the air and can be transported hundreds of miles downwind from a volcano and blanket hundreds of square miles in ash. All ash is a threat to aviation. Ash clouds reduce visibility, damage flight control systems, and can cause jet engines to fail.²⁷² Roughly 300,000 people fly over or near volcanoes every day, mostly those located in Alaska.²⁷³ In 2010, an ash cloud from a volcanic eruption in Iceland forced the week-long closure of airspace for most of northern Europe. The cost of this disruption was estimated at \$10 billion.²⁷⁴

Each volcano produces ash with unique physical properties which means effects vary by volcano. The physical properties of ash from different volcanoes is not so different that the hazard is different, but it does mean that ash from pre-historic eruptions can be traced to a specific volcano by its chemical signature. Major ash effects include:

- Eye and respiratory irritation. Ash is most dangerous to people with pre-existing conditions.
- Building and infrastructure damage. Ash can get as heavy as concrete when wet and does not melt away like snow. In extreme cases it can cause roof collapse and can damage roadways.
- Equipment damage. Ash can clog filters, damage moving parts, and cause electrical short circuits.
- Power outages.
- Travel difficulty due to reduced visibility on roadways and damage to motors.
- Ash can cause severe impact to and disruption of aviation operations.
- Water systems can be impacted by turbidity (water becoming cloudy). Many people worry ash will make drinking water toxic, but most post eruption investigations found water quality unaffected except for sediment.
- Wastewater systems can be damaged by a large volume of ash. Cities with combined stormwater and sewer systems are more vulnerable.²⁷⁵

The USGS's Cascades Volcano Observatory participates in the [Volcanic Ashfall Impacts Working Group](#) that educates the public about ash impacts, mitigation, response, and recovery.

Figure 35. Types of Volcano Hazards²⁷⁶



Post-eruption Sedimentation

Post-eruption sedimentation is the incremental transport of sediment from the headwaters of a river to lower river reaches that can occur days, weeks, or even years after an eruption. Such excess sedimentation can also occur following a large lahar. The resulting increase in sediment downstream can

reduce carrying capacity for river channels and increase flood risk. It is a risk to navigation and the environment that can persist for decades. The US Army Corps of Engineers spent \$400 million mitigating sediment from the 1980 Mt. St. Helens eruption.²⁷⁷

Volcano Hazards That Are Not a Threat to Seattle

A variety of hazards that from volcanoes are localized to the volcanoes immediate area and are therefore not a threat to Seattle. They are described here because many people think Seattle is exposed to them.

Pyroclastic Flows

A pyroclastic flow is a mixture of rock fragments, gas, and ash that travels rapidly (tens of miles per hour) away from a volcano. It hugs the ground, flattening most everything in its path, but can also loft clouds of fine ash. Ejected material melts snow and ice on glaciated volcanoes. The melt water mixes with volcanic material and can create muddy slurries called lahars which are potentially more dangerous because they can increase their size downstream and flow many tens of miles from a volcano. This process caused some of the lahars that raced down rivers during the Mt. St. Helens eruption on May 18, 1980

Volcanic Landslides

Volcanoes are naturally weak structures and experience slope collapses, typically during an eruption. Volcanic landslides can be huge. When Mt. St. Helens erupted in 1980, 2.5 cubic kilometers of rock collapsed. Despite their large size, these landslides are a direct danger only to the immediate area surrounding the volcano. The major danger they pose to communities farther away is by supplying material that, when mixed with water, can transform into a lahar. Post-eruption sedimentation is also a long-term issue for areas downstream.

Volcanic Gases

Magma contains dissolved gases that may escape as magma rises to the surface or be released along with tephra into the atmosphere during eruptions. They can become attached to tephra particles or water droplets and fall with them back to earth. The most common volcanic gas is water vapor, with smaller, though sometimes substantial, amounts of sulfur dioxide, carbon dioxide (a greenhouse gas), and lesser amounts of hydrogen sulfide (a cause of acid rain) among other gases. High concentrations of both sulfur dioxide and carbon dioxide can be life-threatening in high concentrations near a volcano. However, the highest probability effect of volcanic gases is exacerbating existing pollution.

Lava Flows

Most volcanoes of the Pacific Northwest produce a very viscous type of lava that piles up around the vent as lava domes or moves very slowly and extends only a few miles from its source. On occasion, Cascades volcanoes can produce much more fluid lava that can travel several miles.

History

The events listed in this section focus on the most recent activity known from the volcanoes posing the greatest hazard to Seattle. Two Cascade volcanoes have fully erupted in the 20th century; Lassen Volcanic Center in northern California in 1914-1917 and Mt. St. Helens in 1980-86 and 2004-08. Of the 18 volcanoes the USGS ranks as a Very High Threat, 4 are in Washington State. Mt. St. Helens and Mt. Rainier rank second and third and Mt. Baker and Glacier Peak are fourteenth and fifteenth. Mt. Adams is considered a High Threat volcano and ranked thirty-fourth. Mount Hood, although located in Oregon (near Portland) could also pose a threat to Seattle if an eruption included ashfall. It is also a Very High Threat volcano ranked 6th.²⁷⁸

Mt. Rainier

Mt. Rainier poses the greatest volcanic risk to Seattle. The last magmatic eruption is believed to be about 1,100 years ago. This caused lahars that traveled as far as Auburn and raised the level of the Duwamish Valley. Explorers and pioneers of the 19th century reported “smoke” and earthquakes near the mountain, but there is no physical evidence of eruptive activity during this time. In addition, Rainier has experienced six eruptive episodes since the last glaciation:

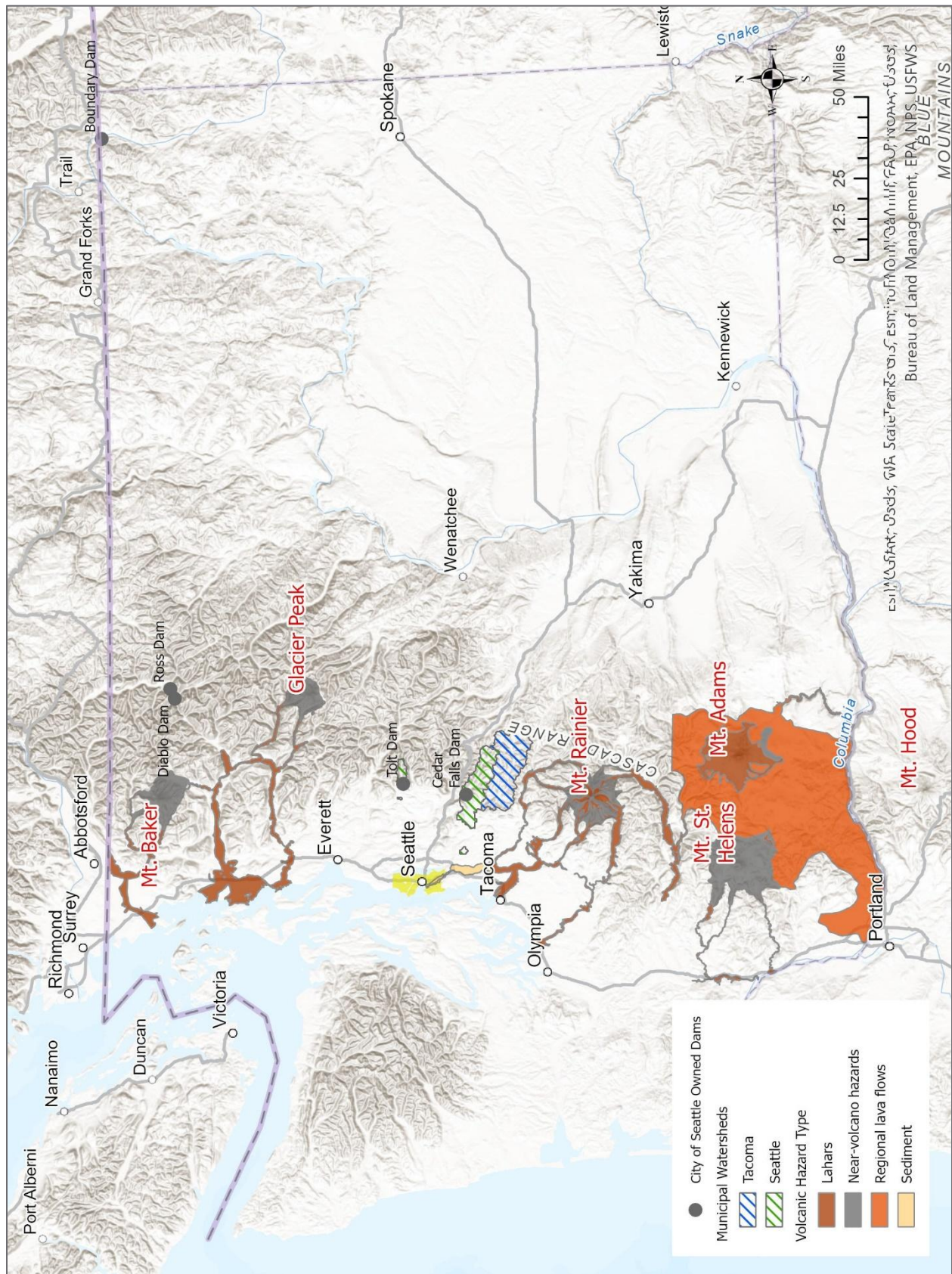
- 11,000 years ago. Deposited ash in Mt. Rainier National Park and triggered at least one lahar.
- 7,400 to 6,700 years ago. Produced four moderately explosive eruptions and three or more lahars that traveled as far as Orting.
- 5,600 to 4,500 years ago. The major event was the Osceola Mudflow which reached Puget Lowlands to the present sites of Tacoma and Kent covering 82 square miles. Puget Sound extended to Kent at the time. Lahars helped create the Duwamish Valley by filling the narrow arm of Puget Sound with sediment.
- 2,700 to 2,000 years ago. Produced lahars that reached Auburn with subsequent sediment reaching the Duwamish Valley.
- 1500 years ago. Small eruptions with lahars.
- 1,100 to 1,000 years ago. One or two lahars reach Auburn.
- 500 years ago. The Electron Mudflow, which traveled to at least the town of Sumner, but there is no definitive evidence of an eruption.²⁷⁹

Prior to the Osceola Mudflow 5,600 to 4,500 years ago, Puget Sound extended 25 miles south to Kent from the present mouth of the Duwamish River. The story of how those arms vanished is connected to Mt. Rainier. Mt. Rainier generates many lahars. During the past 10,000 years, at least 60 lahars of various sizes have moved down valleys that start at Mt. Rainier; the largest was the Osceola Mudflow. It was caused by collapse of hydrothermally weakened rock on the volcano’s east-northeast flank. The large landslide from that collapse rapidly transitioned into a swiftly moving lahar. It may have been triggered as magma forced its way into the volcano. Osceola deposits cover an area of about 212 square miles in the Puget Sound lowland; they buried the area around Enumclaw and extended at least as far as Tacoma’s Commencement Bay and Kent. The Osceola lahar and subsequent lahars extended the mouth of the Duwamish northward to its present location aided by uplift from the last major Seattle Fault earthquake.²⁸⁰

That part of the story ends in 1906. Until 1906 the White River, originating on the north slope of Mt. Rainier, drained into Elliott Bay, connecting Mt. Rainier directly to Seattle. In 1906, the White River was diverted to drain into the Puyallup River and Commencement Bay in Tacoma. The move also redirects the path of lahar along the White River to Tacoma, but Seattle is still at risk, because a large lahar could carve a path through the Kent Valley lowlands to the Green River which runs less than two miles north of the White. The Green River connects directly into the Duwamish.

Eruptions have also spawned lahars. For example, about 2,200 years ago, the National Lahar—triggered during an eruption--inundated the Nisqually River valley to depths of 30-120 feet and flowed all the way to Puget Sound. About 1,200 years ago, a lahar filled valleys of both forks of the White River to depths of 60 to 90 feet and flowed 60 miles. And as recently as 500 years ago, the Electron Mudflow, triggered by a large landslide off the west flank of the volcano, nearly reached Puyallup. The Electron Mudflow has not been correlated with an eruption. The Electron Mudflow was more than 90 feet deep at its head. Its deposits at Orting are as much as 18 feet thick and contain remnants of an old-growth forest.

Figure 36. Washington State’s Volcanoes and Exposed Infrastructure



Mt. St. Helens

The May 18, 1980, eruption was the largest in the Cascades in recent history but produced only a trace amount of ash in Seattle. The eruption began with a magnitude 5.1 earthquake and a large debris avalanche (landslide).²⁸¹ Mt. St. Helens has been consistently the most active of the Cascade volcanoes, with earlier, smaller eruptions in 1800, 1831, 1842 and 1857.²⁸² Mt. St. Helens has been a prolific tephra (ash) producer with numerous eruptions over the past 4,000 years.²⁸³

Out of Washington's volcanoes, Mt. St. Helens is believed to be the most likely to erupt again in the near future. A future eruption probably would not have a major lateral blast or landslide again because of the deep crater that was produced in the May 18, 1980, eruption.²⁸⁴ The USGS ranks Mt. St. Helens as the greatest risk to aviation in the contiguous US.²⁸⁵

Mt. Baker

The last major eruption was approximately 6,700 years ago. Since then, Mt. Baker experienced a small steam eruption in the mid-1800s and an increase in steam and heat.²⁸⁶ Small lahars caused by rainfall or glacier outburst floods occur from Mt. Baker every decade or so. The greatest threat from a future eruption is from lahars, which could reach the Puget Sound near Bellingham.

Glacier Peak

Glacier Peak generated a sequence of six tephra eruptions over a period of several hundred years about 13,000 years ago, but since this series its eruptions have switched from explosive to effusive (more lava flow). Because of this switch, the USGS does not rank Glacier Peak as high a Mt. St. Helens and Mt. Rainier among Washington's volcanos.²⁸⁷ When Glacier Peak was in its explosive eruptive period, the largest eruption ejected more than five times as much tephra as the 1980 Mt. St. Helens eruption. Ash from these eruptions have been found under Lake Washington and Portage Bay underscoring that ash is a risk to Seattle. More recently, Glacier Peak experienced small steam eruptions in the 1700s.²⁸⁸ The Cascades Volcano Observatory estimates that each year there is a 1 in 1,000 chance that Glacier Peak will erupt.²⁸⁹

Mt. Adams

The last definitive volcanic eruption of Mt. Adams occurred between 3,800 and 7,600 years ago. Typical behavior of Mt. Adams over the past several thousand years has been primarily eruptions of cinder cones and lava flows near the base of the volcano; eruptions have seldomly been explosive. The few downwind ash layers it has produced in the last 12,000 years are small in volume and limited in extent.²⁹⁰ Mt. Adams has shown fewer highly explosive eruptions than other Cascade volcanoes. The biggest hazards for people near Mt. Adams are landslides and lahars, neither of which are a direct threat to Seattle.²⁹¹

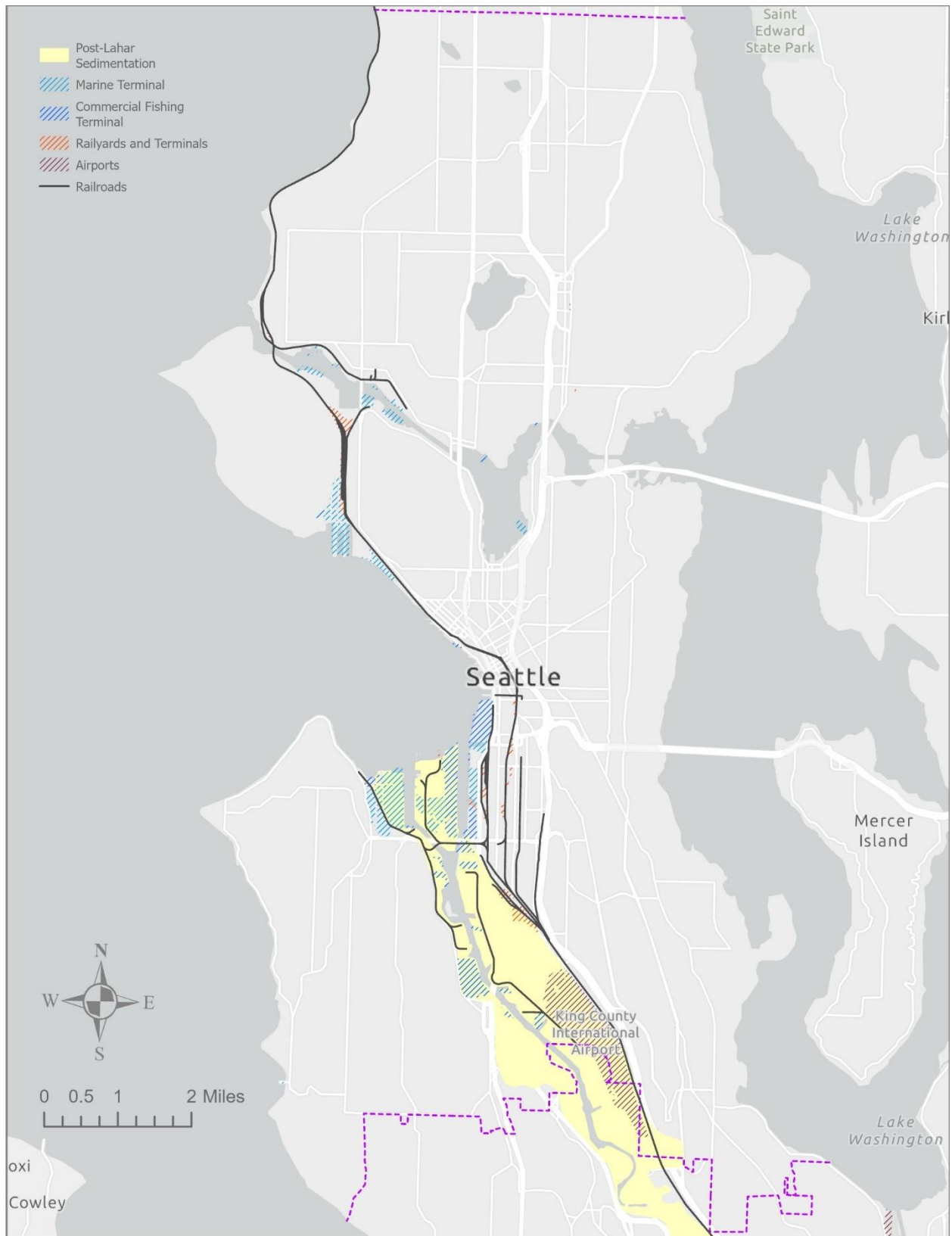
Mt. Hood

Mt. Hood has been intermittently active, most recently in the late 1700s when an eruptive episode lasted for about a decade. Early settlers reported eruptive activity in 1859 and 1865, but no deposits have been found that confirm these accounts.²⁹² Ashfall and pyroclastic flows from Mt. Hood eruptions have been limited in extent.²⁹³ Mt. Hood poses more of a threat to Portland than Seattle.

Vulnerability

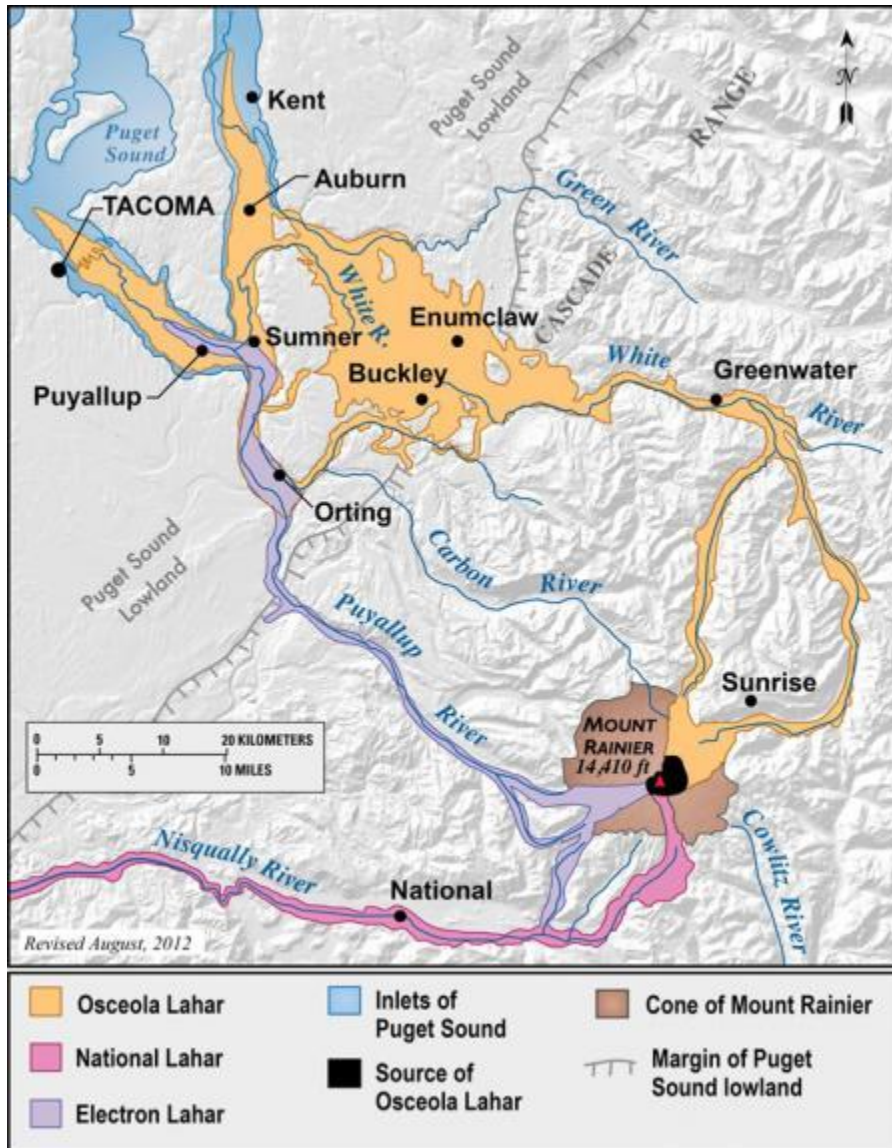
Seattle is vulnerable to post-lahar sedimentation through river systems that connect to Mt. Rainier. Seattle's placement relative to the Cascades volcanoes and the common westerly winds reduce its exposure to ashfall, but it is possible that winds from the east could blow ash to the area. Even if Seattle is not directly or significantly affected by either ashfall or lahars, it can be indirectly affected if the surrounding region is affected.

Figure 37. Areas Exposed to Post-Lahar Sedimentation



City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Figure 38. Past Mt. Rainier Lahars²⁹⁴



Lahar Vulnerability

Kent Valley is more likely than Seattle to be directly affected by a lahar. Seattle is indirectly exposed to potential damage in the Kent Valley because it is heavily dependent on infrastructure located there.

Seattle's major river, the Duwamish, originates on Mt. Rainier's slopes. In theory, a lahar could reach Seattle, but geologists have not found evidence that one has. It is most likely that a lahar would stop south of Seattle in the Kent Valley. Subsequently, sediment would erode and transport farther downstream in a process known as post-lahar sedimentation.

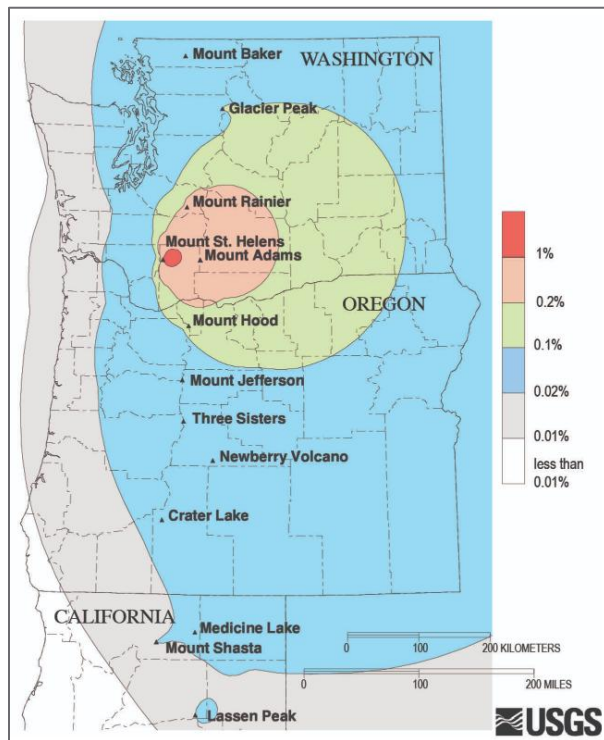
The Duwamish River has levees that provide protection against sediments, but their effectiveness depends on the volume of sediment accumulating on the channel bed. If sediment overtops levees or they fail, low-lying areas along the river could be inundated. Therefore, most of the SODO area should be considered at risk of sedimentation and flood inundation. Most of the land use in this area is industrial or related to transportation. About 3% of the area exposed to post-lahar sedimentation is residential. Mitigating this sediment depends on its volume, transit rate, time of year, and levee

condition among other factors. [Figure 37](#) shows the area identified by the Cascade Volcano Observatory as vulnerable to post-lahar sedimentation.

Seattle's transportation and utility lifelines would be exposed to post-lahar sedimentation in a worst-case scenario. All major utilities cross the area susceptible to post-lahar sedimentation. They include electrical transmission lines, water supply lines, sewer mains and the BP Olympic Pipeline. The area houses key transportation corridors, including I-5, SR 99, SR 509, and SR 599. It includes the King County International Airport (Boeing Field), rail yards, and large parts of the Port of Seattle.

The Kent Valley is exposed to lahar hazards and contains many critical lifelines. They include I-405, the BP pipeline, water lines from Seattle's main watershed, natural gas mainlines, and major power lines. Much of the food that reaches Seattle's grocery stores is distributed from huge centers in this area. Many people who work in Seattle either live in or commute through the Kent Valley. This indirect vulnerability due to exposure of lifelines outside the city extends to the whole Puget Lowland region.

Figure 39. Annual Probability of 1cm Ash Accumulation²⁹⁵



Ashfall Vulnerability

Seattle is exposed to ashfall, but the probability of a significant event is very small. The United States Geological Survey odds are 0.02% per year or 1 in 5000. Volcanic ash deposits from eruptions thousands of years ago have been found in Seattle, but the severity of these events is unclear. One ash layer found was less than 1-inch thick. In the Pacific Northwest, prevailing winds blow from the west to the east. Seattle is west of the Cascades volcanoes. If wind blows from other directions during an eruption, it could carry ash into Seattle.

Seattle is made more vulnerable due to its reliance on watersheds and hydroelectric facilities in the Cascades. Seattle is more likely to be impacted by ash falling into its watershed or onto power infrastructure than by ash falling directly on the city. When ash falls into a reservoir it can affect its turbidity (clearness). Ash is highly unlikely to make water in Seattle's watersheds dangerous to health. The volume of water to ash is too great for the ash to make a significant difference to its chemistry.

Table 15. Volcano Hazard Summary

Volcano	Ashfall	Lahar	Post-Lahar Sedimentation
Mt. Rainier	✓	Highly unlikely	✓
Mt. St. Helens	✓	No	No
Glacier Peak	✓	No	No
Mt. Baker	✓	No	No
Mt. Adams	✓	No	No

The power system can be vulnerable in the right conditions. Ash that falls on electrical insulators can cause flashovers, a disruptive electrical discharge that can cause outages.²⁹⁶ Flashover is more likely to happen when the ash has become wet from dew, light rain, or mist. If enough ash accumulates on transmission lines, it can overload them and increase the risk of an outage. Flashovers occurred in areas with more than 5 millimeters of ash (and rain) and power lines broke due to ash accumulation during the Mt. St. Helens eruption in 1980. It is difficult to fully assess the vulnerability of the hydroelectric power generation system because there have been few instances of this happening.

Seattle is vulnerable to impacts of ash on aviation. When ash enters jet engines, it has been shown to cause many damaging and dangerous effects, including mid-flight engine failure.²⁹⁷ Ash can lead to the closure of airspace, cancelled or delayed flights, and reduced visibility on runways.

Seattle's ground transportation network is vulnerable to ashfall. Reduced visibility and reduced traction on roads can make driving conditions dangerous.²⁹⁸ Additionally, ash can clog track switches for railways. Both the BNSF railway and Amtrak shut down for a day in Montana due to 1 to 2-millimeter ash accumulation following the Mt. St. Helens eruption.²⁹⁹

Consequences

The consequences from ashfall or post-lahar sedimentation mainly pose threats to property, infrastructure, and the environment. Seattle faces secondary consequences of a lahar reaching the Kent Valley.

Lahars and Post-Lahar Sedimentation

A lahar's consequences would depend on where it originated and how far it traveled. Mt. Rainier poses the biggest risk because it can generate very large lahars and sits closer to the densest part of the Puget Sound area than the other Cascades volcanoes. In the most likely case, Seattle would have to deal with the effects of a lahar in areas outside the city. For example, a lahar from Glacier Peak or Mt. Baker could close Interstate 5, north of Seattle. A lahar at Mount St. Helens could close Interstate 5, south of Seattle. In the case of a Mt. Rainier lahar, the greatest consequence is post-lahar sedimentation in the Duwamish River.

In a post-lahar sedimentation event, sediment could wash down the river for years. Lahar material from the Kent Valley could introduce polluted debris into the waterway which is undergoing restoration and cleanup. The increased sediment and dredging operations would set back environmental restoration

efforts. Salmon and other wildlife populations in the Duwamish/Green River floodplain could be devastated if their habitat is dramatically altered.

If sediments accumulated, economic activity in Seattle could be affected. Even a short closure could be costly. Portland lost \$20 million (adjusted to 2025 dollars) when its port closed after the 1980 Mt. St. Helens eruption.³⁰⁰

A lahar and sedimentation could possibly alter the course of several rivers, including the White River which joins the Puyallup River as it flows to Tacoma. They could link it with the Green River instead of the Puyallup River. This would increase water volume and transport sediment toward Seattle.

If sediment breaches the levees along the Duwamish River, the consequences grow more severe. Property, lifelines, and critical facilities would be affected. The property exposed to lahar hazards is predominantly transportation related and industrial but includes 117 acres of residential property. The area is heavily used by the Port of Seattle, Boeing, and commodity distribution centers. The Georgetown and South Park residential communities are in the same area. Given the time sensitivity of many port freight operations and very competitive margins, prolonged outages could have severe economic effects.

If the Duwamish Valley floor is inundated, several vital transportation routes, SR-99 and I-5 could be blocked. Most of Seattle's rail lines, including major railyards, occupy this area. These yards include the Union Pacific yard where Seattle's garbage is loaded daily onto trains bound for landfills in Oregon.

If a lahar were to reach Seattle, there could be lives lost if people cannot evacuate before the lahar arrived. Unlike populated areas closer to Mt. Rainier, Seattle does not have an audible warning system. Transportation, utilities, and economic activity would suffer long-lasting damage due to infrastructure damage. The Duwamish Valley and all the other valleys leading up to Mt. Rainier could be buried under mud ranging from a few feet thick near the end of the lahar to many tens of feet thick closer to Mt. Rainier.

Because the Duwamish Valley is mostly industrial, the highest population exposures are during the day when an estimated 46,600 are in the area exposed to post-lahar sedimentation. At night the estimate drops to 5,577 people, mostly in the Georgetown and South Park areas.³⁰¹

Ashfall

The experiences of Yakima and Spokane in 1980 provide a case study of an ashfall emergency. Yakima received about 3 inches; Spokane received 2 inches. Both communities were shut down for days. The ash falls darkened the sky, causing a "midnight at noon" in Eastern Washington that lasted for 18 hours. The ash caused power outages and damage to sewer treatment equipment. Interstate 90 was closed for one week, and over 1,000 commercial flights had to be canceled.³⁰² It took Yakima 10 weeks to clean up the ash. While both cities are well prepared for snowstorms, both were overwhelmed by the ash.

An ashfall in Seattle would have five potentially large direct impacts:

- Ash would irritate people's eyes and throats, especially those with existing respiratory trouble, but it would rarely cause death.³⁰³ Many people had to wear masks in Eastern Washington or stay inside while the ash fell. The same could happen in Seattle. Blowing ash could prolong these problems, especially if the ash is very fine.
- Traffic would stop if ash covered the roads. Driving can reduce visibility and when ash becomes wet, it is as slippery as ice. Accidents would probably increase. Although the timeframe of an

eruption could generally be predicted, an actual eruption could catch many people on the roads, making it potentially worse than a snowstorm.

- Vehicles and other machines would break down as the ash clogged their moving parts. This would compound traffic and clean-up problems.
- Ash could disrupt the city's utilities. Wastewater systems are especially vulnerable to ash, especially if sewage and stormwater are collected in one network as they are in parts of Seattle. In reservoirs it would increase turbidity, making the water undrinkable until it settled or was filtered out, and could cause environmental damage. It could also damage power distribution and generation facilities, prompting expensive emergency power purchases.³⁰⁴ Wireless communications and public safety would be impeded.
- The City would incur clean-up costs. The City of Yakima paid at least \$1.1 million at the time to remove ash from the streets.³⁰⁵ Considering that cost would be \$5 million in 2025 dollars, and Seattle's population is over 6 times as large as Yakima, the cost of clean-up in Seattle would be significant. These problems could be worse if it were to combine with water and fall from the sky as mud. When ash becomes wet, it acts like cement. The weight could lead to roof collapses throughout the city.

A heavier ashfall would cause more severe versions of problems expected by the more likely scenario. If the ash is acidic or acidic rain falls, injuries and damage would increase. An Alaskan volcano produced acidic ash that burned victims' eyes, throats, and lips, making eating difficult. Other acidic rains burned the skin. Acidic rains have also destroyed clothing and corroded metal. These alarming effects are rare and did not occur during the 1980 Mt. St. Helens eruption.

The costs of a heavy ashfall would halt economic activity for several days or weeks and worsen health outcomes for many people. Since an ashfall would affect the whole Puget Sound region, Seattle could not rely on aid from neighboring governments.

Outlook

The USGS estimates that there is a 1 in 5,000, or 0.02% chance per year, that Seattle will receive ashfall in excess of 1 centimeter.³⁰⁶ The USGS has produced a map showing annual probabilities of 1 cm ash accumulation throughout the West Coast ([Figure 39](#)). Geologists have found volcanic ash deposits from eruptions that happened thousands of years ago in various areas of Seattle. Ash from a Glacier Peak eruption (roughly 13,400 years ago) and the Mt. Mazama/Crater Lake eruption (roughly 7,600 years ago) have been found on the bottom of Lake Washington and Portage Bay.³⁰⁷ Ash deposits that date roughly 200,000 years ago have also been found under Hamm Creek in the Duwamish Valley, but their origin is unknown.³⁰⁸ The Glacier Peak ash layer was less than 1-inch thick, and the amount of ash received from the other eruptions is unknown.

The Cascades Volcano Observatory estimates Mt. Rainier lahars with the potential to cause significant post-lahar sedimentation in the Duwamish Valley occur every 500 to 1000 years.³⁰⁹ Mt. Rainier is a major producer of lahars because of its size and the volume of water trapped in the glaciers along its slopes. Small, localized lahars (debris flows) that are not caused by an eruption on Mt. Rainier are more likely to occur in the summer or fall, when melting water is prevalent and intense rain can fall on exposed, unconsolidated ground.³¹⁰ Most Cascades glaciers, including those on Mt. Rainier, are shrinking. As they retreat, unstable terrain is exposed. As a result, small debris flows are becoming more common, and the released sediment is being washed downstream. This, in turn, decreases the capacity of rivers originating at Mt. Rainier and makes them more likely to overflow their banks. These types of flows are too small to reach Seattle and typically do not go outside the Mt. Rainier National Park boundaries. Although the risk of lahars reaching Seattle is quite small, uncertainty exists because the last

major lahars occurred hundreds of years ago when Puget Sound extended further up the Duwamish Valley.

Conclusions

Casualties are likely to be small compared to the economic effects. A lahar, one of the deadliest volcanic hazards, is extremely unlikely to reach Seattle. Non-typical weather patterns during an eruption could produce ashfalls.

Since geologists can generally detect conditions that precede eruptions, the city would likely have time to prepare itself for ashfall or post-lahar sedimentation. Mitigating sediment loads through dredging and sediment retention dams would lessen the need to move people and economic activity downstream.

Planners should be prepared for ashfall. During the Mt. St. Helens May 18, 1980, eruption, many cities were caught unprepared because they assumed they would not be affected.

4. TSUNAMIS AND SEICHES

This chapter covers hazards caused by water waves: tsunamis and seiches. Both are often triggered by earthquakes but can be caused by landslides and volcanic eruptions which is why they are given their own chapter.

Seattle's biggest tsunami risk comes from the Seattle Fault. A repeat of the last large earthquake on this fault could create waves up to 42 feet tall that would strike Seattle's shoreline within 3 minutes and flood low lying areas around Elliott Bay.

A tsunami from a Cascadia Subduction Zone earthquake would also impact Seattle. Recent models for a large tsunami produced by a magnitude 9 earthquake on this fault show that it would generate waves up to 7 feet in Seattle. At these heights, impacts will be dependent on the tidal stage. This tsunami would cause dangerous currents especially around Harbor Island that could damage watercraft and overwater structures near the shoreline.

Tsunamis generated from distant sources, like Alaska or across the Pacific Ocean, can affect Washington State, but are highly unlikely to have a significant impact on Seattle given that the waves must propagate through the Strait of Juan de Fuca and Puget Sound.

Landslides into or under water as well as earthquakes on other Puget Sound faults that cross water bodies could also generate tsunamis.

A seiche is the sloshing of water in enclosed or semi-enclosed waterbodies caused by seismic waves. Lake Union is our most vulnerable waterbody, but seiches can happen in other lakes and Puget Sound as well. Distant earthquakes can cause seiches even when the earthquake is not directly felt in Seattle. Seiches are standing waves that develop when two propagating waves travel in opposite directions. The National Ocean Service has an [animation](#) that shows how they work. Seiches have not been as extensively modelled as tsunamis and the hazard is not as well understood.

Tsunamis

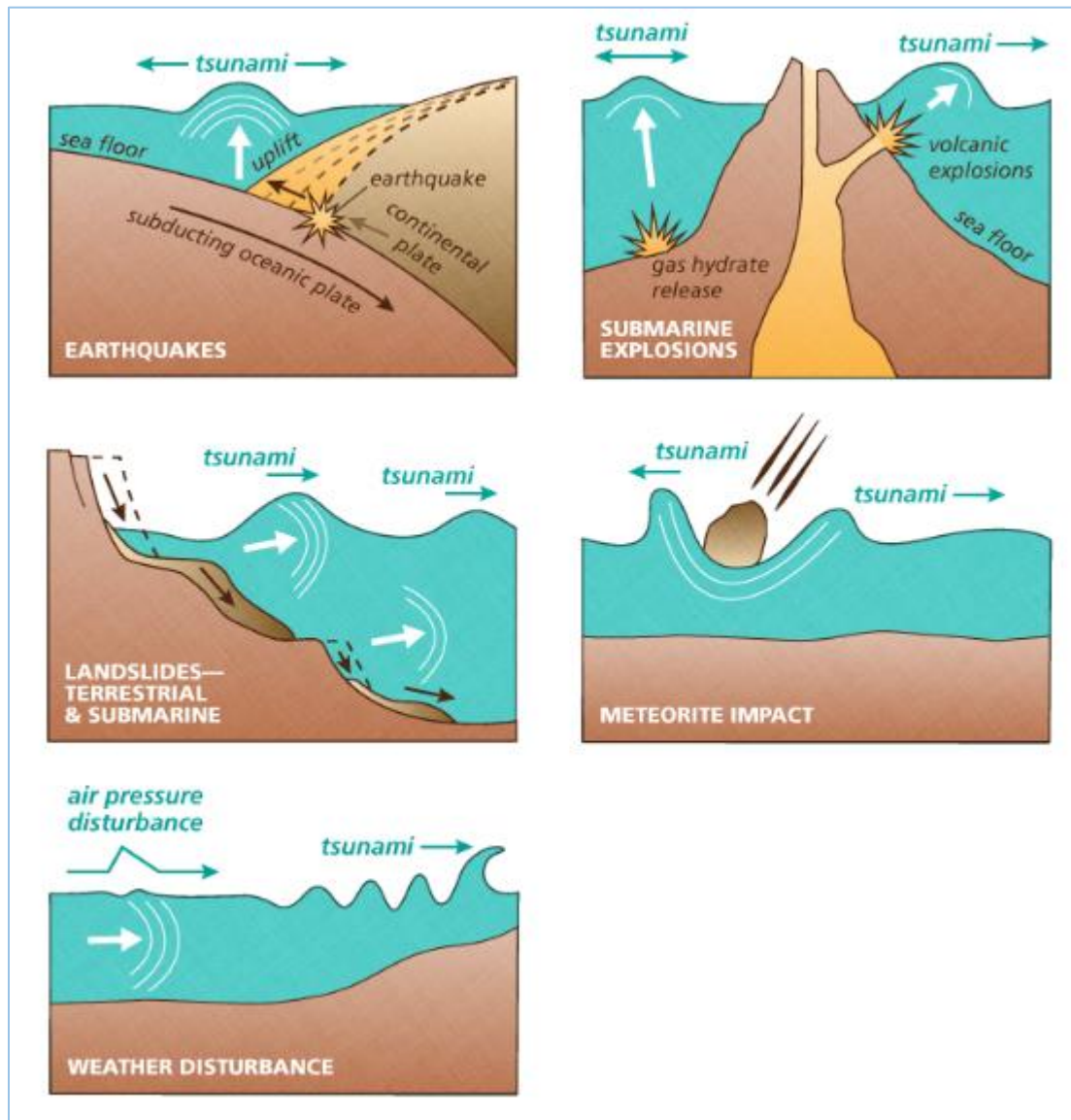
Tsunamis are a series of waves resulting from a sudden, large-scale displacement of water. They can be caused by landslides under or into the water, large submarine earthquakes, eruptions of underwater

Key Points

- ❖ *Lead Agency – Seattle Fire Department*
- ❖ *The greatest tsunami risk is the shoreline along Elliott Bay and Sodo and to watercraft. In the worst case, areas up to a mile inland could be flooded. Inundation would be up to 16 feet deep.*
- ❖ *In Seattle tsunamis can come from*
- ❖ *Seattle Fault and other local faults*
- ❖ *Cascadia subduction zone*
- ❖ *Distant earthquakes*
- ❖ *Landslides*
- ❖ *The worst-case tsunami would stem from a large Seattle Fault earthquake*
- ❖ *The likelihood of M7 or greater Seattle Fault earthquake in the next 50 years is low but would have very severe consequences.*
- ❖ *The greatest seiche hazard is in Lake Union to overwater structure and those directly on the shore.*
- ❖ *Seiches are sloshing in enclosed waterbodies.*
- ❖ *They can be caused by distant earthquakes.*
- ❖ *New research since last SHIVA update:*
 - *New Cascadia and Seattle Fault Tsunami models*
 - *New research on the frequency of Seattle Fault earthquakes*

volcanoes, meteor impacts into a body of water, and some weather systems. In Washington State the most likely sources of tsunamis are earthquakes and landslides.

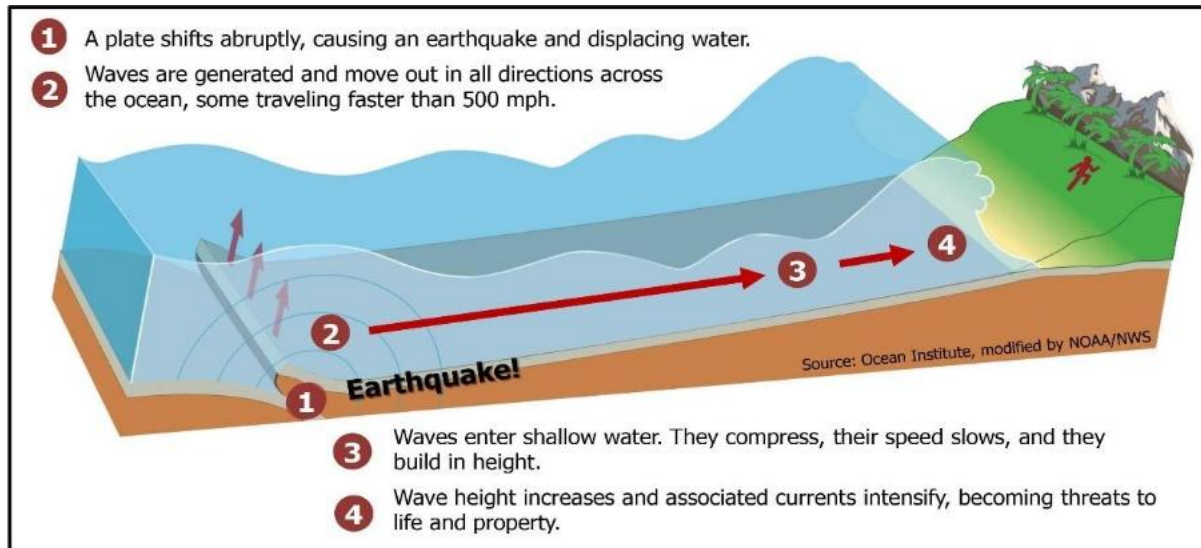
Figure 40. Tsunami Sources



Earthquakes generate tsunamis when the seafloor deforms abruptly and vertically displaces the overlying water column. The displaced water travels outward in a series of waves that grow in intensity as they encounter shallower water near coastlines as illustrated in [Figure 41](#). Tsunamis are hard to detect without instruments in the deep, open ocean where they have amplitudes (heights) of only a few feet but have wavelengths (the distance between wave crests) of hundreds of miles, and travel at speeds the same as jet airplanes.³¹¹ As these waves approach a shoreline and water depth decreases, the front of the waves slow in speed, causing waves behind to rise up, which shortens the wavelength, and increases the wave amplitudes dramatically. As tsunamis near a shoreline, they can reach 100 feet tall and move 30 miles per hour.

Tsunami wave impacts are greatest in and around ocean beaches, low-lying coastal areas, and bounded water bodies such as harbors and estuaries. While tsunamis are often depicted as one large wave, they are a series of waves, with a distance between crests of 60 or more miles in the ocean. The time

Figure 41. Tsunami Generated by Earthquake



between successive waves reaching the shore can vary from 5 minutes to 2 hours.³¹² These waves interact with each other and with shorelines, which is why a single tsunami event can last for several hours. The first waves may not be the largest in the series, nor the most destructive. The tsunami's effects include not only rapid flooding of low-lying land, but also dangerously strong currents. As the water travels inland, it scours the ground and picks up large debris, which gives the waves an additional element of destructive force.

Whether an event causes a tsunami depends on the volume of water displaced and the speed at which it was displaced. Most significant tsunamis are triggered by earthquake events of magnitude 7 or larger that feature large uplift or subsidence of the sea floor, but magnitude alone is not sufficient in predicting a tsunami.³¹³ Along with the vertical movement of the earth during an earthquake, horizontal movement and the [bathymetry](#) of the sea floor influence tsunami generation and size.

Some tsunamis break when they reach land while others rush ashore as a huge mass of water, like a sudden massive tide. Others break far from land and come ashore as a turbulent cascading mass called a bore. The size and speed of the tsunami as well as the coastal area's form and depth are factors that affect the tsunami's shape. The power of a tsunami comes from the huge amount of water behind the wave's leading edge. Normal waves have a small volume, so they dissipate quickly when they strike the shore. Tsunamis do not. Their huge volume pushes the water far inland. This phenomenon is called inundation and runup, and its size is what often determines a tsunami's destructiveness.³¹⁴ The tide at the time of the tsunami influences runup. A tsunami or seiche riding on a high tide presents greater danger than one occurring at low tide.

Tsunamis rarely come ashore without warning. Though localized coastal flooding may precede the first wave the shoreline water may also recede before the first tsunami wave arrives. This is dangerous because many people, unaware of the looming danger, venture too close to shore and are caught by subsequent waves.

Tsunamis generated in enclosed bodies of water can be especially large. The collapse of a 3,000-foot-tall rock wall in a narrow Alaska fjord stripped vegetation over 1,700 feet high on the opposite shore.³¹⁵ While the Seattle area does not have any cliffs nearly that size, it does have steep sea bluffs along enclosed bodies of water, and a high susceptibility for submarine landslides.

Tsunamis triggered by earthquakes pose the greatest risk to Washington's coasts. Washington state faces one of the highest tsunami risks in the United States. Over 175,000 residents and visitors are

located within Washington's tsunami inundation zone at any given time, along with key military, transportation, and economic infrastructure. The location of the earthquake plays a key role in determining the tsunami travel time to a coastal community, as well as its impact on the community. Washington is at risk from both local source and distant source tsunamis, which are outlined in more detail below.

Local source tsunamis are tsunamis for which the first waves arrive at a location in under 3 hours. If a local source tsunami is caused by an earthquake, those nearby will most likely feel the ground shaking. In Washington, these tsunamis are primarily caused by large underwater earthquakes along the Cascadia Subduction Zone (CSZ) and upper plate crustal faults along the Puget Sound such as the Seattle Fault Zone (SFZ).

A Cascadia Subduction Zone tsunami is the greatest local tsunami threat for Washington as a whole, while a Seattle Fault Zone tsunami is the greatest tsunami threat for Seattle specifically. While a Cascadia tsunami would be much larger, it would have to propagate through the Strait of Juan de Fuca and Puget Sound before it reached Seattle. In contrast, a Seattle Fault tsunami would be generated in waters immediately adjacent to Seattle. Both would have significant effects, but the Seattle Fault tsunami would cause more damage.

A large earthquake along the Seattle Fault Zone, such as the estimated magnitude 7.5 event that occurred in the year 923, could generate destructive tsunami waves within Puget Sound. The impacts from a local source tsunami can be severe. The waves for a SFZ tsunami can be potentially dozens of feet high with very fast currents, which cause significant damage to areas within the hazard zone in Seattle. There is very little time for local authorities to respond and for people to evacuate to high ground before the first waves arrive. Strong currents and water level changes would continue for 12-24 hours or longer. These waves would inundate coastal areas within minutes, with strong currents and significant water level changes persisting for hours. The SFZ scenario also poses unique risks to the densely populated and industrialized areas around central Puget Sound, where the proximity to the fault could exacerbate both shaking impacts and tsunami hazards. Washington has other crustal faults scattered throughout the Puget Sound and Salish Sea with unknown tsunamigenic potential.

While a Seattle Fault Zone tsunami would be devastating for Seattle, an earthquake along the CSZ would produce catastrophic tsunami waves that could inundate coastal areas from Vancouver Island to Northern California. Some waves would hit Washington's outer Pacific coast within 10-20 minutes in some locations. These waves would then hit low-lying parts of the northern inland waters and Puget Sound within two hours or more. For King County, casualties for a CSZ tsunami are estimated to be nearly none given wave arrival for much of the County is over 2 hours. A CSZ earthquake and tsunami combined are estimated to damage over 300-400+ buildings, causing 505–616 million dollars of damage to buildings within the range of the tsunami inundation zone in King County.³¹⁶ This does not include economic impacts or damage to maritime, infrastructure, or lifelines.

A Cascadia Subduction Zone tsunami would cause an estimated 50,000–65,000+ casualties within the first hour statewide. This number represents an estimated 29–37% of the total at-risk population in Washington, not including daytime visitors in the inundation zone. A CSZ tsunami and earthquake is estimated to damage 39,000-41,000+ buildings, causing 18–22 billion dollars of damage to buildings within the range of the tsunami inundation zone in Washington.³¹⁷ The last major earthquake along the CSZ occurred in the year 1700 and produced large tsunami waves and subsidence along the outer coast.

With both the CSZ and crustal faults (like SFZ), earthquake shaking could trigger landslides that generate additional localized tsunamis, compounding the immediate impacts. Aftershocks of sufficient size may also produce secondary tsunamis in the days, weeks, and months following a major CSZ earthquake.

Seattle's most significant tsunami hazards are due to earthquakes and landslides. Our understanding of our tsunami risk is thanks to insightful work by scientists finding physical evidence of past tsunamis and modelling potential future tsunamis. The Washington State Department of Natural Resources has an excellent [overview of tsunami causes](#).

Seiches

[Seiches](#) are standing waves in which the largest vertical oscillations are at each end of a body of water with very small oscillations at the center point of the wave.³¹⁸ The waves are created by the sloshing of water in an enclosed or partially enclosed waterbody, like water sloshing in a bathtub. Standing waves have a large vertical component. They can be caused by seismic waves, landslides, atmospheric pressure, and wind. The source displaces water, producing long period waves like tsunamis. In an enclosed waterbody, when the wave reaches a shoreline, it reflects. If the reflected wave meets another incoming wave, a standing wave can build. Even weak seismic waves can cause large seiches if the waves resonate with the waterbody. It works by applying energy at the right time to build wave height just like pumping one's legs to make a swing go higher. Usually, these kinds of seiches are caused by distance source earthquakes. The long period waves generated by earthquakes travel long distances. Larger bodies of water usually have longer frequencies, and it takes longer frequency waves traveling through the ground to create seiches in them. Therefore, these types of seiches tend to occur far from earthquake epicenters.³¹⁹ The biggest danger is from subduction zone or megathrust earthquakes that cause powerful, low frequency ground waves.

In past events, most observed damage from seiches was to watercraft and structures built over the water, but it is possible for waves generated by these types of seiches to run up on shore. However, run up has not been observed locally or modelled.

It is important to note that enclosed waterbodies can also experience conventional tsunamis as well. Tilting of the waterbody caused by ground deformation in an earthquake or by a landslide could push water across a lake where it would run up and inundate the shore.

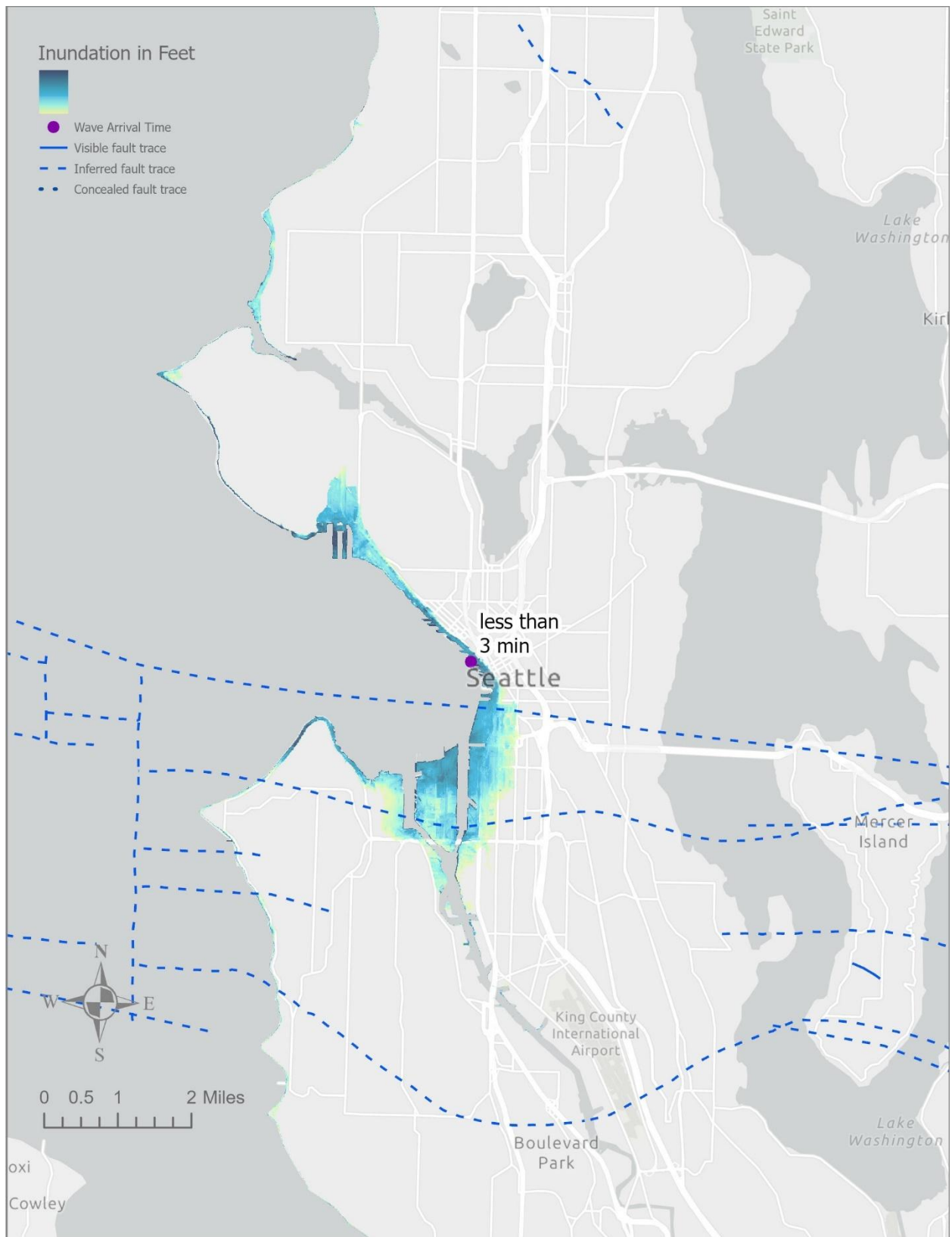
History

Major tsunamis in Seattle are rare but have potentially devastating events. The largest tsunami known to have occurred in Seattle happened over 1000 years ago. Tsunami deposits attributed to the Seattle Fault have been found in five locations in Puget Sound, including Seattle.³²⁰ The most likely source is an estimated magnitude 7.5 earthquake on the Seattle Fault between the autumn of 923 and spring 924 AD.³²¹

The 1964 Alaskan Earthquake caused a tsunami that was detected in Seattle. It raised the water level measured by Elliott Bay tide gauge by 0.8 feet. The waves were higher on the Pacific coastlines of Washington, Oregon, and California. Friday Harbor and Neah Bay recorded maximum wave heights of 2.3 feet and 4.7 feet, respectively, and a home at the head of Discovery Bay was flooded by two separate waves during the night the tsunami arrived.³²² The tsunami's effect was negligible in Seattle because the wave had lost energy as it traveled up the Strait of Juan de Fuca. Whidbey Island may also have acted as a baffle for the incoming waves.

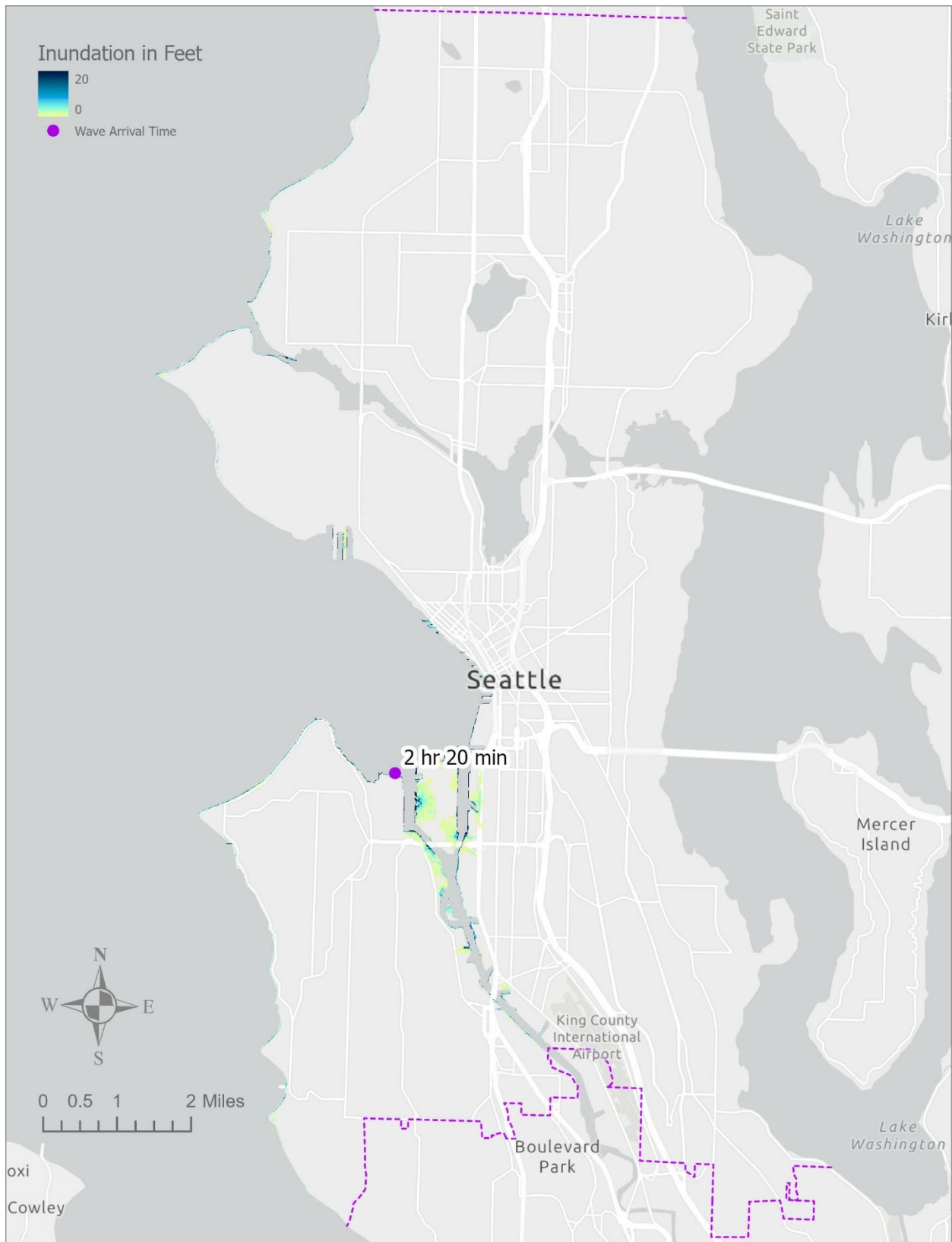
A megathrust earthquake on the Cascadia Subduction Zone in 1700 AD generated a tsunami that impacted the Pacific coastline between Vancouver Island and California, and also sent a damaging tsunami across the Pacific Ocean to Japan.³²³ This tsunami likely left deposits of the same age that have been found under the tidal marshes of [Discovery Bay](#), the [head of Hood Canal](#), and a few locations in lower Puget Sound where local geography focuses waves.³²⁴ A tsunami from a similar earthquake could flood parts of Harbor Island and surrounding areas creating dangerous currents. See [Figure 41](#) for details.

Figure 42. Tsunami Inundation from a Seattle Fault Earthquake Like the 923-4 CE Event



WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Figure 43. Tsunami Inundation from the Cascadia L1 Event



City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Landslides have caused deadly tsunamis in Puget Sound and Lake Washington. The historic examples did not impact Seattle but given the similar geology they are relevant for Seattle.

- 923-4 AD Seattle Fault earthquake triggered massive landslides into Lake Washington and probably caused tsunamis in the lake. Uplift along the fault under Puget Sound formed a tsunami as well.
- Early 1800s, a deadly tsunami impacted the Snohomish people living on [Hat Island](#). No shaking was reported so the cause was likely a landslide off of Camano Island.
- 1894, a 10-foot tsunami caused by a submarine landslide in Commencement Bay killed three people and ruined a railyard.³²⁵ The landslide was not caused by an earthquake.
- 1949, the Tacoma Narrows experienced a landslide that triggered a 6 to 8-foot tsunami three days after a magnitude 7.1 earthquake.³²⁶

Historically, seiches have caused minor damage and no reported deaths or injuries.

- 1891, an earthquake near Port Angeles caused an 8-foot seiche in Lake Washington, big enough to endanger people along the shore.
- 1949, Lake Washington had a seiche following an earthquake near Queen Charlotte Island.³²⁷
- 1964, the Alaska megathrust earthquake caused a seiche on Lake Union that damaged boats by battering them against docks and moorings.³²⁸
- 2002, a M 7.9 earthquake in Denali, Alaska damaged at least 20 houseboats in Lake Union.³²⁹

Vulnerability

Seattle has a highly developed shoreline that makes it vulnerable to tsunami and seiche damage. Large numbers of people work, play, and live near the water. Major port facilities, tourist attractions, and housing surround Elliott Bay. Lake Union's shoreline is home to houseboats, businesses, parks, and museums.

Because Seattle has not experienced a major tsunami in hundreds of years, our understanding of exposure comes from models, specifically one looking at a Seattle Fault rupture like that of 923-4 AD and a Cascadia Subduction zone rupture. Of the two, the Seattle Fault rupture would be much worse although much less likely. The [earthquake chapter](#) details likelihoods for both of these scenarios.

For locally generated tsunamis (e.g., landslides and a Seattle Fault earthquake), the time between the triggering event, the expected shaking duration, and arrival of the wave train (about 3 minutes) makes reaching high ground challenging in many areas.³³⁰ There is not much time to take protective action. Some good news is that high ground is close to the downtown waterfront, the most densely populated exposed area. In many places the distance between sea level and 50 feet is about 350 feet which can be walked by able bodied people in 1-2 minutes if they evacuate immediately and past experience from other disasters shows that many people do not act immediately. Furthermore, people with mobility challenges will not be able to walk 350 feet in under 3 minutes and will need additional solutions. In many places high ground is close, but barriers like fences, train tracks, and walls prevent people from accessing the high ground. In flatter areas, the only places to escape these tsunami waves will be climbing to higher floors in multi-story buildings, but escaping a tsunami will expose people to building collapse. Many of these buildings, especially older unreinforced masonry buildings, are likely to be severely damaged if the trigger is a Seattle Fault earthquake. Additionally, structures already damaged by a landslide or earthquake would be more susceptible to more damage from a tsunami. Most modern, engineered buildings perform better in earthquakes and have performed fairly well in recent

tsunamis.³³¹ Steel frame and modern concrete frame buildings built to seismic codes fared best in the tsunami following the 2011 Tohoku earthquake in Japan.³³² Likewise, the low death toll in the 2010 Chilean earthquake and tsunami was attributed to the country's strict adherence to building codes.³³³

The effect of the built environment is also important. Sea walls line most of Elliot Bay and the Duwamish Waterway. They provide some protection against waves whether they are storm waves, seiche waves, or tsunami waves. In 2017, Seattle replaced its weak, aging seawall to meet current seismic standards. It is more likely to be intact after a major earthquake and capable of deflecting a tsunami. The chance of a Cascadia event overtopping the new seawall is small, but a wave generated by the Seattle Fault could overtop even the new seawall. Buildings can also affect the propagation of waves inland. The first layer of buildings acts as a barrier and tends to decrease wave velocity, but they can also add debris to subsequent waves or increase velocities when waves are funneled between buildings. The worst-case tsunami scenario modeled for Seattle, shown in [Figure 42](#), does not include the effects of the built environment.

Tsunami lifeline exposures to the modelled Seattle Fault tsunami:

- The BP Olympic pipeline, which carries fuel, runs through the area from Harbor Island and along the West Seattle Bridge and the Spokane Street Viaduct.
- Seattle City Light power transmission lines enter the area near the Port of Seattle. There are 30 transmission towers in the area. Additionally, Seattle City Light has underground power infrastructure in the inundation area. Prolonged exposure to saltwater can damage cables and transformers.
- Sewer mains run through the Interbay area to Myrtle Edwards Park and in the south, from downtown through the rail corridor serving the Port and along the West Seattle Bridge. In West Seattle, a sewer main runs along Harbor Ave SW to the Duwamish Head.
- A major steam plant that powers many central Seattle buildings, including hospitals, is at Western Avenue and Union Street.
- None of Seattle's major water supply lines travel through the worst-case tsunami inundation area, but feeder and distribution mains run along the shore from Interbay to SoDo, under 1st Ave South and along the West Seattle Bridge.

Tsunami transportation exposures to a modelled Seattle Fault tsunami:

- Most of Seattle's marine terminals sit in the tsunami inundation area.
- BSNF's Sodo railyards and about half of its Interbay railyard are in the area; all Seattle's north-south rail corridors touch the area.
- The southern entrance to the new SR 99 tunnel is in the area. See the consequences section below for more on its exposure.
- SR 99, 1st Ave S, and the West Seattle Bridge cross the area.
- The King County International Airport is *not* in the area of inundation.
- The floating bridges could be exposed to tsunami waves generated in Lake Washington. No detailed tsunami models for Lake Washington exist as of October 2025 so we do not understand the extent of that exposure. In a description of the SR520 rebuild, the Washington State Department of Transportation considered seiche waves. It determined that they are less

threatening than the windstorm driven waves the bridge is designed to handle.³³⁴ WSDOT also considered seiche waves for I-90.³³⁵

Three factors will influence the size, shape, volume, and potential destructiveness of a tsunami generated by the Seattle Fault: shallow waters above the Seattle Fault, steep shoreline bathymetry, and the shape of Elliott Bay.

- Since Elliott Bay and Puget Sound are shallower than the ocean, there would be less water displaced by a Seattle Fault earthquake. The resulting tsunami would be slower and have less volume than one generated in the deep ocean.³³⁶
- Puget Sound's steeply sloping bathymetry may increase the chance that a tsunami will break on the shore, thus enhancing the tsunami's destructiveness.³³⁷
- The shape of Elliott Bay could increase damage by funneling waves together, thereby increasing wave height.³³⁸

Seattle is also exposed to a Cascadia Subduction Zone (CSZ) tsunami as shown in [Figure 43](#). The area is much smaller than that of the Seattle Fault scenario shown in [Figure 42](#). Still, 553 structures in Seattle intersect with the inundation area. The Washington State analysis introduced above concluded that within King County a CSZ earthquake and tsunami combined could damage over 300-400+ buildings, causing \$505–616 million in damage.³³⁹ While much of this estimate includes damage caused by the earthquake alone and includes areas outside Seattle, it is likely that a big percentage represents direct tsunami damage to Seattle's buildings. Because a CSZ tsunami would arrive two or more hours after the earthquake, people would have time to evacuate, reducing the chances of casualties. Strong currents can damage maritime infrastructure and vessels. Currents from a CSZ tsunami are estimated to be six knots and below. Currents from three to six knots are enough to cause minor damage.³⁴⁰

Seiches

Our understanding of our seiche vulnerability comes from seeing the effects of the 1964 Lake Union and 2002 seiches as well as models developed in the early 2000s focusing on Lake Union. These events were caused by distant source earthquakes. They produced seiches that damaged docks, watercraft, houseboats, and overwater structures. These structures are vulnerable to future seiches which according to modelling would be more severe following a Cascadia Subduction Zone earthquake or an earthquake along a local, shallow fault, such as the Seattle Fault. It is possible that waves from these sources could generate waves that would run up on shore damaging structures farther from the shoreline.

Consequences

This section describes the consequences of seiches and tsunamis separately.

Tsunamis

Not all tsunamis are catastrophic, but the big ones have been some of the deadliest natural disasters. The Seattle Fault is the source of the worst-case tsunami for Seattle. The consequences of a tsunami like the one that occurred between 923 and 924 CE would be devastating. Luckily, distribution of earthquake magnitudes provides good news. The relationship between the total number of earthquakes and magnitude (The Gutenberg-Richter Law) provides some good news that the next Seattle Fault earthquake is not as likely to be as strong as the last one which is thought to be close to the maximum size the fault system can generate. To provide a conservative model for planners, the rest of this section describes a worst case.

The Washington Department of Natural Resources model used to create the map in [Figure 42](#) assumes a maximum of seven meters of uplift on the Seattle Fault's south side (on Bainbridge Island), four meters uplift at Alki Point and one-meter subsidence on the north side at West Point (Magnolia). The model assumes the earthquake happens at high tide which makes inundation worse. It does not account for the effects of sea walls or buildings. It adjusts for their absence by using a greater bottom friction parameter. Doing so has the effect of decreasing the amount of flooding in flat-lying areas.³⁴¹

The largest part of a Seattle Fault tsunami would be in Puget Sound between Seattle and Bainbridge Island, and most of this wave would miss Seattle. Inside Elliott Bay the first wave crest would form a bore with an amplitude of six meters (i.e., six meters above the high tide (MHW) water level). The biggest wave would form on the northern edge of the fault. It would move north, striking Magnolia, Interbay, Myrtle Edwards Park, and the Downtown Waterfront in two minutes and 20 seconds. It would reflect off the steep bluffs of Magnolia and move south reaching Harbor Island about five minutes after the earthquake.

The waves would flood an area up to one mile inland around the Duwamish River's mouth. [Figure 42](#) shows the extent and depth of the inundation. The highest vertical run-ups are about 30 feet along Magnolia, Alki Beach, and east of Alki Point.³⁴² This means that people would need to get at least 30 feet high, or three stories, to have a chance of escaping the waves, if not higher.

Depending on the time of year and day, the shores ringing Elliott Bay are some of the most densely populated parts of Seattle. Survivors of the triggering earthquake would have minutes to reach higher ground. Many people would be trapped in collapsed or damaged buildings and roads would be blocked by debris. The best evacuation strategy in many places would be to seek shelter in the upper stories of buildings. Normally, it would be inadvisable to enter potentially severely damaged buildings but doing so would be safer than facing a tsunami in the open. People caught by the tsunami have a high probability of death or severe injury.

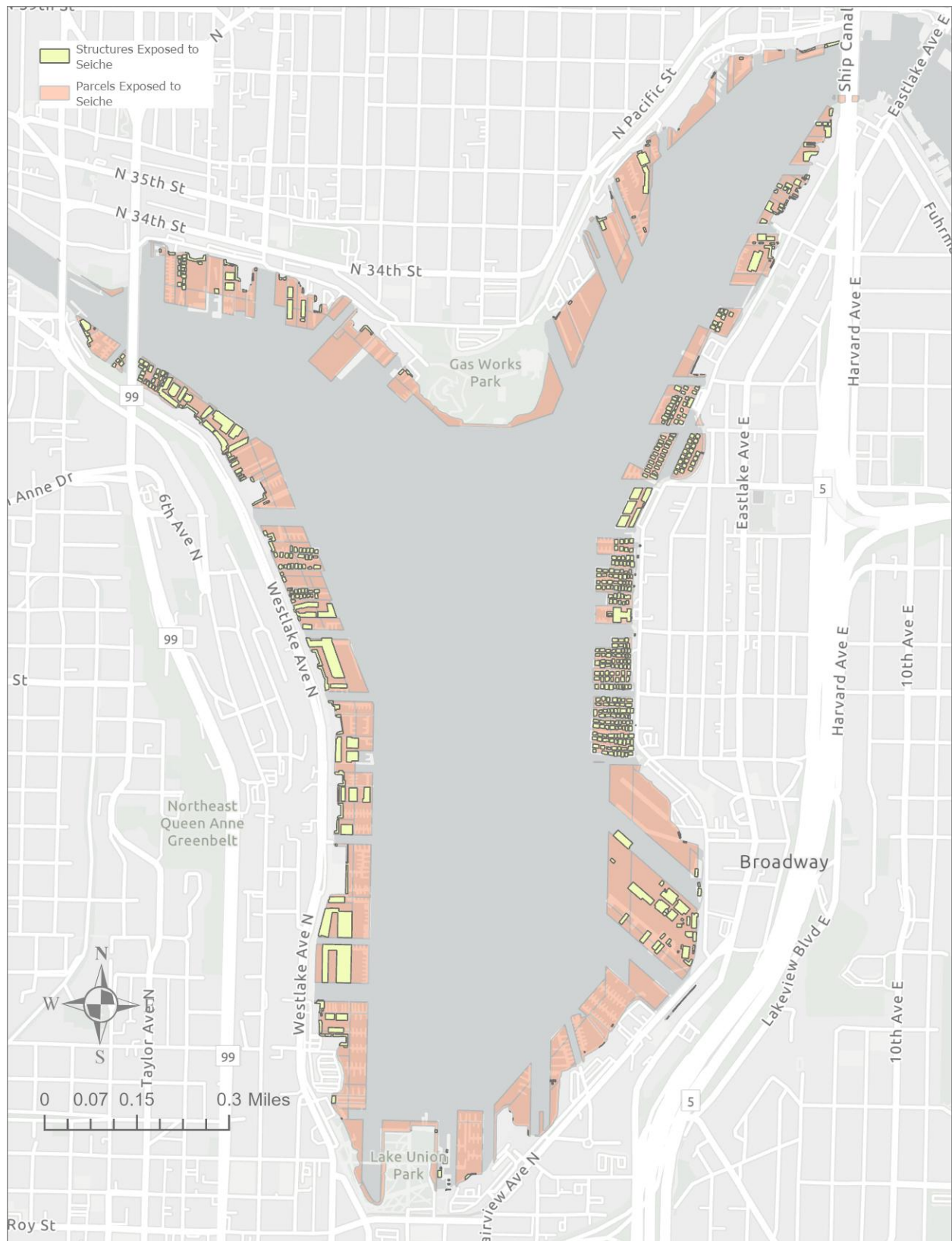
The tsunami would impact most of Seattle's port facilities including critical fuel terminals. Prolonged disruption to the Port would have an economic impact for the city, as essential trade operations would be slowed or halted. The tsunami would also inundate major roadways (SR 99, Elliott Avenue, and the area under the West Seattle Bridge) and railways, slowing recovery efforts.

The NOAA tsunami model predicts ½ to 2 meters of inundation in the area surrounding the south portal to the SR99 tunnel. The model is based on a magnitude 7.3 Seattle Fault earthquake that is estimated to have a 1% chance of happening in the next 50 years. The extent of flooding in the tunnel depends not only on the flood depth, but also the total volume of water, the flow rate, the direction of flow and the grade of the entrance, the wavelength of the tsunami, and the co-seismic subsidence. The tunnel was built with possible flooding in mind. It has six feet of space under the lower roadway where water can collect and has a pumping system to remove it. Emergency exits are spaced every 650 feet. Sea level rise could increase the reach and depth of a future tsunami.³⁴³

The tsunami would likely cause many landslides on the south side of Magnolia and the area east of Alki point. It would likely also trigger fires and hazardous materials spills in the port and industrial areas around Harbor Island. Inundation could affect downtown steam systems. If [Centrio](#) Seattle (previously Seattle Steam) loses generating capacity, Seattle's major hospitals could lose their ability to sterilize medical instruments.

A large magnitude Cascadia Subduction Zone (CSZ) earthquake would produce a tsunami with devastating consequences for the Pacific Northwest especially on the outer coast. For Seattle, the consequences would be severe, but not as dire as the outer coast. [Figure 43](#) shows the inundation area for a magnitude 9.0 earthquake on the CSZ. It is smaller than the inundation area for the Seattle Fault scenario shown in [Figure 42](#). Most inundation occurs on Harbor Island and areas immediately adjacent to it. The land use in these areas is port related and industrial. The highest human exposures are during

Figure 44. Area Exposed to Lake Union Seiche



Esri Community Maps Contributors, City of Seattle, King County, WA State Parks GIS, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA

the day when more people are at work. The tsunami would flood the area's main petroleum depots, container ports, shipyards and a Coast Guard base. It will also flood residential and recreational property along Puget Sound, but it is not projected to flood areas far inland.

As mentioned above, the Washington State Division of Emergency Management produced a loss estimate that combines damage from the tsunami and damage caused by the earthquake itself. It shows a maximum of 25 casualties (injuries and deaths combined) if there is significant delay in evacuating and zero casualties if there is 15 minutes or less delay. Damage is estimated to be between \$500 and \$600 million. Because the estimate combines shaking damage and tsunami damage, it is very possible that the majority of this damage will be from the earthquake itself.

Seiches

Seiches would cause moderate to severe damage to structures on or adjacent to the shore of Seattle's lakes and Puget Sound. Lake Union is likely to experience the most severe consequences. According to Barberopoulou's 2008 modelling, Lake Union could experience wave heights of up to 6 feet (measured trough to crest) for minutes following a distant source earthquake.³⁴⁴ Ships, boats, floating docks, and houseboats would pound violently against each other. Power, water, sewer, gas, and communications lines would be severed. People standing on vessels or near the shore could easily fall into the violently sloshing water. For distant source earthquakes, wave motion would be more up and down than side to side because seiches are standing waves. This lack of horizontal movement means that major inland flooding would not occur (See [Figure 44](#)).

The likelihood of a seiche on other local waterbodies is not as well understood, but seiches in these bodies will probably be smaller than those on Lake Union. The consequences of a Lake Washington seiche could include people near the shore being knocked into the water, and residential and commercial property damage. Damage to the two floating bridges is possible, but seiches were considered in their design. A seiche in Elliot Bay could include damage to port and industrial facilities. If a seiche damages buildings over or near the water, it is possible that the building could catch fire or release hazardous materials.

Outlook

The likelihood of tsunamis and seiches rests on their underlying causes. The earthquake and landslide chapters have more detail on these causes. There is no indication that the most common causes of tsunamis (large landslides and earthquakes) are changing frequency.

Tsunami

Distant earthquakes are the most common causes of tsunamis and seiches recorded for Seattle. Distant tsunamis originating from earthquakes around the Pacific Ocean basin (the "Ring of Fire") are fairly common. They can cause strong currents which can pose a hazard to maritime traffic, but most are not damaging and do not run up on shore. They are also the type of tsunami for which there would be the longest time before wave arrival and therefore allow time for warning to occur. Damage in Seattle from previous distant source tsunamis ranged from nothing to moderate and, to the best of our knowledge, no casualties. While the historic record is limited, these events seem to happen on the time scale of decades.

With three incidents since the late 19th century, landslides have been the most common cause of damaging tsunamis. While it has been 74 years since the last landslide caused tsunami, the frequency of deep earthquakes, like the one that triggered the 1949 event, suggests the likelihood of another earthquake triggered landslide into a waterbody is fairly high.

Earthquakes with a magnitude of 8.0 to 9.0 happen in the northern Cascadia Subduction Zone (CSZ) about every 500 years. In 2021, the Washington State Department of Natural Resources released a study

of what a tsunami from a magnitude 9.0 CSZ earthquake would look like. The inundation is shown in [Figure 43](#). The tsunami would be 3.7 feet at Harbor Island.³⁴⁵

The worst tsunami for Seattle would be triggered by a Seattle Fault earthquake.³⁴⁶ The Seattle Fault runs through Bainbridge Island, across Puget Sound, through West Seattle, Sodo, Beacon Hill and then east to Bellevue (see [Figure 42](#)). Recent research suggests that it can trigger earthquakes up to magnitude 7.8. It last ruptured between the autumn of 923 CE and the spring of 924 CE. Much uncertainty surrounds the frequency of these events. USGS recurrence interval estimates range between 2000 and 12,000 years for any Seattle Fault earthquake.³⁴⁷ Other local earthquake scientists predict a recurrence interval for M7.2 or larger Seattle Fault earthquakes to be every 5,000 to 15,000 years.³⁴⁸ The wide range in these estimates is due to a lack of prehistoric earthquake data. Two recent studies suggest the Seattle Fault ruptured at least six times in the last 15,000 years.³⁴⁹

Because the size of a tsunami depends on the amount of uplift caused by an earthquake and where the ground surface is deformed it is important to understand the magnitude range of possible earthquakes on the Seattle Fault and their likelihood. Statistically, it is more probable that the next Seattle Fault earthquake will be smaller than the one in 923 or 924 CE. In 2005, a team of seismologists and earthquake engineers chose to model a magnitude 6.7 Seattle Fault earthquake than a magnitude 7.5 because it is more likely. They did not model a tsunami for this scenario. A magnitude 6.7 earthquake would probably trigger a smaller tsunami than the one that happened in 923 or 924 CE. The Seattle Fault shows evidence of episodic fault rupture of about 6 feet, enough to produce a tsunami.³⁵⁰ If the fault movement is purely vertical, a magnitude 6.7 earthquake would likely cause about 1 meter (3 feet) or less of displacement on the fault plane, which translates to about 0.5 meters (1.5 feet) of uplift on a 40-degree thrust fault. It would probably cause a fraction of the damage of the NOAA-modeled tsunami following a magnitude 7.3 earthquake or the earthquake-generated tsunami in 923-4 CE.³⁵¹ In contrast, the 923 or 924 CE earthquake caused over 15 feet of uplift.

Other faults potentially capable of producing tsunamis in Puget Sound include the Tacoma Fault, the South Whidbey Island Fault, the Strawberry Point Fault, the Utsalady Point Fault, and the Darrington-Devils Mountain Fault Zone.³⁵² The United States Geological Survey has an [interactive map](#) of these faults

Seiches

Seiches are more common than tsunamis. Both Puget Sound and Lake Washington experienced them in 1891, 1949, and 1964. These events caused light to moderate damage. It is very likely that similar seiches will happen again. A Cascadia megathrust earthquake may cause a much more dangerous seiche than past occurrences in Lake Union and possibly Lake Washington.³⁵³ Cascadia megathrust earthquakes happen on average every 500 years. See the chapter on [earthquakes](#) for more details.

Conclusions

Seattle has an extensive and well-developed coastline. Many recreational and economic activities occur near the shoreline. Both tsunami and seiches would occur with little or no warning. These factors give Seattle an inherent vulnerability to tsunami and seiche hazards. Despite this vulnerability, Seattle's risk is lessened due to the infrequency of the kinds of Seattle Fault earthquakes that generate truly powerful tsunamis and seiches immediately off Seattle's shoreline.

Because of their greater frequency in Puget Sound, landslide-caused tsunamis are the greatest overall risk to Seattle. Landslide-caused tsunamis can be very large and can be triggered by cumulative events like small to moderate earthquakes and heavy rainfall.

The worst case, modeled by the Washington State Department of Natural Resources, would be a devastating blow on top of the worst earthquake Seattle has ever faced. The most recent estimates of

recurrence state that this type of earthquake happens only about once every 5,000 to 15,000 years, but research published in 2023 suggests the fault ruptured four to six times in the last 10,000 years. That suggests the fault is more active than previously thought. The last such event occurred 1,100 years ago. The best estimates give a 5% chance for an earthquake along this fault in the next 50 years. A major Cascadia Subduction Zone tsunami would not be as severe but has a 10% to 15% chance of occurring in the next 50 years.

5. INFECTIOUS DISEASE AND BIOLOGICAL HAZARDS

The COVID-19 pandemic has changed the world in ways few recent disasters have. It erased lives and damaged many more. It revealed how disasters can attack the bonds holding us together as communities. In addition to the direct effects on health, the pandemic changed how we live and work. In 2025, its effects still linger; people continue to contract COVID, many downtowns have yet to return to their pre-COVID-19 levels of activity, school children struggle to achieve pre-pandemic levels of social and academic development, and communities of color and those lacking adequate resources bear excessive impacts. This chapter will examine the effects of possible future biological hazard emergencies on all aspects of our community.

Since it emerged in December 2019, coronavirus disease 2019 (COVID-19) has caused substantial increases in morbidity (illnesses) and mortality (deaths). In King County, as of July 2025, it is responsible for over 3,900 deaths and over 30,000 hospitalizations. These societal consequences demonstrate the community cost associated with biological hazards. The biological hazards covered in this chapter comprise any naturally occurring, accidental, or deliberate biological threat that require extra ordinary measures to contain. Most involve acute outbreaks of infectious diseases that arise suddenly. Public Health Seattle King County (PHSKC) leads the response to disease. The City of Seattle's role is managing the consequences of disease and the public health measures necessary to contain it. Outbreaks can be caused by different pathogens, and common examples include respiratory viruses (e.g., influenza virus, coronavirus), viruses causing gastrointestinal disease (e.g., norovirus, hepatitis A), and bacteria (e.g., pertussis, Salmonella, and E. coli). Pathogens of the greatest concern include novel strains of respiratory viruses due to the lack of community immunity and ease of transmission through respiratory droplets. Novel disease outbreaks caused by respiratory viruses can quickly overwhelm healthcare systems and challenge a community's ability to maintain essential services.

An outbreak is defined as more cases of a disease than is expected in an area among a specific group of people over a particular period. Outbreaks may lead to epidemics, often defined as an unexpected increase in the number of disease cases in a specific geographic area or pandemics, in which a disease rapidly spreads across multiple countries or the whole globe.³⁵⁴ Neither are defined by the severity of the illnesses they cause. They are affected by climate change, changes in land use, increasing urbanization, and global connectedness, which are all driving novel disease emergence and an increased risk of future pandemics. The [CDC](#) and [Public Health Seattle King County](#) (PHSKC) publish information on the connection between climate change and health.

Key Points

- ❖ *Lead Agency – Seattle/King County Public Health*
- ❖ *An outbreak with the same mortality rate as the 1919 flu would cause over 15,000 deaths in King County compared to the 2000 caused by COVID-19.*
- ❖ *The most dangerous diseases are new variants of flu and corona viruses because people have no natural immunity to them.*
- ❖ *To limit disease spread, public health measures need to be enacted including limiting public gatherings, school closures, social distancing, and masking.*
- ❖ *These measures are effective especially if the public complies with them. Seattle had high rates of compliance during COVID-19. They are also highly disruptive to normal community function.*
- ❖ *Exposure to disease is not socially equitable. Poorer, browner communities suffer more.*
- ❖ *Resistance to public health measures increases with time.*

Disease outbreaks can also be caused by deliberate action, also known as bioterrorism. Bioterrorism is the intentional release of viruses, bacteria, or other agents to harm people, livestock, or crops.³⁵⁵ PHSKC has identified priority pathogens that pose the highest threat due to their high mortality rates and their ease of transmission between people. They are anthrax, plague, smallpox, typhus fever, ricin, and viral hemorrhagic fevers.³⁵⁶

Regardless of source, disease surveillance is essential to establish baseline disease levels. PHSKC monitors several disease conditions. It uses disease transmissibility and potential community impacts to measure the following metrics:

- Incubation period: The stage of subclinical disease extending from the time of exposure to onset of disease symptoms.
- Contagious period: The duration after infection during which the person can transmit the infection to others.
- Infectivity: The proportion of exposed persons who become infected.
- Pathogenicity: The proportion of infected persons who develop clinically apparent disease.
- Virulence: The proportion of clinically apparent cases that are severe or fatal.

Outbreaks and regional epidemics regularly occur in the Puget Sound area with varying degrees of community impact. For example, seasonal epidemics of influenza infect many people every year but vary in disease severity. Most influenza seasons are associated with mild disease, although some years can be associated with increased mortality in certain at-risk populations. PHSKC maintains [dashboards](#) to show the effects of respiratory illnesses in King County. Other epidemics, like whooping cough, affect only a small portion of the population. These common scenarios are normally handled within the existing healthcare system and do not typically lead to high levels of morbidity and mortality.

Many conditions contribute to a virus becoming an epidemic.³⁵⁷ They include:

- Mutations that cause viruses to evade immunity.
- Spillover, when viruses jump from animals to humans. Climate change and encroachment into wildlife habitat can be a factor in spillover.
- High transmissibility and asymptomatic spread.
- Public health system weaknesses including low vaccination rates and underfunding public health agencies
- Human factors, including high concentrations of susceptible populations, dense urbanization, and accelerated global travel.

Potential sources for the next disastrous disease outbreak include:

- New pathogens and novel variants (like COVID-19).
- Pathogens acquiring resistances.
- Zoonoses (pathogens jumping from animals to people).
- Bioterrorism.

While endemic influenza viruses and coronaviruses have led to seasonal epidemics, novel strains of these viral pathogens have been the historical causes of pandemics. The emergence of these pathogens often occurs when treatment and preventative vaccines are not yet available and thus place a substantial burden on the healthcare system to provide the necessary supportive care. The need to devote resources to fighting an epidemic can lead to indirect effects.

Among all the hazards analyzed in this document, disease is the greatest risk to human life. In addition to the direct threat to our health, disease affects our economy and social life as people independently curtail activity, and as government enacts public health countermeasures to mitigate disease spread. The longer the disease persists, the bigger the effect on social life and the economy.³⁵⁸ PHSKC developed a [dashboard](#) that revealed some of these impacts in King County including a 34% rise in domestic violence, and increase in food insecurity, and a 21% decrease in traffic collisions.

Common disease outbreaks include influenza, coronavirus, norovirus, pertussis, hepatitis A, Salmonella, and E. coli. Novel strains of influenza are a great risk to King County, because of the lack of immunity to a new influenza virus strain, the potential for severe illness, and the high degree of transmissibility from person to person.

The worst-case scenario is the outbreak of a new disease with high rates of morbidity and mortality. New disease outbreaks can quickly overwhelm local healthcare facilities and healthcare providers, and challenge society's ability to maintain critical services.

For King County, the Communicable Diseases Epidemiology & Immunization Section (CD-Imms) within Public Health – Seattle & King County (PHSKC) investigates and coordinates the surveillance of communicable disease cases and outbreaks. The CD-Imms Section monitors dozens of [communicable diseases](#) and routinely assesses any seasonal fluctuations in diseases for signs of a potential outbreak (i.e. above normal expected levels). For example, incidence of influenza cases can fluctuate seasonally, and while influenza may infect many people every year, most cases are mild. Other outbreaks, like whooping cough, are very severe but infect only a small segment of the population. These epidemics can typically be handled within the healthcare system without activating emergency management protocols; however, some diseases, even if only affecting a small group of people, can prove resource intensive to contain spread. Disease outbreaks place an immediate threat to our health system's capacity, and acute disease outbreaks can degrade or paralyze critical medical services. King County hospitals were at or near capacity for much of the two-year span of COVID-19. Some states and communities have had to move to crisis levels of care where medical staff must choose which patients with life threatening conditions get treatment.

Many potentially devastating diseases are spread through physical contact, ingestion, insects, animals, and inhalation. Airborne diseases and those spread through physical contact pose higher risks to the community because they are difficult to control. Diseases such as influenza, Pertussis, Tuberculosis, and meningitis are all spread through these methods and pose a significant threat to our community.

Two virus types that infect our respiratory systems, influenza and coronaviruses, constitute the biggest pandemic risks. A pandemic influenza is a new influenza virus that is much more severe than the typical seasonal "flu." Similarly, a novel coronavirus is a new type of coronavirus. People have little to no natural resistance to them, so they spread more easily and can cause more deaths. Adding to the impact is the gap between the virus emerging and the development of a vaccine.

Bioterrorism

Bioterrorism is the use of biological agents as a means of attack. The 2001 anthrax attacks are the most prominent example. Seattle has never experienced an act of bioterrorism. The CDC defines bioterrorism as the biological agents (microbes or toxins) used as weapons to further personal or political agendas (See the Terrorism chapter for other types of terrorism).³⁵⁹ A biological attack would most likely be covert, meaning people would not express symptoms immediately. PHSKC identify six priority agents that pose the highest threat due to their high mortality rates and their ease of transmission between people. They are anthrax, botulism, plague, smallpox, tularemia, and viral hemorrhagic fevers.³⁶⁰

History

Throughout the 20th century several epidemics and pandemics have affected Seattle and King County.

Influenza (H1N1) 1918-1919: The highly virulent influenza pandemic of 1918 caused more than 500,000 deaths in the United States and more than 40 million deaths around the world. The 1918 pandemic first arrived in Seattle in October 1918; over the next six months the virus claimed an estimated 1,531 lives in Seattle. Unlike many influenzas, this one killed many young, otherwise healthy adults.

Influenza (H2N2) 1957-1958: The influenza pandemic of 1957 was less severe than the 1918 pandemic and caused a total of 70,000 fatalities nation-wide.³⁶¹

Influenza (H3N2) 1968-1969: The influenza pandemic caused more than 34,000 deaths in the U.S. and caused severe morbidity and mortality around the world.³⁶²

Influenza. 2009 (H1N1) Like the 1918 pandemic, the H1N1 outbreak of 2009 affected young and healthy populations as well as those with chronic diseases. This increase in morbidity caused strain on the local healthcare system. King County activated its Pandemic Disease Plan and Seattle closed three schools in response to the disease.³⁶³ Although the H1N1 virus was not virulent and there were not nearly as many fatalities as previous pandemics, the outbreak caused a larger than usual amount of disease in the community than the seasonal influenza virus does.

SARS-CoV-2 (COVID-19) 2020-present: The COVID-19 pandemic was the most globally impactful disease outbreak since the 1918-9 influenza. As of July 2025, 3,900 people have died in King County and over 30,000 have been hospitalized. The highest rates of death were in parts of Auburn, Federal Way, and Seattle's Pioneer Square / Chinatown areas ([Figure 45](#)). Mitigation strategies like masking and social distancing were effective at slowing the spread of disease, but nationally, politicization of the pandemic and subsequent spread of misinformation caused mistrust of these strategies. Seattle's and King County's compliance with public health measures, including broad uptake of COVID-19 vaccinations, likely attributed to relatively lower case counts and death rates compared to similarly sized metropolitan areas.

Measures to slow disease transmission imposed societal costs:

- The unemployment rate skyrocketed but quickly rebounded. The unemployment rate in the Seattle-Tacoma-Bellevue Metropolitan Statistical Area rose from 6.3% in February 2020 to 16.5% in April 2020 but fell to 6.1% in November 2020.³⁶⁴
- The hardest hit sectors were manufacturing, aerospace manufacturing, and the leisure and hospitality industries.³⁶⁵
- BIPOC workers were more likely to file unemployment claims as were caregivers regardless of race, indicating a disproportional impact on these groups.
- People spent 14% less time out of their homes, which decreased economic activity.
- People spent less time outside their income 'bubble' and less time at places where the predominant income is different than their own. The research suggests Seattle is becoming more segregated.³⁶⁶
- A study conducted by the University of Washington found that only 24% of restaurants in a 44-census block area remained open in May/June with only a 10% improvement by the end of 2020. Federal assistance like the Paycheck Protection Program helped many of these businesses.

The areas highest in employment and population density were the hardest hit lending support that the urban core of Seattle hollowed out.³⁶⁷

- In February 2023, downtown Seattle office work was at 55% of pre-pandemic levels with at 21.2% office vacancy rate compared to a rate of 6.6% in the same period in 2019.³⁶⁸
- Washington State children lost the equivalent of a half of year of schooling as measured by test scores in math and reading from 2019 to 2023.³⁶⁹

Bioterrorism: No bioterrorist incidents have occurred in Seattle, but the wider Pacific Northwest region has seen isolated incidents that were not large enough to trigger local governmental emergency response plans. While potentially catastrophic, significant barriers exist to cause catastrophic damage and thus make significant bioterrorism unlikely.³⁷⁰

- 2013. Threatening letters containing ricin were intercepted in Spokane, Washington.³⁷¹ They were addressed to military bases and U.S. government officials. Nobody was injured from the letters.
- 2009. Eleven gay bars and the alternative weekly, The Stranger, receive letters threatening to target the businesses with ricin. An attack did not occur.³⁷²
- 2001. Several locations on the East Coast were struck with anthrax.
- 1984. Followers of the Bhagwan Shree Rajneesh spread salmonella on food items in restaurants in the Dalles, Oregon; there were no deaths, but 751 cases of illness were confirmed.³⁷³

Vulnerability

What makes a community vulnerable (i.e., more prone to suffer adverse effects) to disease is highly complex. Overall disease vulnerability encompasses both Seattle’s vulnerability compared to other locations as well as the vulnerability of individuals and groups within Seattle relative to one another. Public Health Seattle King County is the lead public health agency for King County. It has more comprehensive information on this subject than is considered here, including a [tool](#) to help people understand who is most vulnerable to COVID-19.

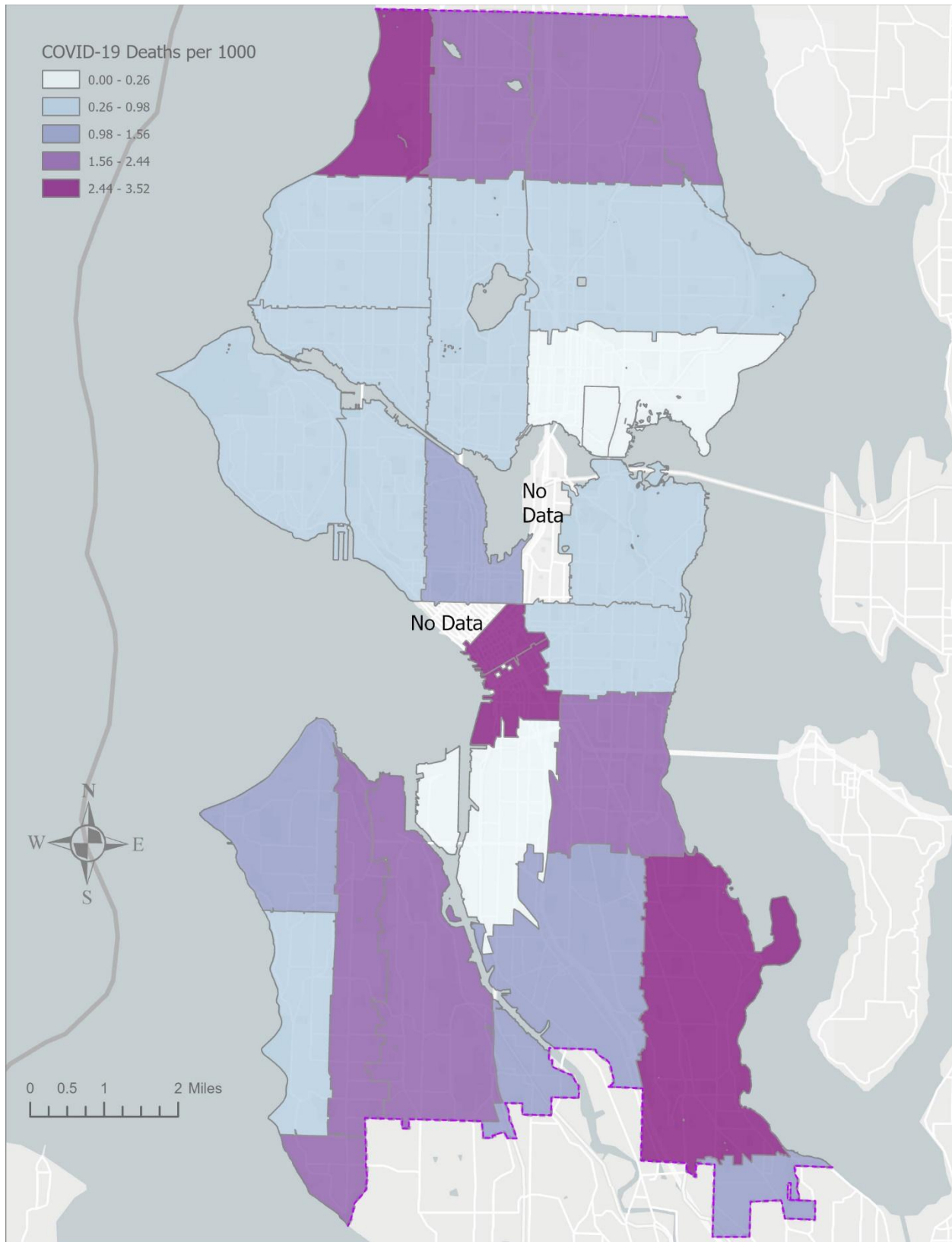
Avoiding large outbreaks relies on local and global disease surveillance, quick action by public health authorities, and the public adhering to public health guidance. Public health measures buy time to develop treatments and vaccines. The 2003 SARS outbreak was limited to 115 cases in 29 states due to quick action. If an infectious disease becomes widespread nationally it will likely spread to the Seattle area.

The ability to quickly craft public health guidance and the willingness of the public to adhere to it affects Seattle’s vulnerability. The COVID-19 experience provides insight into how the public may react to a future incident. For COVID-19, two of the most important non-pharmaceutical interventions were the wearing of masks in public spaces and social distancing.

King County required masks to be used at various times and places during the COVID pandemic. Masks have been shown to be effective in slowing disease transmission and reducing COVID-19 disease effects.³⁷⁴ Washington State had good rates of mask usage and social distancing. Data from December 2021 to July 2022 shows mask usage hovering about 80% usage until May, with a dip in the summer and then climbing back into the 60% range in fall and winter to 2021/22.³⁷⁵

Social distancing began almost as soon as King County issued a Proclamation of Emergency on March 1st, 2020. Mobility as measured by using anonymous cell phone data dropped in King County from normal on March 2nd, 2020, to just 33% of normal by March 20, 2020. It essentially fell to zero after Governor Inslee’s March 23rd, 2020 “Stay Home, Stay Healthy” order that implemented mandatory telecommuting

Figure 45. COVID-19 Deaths per 1000 residents in Seattle by Zip Code Tabulation Area



Source: Public Health Seattle King County

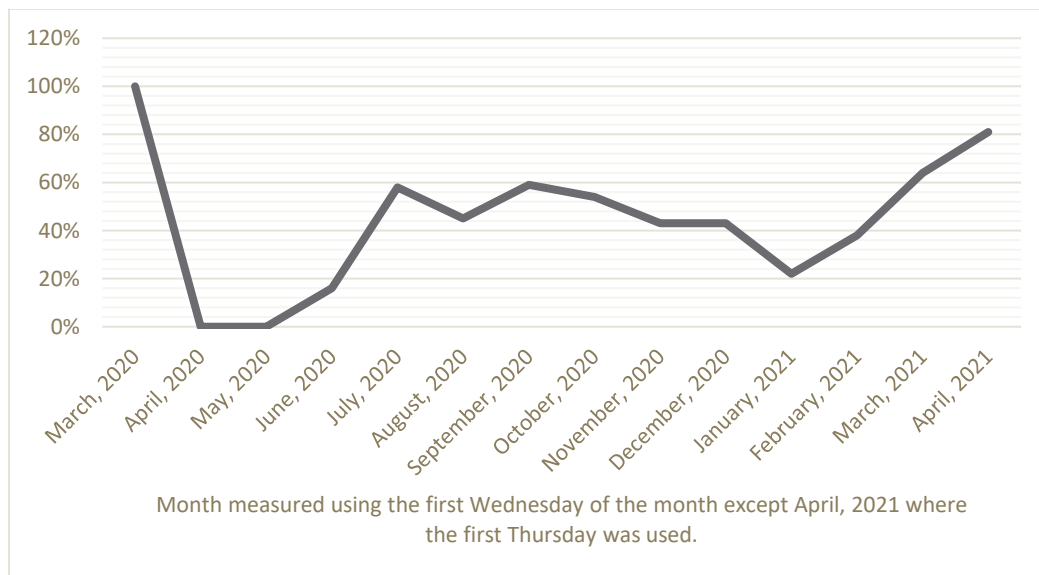
for all employees not holding positions classed as First Responders or Mission-Critical. See [Figure 46](#) for more information.³⁷⁶

While each of the lives lost and impacted was more than hoped for, King County’s non-pharmaceutical interventions likely had a positive effect. Of the 20 most populous counties in the US, King County had the fewest cases per 100,000 residents and the second fewest deaths per 100,000 residents through March 2023.³⁷⁷ It suggests that King County reduced vulnerability for average negative consequences relative to many urban areas.

Despite relatively low cases and deaths per 100,000 in King County compared to other urban areas, the averages seen in these statistics can hide severe inequities. During the COVID-19 pandemic, older individuals, low-income households, and communities of color suffered more than the younger, wealthier, whiter parts of our community. Data from the early part of the pandemic show cases were four times higher for Hispanics, Native Hawaiians, and Pacific Islanders than for White and twice as high for Blacks as for Whites.³⁷⁸

A zip code’s percentage of people of color and hospitalization rates per 1000 people is weakly but positively correlated as shown in [Figure 47](#).³⁷⁹ Deaths in Seattle positively correlate with age, especially if rates of poverty among people 60 and over are considered, as shown in [Figure 48](#). These figures show that in Seattle zip code areas the greater the proportion of people of color, the greater the number of hospitalizations, and the greater the proportion of older individuals in poverty, the greater the number of deaths. The degree of correlation is measured by the R-squared number. The values in the .33 to .37 show that race, age, and poverty are important, but not the only factors determining the rate of COVID-19 hospitalizations and deaths in a zip code area.

Figure 46. King County Mobility as percentage of pre-pandemic baseline



Source: [Mapping Mobility Changes in Response to COVID-19](#) Accessed 3/21/2024

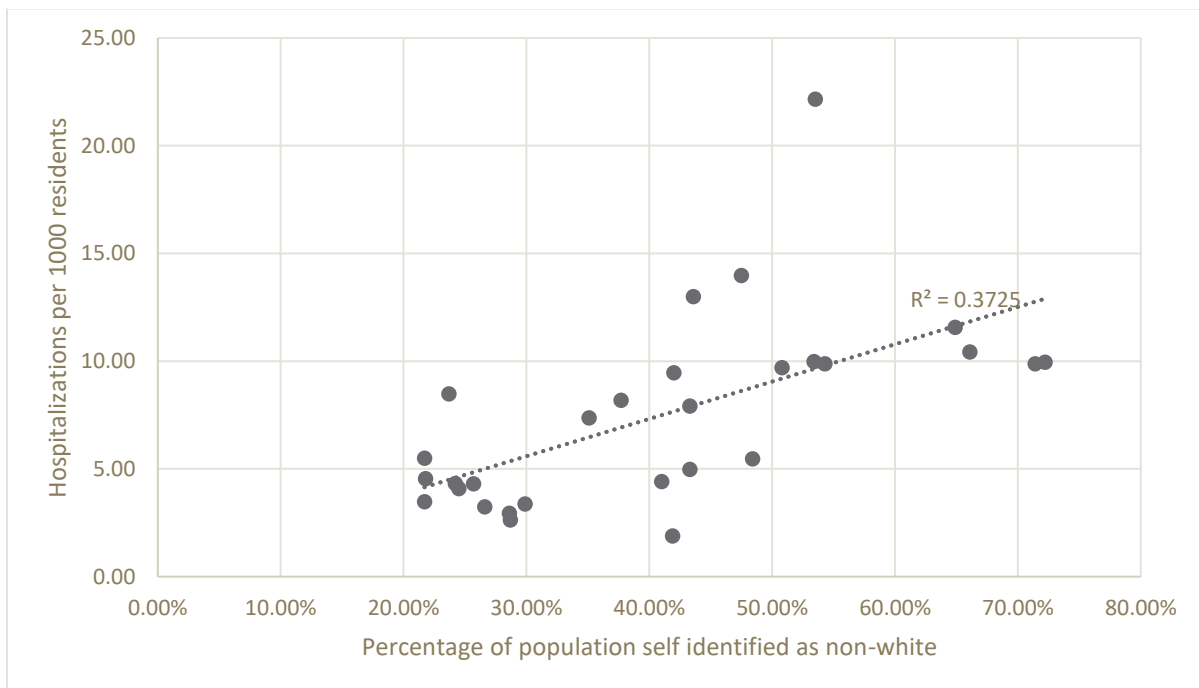
Although some children were severely affected by COVID-19 and occasionally suffered a dangerous complication, referred to as multisystem inflammatory syndrome in children (MIS-C), children, as a group, were not as heavily impacted. This situation surprised many subject matter experts. Many

disease outbreaks affect children more than the adult population and are likely to do so in a future outbreak.

People experiencing homelessness are disproportionately impacted by most disease outbreaks. Many people living homeless and with health problems have difficulty getting prompt treatment. Living conditions – like crowding in shelters and fewer opportunities for personal hygiene – can contribute to the spread of disease. If someone has an underlying medical condition, alcohol, or drug use, or has a weakened immune system, they are even more susceptible. In 2017 and 2018, King County’s Communicable Disease Control, Epidemiology & Immunization unit (CD-Imms) responded to increases in several infectious diseases among persons experiencing homelessness. New infections and outbreaks in this population continue to be reported and might continue to rise given the increase in people experiencing homelessness in King County.

Seattle has a large concentration of healthcare resources, but in an epidemic or pandemic these resources can be stretched or overwhelmed by the increase in demand that accompanies an outbreak situation. The Seattle area also provides specialized medical care for a large geographic area, including one of the region’s pediatric hospitals and the only Level 1 Trauma center for Washington, Idaho, Montana, and Alaska. In addition, Airlift Northwest, located at Boeing Field, is the only life-flight agency serving the same four-state region. These facilities must continue serving the wider geographic area during a localized outbreak.

Figure 47. Seattle Zip code tabulation areas. Hospitalizations vs percentage non-white population



The Health Disadvantage Index ([Figure 49](#)) shows where people face higher health burdens in general. People in these areas are more likely to work jobs that preclude remote work, face barriers that limit their access to medical care, and have underlying health conditions typically face the greatest consequences of disease. Those with existing health disadvantages (diabetes, asthma, disabilities, low life expectancy, etc.) are more likely to live in South Seattle (Pioneer Square, Sodo, Rainier Valley, Delridge) and North Seattle (Lake City, Bitter Lake, Northgate).

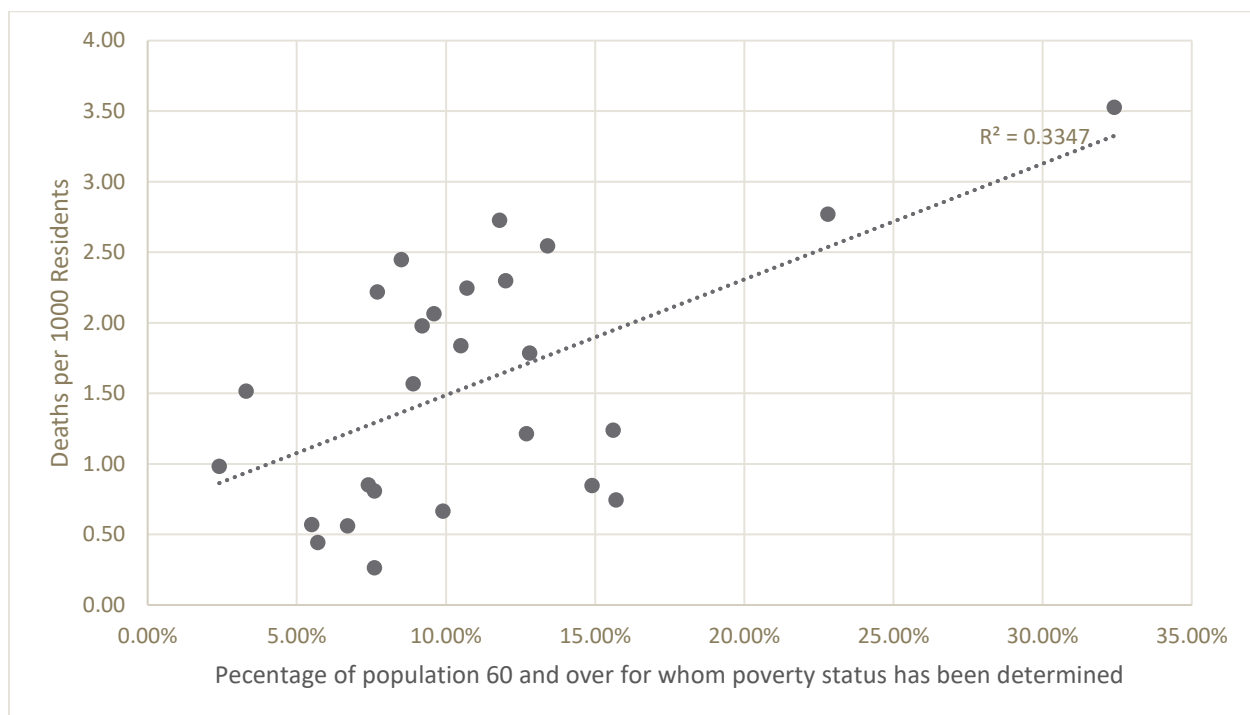
Vulnerability to Indirect Effects

Protecting the public’s health is the most important priority in a disease outbreak, but measures to slow the disease, especially social distancing and restricting social gathering, impose societal costs. Exposure to these costs is not equal, especially the longer an outbreak continues. People working in the hospitality, travel, and entertainment industries are likely to be laid off or lose their jobs. Children suffer academically and socially as education switches to online learning. Many children rely on social services provided at schools and lose these services when schools go online. During COVID-19, many supply chains were disrupted as factories and transport curtailed operations affecting the general population.

Consequences

COVID-19 highlighted the short and long-term toll that a pandemic can have on our communities. Death and severe illness are the most notable and visible consequences of disease. COVID-19 has killed over 3,900 King County residents and required hospitalizations for more than 30,000, yet a future pandemic could be worse. 1918 influenza pandemic killed a greater percentage of its victims than COVID-19. The US Census Bureau estimates the 1918 killed 1531 people in Seattle at a time when the city was much

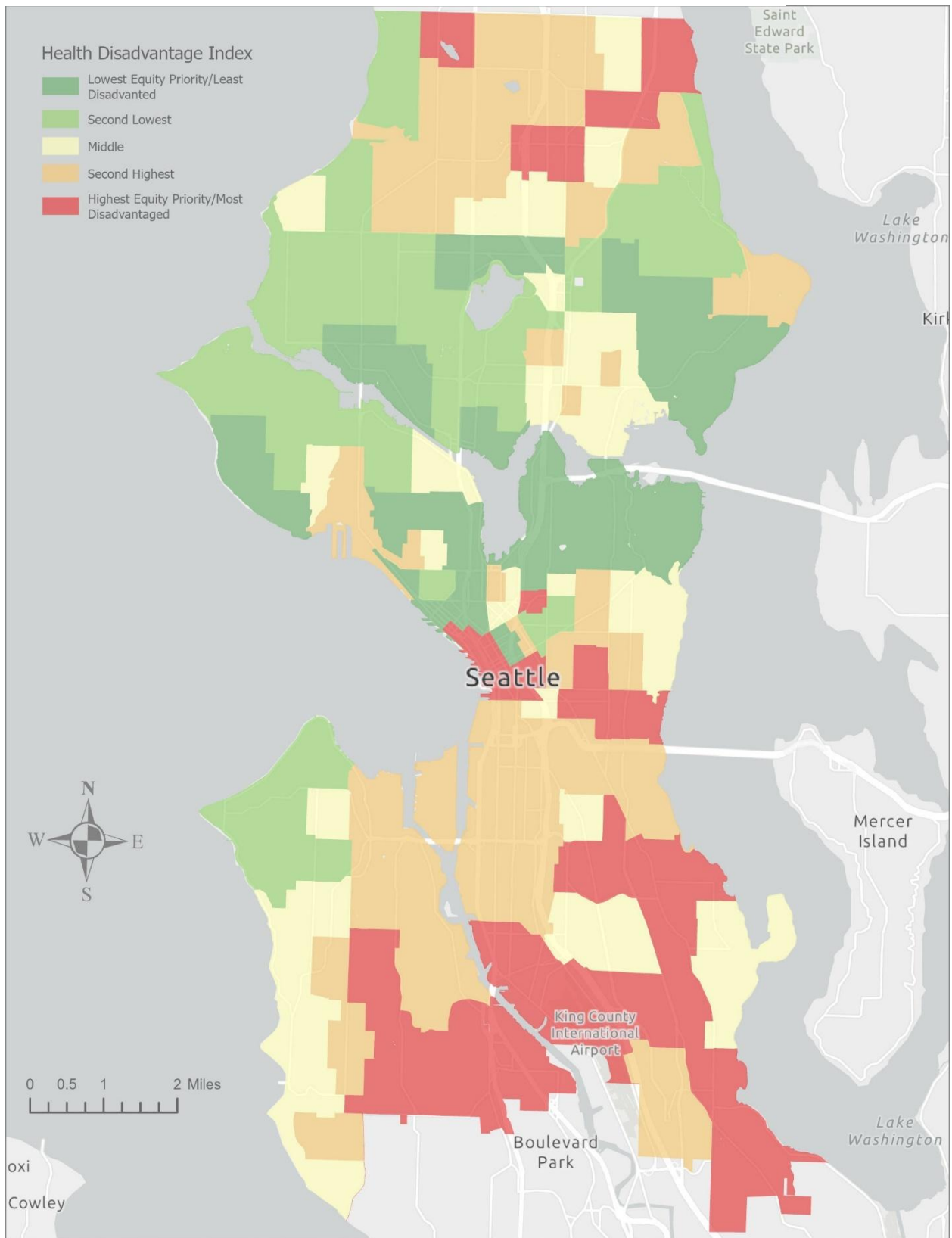
Figure 48. Seattle Zip code tabulation areas. Death rate vs percentage 60 and over in poverty



smaller (315,000 compared to 816,000 in 2025).³⁸⁰ If a new pandemic were to kill proportionately as many people, the result would be nearly 4000 deaths in Seattle alone. Seattle represents a third of King County’s population, suggesting 12,000 lost lives would be lost across King County.

Pandemics have long term consequences for many survivors. Post COVID-19 Conditions (PCC) or “long COVID” are chronic debilitating symptoms experienced by many survivors of SARS-CoV-2 infection. Symptoms can include fatigue, “brain fog,” palpitations, mood and sleep changes, headaches, and shortness of breath. To date, there are no specific treatments available for PCC, and it is unknown how long these symptoms may last.

Figure 49. Health Disadvantage Index



Source: City of Seattle Office of Planning and Community Development. This index ranks census tracts with seven equally weighted measures: 1) Adults with no leisure time physical activity, 2) Adults with diagnosed diabetes, 3) Adults with obesity, 4) Adults who reported mental health as not good, 5) Adults with asthma, 6) Low life expectancy at birth, 7) Adults with one or more disability

Disease outbreaks can cause widespread social disruption as schools, businesses, government agencies, and non-profit organizations curtail operations due to employee absenteeism, illness, or from non-pharmaceutical interventions. The effects of these curtailments grow the longer the disease persists, and COVID-19 demonstrated how long this can be. COVID-19 has had a massive disruptive effect on Seattle as a community, especially with the switch to remote work by many employees, the continuing high commercial vacancy rates, and the increase in online retail. COVID-19 arrived at the same time as the technology that allowed those with means to work, shop, and socialize remotely. It may have had uniquely outsized effects on social shifts, but a future prolonged pandemic may cause socio-economic life to shift even further online. Loneliness is a severe effect of social distancing and life lived online. Future pandemics are likely to be the same. Many studies have found that COVID-19 negatively affected the mental health of many people.³⁸¹ Alcohol related deaths increased by 25% in 2020.³⁸² Similarly, suicide rates increased during COVID-19 and other epidemics.³⁸³ Switching to online learning has had a negative effect on student learning, especially in math.³⁸⁴ So many segments of society were impacted that we will be measuring the effects of COVID-19 for years to come.

Outlook

The Puget Sound region is tightly integrated with the rest of the country and world. If a disease has a global footprint, it is likely that it will spread to the Seattle area. A coordinated effort to conduct disease surveillance and implement public health measures early at the local, state, national, and international levels is imperative to mitigate the potential impact of a pandemic.

While it is not known when the next pandemic will occur, factors such as increasing air travel, habitat destruction, and climate change are increasing the risk of these events occurring. A 2021 study estimates that a person born this year has a 38% chance of experiencing a COVID-19 level event over the course of their life assuming the rate of pandemics is not increasing.³⁸⁵

The COVID-19 pandemic has exposed and exacerbated existing health disparities in our communities. The underlying structural inequities in health and socioeconomic factors that placed people of color at increased risk at the outset of COVID-19 remain. People experiencing homelessness are also likely to be at risk of being disproportionately impacted given limited access to prompt medical care and living conditions that can contribute to the spread of disease.

Climate Change

Climate change could influence the likelihood or severity of future disease outbreaks. Climate change can affect diseases carried by animals (vector-borne diseases) as hosts change their ranges and behavior. It can also affect host immunity. Likewise, warming water temperatures could affect organisms that contribute to water and food-borne diseases in ways we cannot predict now.³⁸⁶

Terrorism

Due to the extremely limited number of cases in which biological agents were used as weapons and the great uncertainties around potential bad actors' capabilities, motivations, and opportunities, it is impossible to estimate the likelihood of an attack. Although the materials needed to make a biological weapon are readily available and inexpensive, there are many barriers to success. Barriers include creating a successful strain of a disease, producing a sufficient amount, and successfully distributing it where it will infect people.³⁸⁷ While terrorists groups continue to have an interest in obtaining and using biological weapons, most experts believe that conventional weapons (e.g. firearms and bombs) will continue to be the weapons of choice in the future attacks, because they are more easily acquired, cause immediate harm, and have fewer countermeasures.³⁸⁸

Conclusions

Disease outbreaks are the deadliest hazard facing Seattle. They are also profoundly disruptive to a community's social life. Many diseases can cause epidemics and pandemics such as pertussis, hepatitis A virus, *Salmonella*, *E. coli*, West Nile virus, and tuberculosis, but influenza or coronavirus is the most likely to cause the next widespread disastrous outbreak like COVID-19. Outbreaks can cause greatly increased levels of morbidity (illness) and mortality (death) within the community, in addition to overwhelming the healthcare system and disrupting essential community services through staff absenteeism. Public Health – Seattle & King County manages the ESF-8 Health, Medical, and Mortuary Response plan and is responsible for monitoring and responding to any potential disease outbreak.

6. SOCIAL UNREST

This chapter uses ‘social unrest’ as an umbrella term to cover a wide range of collective actions that disrupt the community and often endanger lives and property. It includes riots, protests, demonstrations, rallies, marches, strikes, direct actions, and civil disobedience.

Because definitions for these events are often politicized, this section highlights the legal definitions and common theoretical frameworks to ground the analysis without getting too detailed. Due to the increasing presence of violent domestic extremists confronting or participating in collective actions, this chapter links to the [Terrorism and Targeted Violence](#) chapter.

Social unrest includes a wide range of activities from non-violent to violent, legal to illegal, criminal to principled, and highly planned to completely spontaneous. They can be actions taken against institutions or they can be conflicts between groups. The most concerning types are those that include widespread violence against people followed by those that include widespread violence against property. Even peaceful actions can, and often are, designed to stress essential community functions and services. For example, a legal, peaceful strike may not require law enforcement response, but it could disrupt public services such as education, transportation, or utilities. Many collective actions are structurally complicated, especially on questions of violence. Actions that start peacefully can become violent. Some actions include a violent minority within a much larger peaceful group.

Most social unrest involves speech. The right of people to peacefully gather and express discontent is enumerated in the First Amendment to the US Constitution. Public disapproval is often in the form of marches, rallies, and demonstrations. Nearly all are peaceful. The [Armed Conflict Location & Event Data Project](#) which tracked protest events nationwide following the murder of George Floyd found that despite popular perception, over 95% of all demonstrations were peaceful.³⁸⁹

Key Points

- ❖ *Lead Agency – Seattle Police*
- ❖ *Social unrest as defined here includes civil disorders, riots, mass civil disobedience, and strikes. They differ in their legality and tactics (especially the use or avoidance of violence), but all are acts by groups of people that are intended to disrupt a community or organization.*
- ❖ *The ability to gather peacefully petition governments is enshrined in the US Constitution, the Washington State constitution, and numerous federal, state, and local laws.*
- ❖ *In the US federal system, states, and by extension, local governments, retain police powers which grant state and local government the ability to maintain the public good which includes public health and safety. Social unrest that threatens public health and safety through violent acts is not legally protected speech.*
- ❖ *Civil disorder is a violent public disturbance by crowds that causes immediate danger, damage or injury to others or their property.*
- ❖ *Some nonviolent protests attract a violent fringe that use the larger group as cover for property damage and attacking public safety personnel. These situations can be challenging as police attempt to balance free speech rights with public safety.*
- ❖ *Civil disobedience is the nonviolent refusal to obey certain laws as an act of political protest. Civil disobedience is illegal but non-violent.*
- ❖ *Strikes are collective work stoppages by employees designed to force an employer to meet employee demands. Most strikes are legal and peaceful, but some are illegal and/or violent.*

For local governments, First Amendment rights of those seeking to petition the government must be balanced with the rights of non-protesting citizens to be safe and exercise their own First Amendment speech. Typically, this is accomplished by rules designed to allow non-protesting citizens to move freely and for those protesting to respect private property.

Social media has transformed how people organize. It has simplified organizing and made it easier to coordinate large groups, however the ease of organizing has often meant that groups organizing collective actions lack strong bonds and the crowds they summon do not share a deep connection. Social media enables large crowds to form, especially when a particular issue dominates online discussions, but the people in the crowds do not know each other well and lack a common set of strategies.³⁹⁰ As a result, collective actions have become larger but often fail to generate sustained campaigns.

The following is a very loose taxonomy for collective actions. Many actions blur the distinctions between these categories.

Protests, Demonstrations, Marches and Rallies

Demonstrations, marches, and rallies are a common form of dissent. The vast majority are peaceful and do not significantly disrupt the community to the degree that emergency measures are required to manage the consequences. Protest leaders and law enforcement can meet before the event to develop mutual understanding and often do. Most of these actions are over in less than a day, but some like the Occupy Movement last multiple days. The Occupy Seattle protest lasted in various locations from October into December.

Civil Disobedience

Civil disobedience is the peaceful refusal to obey laws regarded as unjust with the intent to persuade the government to change them. Sometimes there is not a direct connection between the law broken (e.g., trespass) and the issue being protested, as when demonstrators blockade a private business to protest what the business is doing. Despite being non-violent, widespread civil disobedience disrupts community functions and can be confrontational. Examples include taking over street intersections, blocking highways, and disrupting public events. During past incidents, access to emergency services, like emergency transport, has been disrupted.

Strikes

Strikes are the organized stoppage or slowdown of work to force an employer to grant concessions. Most are organized by labor unions. 16.5% of workers in Washington State are represented by unions.³⁹¹ Today many strikes are legally protected, but some are not. Washington State does not permit uniformed employees like police officers and firefighters to strike (Revised Code of Washington 41.56.490).³⁹² Many public union contracts also have no strike clauses as well. Strikes are most disruptive to the businesses or organizations involved, but if the strike involves critical services, the whole community is impacted. Even strikes by small numbers of workers in key industries can have a have an oversized effect. In November 2021, 330 teamsters who deliver concrete went on strike against four suppliers in the Seattle area. The prolonged strike halted numerous construction projects.

Most strikes happen in a single company or industry. A general strike is one in which most workers in an area or country refuse to work until their demands are met. They are often used to achieve broad economic or political objectives like the overthrow of an unpopular government. The 1919 Seattle General Strike was launched to support striking shipyard workers. There has not been a broadly supported general strike in the United States since the Great Depression.

Riots and Civil Disorder

Violent group actions are the most hazardous type of social unrest. They are commonly described as riots, but the term is hard to define precisely because it is often politized. The US Federal Code defines a riot as

“a public disturbance involving (1) an act or acts of violence by one or more persons part of an assemblage of three or more persons, which act or acts shall constitute a clear and present danger of, or shall result in, damage or injury to the property of any other person or to the person of any other individual or (2) a threat or threats of the commission of an act or acts of violence by one or more persons part of an assemblage of three or more persons having, individually or collectively, the ability of immediate execution of such threat or threats, where the performance of the threatened act or acts of violence would constitute a clear and present danger of, or would result in, damage or injury to the property of any other person or to the person of any other individual” (18 USCS § 2102).

In practice, a riot is usually thought of as an event larger than three people and one that involves a significant breakdown of social order. Many mass gatherings have acts of violence. It is not clear how much violence has to happen for the gathering to be a riot. Even a parade could technically be called a riot if people in the crowd commit acts of violence. The term is unavoidably political. Events are often labelled as riots to discredit people and groups involved. On the opposite side, violent behavior is often justified by calling it a ‘civil resistance’ or an ‘uprising’ to downplay the impact of the violence.

The Revised Code of Washington 9A.84.010 defines a crime for “*acting with three or more other persons, he or she knowingly and unlawfully uses or threatens to use force, or in any way participates in the use of such force, against any other person or against property*”. This crime is very similar to the federal definition for riot but calls it ‘criminal mischief’.

Civil disorder is often used as a more neutral term. The federal legal definition of *civil disorder* is “*any public disturbance involving acts of violence by assemblages of three or more persons*” (18 USCS § 232). Civil disorder and riot are used as synonyms in parts of the US Code (5 U.S. Code § 7313). Under the Revised Code of Washington, civil disorder is defined as “*any public disturbance involving acts of violence that is intended to cause an immediate danger of, or to result in, significant injury to property or the person of any other individual.*” (RCW 9A.48.120).

This analysis labels an event as a riot if that is the consensus term used for it. Where there is not a consensus, more neutral terms are used.

Early theories of riots and civil disorders placed these events within the larger context theories of crowds in general. They saw crowds as composed of criminal, deranged members of the lowest social strata. When people gathered in crowds, they developed a collective mind that became irrational. They collective actions as the result of a breakdown in social control and became known as the breakdown theory.³⁹³

The Kerner Commission, formed by President Johnson in 1968 after a wave of riots swept the United States, laid the foundation for contemporary thinking about civil disorder.³⁹⁴ The Commission distinguished “communal” and “commodity” riots.³⁹⁵ Communal riots involve direct attacks by one group on another. Minorities are especially vulnerable. The notorious 1921 Tulsa Race Massacre was a communal riot. An armed white mob attacked the Greenwood neighborhood in Tulsa targeting people and property. They killed hundreds of black Tulsans and burned more than a thousand homes. Communal riots cause high casualties and often occur on the border between the communities involved or at some contested public spot like a beach or playground. In the 20th century, they were most common from the turn of the century through the 1920s. Commodity riots start within the heart of a community instead of the fringe. Their violence is generally aimed at symbols of the prevailing social

structure. Because property is the primary target, casualties tend to be lower in commodity riots than communal riots. The Kerner Commission classified the 1960s riots as commodity riots.³⁹⁶

The Kerner Commission model has gaps that more recent research has attempted to fill, but scholars are a long way from developing a consensus about what triggers civil disorder, how they progress, and what causes them to end. Even basic questions about why protests about the same issue are peaceful in some places but violent others are not understood. Most scholarship emphasizes civil disorder as a form of protest, but some disorders, like the 2001 Seattle Mardi Gras Riot, don't have an issue.

After the Kerner Commission, sociologists led by Charles Tilly developed the dichotomy between 'routine' (e.g., election rallies and peaceful protests) and 'non-routine' collective actions (e.g., collective violence and riots). They saw collective actions as a rational attempt to gain power and change social conditions. They emphasized the ability of groups to network. This theory is known as resource mobilization. Proponents of a revised breakdown theory argue that resource mobilization works only for 'routine' collective actions.³⁹⁷

Some theories emphasize flashpoints and structural violence that build up in a community during an incident, even a minor one. When this proves too much, all the pent-up anger comes to the surface. This approach has been criticized for downplaying how complex events play out and justifying violence.³⁹⁸ These critics say we should look more at interactions within a crowd and between the crowd and law enforcement, especially if there is a delay between the flashpoint and public violence. They point to escalating tensions between a crowd and the police with a tit-for-tat escalation on both sides.³⁹⁹

These approaches both stress conflicts between crowds and governments while ignoring conflicts between two or more groups. The United States has not seen the types of inter-group violence that it did in the early 20th century. Research from other countries point to breakdowns in social institutions, the ostracizing of one group by another, and a spiral of conflict often driven as a political strategy.⁴⁰⁰

Many civil disorders evolve out of protests, rallies, and marches, but not all. Some are situational, such as those following sporting events or developing during power outages. Chicago experienced riots over multiple years in the 1990s, each time the city's basketball team won the NBA championship. After the 1992 victory, riots led to two deaths and almost 700 arrests.⁴⁰¹ A riot arising from the 1977 New York City blackout led to over 1,000 fires and 1,600 stores being looted.⁴⁰²

Prolonged power outages and natural disasters often heighten a community's fear of subsequent civil disorder, but the risk of looting is widely overstated. Disasters most often promote cooperative behavior.⁴⁰³ In the week following Hurricane Sandy, crime dropped by one third in New York City. Additionally, after Hurricane Harvey hit Harris County Texas in 2017, there were only 63 people charged with storm-related crimes (including burglary and theft) in a county of 5 million people.⁴⁰⁴

Most recently civil disorder has centered on racial injustice and politics. The George Floyd protests that swept the country in 2020 were the latest in a string of incidents going back to the 1992 LA riots. In the past few years, the political landscape appears to be the main motivator behind civil disorder. Many cities in the U.S. have experienced clashes between groups that identify with the far-right or far-left of the political spectrum. The most prominent are white supremacist and anti-fascist ("antifa") groups, both of which have discussed and acted out the use of violence to defend their beliefs. The clearest example was the attack on the U.S. Capitol building on January 6, 2021. Locally, far left and far right groups have come into conflict, most notably at the University of Washington in 2017 when one person was shot and injured.⁴⁰⁵

Many of Seattle's violent collective actions include black bloc tactics in which a subset of people participating in a rally or march engage in property destruction and confrontations with police. Most of the targets are chosen for their symbolic importance representing large corporations, law enforcement, and the justice system. Many participants are anarchists. Benjamin Case who interviewed 27 anarchists

about their use of black bloc tactics. He concluded that “the collective violation of the sanctity of private property and police authority are deeply symbolic for participants.”⁴⁰⁶ There is disagreement about how effective these tactics are, but the meaning of these tactics for participants explains why these tactics persist in most non-peaceful protests in Seattle.

History

Seattle has experienced periodic civil disorder, large-scale disruptive protests, and strikes throughout its history. The issues have been different in each case. The tactics used in the disruptions have also evolved.

Two databases have been developed to catalog recent protests and conflicts. The differences in the number of actions they include and the percentage they identify as ‘peaceful’ highlight the complexity of classifying collective actions.

The [Crowd Counting Consortium](#) has cataloged 1842 political crowds in Seattle since 2017 mostly through media reports. 1.3% or 24 actions were identified as having property damage or injuries to the crowds or officers as occurring during the actions, meaning 98.7% were classified as peaceful.⁴⁰⁷

The [Armed Conflict Location and Event Database](#) gives a much lower percentage of peaceful protests at 80%. The differences result from a different taxonomy and by not including many of the small events found in the Crowd Counting Consortium database. It covers events in Seattle from January 1, 2020, to the present. It contains 497 events in Seattle of which 407 are listed as ‘peaceful protests’ and 90 as not peaceful.

1886 Attempted Eviction of Chinese Residents

In 1886 a crowd attempted to evict Chinese residents from the city. The mayor called out the militia to prevent the expulsion. The crowd resisted. Fighting erupted. Troops fired on the crowd, killing two people.⁴⁰⁸

1919 The Seattle General Strike

The next wave of civil disorder centered on the labor movement. There were disturbances from 1900 to 1919, but there was no large-scale violence in Seattle itself as there was in other parts of the state. The biggest event was the general strike of 1919 that lasted for three days and passed without any violent incidents.

1934 West Coast Waterfront Strike

On May 9, longshoremen in every West Coast port went on strike. The strike lasted until July 31 when workers returned to work after securing most of their demands. The strike was violent. Two striking workers were killed in Seattle. Government and business blamed the strike on communist agitators. Confrontations between police and strikers culminated in melee at Smith Cove (Interbay) on July 18.⁴⁰⁹ Other strikes followed during the 1930s in Seattle included one by newspaper writers in 1936.

The 1960s: Civil Rights, Vietnam War Protests, and the Youth Movement

As with the rest of the nation, Seattle experienced strife connected with racial tensions, the Vietnam War, and the youth movement. Between 1964 and 1968 the U.S. had a total of 329 civil disorders in 259 cities in which 220 people were killed.⁴¹⁰ During those upheavals, Seattle remained a secondary site for national trends. Social changes involving young people also led to unrest. In 1969, youths and police confronted each other in the University District over two nights. The flashpoint was the attempt to shut down parties.

1967 Post MLK Assassination Disorders.

The late 60s were a period of high racial tension nationally. During the summer of 1967, disorder broke out in many cities. The unrest spread to Seattle, but it was minor compared to other places.⁴¹¹ Even

though Seattle avoided additional large-scale incidents, tensions remained high and resulted in several police officer shootings during the late 1960s and early 1970s.

1969 – 1973 Vietnam

Seattle saw several large marches against the Vietnam War, but these were mostly peaceful. Most of these happened from 1969 to 1973. In the last large protest, a crowd of nearly 5,000 university students shut down I-5.⁴¹²

1992 Rodney King Verdict / LA Riots

After the acquittal of four police officers accused of beating Rodney King, small groups of people roamed the downtown streets smashing windows, lighting dumpster fires and overturning cars. The next day, people angered by the verdict rallied at the Federal Building. Many residents and workers feared more violence and avoided downtown. After the rally broke up, some groups moved around downtown as they did the night before. Others went to Capitol Hill where they set fires and attacked the East Precinct Police Headquarters. The fires provoked a citywide crisis. Suburban fire trucks were called in to help as the city exhausted all its mutual aid. There was a serial arsonist also active at the time. If he had set fires that night, it would have made the situation even more difficult. Another protest occurred in the University District. That protest was largely peaceful, but protesters occupied I-5 for a while.⁴¹³

1999 WTO Protests

From November 29 to December 3, 1999, Seattle hosted the World Trade Organization (WTO) conference. During the first day of the conference, a large confrontation lasted all day in the area near the convention center. Some of the protesters threw rocks and bottles. The police responded with tear gas, pepper spray, and blunt impact projectiles (beanbag, cork, and rubber). The mayor responded by declaring a state of emergency that established a limited curfew in the area surrounding the conference site and hotels. The Washington State National Guard was mobilized. The next day witnessed a smaller downtown protest, and the night featured an action that required police action on Capitol Hill.

The large number of protesters (over 40,000), their tactics, and their organization overwhelmed the approximately 400 police officers securing the conference venues. The protest was a loosely affiliated federation of activist groups. The organizers divided downtown into thirteen wedges, and each group was given one wedge. Their use of the Internet (then new for organizing), cell phones, radios, and other technologies combined with a very loose organizational structure, and more provocative tactics was unprecedented in Seattle. Many groups were non-violent but seemed determined to provoke an active police response. A small group of protesters was violent. They were joined by non-politically motivated individuals. Both groups committed acts of vandalism, smashing windows, spray painting buildings, and setting fires. Both the protest groups and the police seemed to get better at isolating these people and avoiding violent confrontation as the week continued.

Over 600 people were arrested. There were no deaths, but 92 people were treated at local hospitals. 56 police officers filed injury reports, with the most serious being a burned hand. It was estimated that downtown businesses sustained \$3 million in property damage. Retailers lost an estimated \$17 million in sales during the 5-day conference. The protests cost the City of Seattle around \$9.3 million.⁴¹⁴

2001. Mardi Gras Riot

In February 2001, chaos erupted for two consecutive nights during Mardi Gras. A crowd of between 5,000 and 7,000 began to fight and vandalize property. Police officers were withdrawn from the crowd over concerns for officer safety and to avoid inciting the crowd. One person was killed. Damage was estimated to be between \$100,000 and \$200,000. This was a non-political riot, with no element of protest involved. An after-action review recommended intervening to disperse the crowd sooner.

2012 to 2019 May Day Protests

Following the 1999 WTO unrest, May Day has been a complex event featuring permitted, large, and peaceful rallies and marches as well as unpermitted marches by more aggressive groups using black bloc tactics that engage in property destruction and violence against police officers. The people engaging in these tactics usually gather in the evening. Crowds have typically numbered between 200 and 600. The City of Seattle Emergency Operations Center (EOC) activated for May Day unrest from 2012 to 2019 after which more aggressive May Day unrest generally ebbed and EOC activations were not necessary.⁴¹⁵

2017. Inauguration Day Shooting

Mostly peaceful protests happened throughout the city on January 20, 2017, the day Donald Trump was inaugurated as president. Confrontations between the president's supporters, anarchists, and socialists began to escalate at the University of Washington campus, where conservative news editor, Milo Yiannopoulos, was scheduled to speak. The crowds threw bricks, fireworks, and paint at police officers. Josh Dukes, a member of the Industrial Workers of the World, was shot in the abdomen but survived.⁴¹⁶ Two individuals, who are believed to have come to the protest to invoke violence, were charged with the assault.

2020 George Floyd / Social Justice Protests

George Floyd was murdered by Minneapolis Police Officer Derek Chauvin May 25, 2020. The murder triggered protests focusing on the use of force by law enforcement against African Americans and structural racism. Protests began in Seattle on May 29 in the Chinatown / International District. Some in the crowd broke windows, including small restaurants struggling to stay open during the COVID-19 pandemic. The next day a large march occurred in downtown Seattle. Attendance was in the thousands. While most march and rally attendees were nonviolent, a small group committed property crimes including breaking windows, burning cars, and throwing objects at police officers. Police responded with pepper spray, tear gas, and blast balls, some of which struck nonviolent protesters and inflamed feelings further. Protests continued with the center of activity shifting to Capitol Hill over the next few days. Protesters frequently occupied I-5 in downtown Seattle. One person was struck by a car and killed. Protests occurred outside the East Precinct on Pine St. On June 7 a man drove into the crowd, stopped, and shot a person attempting to intervene. June 8 large clashes occurred between protesters and the police. Most protesters were loud and confrontational, but nonviolent. Some threw objects at the police. Late in the night police cleared the area using tear gas. Concurrently, police were preparing to leave the East Precinct. On the morning of June 9, the building was sealed and empty. Protesters claimed the surrounding area as the Capitol Hill Organized Protest (CHOP) then the Capitol Hill Autonomous Zone (CHAZ). Police did not maintain a presence in the area. The largest gathering occurred June 12 when approximately 60,000 gathered in a Black Lives Matter organized peaceful, silent march.⁴¹⁷ Shootings occurred in or near the CHAZ June 20, 21, 23, and 29. On July 1, Police cleared the CHAZ and returned to the East Precinct.

Confrontational protests continued into late July driven in part by sustained nightly protests in Portland centering on the federal courthouse and strong handed push back by federal authorities. Protesters often blocked I-5. On July 4th a motorist struck and killed Summer Talyor, one of the protesters.

On July 19th a small group armed with clubs and bats joined a large group concluding a peaceful rally in Westlake Park. The tactics were like many other black bloc actions in which a small group integrates into a bigger group to commit acts of property destruction and violently confront police. Several businesses were damaged, 2 arrests were made, and 12 police officers were injured. On July 25th, protesters confronted police near the East Precinct and the construction site for the new King County Juvenile Detention Center. Four trailers were burned. Stores seen as police friendly were damaged. 47 people were arrested, and 21 police officers injured.⁴¹⁸

George Floyd’s murder and its protest forced our community to confront ongoing racism across all sectors of our society. Calls were made to defund the Seattle Police Department that were supported by members of the City Council. Cuts were made, but the police department was not defunded. The City’s Race and Social Justice Initiative gained new energy. Many private companies and organizations likewise renewed efforts to combat structural racism, but with time, much is left undone.

Vulnerability

Social disruptions often target community vulnerabilities, places, or systems where pressure will be most strongly felt. In Seattle, many cases of social unrest happen in our most built-up neighborhoods (Downtown, Capitol Hill, and the University District), around large public institutions (the Federal Building, the University of Washington, Seattle Central Community College, the King County Juvenile Detention Center, or the King County Jail), and on major transportation routes like I-5. These areas are both places where many people gather or pass through, making them easy gathering spots for people looking to make statements or get noticed. They are also the spots where disruptions have a big impact.

The greatest vulnerability is the transportation network, as it creates the greatest disruption for the general public. Seattle lacks significant reserve capacity in its road network. I-5 is by far the most heavily used corridor in the state. Because of its significance, demonstrations have targeted it.

Downtown is a frequent site for demonstrations. The WTO protests closed large parts of downtown at the start of the holiday season. Businesses, especially those connected to big corporations, are often direct targets of property crime. Others suffer indirectly due to a lack of business. The holiday season is an especially vulnerable time for retail businesses. Small retail and food service businesses are the most vulnerable because they front streets where civil disorder occurs and are often underinsured.

On several occasions ethnic, racial, religious, and political groups have been targets of crowd violence. Most of the examples from Seattle’s history are long in the past. The current events surrounding police violence and the African American community have increased racial tensions across the U.S. Additionally, hostility appears to be targeted towards political opponents and minority groups, suggesting a possible shift towards communal conflict. During COVID-19 hate crimes against Asians and Asian Americans increased showing that communities that are perceived to be connected to hot button topics are especially vulnerable.

Confidence in government and community reputation are two factors that are especially vulnerable to these types of events. Social unrest is often a direct challenge to law enforcement and the political authorities. While the response to any disaster is very important, it is especially critical when people are directly challenging the authorities when government conduct is directly under scrutiny. Besides the loss of faith in authority, a community’s reputation is sensitive to conflict and disorder. As disaster sociologist Enrico Quarantelli stated, riots “seem to leave more of a residue” than natural disasters.⁴¹⁹

Consequences

As the Quarantelli quote indicates, social unrest can have longer and wider ranging consequences than other hazards, but the ‘seem’ in the quote is telling. The causes of unrest have been studied far more than the consequences. What we have is limited, narrow in scope, and limited to case studies.

The event consequences (or set of events) vary by type of event, location, duration, and intensity. A strike may have a direct impact on a critical service. Demonstrations with significant civil disobedience may disrupt public spaces and transportation routes. Civil disorder or riots may cause casualties and property destruction. Most events have a political or social aim whether explicitly stated or not. A major consequence is whether this aim is achieved. The biggest events have long term effects on community memory and self-perception.⁴²⁰

Most incidents of unrest are confined to one neighborhood. They feature widespread minor property damage and injuries due to the dispersal of crowds or fighting between members of the crowd. Usually, they are limited to one or two nights of intense activity, although sometimes they are followed by a longer period of tension and low-level conflict.

Services and Community Lifelines

Many collective actions target community lifelines and services. The most common is transportation. Shutting down key streets, intersections, and freeways is a common act of civil disobedience. One demonstrator was killed in 2020 while blocking I-5. Most blockages have been resolved in a few hours.

Strikes are collective actions that can affect key services and community lifelines for much longer. The most common are strikes affecting public education. Teachers for Seattle Public Schools went on strike in 2015 and 2022. In 2015, the strike caused major disruptions to the local economy because many parents lacked childcare and had to stay home with their children. In 2022 teachers walked out again. The effects were mitigated because many parents were able to work remotely.

While public sector strikes are not legal in Washington State, this does not mean they are not possible. Washington State ferry workers went on strike for 20 days in 1976. The action caused significant transportation disruptions. Since 1970 there have been several major public sector strikes in the US. The 9-day New York City Sanitation Worker's Strike led to a massive amount of garbage on city streets affecting public health and safety. In 2005, transit workers staged a 3-day strike in New York City making it difficult for millions of commuters to get to work. In 2023, many Los Angeles city workers staged a 1-day strike across multiple lines of business. Private sector strikes could also have a major effect if they impact key lifelines like energy and communications.

Property damage (examined below) can severely impact key services. A report in the Journal of the American Pharmacists Association on impacts of the 2020 protests in Chicago stated, "The health impact owing to the dearth of pharmacies and pharmacy services in segregated South Side black communities was exacerbated in the aftermath of the looting owing to the pharmacy closures." It added that one major pharmacy had 85 locations in Chicago were damaged with 1 set on fire.⁴²¹

Public Safety

Most collective actions are not violent, especially those that are small and well organized. In popular discourse events are often divided into violent and nonviolent, but it is more helpful to think of violence as a continuum. Many violent events feature acts of vandalism and property destruction like broken windows. A small number of events account for most deaths, injuries, and property destruction. In 2020, the ACLED database recorded 7,750 demonstrations linked to BLM in the US in 2,440 locations.⁴²² The number of deaths is hard to estimate. The New York Times estimates at least 6, Forbes puts the number at 19, and the Guardian says at least 25.⁴²³ These numbers do not include the 2 people killed in the CHOP in violence indirectly related to the protest. Deadlier unrest happened in the 1992 LA riots in which 46 people lost their lives.⁴²⁴ Injuries are many times greater and often impossible to estimate. During the 2020 protests and riots in Seattle dozens of officers and hundreds of participants and bystanders were injured.

The growing conflict between political opponents raises concerns about future violence. After the 2016 election politically charged violence increased nationally, culminating with January 6th, 2021, Capitol Insurrection. Seattle experienced some of this violence when a person was shot and injured in 2017 at a rally at the University of Washington on Inauguration Day.

Counter demonstrators are becoming increasingly common including participation by non-state actors on both the left and the right, including groups such as Antifa, the Patriot Front, the Proud Boys, and the Boogaloo Bois. A new tactic is car ramming attacks. ACLED logged over 55 car ramming attacks during

the 2020 protests.⁴²⁵ Guns are prohibited at permitted events under [Seattle Municipal Code 12A.14.175](#), but guns have been noticed at unpermitted events like the CHAZ/CHOP area during the George Floyd protests.⁴²⁶ The threat of gun violence between groups or between demonstrators and law enforcement is growing.

Social media now makes it easier to organize events online. If an overarching controversy is dominating public discourse these events can get very big with minimal planning by organizing groups. The events are broad, but shallow. Nobody knows who is going to turn out. Crowds are comprised of many different groups with different agendas and tactics. They can include counter demonstrators. Organizers do not have the same level of control they have for smaller events. Individuals may not feel safe and may arm themselves. Armed far-right counter demonstrators have been appearing at demonstrations. As a reaction, the John Brown Gun Club, a far-left group, has been active in recent collective actions and was present in 2020 in Seattle.

Property Damage

Property damage is a common occurrence in Seattle's more 'non-routine' collective actions. The damage has skewed towards businesses and government buildings. This profile will probably continue unless there is a return to the kind of communal rioting of the early 20th century.

After the WTO protests, May 1st has become an almost annual event for anti-capitalist activists who routinely target corporate retail outlets like Starbucks. Typically, May 1st includes a large, peaceful rally and march during the day and more radical, unpermitted demonstrations in the evening when most of the property damage happens. Most of this damage is chosen for its symbolism and is limited in scope.

Property damage during the 2020 protests was significantly worse in Seattle and other parts of the country. Locally, damage ranged from breaking windows, looting, and arson. The City of Seattle settled a \$3.6 million lawsuit brought by businesses impacted by the CHOP. An additional lawsuit brought by different businesses for CHOP impacts is still ongoing as of April 2024. Multiple businesses in Seattle's suburbs of Bellevue and Tukwila were looted during the same 2020 protests. Two police cars were burned, and arson was attempted at the East Police Precinct after it was abandoned temporarily.

The worst damage in 2020 happened in Minneapolis where the conflict was centered. Over 1,500 properties were damaged including 164 arsons.⁴²⁷ The total cost was estimated at \$500 million with 60% of the losses uninsured.⁴²⁸ Most damage, in contrast to past damage in Seattle, also happened outside the central downtown core in neighborhoods along Lake Street and University Ave.

Long Term Consequences

Many incidents of social unrest attempt to bring about social and policy changes. This aspect makes them different than natural disasters. Strikes are the clearest example, where workers make explicit attempts to change legally binding labor contracts. Governments often react with policy changes designed to mitigate the circumstances that caused the unrest. The 2020 protests sought to defund police departments, including Seattle's. A major demand was to cut the Seattle Police department budget by 50%. While this demand was ultimately not met in full, the police department budget which had grown by 68% from 2010 to 2020 shrank in 2021. Many officers left the force. The department continues to struggle with staffing. Future unrest will demand new and yet unknown policy changes and could result in major changes to City governance.

Aside from policy changes, government reaction to social unrest can lead to an increase in attempts of social control with a heavy law enforcement emphasis, which is often a major driver of grievances that trigger unrest. The City of Stockholm reacted in this manner after 2013 rioting.⁴²⁹

The most important consequences for those directly involved: participants, victims (if any), and people living in the communities where they happen. Strikes cause long lasting changes for striking workers, businesses, and people depending on essential services. Campaigns of protest and civil disobedience can permanently shift our culture. Civil disorders and riots can make participants feel empowered as when a person participating in a black bloc stated that transgressing rules about private property and police authority was “thrilling” and that the “world is so much more interesting and there is so much more to be done.”⁴³⁰

Nationally, insured losses from the 2020 protests exceeded \$2 billion, with one third of those losses coming from just three retailers. The concentration of insured losses in a handful of companies echoes experiences in Chile and Turkey. It is not clear how the insurance industry or large retailers will react to this information. Will insurers be less likely to include riot damage in their policies? Regardless, many small businesses are underinsured. A New York Times article profiled small businesses struggling in Kenosha, Wisconsin, where 35 businesses were destroyed and 80 damaged. Many were owned by immigrants and lack the funds to reopen. Several apartments were destroyed as well, leaving occupants homeless. Anecdotally, many of these businesses do not come back, degrading the local economy and limiting access to services.⁴³¹

Cities that suffer civil disorders can be perceived as unsafe. Community leaders worry about losing investment and tourism, especially when violence has been highly visible.⁴³² The Los Angeles Times reported that commercial real estate investment and tourism slowed down after the 1992 L.A. riots, in some areas for years. After the CHOP was established after the 2020 protests, many conservative media outlets pointed to it as an example of Seattle’s lawlessness. It is not clear whether this coverage has had an effect on the area economically.

Many media accounts link riots with “white flight” and the concentration of poverty in central cities, but few peer-reviewed studies have been conducted. William Collins and Robert Margo used a statistical model to link a decrease in home property values, especially for Black homeowners, to the severity of civil disorders in the 1960s.⁴³³ The decreasing home values point to a struggle to restore some communities. Some face the opposite risk of accelerated gentrification. After riots in Tottenham in 2011, England, redevelopment proposals threatened to displace longtime residents.⁴³⁴

Social unrest, especially destructive social unrest, has more lasting negative emotional impacts than natural disasters. Social unrest is the result of personal conflict. In violent unrest, those participating felt angry enough to break norms about committing acts of violence and the people on the receiving end of this violence feel violated. Even people not directly involved feel drawn in by watching events in the media. This mood of mass victimization is the most widespread effect of social unrest. These effects can last for years.⁴³⁵

Outlook

Social unrest is impossible to predict far in advance. It is the function of social interactions where change is orders of magnitude faster than environmental and geologic hazards and the phenomenon is orders of magnitude more complex. The likelihood of future social unrest rests in issues that frustrate people (social justice, politics, even sports) and the disposition of crowds at large gatherings. While we know broadly the kinds of events that could trigger social unrest, it is impossible to predict which exact event will launch our next wave of social unrest.

While the biggest actions in Seattle have seemed to occur when Seattle was the primary focus of a conflict rather than a secondary site, such as the WTO protests, events in recent years show that conflict or injustice in other parts of the United States can also trigger social unrest locally. Seattle’s emergence as a leading cultural and economic center increases the chance that controversial events will be hosted here.

Every several decades, Seattle seems to go through surges of activity related to a hot button social issue. In the late 19th century it was immigration, in the early 20th, it was labor unrest; in the 1960s, it was many issues - the Vietnam war, intergenerational conflict, and race; in the 1990s, race and globalization; in the 2000s, race and politics. The 2001 Mardi Gras incident was like the 1969 University District events in that they did not have an overt political cause. They escalated due to conflict between people in the crowd combined with alcohol, crowding, and racial tensions as contributing factors. Generally, social unrest has taken on similar patterns of activity, with different motivating factors or details. When Seattle is a secondary site to the main conflict, as was the case with the Ferguson protests in 2014, the unrest has been smaller than that at the primary location.

The political polarization occurring in the United States has resulted in incidents of violence. This perception of greater divisions between groups could increase the likelihood of civil disorder or riots in the future though they are even more likely to be lone actors attacking people they don't like.⁴³⁶ Social media may be changing the risk of social unrest as well, as well as the role foreign governments may play. Twenty-eight countries have been identified as using real or fake social media profiles to manipulate foreign or domestic opinions to try and provoke conflict.⁴³⁷ It is unclear whether these emerging political challenges will increase the amount of social unrest.

Conclusion

Severe social unrest can occur in any community. It is impossible to know which issues will precipitate the next large instance of social unrest, but social inequities and political polarization persist as hot buttons. The flashpoints theory for civil disorder argues that grievances can build outside the view of those immediately affected until they explode as 'black swan' events. The best mitigation strategy is working to reduce racial and social inequities and political divides that fuel these events.

The number of deaths in the 2020 protests was lower than the 1992 L.A. riots, which is somewhat 'encouraging' given the vastly bigger scope of the 2020 events, the increasing number of firearms, and extreme political divides. Given the dangers of easy access to weapons and extreme political views, the lower casualty count for recent social unrest cannot be taken as a given. Nor should it be forgotten that most collective actions are peaceful, and that the expectation of violence can breed violence.

The 1,500 locations damaged in Minneapolis offer a somber reminder that Seattle's recent history with property destruction could be much worse. Seattle's recent unrest focused on downtown and Capitol Hill. The Minneapolis example shows that we should pay attention to all our neighborhoods to ensure they are healthy and thriving.

7. TERRORISM AND TARGETED VIOLENCE

This chapter covers mass casualty attacks including those driven by ideology with an intent to intimidate, terrorism, or by personal grievance, targeted violence. Despite similar consequences, distinctions between ideological and non-ideological actors are important to note because actors can exhibit different behavior and have different target profiles. Recently, however, the line between terrorism and targeted violence is blurring. A recent Reuters analysis concludes that many acts of U.S. targeted violence mix personal grievance and ideology.⁴³⁸

Mass casualty attacks overlap with many hazards in this analysis. Attacks can be perpetrated using a wide variety of means: bombs, chemicals, firearms, biological agents, infrastructure sabotage, and vehicles. Other chapters in this document include a discussion of terrorism when the hazard itself is used as a means of attack.

The bipartisan [Center for Strategic and International Studies](#) states that “The largest terrorist threats facing both the United States and Canada are domestic and motivated by far-right ideologies and conspiracy theories – and, to a lesser extent, far-left ideologies”.⁴³⁹

Terrorism

The Al-Qaeda attacks on New York City’s World Trade Center and the Pentagon on September 11, 2001, completely changed the perception of terrorism as a hazard in the U.S. It massively altered the U.S. approach to terrorism with the creation of the Federal Department of Homeland Security. Locally, Seattle staged one of its biggest emergency preparedness exercises around a terrorism scenario in May 2003 with federal and state partners with Top Officials (TOPOFF) exercise.

While this chapter focuses on consequences, defining terrorism is important to be able to measure it. Multiple definitions exist. The [Global Terrorism Database](#) describes it as “intentional act of violence or threat of violence by a non-state actor” where two of the following three criteria are true:

1. The violent act was aimed at attaining a political, economic, religious, or social goal.

Key Points

- ❖ *Lead Agency – Seattle Police*
- ❖ *Domestic violent extremists have committed more attacks recently. Many actors self-radicalized through social media and many attacks blend a mix of political and personal grievance.*
- ❖ *The consequences of the attack depend on the tactics employed by the threat actor, such as active shooter(s) events, bombings, arson, murder, kidnapping and hostage-taking, maritime attack, and hijacking or skyjacking. Other chapters cover cyberattacks, biological hazards, infrastructure failure, and hazardous materials incidents (including bombs).*
- ❖ *Vehicle ramming attacks have become increasingly common*
- ❖ *The 9/11 World Trade Center attacks in New York City changed the national perception of our vulnerability and response to terrorism in the United States. However, the use of large-scale tactics remains rare, and has not been successful in the United States since 9/11 by foreign actors.*
- ❖ *The threat of terrorism and violent extremism has grown with the interconnectedness afforded by the internet.*
- ❖ *The number of targeted violence incidents has increased over the last decade*
- ❖ *It remains nearly impossible to predict violent attacks, but security and intervention measures are continuing to evolve with the use of new tactics employed by threat actors.*

2. The violent act included evidence of an intention to coerce, intimidate, or convey some other message to a larger audience (or audiences) other than the immediate victims.
3. The violent act was outside the precepts of International Humanitarian Law.⁴⁴⁰

Legally, terrorism is defined in federal law in several locations. Title 28 of U.S. Code of Federal Regulations defines terrorism as “the unlawful use of force or violence against persons or property to intimidate or coerce a government, the civilian population, or any segment thereof, in furtherance of political or social objective.”⁴⁴¹

The FBI differentiates terrorism as international or domestic. It defines international terrorism as “Violent, criminal acts committed by individuals and/or groups who are inspired by, or associated with, designated foreign terrorist organizations or nations (state-sponsored).”⁴⁴² The September 11, 2001,

Hazards With Terrorism Nexus

- ❖ Biological Hazards
- ❖ Social Unrest
- ❖ Cyber Incidents and Disruptions
- ❖ Transportation Incidents
- ❖ Fires
- ❖ Hazardous Materials Incidents
- ❖ Infrastructure and Structural Failures
- ❖ Power Outages

attacks on the World Trade Center and the Pentagon were international terrorism. This category also includes acts by people living in the US who have connections to foreign groups. It calls incidents perpetrated by this class of people Homegrown Violent Extremism. The 2013 Boston Marathon bombing falls into this category.

The FBI defines domestic terrorism as “violent, criminal acts committed by individuals and/or groups to further

ideological goals stemming from domestic influences, such as those of a political, religious, social, racial, or environmental nature”⁴⁴³ The 1995 Oklahoma City bombing was domestic terrorism.

The distinction between international and domestic terrorism is important legally. To protect civil liberties, the federal government does not have a category of “domestic terrorist organizations” as it does “foreign terrorist organizations”. Despite having a definition of domestic terrorism, the federal government does not have a mechanism to charge individuals with domestic terrorism nor is it a crime to belong to a group that espouses violent actions.⁴⁴⁴ Despite the clear legal distinction, in practical terms the internet blurs the distinction between international and domestic terrorism. Individuals can freely communicate across the planet in an ecosystem of hate that transcends nationality and specific ideologies. Terrorism researcher Jacob Ware posits we are in a third generation of online radicalization where:

- The first generation consisted of radical groups using the Internet to spread their message. Communication was one-way. Recruiting was a major activity.
- The second generation was the use of large social media platforms. Two-way communications allowed echo chambers to intensify radicalization. Individualized search results created “Algorithmic radicalization”. Organizations became less important. More terrorist acts were committed by individuals acting alone.
- The third generation has seen a shift away from large, open social media platforms to end-to-end encrypted apps like Telegram. Ideology has become less important as people jump from topic to topic across the Internet. As noted above by Reuters, many radicalized people espouse a vague mix of ideology and personal grievance. The rise of meme culture and violent online rhetoric makes it hard to identify which individuals will act. Targets have become more diffuse. Lone actors are the most common perpetrators. The time between radicalization and action is decreasing with the result that many actors have less experience and practice. Violent

individuals become their own propagandists by writing and publishing manifestos and live streaming attacks.

Ware speculates that we may be entering a fourth generation involving the use of AI, 3D printing, and drones, but that we will not know for sure until the next type of attack comes.⁴⁴⁵

Understanding the ideological drivers for terrorism is important for understanding vulnerabilities and consequences but carries the risk of casting aspersions on protected speech. The First Amendment of the US Constitution protects a wide array of speech from government censorship. It is essential to recognize that it is violent action that is the hazard and not motivating ideology.

The Center for Strategic and International Studies (CSIS) compiled a database of terrorist attacks in the US from January 1, 1994, to December 31, 2021. It categorizes motivations in four broad categories:

- Religious extremism. Motivated by faith-based belief system such as Christianity, Hinduism, Islam, Judaism, and other faiths.
- Ethnonationalist extremism. Motivated by ethnic or nationalist goals.
- Far left extremism. Motivations include anti-capitalism, environmental causes, animal rights, anarchism, pro-communist beliefs, Black nationalism, law enforcement, and anti-colonialism.
- Far right extremism. Motivations include racial or ethnic supremacy, opposition to government authority, misogyny, conspiracy theories, and opposition to abortion.⁴⁴⁶

The lines between these motivations are porous and many actors combine multiple motivations. For example, the perpetrator of the Christchurch, New Zealand mosque attacks was motivated by white supremacist (far right) and environmental (far left) extremism.

Despite the increasingly blurry line between politically and personally motivated violence, some attacks are driven purely by personal and private reasons. These include workplace violence, school shootings, and other violence in public spaces. An example is the 2017 Las Vegas mass shooting. Regardless, the consequences are often indistinguishable from third generation terrorist attacks.

The [Global Terrorism Index](#) provides a look at the U.S. as compared to the rest of the world. The index is defined as “a composite measure made up of four indicators: incidents, fatalities, injuries and hostages. To measure the impact of terrorism, a five-year weighted average is applied.” The U.S. has an index value of 3.52. Lower than Germany but higher than France, the U.K., and Canada. [Our World in Data](#) is another resource to look at terrorism on a global scale. It offers a slightly different take than the Global Terrorism Index. It shows that the US suffers more terrorism deaths than other rich countries, but less than 100 deaths per year, except for 1995 and 2001, and that US deaths are orders of magnitude less than many other countries.

There is concern that terrorist groups or individuals may attack using chemical, biological, radiological, or nuclear (CBRN) agents as weapons of mass destruction (WMD). CBRN attacks are rare and ones that achieve mass destruction are exceedingly rare. Since 1992 the University of Maryland’s [Violent Non-State Actor CBRN Event Database](#) lists 47 attacks since 1992 or 1.42 incidents nationally per year. The database includes incidents like bear spray attacks that involve non-lethal chemicals.⁴⁴⁷ A 2018 analysis concludes, “Some of the hype surrounding WMD terrorism is overblown. Despite clear interest on the part of our most vehement and capable adversaries, a true WMD is likely out of their reach in all but a few scenarios”, but cautions, “technologies seem to favor the adversary.”⁴⁴⁸

Drones are an emerging terrorist threat. There have not been any successful attacks in the US, but the decreasing cost, increasing ease of use, technical advances, and the techniques developed on the battlefield in Ukraine are making drone attacks more likely. Terrorist organizations have used drones in conflicts in the Middle East and Africa, including using them to deploy chemical weapons. The most sophisticated of these organizations have state support but are less active in the US. Non-state

supported organizations and individuals still face significant barriers to producing weaponized drones, especially managing complex supply chains. Furthermore, they likely still prefer tried-and-true methods over unproven technologies. Despite these challenges, new technologies developed on in the Ukraine War may make drones attractive to dangerous groups and individuals. These include AI assisted targeting, autonomous weapons systems, AI assisted control allowing one pilot to control multiple drones, fast first-person view (FPV) drones capable of flying over 80 MPH, and fiber-optic control that makes jamming very difficult. Making the situation even more worrying are the significant gaps in counter-drone capabilities in the US especially at the local level. Currently, “only federal agencies like the FAA, Defense Department, Homeland Security Department, and FBI have explicit legal authority to shoot down drones or disrupt them through hacking and jamming technology.”⁴⁴⁹ Federal legislation is being developed but is limited to pilot projects. All these developments point to drones becoming an increasing risk.

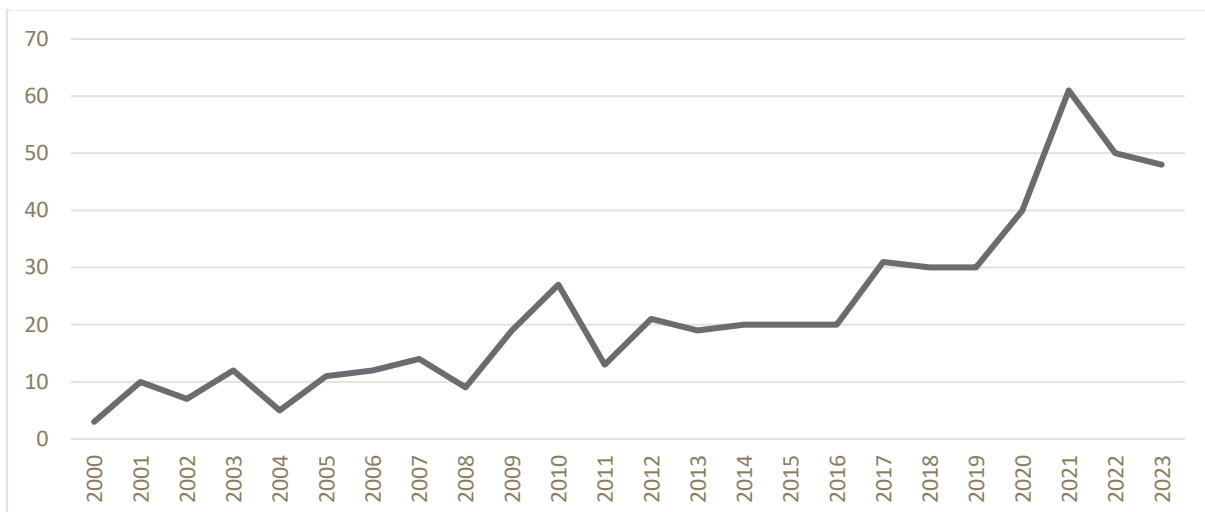
Active Shooter Incidents

Active shooter incidents are a form of targeted violence, and a terrorist attack can be an active shooter incident. The FBI defines an active shooter incident as “one or more individuals actively engaged in killing or attempting to kill people in a populated area.”⁴⁵⁰ The ‘active’ part of the definition implies the incident is ongoing which affects response. The definition overlaps significantly with the terrorism definitions given above, highlighting the impossibility of drawing a clear line between terrorism and personal acts.

The number of active shooter incidents have increased and have received greater media attention since the landmark Columbine High School Shooting on April 20, 1999, in Colorado. The deadliest active shooter incident in recent U.S. history occurred on October 1, 2017, when a gunman killed 58 people at a concert in Las Vegas.

An active shooter incident is defined by the action, not by the attacker’s motive. Not all active shooters impulsively and randomly open fire in a public place. Active shooters have demonstrated extensive planning, deliberation, and reasoning in the commission of the attacks.

Figure 50. Active Shooter Incidents in the US 2000 to 2023



Source: U.S. Federal Bureau of Investigation [FBI]. (2024, June)

The FBI published reports on targeted violence incidents in the U.S. between 2000 – 2023 indicating:⁴⁵¹

- There were 333 incidents with 135 meeting the definition of a mass killing (3 or more killings in a single incident).
- The incidents resulted 2,851 casualties with 1,062 killed.
- The number of active shooter incidents increased with a doubling of incidents during COVID, followed by a drop from 61 in 2021 to 50 in 2022, but it is too early to know if the decline will continue.
- The incidents took place at commerce/business locations (46%), educational institutions (24%), government institutions (10%), open spaces (9%), residences (4%), places of worship (4%), and healthcare facilities (3%).
- Over half of the incidents ended before police officers arrived.

Concern around school shootings has grown in the U.S. These incidents violate our ideal that schools should be safe places for children. However, while active shooter incidents may be trending upward generally, there is mixed evidence that school shootings are also on the rise. One report that looked at school shootings between 1940 and 2018 revealed that the number of school shootings in the last 18 years has already surpassed the total number of school shootings that occurred in the 20th century.⁴⁵² However, another report found that the number of students killed in school shootings has actually decreased since the 1990s.⁴⁵³ Nevertheless, school districts, including Seattle Public Schools, are actively working on developing stricter security policies. Seattle Public Schools will continue to engage in lockdown drills and promote the “run, hide, fight” training (escape if you can, hide if you can’t, and fight if you must) for situations with a direct encounter with a shooter. All Seattle public schools can lock all doors, and they plan to install cameras at front doors to view visitors before granting access.⁴⁵⁴ Any school security measure must be balanced with the fact that schools are public institutions, and it is impossible to completely secure such facilities.

History

Seattle has experienced activity related to terrorism, but never a large-scale terrorist incident. There have been many small-scale incidents that fit into the terrorist mold and could represent the first step in a pattern of escalation. They relate to both domestic and international terrorist groups. Foreign terrorist groups also use the U.S. for fundraising and recruiting. Some news stories that feature recruited Americans going abroad to fight make it seem as if this is a new phenomenon, but it dates back at least to the early 20th century with heavy Irish Republican Army fundraising in the U.S.

Seattle has also experienced domestic violent extremist (DVE) and active shooter incidents. Seattle events are listed as well as events with ties to Seattle.

After 1995

1996. Not a terrorist incident but reveals what can happen when ill-conceived actions happen at a time of heightened concern one year after the Oklahoma City bombing killed 168 people. A man parked his truck in the middle of Westlake Park, slashed the tires and walked away. His truck had a huge metal heart in its bed and the word “bomb” printed on its bumper. He intended the action as a protest but instead caused a massive bomb scare. Nine downtown blocks were evacuated during a busy weekday afternoon while the police investigated.

1999. A man, AKA the “Millennium Bomber”, was caught smuggling bomb-making materials into the U.S. at Port Angeles. He was an Algerian man with links to Osama bin Laden. He had hotel reservations in Seattle close to the Seattle Center. The New Year’s celebration at the Center was cancelled as a precaution. It was later determined that the actual terrorist target was Los Angeles.

2001. The Earth Liberation Front, a domestic terrorist group, claimed responsibility for firebombing attack against a University of Washington building. The fire caused \$6 million in damage and destroyed rare plants, books, and years of research.

2002. A man pleads guilty to aiding the Taliban government in Afghanistan.

2006. A man shot six people, one fatally, at the Jewish Federation of Greater Seattle. Haq was not connected with terrorist groups, but his motives were deemed political. This incident is an early example of the type of incidents that are becoming increasingly common in which individuals, often beginning with mental health problems, self-radicalization, and then committing acts of violence out of a mix of political and personal motives.

2006. A man killed seven in a mass shooting at a house party in Capitol Hill.

2009. A man set fire to police vehicles then later shot and killed a police officer. A court determined Monfort had political anti-police motivations.

2009. Eleven gay bars and the alternative weekly, The Stranger, received letters threatening to target the businesses with ricin. An attack did not occur.⁴⁵⁵

2011. Two men were arrested and charged with conspiracy after planning to attack the Military Entrance Processing Station (MEPS) in Seattle with machine guns and grenades. They had initially planned the attack for Joint Base Lewis-McChord.

2012. A man shot and killed four people at Café Racer and killed a fifth person near downtown Seattle while attempting to escape.

2014. A man attempted to set fire to a gay nightclub in Capitol Hill while 750 people were attending a New Year's Eve event.

2014. A man open fired at Seattle Pacific University, killing one student and injuring two students.

2014. A man killed four people, including a gay couple, as part of a personal vengeance against the U.S. government for its actions in the Middle East. In 2004, he was arrested and prosecuted for his role in a bank fraud scheme to finance fighters traveling abroad and had known links to a disrupted terror cell in Seattle in 1999.

2017. A man was arrested and charged with receiving incendiary explosive device materials to make a bomb that was to be used in connection with 2016 May Day events.

Before 1995

1919 Anarchists associated with the International Workers of the World (IWW) send 36 mail bombs to various political and financial leaders throughout the country including Seattle Mayor Ole Hanson. Most bombs failed to reach their targets. One person was severely injured. The bomb sent to Hanson failed to detonate. The incident was probably related to Hanson's strong response to the Seattle General Strike earlier in the year.⁴⁵⁶

1928 A series of bombings at movie theaters related to labor disputes. No reports of deaths or injuries. The bombings may have been due to a long-running labor dispute.⁴⁵⁷

1969. Bomb explodes on June 29 at 3:30 AM in the University of Washington Administration Building foyer causing \$291,000 (or \$2.5 million adjusted for inflation). No claims of responsibility.⁴⁵⁸

1970. Members of the Seattle chapter of the far-left Weather Underground bomb Clark Hall at University of Washington, home of the Reserve Officers Training Corps (ROTC). A warning was phoned into the university. The incident occurred at 2:45 AM. No casualties were reported. Damage was estimated at \$100,000 to \$150,00 (\$0.9 to 1.3 million adjusted for inflation)

1975. The Capitol Hill Safeway was the site of two bombings days apart. The first bomb detonated as the bomber placed it, killing him. The bomber was a member of the far left. The second bomb injured seven people. The attack was part of a series of bomb threats against targets across Western Washington including the Seattle Federal Building, the Snohomish County Courthouse, and the Ferris wheel at the Western Washington Fair.⁴⁵⁹

1975. On New Year's Eve 1975, the man from a far-left group bombed a City Light substation in Laurelhurst. No casualties were reported. The perpetrators issued a warning at 11:30 P.M. Police evacuated residents. The bomb detonated at 12:10 A.M. The substation was 'virtually destroyed' and left 2000 customers without power. Seattle Children's Hospital was forced to use back-up emergency power. The perpetrators stated the bombing was carried out in solidarity with striking City Light workers (see [Social Unrest](#)). The same night a Safeway distribution center in Bellevue was bombed.⁴⁶⁰

1984. Members of The Order, a racist Aryan Nations offshoot, robbed an armored car at Northgate mall. They fled to Whidbey Island and were subsequently killed in a confrontation with police.

1993. Two bombs exploded in Tacoma in July, causing some property damage. The American Front Skinheads group was responsible. They are also suspected of bombing a gay bar on Capitol Hill.

The Southern Poverty Law Center recorded 28 active hate groups in Washington State in 2022 up from 15 in 2010.⁴⁶¹

Vulnerability

Seattle is the most densely populated area of the Pacific Northwest, the hub of the regional economy, and home to many cultural, sporting, and entertainment events. It presents a target rich environment for extremists interested in attacking places with symbolic value. Complex attacks have targeted people and places with high symbolic value like the Pentagon and World Trade Center in the 9/11 attacks or a federal building in the 1995 Oklahoma City bombing.

Because of the attacks in the late 1990s and early 2000s, many government and business targets were hardened. The unfortunate side effect of this success is that violent actors are now seeking out less well protected targets like houses of worship, businesses, and festivals. Now, any public space can be a target, especially densely populated spaces. Non-politically motivated perpetrators often have a personal connection to their targets such as workplaces, schools, and houses of worship. Politically motivated perpetrators often target places associated with people and groups they hate like houses of worship, LGBTQ+ nightclubs, parade routes, and schools. Because potential targets exist throughout the city, it is impossible to determine geographically based risk areas as can be done for many natural hazards.

While targets vary widely, and an individual's or group's motivations suggest a preference for targets based on past attacks, but this does not mean targets are static. Extremists often have multiple motivations which can make predicting targets even more difficult.

- Far right extremists have targeted houses of worship; businesses catering to minorities, the LGBTQIA+ community, and women; individuals (i.e., assassinations); critical infrastructure; government facilities; law enforcement; and left-wing demonstrations
- Far left extremists have targeted businesses; animal research facilities; organizations perceived to exploit the environment; right-wing gatherings; government facilities; and law enforcement.
- Religious extremists and those motivated by religiously based foreign terrorist organizations have often targeted US military facilities, but the January 1, 2025, attack in New Orleans inspired by ISIS targeted a New Year's festivities.

Fatalities from terrorism are dominated by the September 11, 2001, attacks which were religiously motivated, but in most years after 1995, the majority of deaths were due to far-right attacks. The reason

far-right attacks have claimed more lives is due to the prevalence of firearms and explosives in their attacks.⁴⁶²

Incidents have commonly been enclosed facilities where the shooter has an easy choice of victims; where people are crowded together, and escape is difficult. However, recent incidents such as the Las Vegas concert shooting or the vehicle ramming attack in Nice, France show that violent attacks also have occurred at outdoor venues where people are gathered. Seattle's public spaces, institutions, and buildings will never be fully secure, and communities must balance their vulnerability to attacks with their desired quality of life.

The US is highly vulnerable to drone attacks because of large gaps in local law enforcement's ability to use counter-drone technologies. New technologies are increasing the potential for drones to evade countermeasures and increasing their ability to inflict damage. While drones are an emerging threat and no attacks have occurred in the US as of mid-2025, the FBI has observed an increase in the commission of crimes with intent to cause injury. Further evidence of vulnerability is the nearly 3000 drone flights into restricted air space over NFL games in 2023.

Consequences

The impact of a violent attack depends on the attacker's motivation or desired outcome, the tactic used, the location, weapon type, emergency response, and success of the attack.⁴⁶³ Most recent attacks have targeted people and caused high loss of life. Nothing in recent history indicates a change in this attack profile. Even a lone perpetrator can kill dozens of people.

Violent attacks can have a lasting psychological component. The community at-large can become traumatized both because they identify with the victims and because attackers often target well-known, public places. The sense of public trauma is further heightened by the overwhelming media coverage. Through the media, people watching the event on television feel personally attacked. If the place attacked is an important landmark, a community may feel its own identity is under attack.

The physical damage done in an attack, along with the psychological impacts on the community, can have significant negative economic impacts. The 2015 terrorist attacks in Paris cost an estimated \$2 billion in damage to the city mainly through tourism losses.⁴⁶⁴ Schools that have experienced an active shooter event often have to remodel or rebuild the school or specific site of the event to mitigate the psychological impact on students.⁴⁶⁵ An attack could deter people from going to public places, even if it occurred in a different city or country, hurting local businesses and institutions.

Most terrorist, violent extremist, and targeted violence incidents occur at a single site, but multi-site incidents (also known as Complex Coordinated Attacks (CCAs)) are possible and have been deployed by terrorists. While single/paired shooter scenarios can cause a significant amount of damage and casualties, the prospect of a CCA event is even worse, as illustrated by the attack in Mumbai in 2008 or the Paris attacks in 2015. In Mumbai, heavily armed terrorists launched ten coordinated attacks. The attacks lasted almost 72 hours, resulting in 173 deaths, and locked down much of downtown Mumbai. In Paris, terrorists used guns and suicide bombs at six different locations across the city, including a concert hall, restaurants, and outside of a sports stadium. The attacks lasted 3 hours and resulted in 130 deaths with hundreds more wounded. While these are extreme and rare examples, they illustrate what is possible.

Drones now account for 70% of casualties in the Ukraine war.⁴⁶⁶ The scale of drone use in the war is massive and proves their extremely lethal potential. Terrorist organizations and lone actors do not have the ability to use drones at this scale, but they could be stockpiled for a massed attack. With increasing payloads and the ability to precisely target weak points, they could cause high numbers of casualties and damage to critical infrastructure especially if multiple drones are used in an attack.

Outlook

The rise of political polarization has driven violence by political extremists. It is important to note that perpetrators of violence do not represent the views of mainstream political parties. The years after 2014 saw a rise nationally in attacks by far-right individuals and groups. Possibly as a result of this rise in attacks, there was a rise in far-left violence because of a perceived need for security. After 2019, the percentage of violent incidents associated with demonstrations noted by the Center for Strategic and International Studies from 2% to 47% due to the protests following the murder of George Floyd.⁴⁶⁷ While the vast majority of protests were peaceful, the volume meant that the small percentage of protest that became violent, caused the increase noted above. The Center for Strategic and International Studies notes this ‘security dilemma’ can cause an increase in violence as actors on opposing sides attempt to improve their own security.⁴⁶⁸

The most likely attacks are loosely organized attacks by far-right lone actors using firearms, but other actors cannot be ruled out. The January 1, 2025, truck ramming and shooting in New Orleans, was committed by an individual loyal to ISIS.⁴⁶⁹

As noted in [Figure 50](#), the number of active shooter and mass casualty attacks is increasing. The US Department of Homeland Security analyzed domestic violent extremist attacks from 2010 through 2022. The analysis found that the number of mass casualty attacks began rising in 2015.⁴⁷⁰ The number furthermore spiked during the COVID-19 pandemic. Although 2022 saw a decrease, it is too early to tell if this is a trend. The U.S. government maintains the Profiles of Individual Radicalization in the United States (PIRUS). In 2021, 90% of the offenders listed had far-right connections. The Anti-Defamation League (ADL) tracks hate incidents. It found a rise in far-right activity in Seattle starting in 2017.⁴⁷¹ Many of the far-right individuals and groups maintain a fixation on firearms and with the number of firearms in the U.S. dramatically increasing, violent actors have easy access to weapons. Together, these factors indicate Seattle has a high risk of experiencing a lone actor attack.

A U.S. Department of Homeland Security analysis found that only 3 attacks since 9/11 have been directed by foreign terrorist organizations.⁴⁷² The threat from these organizations have evolved from complex, large-scale attacks to simple, self-initiated attacks by individuals. Although, a large-scale terrorist attack cannot be ruled out, it is a low-probability event. The 2023 National Threat Assessment finds that Al-Qaida remains committed to attacking U.S. interests, but that the greatest threat is in regions where its affiliates operate rather than in the U.S. homeland. The same report mentions the possibility that extremist individuals and groups may gain experience by participating in the Russo-Ukraine War and bring this new experience to bear in staging attacks in the U.S.⁴⁷³

Attacks using chemical, biological, radiological, or nuclear agents are very rare with 1.42 events happening per year in the US, with most having minor consequences. These technologies are likely becoming easier for violent actors to acquire, but the ease of conventional attacks makes the use of these expensive and complex weapons very unlikely. The use of drones for terrorist attacks is furthermore an increasing possibility. While many terrorists will prefer cheap and tried-and-true means of attack, the decreasing cost and increasing ease of use along with improvement to lethality may tempt terrorist actors to use a new technology.

Conclusions

It is nearly impossible to predict terrorism, domestic violent extremism, and active shooter events. The pace and severity of attacks appear to be increasing, and tactics are continuing to evolve. Seattle has become a major economic and cultural center, increasing its symbolic value and therefore, its likelihood of being targeted. The downtown area is densely populated and thick with attractive targets. Much of Seattle’s economic and social life is concentrated in this area and is vulnerable to disruption. Terrorism and targeted violence remain extremely concerning because of the deliberate intent to harm and the very real possibility of a large number deaths and injuries in any attack.

8. CYBER DISRUPTIONS

This chapter analyzes the threats posed by cyber disruption resulting in the loss or compromise of digital infrastructure. It analyzes all the critical digital infrastructure affecting the Seattle community with an emphasis on infrastructure operated by the City of Seattle.

Complex modern economies rely on increasingly sophisticated digital infrastructure. Commerce, transportation, healthcare, communications, and utilities all require digital infrastructure to function at the efficiency needed to support our community. Digital technologies have radically transformed all aspects of modern life by making services and infrastructure more effective. However, this benefit introduces a myriad of vulnerabilities, both potential and real. Digital technologies are used to store personal data online where it can be vulnerable to theft. A complete analysis of all threats to digital infrastructure is beyond the scope of this chapter. However, this chapter offers an overview of the major threats to the Seattle community.

Causes

Digital systems can be damaged by human errors, cyber incidents (i.e., attacks), electro-magnetic pulse (natural or man-made), or physical damage as a secondary impact from another hazard.

Cyber Incident

The National Institute of Science and Technology (NIST) defines a cyber incident as “Actions taken through the use of an information system or network that result in an actual or potentially adverse effect on an information system, network, and/or the information residing therein.”⁴⁷⁴ Cyber incidents are intentional actions carried out by individuals, organizations, or

government entities. They range from unsophisticated attempts made by amateur hackers using canned computer scripts, to sophisticated attempts involving state actors. There are many types of incidents in between these extremes (Table 16). A cyberattack is a type of cyber incident which NIST defines as “any kind of malicious activity that attempts to collect, disrupt, deny, degrade, or destroy information system

Key Points

- ❖ *Lead Agency – Seattle Information Technology Department*
- ❖ *The U.S. economy is dependent on computer systems and the Internet to maintain basic functionality.*
- ❖ *Computer systems can face disruptions due to human error, intentional cyberattacks, physical damage from secondary hazards, and electro-magnetic pulse (EMP).*
- ❖ *Cyberattacks have the potential to cause Internet or utility outages, leaks or loss of sensitive data and information, compromised critical infrastructure or services, or physical destruction.*
- ❖ *The City of Seattle faces daily cyberattack attempts but has not yet suffered a major successful attack. The biggest risk is an attack on critical infrastructure like transportation, water, or power systems. Manual backups still exist for these systems, but overall services would suffer on manual backup.*
- ❖ *Seattle faces a growing threat of cyberattack as more of the city’s infrastructure and basic functions are connecting to the Internet. Traditionally non-computerized items (e.g. watches, thermostats, printers) are being connected to the Internet and providing new access pathways for hackers.*
- ❖ *While a catastrophic cyber-attack or disruption has not yet occurred in our world, the consequences of an attack in Seattle could severely harm the public and degrade or halt basic city functions and services.*

resources or the information itself.”⁴⁷⁵ Attacks are deliberate actions while incidents are the consequences regardless of motive.

Table 16. Cyber Incident Types

Espionage	Use of authorized access to gain sensitive or classified information for financial, military, or political reasons.
Data breach	Stealing valuable personal, corporate, or government data, most often for financial gain by selling it.
Ransomware	Denying a person or organization access to their data or digital systems until a ransom is paid. Often done with a threat to publish the data.
Denial of Service	Overwhelming a digital system to prevent use of the system.
Defacement	Changing the appearance of websites. Often done for propaganda or to embarrass the victim. Often called “hacktivism”.
Sabotage	Using authorized access to destroy data, hardware, or physical infrastructure
Misinformation	Corrupting data and information in the victim’s digital infrastructure. Increasingly done with AI. Example: Injecting false information into an AI’s training data so it comes to false conclusions.

Of special concern for emergency management are cyber incidents that disrupt critical infrastructure and services. They include attacks on hospitals, power grids, emergency dispatch, transportation, government services, and banking. These incidents cause public safety emergencies requiring extensive coordination across the public and private sectors to resolve.

State actors have become more willing to launch damaging cyberattacks. In 2018 the Worldwide Threat Assessment of the US Intelligence Community concluded that multiple nation-state actors pose an increasing threat of cyberattack to the United States.⁴⁷⁶ The 2016 Russian hacking of the Democratic National Committee (DNC) and subsequent leaking of thousands of DNC emails during the presidential election is an example of this new aggressiveness.⁴⁷⁷ The Russia-Ukraine war has boosted the use of cyberwarfare both between the combatants but also as a non-military means to strike opponents allies. The 2023 Worldwide Threat Assessment of the US Intelligence Community expanded on these ideas noting the increasing involvement and sophistication of organized crime in ransomware attacks and the new threat posed by AI in launching misinformation campaigns.⁴⁷⁸

Space Weather

Space weather is the result of activity on the sun’s surface. It is constantly ongoing just like weather on earth and is typically benign. Two types of space weather phenomenon, solar flares and coronal mass ejections can negatively affect power and digital systems on earth. Both arise when the sun’s magnetic field suddenly changes and can occur at the same time but are not the same. NASA has a [presentation](#) explaining the difference.

Solar flares are huge bursts of energy that travel from the sun at the speed of light. The energy from a solar flare is a risk to satellites and GPS equipment. Electronics in space are the most vulnerable because they are not protected by the earth’s magnetosphere. Communications and navigation (GPS) systems that depend on satellites can be disrupted if satellite electronics are destroyed. Besides damage to satellites themselves, radio signals between satellites and the earth can be disrupted. The effects can last for hours or days.

[Coronal Mass Ejections](#) (CME), are large expulsions of superheated gas called [plasma](#). They can reach the earth in as fast as 15-18 hours, but many take days. CMEs also pose a danger to objects in space, but unlike solar flares, they can affect the surface of the earth. They do so by disturbing the magnetosphere that protects the earth's surface from cosmic radiation causing a geomagnetic storm.⁴⁷⁹ This energy cannot damage small electronics directly but is a threat to power cables and pipelines (see the [Power Outages](#) chapter).⁴⁸⁰ By overloading electrical lines, geomagnetic storms can indirectly damage digital infrastructure through power surges. Shielding cables and using surge arrestors can prevent or mitigate much of this damage. Fiber optic cables cannot be directly affected, but long fiber optic cables that form the Internet backbone, many of which run under the sea, can be impacted because they rely on signal boosters every 50 to 150 kilometers. They are powered by electrical cables running along the fiber optic cable. If even one signal booster fails, the entire fiber optic cable will go dark. Repair involves sending a ship to bring the affected equipment to the surface and replacing it.

The largest geomagnetic storm in historic times was the 1859 Carrington Event which destroyed telegraph lines. It was 100 times as strong as a 1989 storm that caused a nine-hour power outage in most of Quebec and destroyed a transformer in New Jersey and 10 times stronger than a storm in 1921. Scientists have identified storms even bigger than the Carrington Event in 774 and 993 A.D. These massive storms happen about every 500 years.⁴⁸¹

Some have made apocalyptic predictions about the effects of space weather (as well as EMP attacks, covered below). These predictions are almost certainly overwrought, but space weather is a real hazard. To mitigate the threat, NASA has created a [Space Weather Prediction Center](#) which can predict most events hours to days in advance giving equipment operators the chance to mitigate damage by powering down equipment and shedding load. Despite the dire claims, scientists remain concerned. The Federal Government released the [Implementation Plan of the National Space Weather Strategy and Action Plan](#) in December 2023.⁴⁸² The plan highlights many gaps in our understanding about how geomagnetic storms affect the earth's surface and equipment on it.

Electromagnetic Pulse (EMP) Attack

An EMP attack is the use of a pulse of electromagnetic energy to deliberately attack digital and power infrastructure. EMPs can be caused by anything that generates electromagnetic energy, but the most significant are nuclear weapons which can generate an electromagnetic pulse (EMP) if detonated at high altitude (30km or more) or in space. EMP causes the same type of damage as a geomagnetic storm, but with a broader range of effects which are classified as E1, E2, and E3 EMP. Geomagnetic storms are a natural E3 EMP. E2 EMP is slightly more intense, such as an energy pulse created by lightning. E1 EMP directly damages or destroys electronic equipment. Even more dire predictions have been made about the threats EMPs pose than geomagnetic storms. Some claims predicted that a single well-placed nuclear weapon would destroy electronics across most of the U.S. and collapse the U.S. power grid for years causing social breakdown and mass starvation. Most experts dispute these claims as alarmist. The debate became politicized with those on the right pushing the EMP threat and those in the center and left remaining skeptical.

To bring more empirical evidence to the debate, in 2019 the Electrical Power Research Institute (EPRI) released a report that indicated EMP is a risk, but much lower than predicted by EMP hawks. It tested the effects of all three types of EMP on electronic and power equipment. It built a local E1 EMP field producing up to twice the expected energy release of an EMP attack, they found that 5% to 20% of the testing equipment was damaged. It used models developed at Oak Ridge National Lab to test the effects of E3 EMP on power cables and models used to assess lightning risk for E2 EMP. It then modelled the effects of an EMP attack on the U.S. grid (denoted as 'interconnection-scale'). Their limited modelling suggested that "E1 EMP alone were not found to causes immediate interconnection-scale disruption or blackout" but that the finding was "not conclusive" due to model constraints.⁴⁸³ E2 EMP would not

exceed the threat currently posed by lightning. It found that E3 EMP could cause a “regional blackout encompassing multiple states”. It offered suggestions for hardening electrical systems to mitigate damage. See [Power Outages](#) for more information.

In 2019, the Federal Government issued an Executive Order on Coordinating National Resilience to Electromagnetic Pulses. The order directed the Federal Government to conduct hazard and vulnerability assessments as well as further research into the effects of EMP on critical infrastructure.⁴⁸⁴ In 2023, the Federal Department of Energy released a guide for utilities to do vulnerability assessment for both geomagnetic storms and EMP attacks.⁴⁸⁵

Physical Damage

Cyber disruptions can also happen as secondary effects from other hazards. Earthquakes, floods, fires, and other hazards can destroy digital infrastructure and impede communications. Most of the time effects are limited due to the availability of back-up systems and the ability to route networks around problem sites. Nevertheless, if a significant network node goes down, the effects could be widespread and possibly prolonged. Communications can be disrupted by physical damage to cables or wireless equipment. In Seattle, accidental damage to cables has occurred during construction or paving projects, causing temporary Internet and phone outages for thousands of customers.⁴⁸⁶ Larger scale disruptions could occur if key Internet cables are damaged, as occurred in 2024 with key Red Sea cables that disrupted Internet traffic to much of Africa.⁴⁸⁷

Indirect Effects

Other hazards, including human error, can impact digital networks and information. Power outages can create cyber disruptions, such as in 2006 when many parts of Seattle lost power for days. Many individuals and small businesses had trouble powering computers and mobile devices. As computers become our primary tools for gathering information and communicating, their loss can endanger public safety and welfare. If the power goes out and fuel delivery to generator sites is impaired, bigger sites like communications hubs and data centers could go down causing disruption if they are not adequately backed up. Additionally, some of the City’s communications equipment is in rooms with high-power sprinklers. If there was a fire in one of these buildings or a sprinkler head was knocked off, it could damage equipment and cause disruptions to City communications.⁴⁸⁸

Digital Ecosystems

The world’s digital infrastructure can be thought of as a single global digital ecosystem connected through the Internet. Both our local economy and the global economy depend on this ecosystem to maintain our level of well-being. It includes the Internet backbone, local networks, applications, services, AI, data, servers, general purpose computers, phones, and specific purpose (embedded) computers. Even systems not connected directly to the Internet (i.e., air gapped) have indirect contact via physical media. This section outlines how these components are involved in cyber incidents and disruptions.

General Purpose Computers

A computer built to handle many tasks is a general-purpose computer. The class includes personal computers, most servers, tablets, and smartphones. They run common operating systems like Windows, iOS, and Linux operating systems and use industry standard hardware components. Being general purpose gives these computers great flexibility but also creates many openings for hostile actors to exploit. Being built from commercial components reduces cost but also means that the same hostile actors can achieve economies of scale when writing malware. Statista calculates there were 768 million of these devices in the U.S in 2022.⁴⁸⁹

Special Purpose Computers and the Internet-of-Things

Special purpose computers have dedicated functions. A computer that assists in the control of a car or controls industrial machinery is a specific purpose computer. Many of these computers are embedded systems integrated into mechanical or electronic devices. An estimated 18 billion were in use in 2024. That number is projected to be 39.6 billion in 2033.⁴⁹⁰

These computers have a wide range of applications from consumer electronics, industry, transportation, medicine, and facility management to defense. Miniaturization is pushing their integration into smaller and smaller devices. Where previously these devices were often isolated from the Internet, more are now being connected. Everyday items, from printers to baby monitors, make up a growing body of objects connected to the Internet, called “the Internet of things” (IoT).

Supervisory Control and Data Acquisition (SCADA) Systems

SCADA is a class of industrial control systems (SCADA can also be referred to as ICS – industrial control system, or OT - operational technology) that can include embedded systems, general purpose computers, and communications equipment. They provide real time data flow between sensors, workstations, and other networked devices in a system, as well as allowing for monitoring and control.⁴⁹¹ They are used in power generation, transmission, and distribution; traffic control; water treatment, water distribution, drainage, and waste; oil and gas transmission; dams; transportation monitoring; manufacturing; and communications. Many systems incorporate sensors to monitor infrastructure activity (e.g., water flow), a computer system that executes programs to control devices (e.g., a valve) based on sensed information, a database, and a human-machine interface to allow people to program them. Most are now linked to private networks to allow components to be controlled based on the status of a whole system.

Artificial Intelligence (AI)

The International Standards Organization (ISO) defines artificial intelligence as “a technical and scientific field devoted to the engineered system that generates outputs such as content, forecasts, recommendations or decisions for a given set of human-defined objectives”. In plain language it means machines that are able to learn, reason, and problem solve. Older AIs are used for analytics and predictions within a narrow scope. Newer generative AI creates new data. AI requires training on huge data sets and a system of rules arranged in a neural network. AI introduces a new set of cyber security vulnerabilities. These include:

- **Evasion attacks** are attempts to evade the proper behavior of an AI by giving it unexpected information. An example includes a possible attack on self-driving cars by altering road signs that cause the cars to crash.
- **Poisoning attacks** occur when a bad actor introduces corrupted data into a training dataset before deployment causing the AI to give erroneous results.
- **Inversion attacks or privacy attacks** use queries to an AI to reveal its training data. Doing so can reveal private sensitive information.
- **Extraction attacks** are attempts to get the model the AI uses. Doing so helps create more successful evasion attacks.⁴⁹²

Adversarial machine learning is the study of security vulnerabilities in artificial intelligence. The field is still in its infancy and an evolving legal and regulatory environment.

History

The following is a history of significant space weather events and cyber incidents. No EMP attacks have ever happened, but above ground nuclear tests have caused EMP events in the past.

Space Weather and EMP Events

Because geomagnetic storms are directly felt through their effects on electrical equipment, we do not have direct evidence for them before the 1859 Carrington Event. Older events are inferred by sudden spikes in carbon-14 in tree rings and beryllium in ice cores. The biggest known storm happened more than 14,000 years ago based on this chemical evidence.

774 CE. This storm was an order of magnitude larger than the 1859 Carrington Event storm.⁴⁹³

993 CE. This storm was 60% smaller than the 774 storm, but still much more powerful than the Carrington Event.⁴⁹⁴

1859. Carrington Event. This is the benchmark for solar storms. The storm shut down telegraphic lines and ignited fires in telegraph offices but had no effect on wider society due to the extremely limited use of electrical equipment at the time.

1921. Railroad Storm. This storm was nearly as powerful as the Carrington Event. It caused widespread outages in the New York region to telegraphs, telephones, and railroads. The latter were due to the failure of electrically controlled switching equipment.

1962. Starfish Prime was an above ground nuclear test in the Pacific. It caused damage to electrical equipment in Hawaii. This test is the basis for concern about EMP from nuclear weapons.⁴⁹⁵

1972. Solar storm caused power grid disturbances and detonated naval mines in waters off North Vietnam.⁴⁹⁶

1989. Solar storm caused nine-hour power outage in Quebec and damages transformer in New Jersey. This storm alerted the electrical power industry to the danger posed by space weather. Many utilities began hardening their systems following this event.

2012. A Carrington size coronal mass ejection narrowly missed the earth.

Cyber Incidents and Accidents

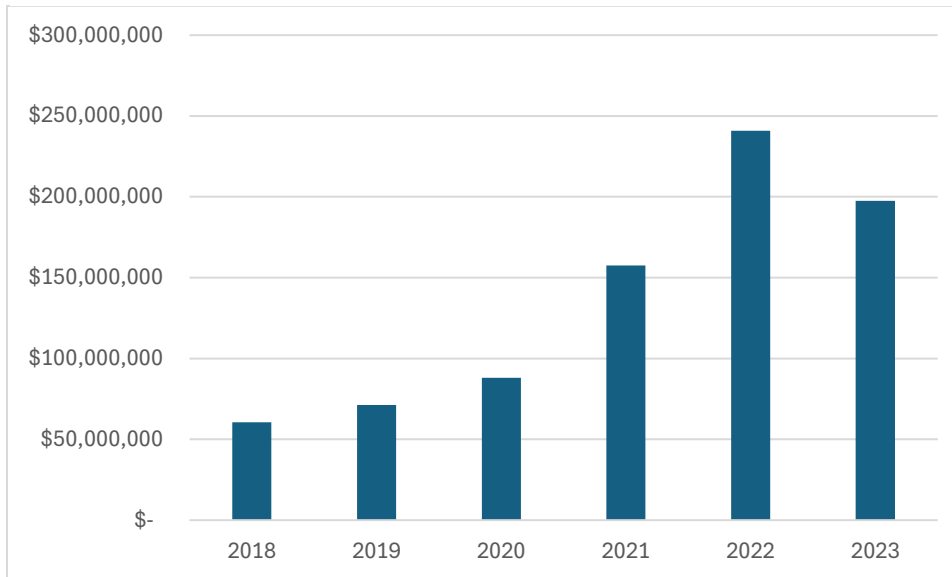
Small scale cyberattacks give useful insight into the level of malicious activity our area is undergoing. The FBI runs the [Internet Crime Complain Center](#) (IC3). It enables people and businesses to file complaints about Internet crimes and provides dollar loss data at state level. More background cyberattacks point to a higher chance of a high consequence attack. The data show a large increase from 2018 to 2022 with a drop in 2023. The reason for the drop is unclear.⁴⁹⁷

The following is a history of significant cyber incidents in the Seattle area or in other locations that are indicative of the risk Seattle faces. Our area has a broadly similar threat profile as the rest of the United States. Cyber threats are new relative to other hazards. We have not experienced all the types of damaging incidents it is possible to experience. The Center for Strategic & International Studies (CSIS) maintains a list of [significant cyber incidents](#). The cybersecurity company, Comparitech, maintains a database and map of targets of ransomware at <https://www.comparitech.com/ransomware-attack-map/>. Finally, the Washington State Attorney General maintains a [database of data breaches](#) affecting Washingtonians.

The Russia-Ukraine War has given the world a test case for what full scale cyber warfare looks like. Russia has one of the most powerful cyber warfare capabilities. The war has been the most intense use

of hostile cyber operations in history, but cyber operations have had a limited effect on fighting. Most cyber operations are now aimed at espionage and misinformation.⁴⁹⁸

Figure 51. Annual cybercrime losses in Washington reported to FBI Internet Crime Complaint Center



2008. Cyber Incident. Stuxnet. The first verified use of a computer virus to destroy physical infrastructure. It was developed and deployed by the U.S. and Israeli governments to destroy centrifuges in the Iranians nuclear program. The attack was very complex and expensive at an estimated \$1 billion. The virus came to light in 2010. It infected 20,00 centrifuges and destroyed 900 of them.⁴⁹⁹

2009 (Local). Physical Damage. An electrical fire took Fisher Plaza data centers offline, bringing down several eCommerce sites including a credit card validation service. The fire also disrupted KOMO TV and radio.⁵⁰⁰

2014 (Local). Cyber Disruption Most of Washington State experienced a 6-hour 911 phone system outage due to human error. Around 4,500 calls went unanswered.⁵⁰¹

2016. Cyber Incident Ransomware. San Francisco Municipal Transportation Agency (the Muni) was hit with an attack that locked operators out of computers and customers out of kiosks. The attack affected payments. Muni offered customers free rides for two days. Administrators restored its systems without paying the demanded \$73,000 ransom.⁵⁰²

2017. Cyber Incident Ransomware. A ransomware attack shut down the port terminals of Danish shipping giant Maersk for two days, causing an estimated \$300 million in associated costs.⁵⁰³

2017. Cyber Attack. Russian government hackers broke the business side of the Wolf Creek Nuclear Operating Corporation in Kansas. This was the first time U.S. nuclear facilities were compromised. The U.S. Department of Justice indicted three Russians for the attack in 2022. The attack was part of an effort targeting hundreds of energy sector facilities across multiple countries.⁵⁰⁴

2017. Cyber Incident Virus. Schneider Electric was forced to shut down operations of a power plant in the Middle East after malware compromised its industrial control systems. Analysis by security researchers indicated that the attack was sponsored by a nation-state.⁵⁰⁵

2017. Cyber Incident Ransomware. A ransomware virus called WannaCry affected over 230,000 computers throughout the globe.⁵⁰⁶ It did not require any user interaction to spread. Boeing was attacked, but there was no interruption to business.⁵⁰⁷ It affected the UK's National Health Service,

causing system outages at hospitals and forcing ambulances to be rerouted. It was the first time the UK convened its emergency committee due to a cyberattack.⁵⁰⁸

2018. Cyber Incident Ransomware. An important support application for Baltimore’s 911 system, the Computer Aided Dispatch (CAD) system, was infected with malware and taken offline for 17 hours. During the attack, the 911 phone system continued working, but dispatchers were not about to access caller details and had to resort to a manual system.⁵⁰⁹

2018. Cyber Incident Ransomware. The City of Atlanta was hit with SamSam ransomware infecting nearly all of Atlanta’s city agencies. The attack affected court scheduling, online bill payments, and access to police dashboard cameras. Attackers demanded \$51,000 in cryptocurrency to restore the city’s data. Atlanta spent \$17 million to recover its system. (CSIS). The U.S. government charged two Iranian nationals in the attack.⁵¹⁰

2018. Cyber Incident Ransomware. The Colorado Department of Transportation (CDOT) was struck with ransomware affecting business operations but not transportation operations. Most importantly, processing \$100 million in employee pay halted. The cause was a temporary testing server connected to the Internet that lacked the usual security safeguards. The attack cost \$1.7 million in overtime, meals, and equipment.⁵¹¹

2019. Cyber Incident Ransomware. The City of Sammamish lost access to most business systems, but public safety systems remained functional. The city had a cyberinsurance policy which covered some of the costs of response.⁵¹²

2020. Cyber Incident Ransomware. A woman died in Germany after her emergency transport was diverted a hospital under a ransomware attack. The death is the first attributed to a cyberattack.⁵¹³

2020. Cyber Incident Ransomware. Universal Health Systems (UHS), which runs 400 sites, sustained a ransomware attack that took its electronic health records offline for three weeks. Ambulance and elective procedures had to be diverted to non-UHS facilities. The attack cost UHS \$67 million.⁵¹⁴

2021. Cyber Incident. The water system of Oldsmar, Florida was the target of an attack to increase the amount of sodium hydroxide (lye) 100-fold. The attacker used a remote access application like the kind used by IT support staff to access a computer with water system control software. The attack was quickly noticed and prevented. Managers emphasized that the water system has monitors to check the amount of sodium hydroxide and that these monitors would have shut down the water system automatically.⁵¹⁵

2021. Cyber Incident Ransomware. One of the largest fuel pipelines in the United States transporting nearly half of the East Coast’s fuel, Colonial Pipeline, was struck with a ransomware attack causing the pipeline operator to shut the pipeline from May 7 to May 12. Several airports had to adjust operations. Panic buying caused fuel shortages in some areas even as supply remained available. Prices rose modestly. The attack was committed by a criminal group which restored systems after a bitcoin ransom was paid. The U.S. Department of Justice was able to recover more than half of the ransom. The attack underscored the vulnerability of the nation’s energy sector to attack. The hackers were able to gain access with a single stolen password. Colonial’s system did not have multi-factor authentication.⁵¹⁶

2023 Cyber Incident. Russia attacks Ukrainian telecom Kyivstar wiping the company’s computers. The attack kept it offline for eight days. Ukrainians who depend on Kyivstar to deliver air raid warnings were at risk, but the cyberattack was not accompanied by a missile attack.⁵¹⁷

2023 Cyber Incident Data Breach (local). Fred Hutchinson Cancer Center had a data breach of over 800,000 patient records. The criminal then extorted patients using the data.⁵¹⁸

2024 Accident. AT&T experienced a system-wide outage due to a failed network update. Approximately 25% of its users lost service, including FirstNet, the AT&T run service for first responders. FirstNet was restored after three hours. The outage affected calls to 911 and commercial sales.⁵¹⁹

2024 Cyber Incident Ransomware (local). Seattle Public Libraries was hit with a ransomware attack. This attack rendered most of the library system's services unavailable including online access to user accounts, e-resources, in-building wi-fi, and public computers.⁵²⁰ The attack followed similar events in Toronto and London. Analysts speculate that organized crime is targeting schools and libraries because they provide critical services for vulnerable members of the community. The cutting of services pressures local governments to pay ransoms.⁵²¹ The attack was first noticed on May 25th. All services were restored on September 3rd.

Vulnerability

Seattle faces two types of vulnerability: EMP (space weather and EMP attack) and cyber incidents.

Space Weather and EMP

The effects of geomagnetic storms are stronger near the poles. The effects of the 1989 storm dropped significantly below 40° north latitude. Studies of geomagnetic storms often use this latitude as a marker for increased vulnerability. Seattle's location at 47° north latitude makes it more susceptible to geomagnetic storms.

Geology can change the intensity of low frequency electromagnetic energy (EMP 3). Both EMP attacks and geomagnetic storms generate this energy. A 2018 study of the Pacific Northwest examined 67 points, four near Seattle, for their conductivity. Each point near Seattle was predicted to have higher than normal intensities with one site north of Seattle showing significantly higher intensity. Power lines in these areas would be at higher risk. The study authors cautioned that their analysis only modelled selected points, and a more comprehensive analysis is needed.⁵²²

Most of the City of Seattle's key infrastructure has surge protection with fused power supplies. This equipment reduces the chance that sensitive electronics controlling the infrastructure will be damaged.

Cyber Incidents

Critical facilities such as hospitals, emergency medical services (EMS), utilities, and 911 centers increasingly rely on digital infrastructure. If their functions were to be disrupted or compromised by a cyber incident, public safety would be compromised. However, most of these emergency service facilities have continuity of operations plans that include procedures for manual operations, but manual operations would entail service reductions.

Seattle's concentration of healthcare services creates an inviting target for cyberattacks. Seattle healthcare providers have had data breaches but have not suffered an incident disrupting service. However, Fred Hutchison patients were extorted by the criminals who committed the data breach. Past compromises generally mean increased vulnerability.

As a local government, the City of Seattle is a target. Its publicly run utilities most likely make city government more attractive as a target. The City of Seattle has not had a data breach or ransomware attack. It maintains a robust IT security program based on [Center for Internet Security](#) (CIS) and [National Institute of Standards and Technologies](#) (NIST) standards. The lack of past cyber incidents does not guarantee the future; it suggests the city government is relatively less exposed. The City of Seattle maintains cyber insurance to reduce its financial exposure.

Industrial control systems (ICS) and supervisory control and data acquisition (SCADA) systems control critical infrastructure making them targets for hostile actors. Recent ransomware attacks, like the one on Colonial Pipeline, targeted business systems because they are more exposed to the Internet and are often perceived to be less critical and therefore less protected.

SCADA systems can be vulnerable to attack due to insecure design, human interactions, and configuration.⁵²³ Many systems are aging, and were not designed with cyber security in mind, but rather for processing efficiency. Older systems often relied on the “security by obscurity” principle (i.e., the system would be secure as long as its design remained secret). Many now lack security features needed in our increasingly interconnected and sophisticated digital world. While many SCADA functions are machine-to-machine interactions, humans still interact with these systems on some level and can unintentionally provide access to an attack. Weak configuration of operational technology can make a SCADA system vulnerable, especially when it is connected to the Internet for convenience. For this reason, many SCADA operators do not allow their networks to connect to the Internet. Despite the prevalence of this policy there is pressure to connect, and it is easy for staff to mistakenly do so.

Nationally, many SCADA operators are not patching systems due to concern that patching will cause system outages, that it is not needed because systems are not directly connected to the Internet, or that the equipment is so old that there are no patches available. Some organizations simply lack the capacity and resources to keep up with patching.⁵²⁴

Locally, the City of Seattle launched major SCADA upgrades over the past ten years. Seattle City Light (SCL) implemented a new Energy Management System that modernized their 1980s era SCADA systems. The new system allows SCL to utilize more “smart grid technologies,” such as wireless meters that automatically track wattage and transmit data.⁵²⁵ Seattle Public Utilities (SPU) also underwent a major upgrade to their SCADA system in 2015.⁵²⁶ Additionally, Seattle’s water transmission and distribution systems are mostly gravity feed which means that pumps are less important than in many other regions. Less reliance on pumps reduces the water system’s vulnerability to cyber disruption.

As more of our transportation systems become “smart”, we become more vulnerable because cyberattacks and malfunctions can disrupt our transportation system, or worse, cause harmful or fatal accidents. All modes of transport: roads, rail, air, and marine all have major computerized components. These computers run signals, communications, controls, and vehicle subsystems. An attack that gains control of these systems could cause major vehicle collisions. One study found that it is possible to hack semi-trucks to take over acceleration functions and remove braking capabilities when the vehicle is at speeds under 30 mph.⁵²⁷ The same study concludes that these types of attacks are not just limited to the software on semi-trucks, but most other vehicles as well.

As communication networks move towards using Voice Over Internet Protocol (VOIP) services, they become more vulnerable to attack and other digital disruptions. Fortunately, many critical services, like EMS and utilities, have their own radio networks or satellite phone capabilities to ensure they can still communicate in the event of an attack or natural disaster that disables their VOIP systems.

The Seattle region is home to many large companies that support the local economy such as Amazon, Boeing, and Microsoft. A significant attack on one of these companies that either compromises consumer information or halts business operations would have negative economic implications for regional business. Seattle is also very trade dependent. The high volume of products and money that move through the port makes the city’s trade and business operations a target for cyberattack.⁵²⁸

Physical Damage

Digital infrastructure is exposed to physical damage from due to natural man-made hazards. Earthquakes are an especially dangerous hazard for Seattle. An analysis of the Pacific Northwest’s Internet infrastructure found that most of it was exposed to a 2% chance of ‘severe’ shaking over a 50 year period and had a 10% chance of experiencing ‘very strong’ shaking over the same 50 year period as measured by the Modified Mercalli Intensity scale (see [Earthquakes](#) for more information on this scale). The analysis was not peer reviewed and did not estimate the failure rates for the exposed infrastructure but provides valuable insight into exposure levels.⁵²⁹

Consequences

Assessing the consequences of cyber disruption is challenging. The digital age is only a few decades old, and technology is rapidly evolving. Disruptions can result via physical damage, blocked signals, or software failure (accidental or intentional), but the consequences are similar: the loss of critical systems, services, and data for an extended period. Despite limitations and challenges with estimating the costs of Internet outages, the Internet Society's [NetLoss](#) tool estimates the cost of Internet shutdowns at a national scale.

Space Weather and EMP Attack

A space weather event like the 1859 Carington Event or larger would induce currents power and communications cables. Most space weather events can be predicted, and with warning the damage can be mitigated. If not mitigated, induced currents could cause power outages, disrupt Internet traffic on a global scale during the storm, and damage unprotected digital infrastructure via power line voltage spikes over potentially, a large part of the globe. Devices that are plugged into a power source, powered on, and not protected by a surge protector or arrestor could be harmed. In this case, it would be the last digital mile that would suffer the most. With computers embedded in billions of devices, many components of infrastructure, commercial, and personal systems could fail.

Satellites are more exposed to space weather. Services like GPS that depend on them will be more heavily impacted. In most cases, these services will be disrupted and not permanently damaged.

Cyber Incidents

The most likely cause of cyber disruption is cyberattack. The worst cases would take down critical digital infrastructure with detrimental effects on public safety. Any attack that affects healthcare, power, water, or emergency communications will have negative consequences for the public. Being unable to access a medical record or reach an emergency dispatcher is potentially life threatening. Most City of Seattle departments are required to have Continuity of Operations Plans (COOP) to ensure delivery of key services but would have to prioritize which services they provide. In recent high-profile attacks, some services were restored within days, but other services took weeks to months to restore.

Successful attacks on SCADA systems would have more severe consequences. The loss of control over the water SCADA system could force Seattle to rely on manual backup systems that would reduce overall efficiency and potentially cause utility outages. In the power arena, an experiment demonstrated that it is possible to destroy electrical generators by sending them instructions that cause them to overheat.⁵³⁰ Attacks or accidents could also damage turbines in power generation facilities. Losing generation facilities would reduce Seattle's power capacity and could lead to brownouts especially if an attack on the power system occurred during peak demand (during the winter in the Pacific Northwest).

A successful ransomware attack on general City of Seattle business systems would impede important government services. It is impossible to know which services, but the city government handles many direct services like utility billing, building permits, human services, childcare, housing assistance, recreation classes, and many more.

Physical Damage

Some of Seattle's natural hazards such as flooding, fires, or earthquakes can cause physical damage that in turn triggers a cyber disruption. Such a cyber disruption could feed back into the consequences of the primary hazard. A 2016 earthquake in New Zealand led to five days of outages and the 2011 Tohoku earthquake resulted in up to two days of losses. The Internet traffic monitor Cloudflare Radar note drops of 57% to 94% in hard hit Turkish areas following the 2022 earthquake.⁵³¹ Ready.gov lists a cell phone, a means of getting information along with food, safety equipment, and medicine as an essential part of a disaster kit.⁵³² People and businesses who lose connectivity face heightened risk. For example,

following earthquakes, the affected public would not get critical warnings about aftershocks and post-earthquake fires. Much of the Pacific Northwest's Internet infrastructure is exposed to a significant seismic hazard making it likely that communications will be degraded after a large earthquake.

Outlook

The number of ransomware attacks is increasing. These attacks are predicted to grow with a 63% increase in cost world-wide by 2027.⁵³³ The use of cyberattacks as a weapon in international conflicts is also increasing, but a major attack causing widespread and prolonged outages to critical infrastructure is unlikely. The main threat will continue to be ransomware and data breaches.

The doomsday scenarios painted by those who fear EMP, and space weather are not realistic. Space weather is a risk, especially to the power grid, but can be mitigated. Many questions remain about EMP, but the empirical testing done so far suggests a lower risk than initially thought. Even if a hostile actor with a limited nuclear capability wanted to attack the U.S., it would likely use the weapon to blow up a target rather than attempting an EMP attack. As Professor Yousaf M. Butt wrote, "A weapon of mass destruction is preferable to a weapon of mass disruption."⁵³⁴

A 2019 paper estimated the probability of solar flares capable of generating a Carrington Event or larger solar storm to be between 0.46% and 1.88% by 2029.⁵³⁵ Another model put the probability higher at 12%.⁵³⁶

Cyberattacks are the major threat for cyber disruptions. Digital infrastructure is ubiquitous. Our critical infrastructure runs on it. Our vital records are recorded in it. Most of this infrastructure is connected to the Internet. Such an inviting and available target guarantees bad actors will continue attacking digital infrastructure.

In 2014, the Pew Research Center asked 1,642 experts in Internet evolution and technology if they thought by 2025, a major cyberattack will have caused widespread harm to a nation's security and capacity to defend itself and its people (widespread harm being defined as significant loss of life or property losses, damage, or theft at the level of tens of billions of dollars). 61% of the respondents answered 'yes', citing the increase in sophisticated tactics in recent years, the history of successful attacks on infrastructure (Stuxnet), and the fact that security was not the main priority in designing Internet applications. A smaller number of respondents dismissed or downplayed doomsday predictions citing improvements in security, the threat of retaliation, and the self-interest of people with a financial stake in cybersecurity.⁵³⁷

Despite many large cyber incidents since the 2014 article, including the major ransomware attacks outlined above, there has not been many catastrophic incidents as was predicted in 2014. The 2022 Russian invasion of Ukraine was a near perfect test case for judging the real-world effects of destructive cyberattacks. Russia, one world's most cyberwarfare capable nations, had no reason to hold back destructive cyberattacks on Ukraine. Cyber operations have become a part of overall military operations, but they have not been transformative. The most destructive was the December 2022 attack on the private Kyivstar telecom system. While the possibility for a cyber incident with dire real-world consequences cannot be entirely dismissed, the Russian Ukraine War suggests cyber doomsaying is overhyped.⁵³⁸

The City of Seattle is constantly facing cyberattacks on its digital systems. Most are minor, unsophisticated, and unsuccessful, but the 2024 recent ransomware attack on the Seattle Public Library underscores the risk to even local governments with robust cybersecurity. While the library attack was not a disaster for the entire community, it severely impacted vulnerable people who rely on it for Internet access

Conclusions

Seattle has two major cyber disruption threats: cyberattacks and geomagnetic storms. Cyberattacks are the most frequent cyber disruption but will most likely not cause a major disaster. Massive geomagnetic storms have the potential to cause major disruptions but are less common (1% to 12% chance per decade) and uncertainty exists about the extent of their effects. Accidents, physical damage, and EMP attack are secondary threats. Accidents can be significant like the 2024 AT&T outage but are usually resolved quickly. Physical damage is mostly a secondary impact due to a larger event like an earthquake. EMP attack is highly unlikely, and its effects are disputed by experts.

Cyberattacks are a growing threat to the Seattle area. Ransomware attacks, because they are designed to disrupt operations, are the most directly impactful to the community at large. The chances of a ransomware attack causing a large disaster for Seattle are low. To date, ransomware attacks have only affected individual organizations. While the impact on the organization can be big for that organization and its stakeholders, wider community impacts have been limited. The Colonial Pipeline attack came the closest to developing into a disaster level event. Cyber incidents caused by international conflict pose a bigger threat. Cases of malware infecting computers connected to critical infrastructure suggest an intent by hostile countries to disrupt U.S. energy and communications if conflict arises. While this threat is real and significant, the resilience of Ukraine's digital infrastructure in the face of Russian cyberwarfare suggests the threat can be mitigated.⁵³⁹ Artificial Intelligence is a new attack vector. Many analysts are concerned about its vulnerability and potential as an offensive tool.

Geomagnetic storms have long been known as a hazard to the power grid, and they increasingly pose a danger to the Internet, satellites, GPS, and communications as these systems grow. While apocalyptic predictions have been made about the effects of massive geomagnetic storms and EMP attacks, which are similar, experts disagree about the frequency of damaging storms, sensitivity of equipment, and the ability to prevent damage during a storm (e.g., by disconnecting equipment). As one writer put it, "the current Internet infrastructure has not been stress-tested by strong solar events."⁵⁴⁰ Technology fixes are available to mitigate risk to most equipment. Given the potential harm a geomagnetic storm could cause, critical infrastructure owners should invest in mitigation. These actions also protect infrastructure from EMP attack. The City of Seattle owns its own power infrastructure, but the major risks to digital infrastructure are to submarine Internet cables and satellites, both out of local control. The Federal government has a National Space Weather Action Plan. It has created the [Space Weather Prediction Center](#) and [launched satellites](#) to study the sun and help predict harmful space weather events.

9. TRANSPORTATION INCIDENTS

This hazard encompasses major accidents involving transport conveyances: road vehicles (trucks, buses, cars), trains, aircraft, and marine vessels. Pipelines are considered transportation but overlap with hazardous materials incidents. Bridge collapses are included in [Built Environment Failures](#). Attacks using transportation conveyances as weapons are considered here but are also covered in the [Terrorism and Targeted Violence](#) chapter.

Modern transportation systems have become much more safe than in the past, but the increasing size of vessels, the increasing density of the spaces in which they operate, and their increasing complexity mean that when accidents occur, they can cause high casualties, extensive property destruction, and environment degradation. The March 26, 2024 collapse of Baltimore’s Francis Scott Key Bridge after being struck by a container ship illustrates the immense destruction transportation accidents can cause.

Seattle is the densest transportation hub in the Pacific Northwest. With two major freeways, a busy port, the state’s largest ferry dock, numerous cruise ship sailings, two rail systems terminuses, a major pipeline, and two airports, Seattle is crisscrossed everyday by large numbers of vehicles and vessels. Transportation is essential to Seattle’s wellbeing as a community. To understand how these systems support the community see the [Community Profile](#)’s outline of Seattle’s transportation systems and infrastructure.

While this chapter focuses on incidents in the city, accidents outside Seattle can affect us too. This was the case in 2000, when Alaska Airlines flight 261 crashed into the Pacific Ocean, killing all 88 passengers and crew. Forty-seven of them were from the Puget Sound area.⁵⁴¹ This tragedy did not require use of Seattle emergency management system but had a large impact because Alaska Airlines is headquartered near Seattle and many of the passengers lived locally.

Aviation

The Seattle-Tacoma International Airport is Seattle’s primary commercial airport. It is outside the city, but northern arrival and departure flight paths overlay the city ([Figure 54](#)). The King County International Airport straddles the city limits in the Duwamish Valley and is one of the busiest non-hub

Key Points

- ❖ *Lead Agency – Seattle Transportation Department*
- ❖ *While there have been huge gains in the safety and reliability of transportation systems, large, deadly accidents still happen today.*
- ❖ *Disruptions in one part of Seattle’s transportation system can cascade and can spread from one transport mode to another.*
- ❖ *Aviation: The worst case is an aircraft crashing in the city. The chance of is very low but approaches to SeaTac and Boeing Field take aircraft over the city.*
- ❖ *Marine: The major hazards are collisions with infrastructure and a cruise ship accident near Seattle. The 2024 Key Bridge accident in Baltimore highlights the consequences of a container ship collision.*
- ❖ *Rail: The main hazards are derailments, collisions, and tunnel incidents. Seattle has several miles of tracks that are exposed to landslides as well. Each week about 1,100 tank cars carrying highly flammable oil pass through the city. One of these trains derailed in 2014, but no oil was spilled.*
- ❖ *Motor vehicles: Motor vehicle collisions account for roughly 95% of all transportation related deaths and even more injuries. While this number represents mostly single or two-vehicle accidents, Seattle has had a few large -scale motor vehicle incidents.*

airports in the United States. It serves small commercial airlines, private pilots, corporate jets, military aircraft, and Boeing Company operations. Because of its alignment and proximity to Elliott Bay, air traffic to this airport spends less time over Seattle, but it is at low elevation when it is. Smaller aircraft and Boeing aircraft use the Renton Municipal Airport south of Seattle, and Kenmore Air operates floatplanes from Lake Union and Lake Washington. Flight operations out of these airports constitute the major aviation hazard for Seattle.

[53% of all commercial aviation](#) accidents occur during landing.⁵⁴² Because of this fact, the FAA requires airports to create [Airport Emergency Plans](#). The FAA details the structure and elements required by these plans including how to coordinate with surrounding jurisdictions for accidents happening off airport property.

Aviation operations are classified into commercial, military, and general. Commercial includes scheduled and non-scheduled air transport including freight. The general category includes transport that is neither military nor commercial. The vast majority of accidents, including fatal accidents, involve general aviation. Most of these accidents are small enough not to require activation of local emergency management systems.

Marine Transport

Seattle is surrounded and bisected by water. It is a major maritime center, and much of its waterfront is a working waterfront. The Port of Seattle merged with the Port of Tacoma in 2015 to create the Northwest Seaport Alliance. Together they are the 5th largest port in the U.S. by volume.⁵⁴³ The Port of Seattle handles container cargo, bulk cargo (grain), and cruise ship operations. Additionally, Seattle has three heavily used passenger ferry routes, the Ballard Locks that connect Lake Washington to Puget Sound, and a large commercial fishing fleet.

Maritime accidents include many different mishaps, such as grounding, capsizing, sinking, collision, fire, explosion, and chemical spill. Worldwide, some of the worst maritime accidents have involved the sinking of passenger ferries. Many maritime accidents have a hazardous materials component. Great environmental damage has occurred because of oil spills.

Rail

Seattle is home to two freight networks, Burlington Northern Santa Fe (BNSF) and Union Pacific (UP), and to passenger operations for Amtrak and Sound Transit. Tracks are exposed to many hazards. They run from south to north through Seattle starting in the liquefaction-prone Duwamish Valley, through SoDo and Seattle's stadium district, into the Great Northern Tunnel, under downtown, and between Puget Sound and landslide prone bluffs. The Great Northern Tunnel is of special concern. It was built in 1904 before modern safety standards and lacks fire suppression equipment. Both freight carriers support the Port of Seattle with intermodal operations. BNSF runs up to 18 coal trains per day through Seattle. Each one is more than one mile long. In 2013 BNSF began moving significant amounts of crude oil through Seattle, mostly Bakken crude, which has a volatility comparable to gasoline. It is shipped in trains consisting of 100 cars that are more than a mile long.⁵⁴⁴ The Great Northern Tunnel is used by oil trains, Amtrak, and Sound Transit, bringing dangerous cargo and passenger rail into close proximity. The 2024, East Palestine Ohio train derailment brought renewed attention to rail safety. Train accidents often involve hazardous materials releases which are covered in a [separate chapter](#).

Road Transport

Most trips taken in the United States are on roads, and most transportation related fatalities happen in traffic accidents. Of the 44,546 transport related fatalities recorded by the U.S. Department of Transportation in 2022, 42,514 or 95.43% were deaths on roadways. In Seattle, 30 people died in traffic

accidents in 2022.⁵⁴⁵ The City of Seattle launched [Vision Zero](#) to end traffic deaths and serious injuries on city streets by 2030.

Occasionally, road accidents become major emergencies. When they do, it is often because they include extenuating circumstances: mass casualties, hazardous materials, prolonged impacts to roadways, and damage to structures. The 2015 collision between a tourist amphibious duck vehicle and a bus transporting foreign college students on the Aurora bridge was one such emergency. The accident caused multiple fatalities and dozens of injuries, and involved international students and visitors, prompting U.S. State Department and foreign embassy engagement. The response required securing storage for large pieces of evidence for a National Transportation Safety Board investigation, deenergizing powerlines, supporting foreign victim relatives, and managing the prolonged outage of the Aurora Bridge. It highlighted how incident complexity can prompt the need for a prolonged multi-agency response. The Seattle Emergency Operations Center activated for four days to handle the accident.

Pipeline

A BP pipeline spur runs from Harbor Island southeast to Renton following an easement for power transmission lines. The pipeline delivers jet fuel to SeaTac and gasoline to Harbor Island for shipment to Alaska. A spill or break in the pipeline would constitute a hazardous materials release, which is discussed in that [chapter](#).

History

This section focuses on incidents after 1997 because transportation safety has vastly improved over time. It concentrates on incidents in the Seattle area but includes trend data and relevant incidents outside the area.

The federal government collects data on transportation accidents that illuminate the hazard. The National Transportation Safety Board's [Case Analysis and Reporting Online \(CAROL\)](#) database is a key resource for significant transportation accidents. It contains aviation records from 1962 to the present and surface mode (rail, highway, marine, pipeline, and hazardous materials) from 2010 to the present. In a complementary database the [Bureau of Transportation Statistics](#) shows the vast majority of transportation fatalities happen on the road.⁵⁴⁶

Aviation Overview

Commercial air travel, the major risk for large accidents, has become much safer in the last fifty years. In 1970, there were 6.46 fatal accidents per million flights, whereas in 2021 there were only 0.46. This is 14-fold decrease.⁵⁴⁷

The National Transportation Safety Board's Case Analysis and Reporting Online (CAROL) database identifies 54 aviation accidents and incidents occurring in Seattle or SeaTac between January 1, 2000, and July 10, 2024, with 10 of these causing injuries and 1 (detailed below) resulting in fatalities.

Maritime Overview

Seattle has a large maritime sector giving a correspondingly large exposure to marine accidents. The National Transportation Safety Board has investigated 5 marine accidents in Seattle in the 21st century. None of these incidents required use of the City of Seattle emergency management system. Only one, involving a Washington State ferry, involved passenger transport.

Seattle is home to a major fishing fleet working on the Bering Sea. Fishing is a dangerous business and there have been several ships that have sunk, most recently the sinking of the F/V Destination in February 2017, taking with it all six of its crewmembers.⁵⁴⁸

Rail Overview

Seattle is a terminus for the BNSF and Union Pacific Railways. Derailments have occurred in Seattle, but none since 2000 have been serious enough to trigger an investigation by the National Transportation Safety Board. The tracks north of Seattle have been closed due to landslides. In 1997, a freight train was knocked into Puget Sound by a landslide. In the 2010s rail shipments of coal and crude oil increased.

Passenger rail is still recovering from pre-pandemic highs. In 2022, the Amtrak Cascades route between Vancouver, BC, and Portland OR had 381,000 riders.⁵⁴⁹ While no major incident has happened within Seattle city limits, Amtrak 501 traveling from Seattle to Portland derailed south of Tacoma on December 18, 2017, during its inaugural trip. Three passengers were killed and over 80 were injured.⁵⁵⁰ Sounder Commuter rail, which runs between Everett and Tacoma, began in 2003. The Sounder has not had a major accident.

Motor Vehicle Overview

Although few roadway accidents require emergency management involvement, they are a serious cumulative hazard in the Seattle area. In rare cases, roadway accidents have severe and complex consequences that require extended multi-agency response. Several major bus related incidents have occurred in Seattle and are highlighted below. Fuel tanker accidents have endangered lives and closed major roadways. Another danger is multiple vehicle accidents. In 2002, 216 vehicles were involved in a single accident.

Major Incidents after 1997

November 27, 1998. Motor Vehicle. A passenger on a Metro bus shot and killed the driver as the bus was heading south on the Aurora Bridge. The bus crashed off the bridge, struck an apartment building and then the ground 50 feet below. The shooter, driver, and one passenger died, plus 29 passengers were injured.⁵⁵¹

June 10, 1999. Pipeline. Bellingham. A 16" diameter section of the Olympic pipeline ruptured spilling 277,000 gallons of gasoline near Whatcom Creek. The gasoline exploded killed 3 people.⁵⁵² This incident focused attention regionally on pipeline safety. Seattle has a spur of the same pipeline that runs from Harbor Island to Renton.

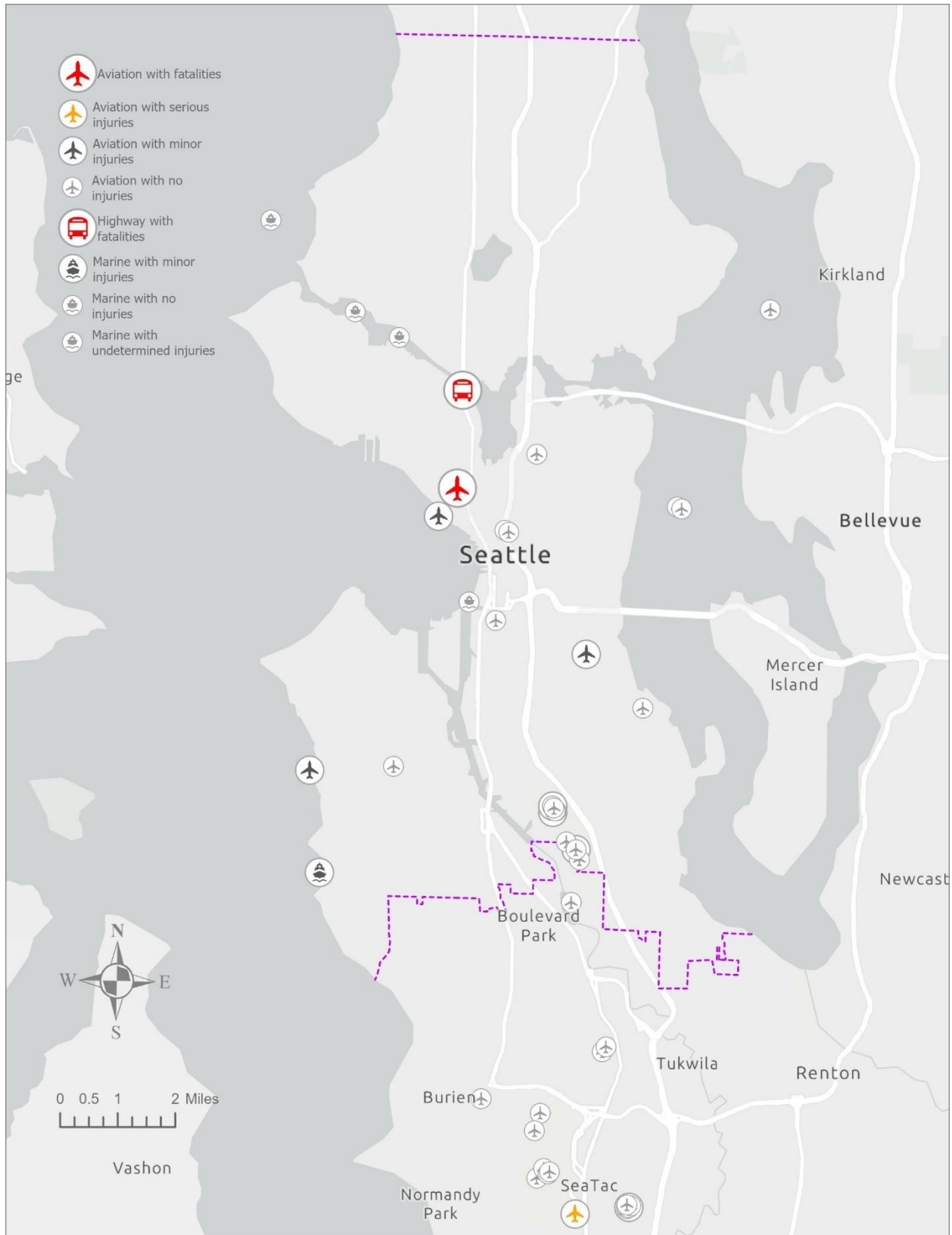
January 31, 2000. Aviation. California Coast. Alaska Airlines Flight 261 crashed into the Pacific in route from Puerto Vallarta, Mexico to Seattle. All 83 passengers and five crewmembers died. Although the crash did not occur in Seattle, it had a big impact because Alaska Airlines is headquartered near Seattle and many of the passengers were from Seattle.⁵⁵³

December 19, 2008. Motor Vehicle. Seattle. In a narrow escape, a charter bus slid down an icy Capitol Hill street. It crashed through a barrier along I-5. Half the bus teetered over a steep embankment along the freeway. Thankfully, all passengers were able to exit the bus safely. No casualties resulted.⁵⁵⁴

March 18, 2014. Aviation. Seattle. KOMO-TV helicopter fatally crashed on Broad Street near the Space Needle immediately after taking off from Fisher Plaza. The pilot and a car driver were killed. Another driver was critically injured.⁵⁵⁵ This incident, while serious, did not require use of the City's emergency management system.

September 24, 2015. Motor Vehicle. Seattle. A surplus WWII amphibious vehicle used as a tourist vehicle broke an axle on the Aurora Bridge. It crashed into a charter bus transporting recently arrived

Figure 52. NTSB Investigated Accidents 2008 to 2024



City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

international students. Five people died, and dozens were injured. The bridge was closed to traffic for roughly 12 hours.⁵⁵⁶

December 22, 2020. Rail. Custer, WA. Ten cars of a BNSF train transporting Bakken crude oil derailed near Custer, Washington north of Bellingham. Three cars caught fire. The fire caused no casualties but spilled 29,000 gallons of oil. The Federal Railway Administration concluded sabotage exacerbated by faulty actions by the BNSF crew caused the derailment.⁵⁵⁷ A similar train exploded in 2013 in Lac-Mégantic, Quebec killing 47 people.

December 10, 2023. Pipeline. Conway, WA. The Olympic Pipeline spilled 25,000 gallons gasoline into Bulson Creek east of I-5 near Conway. Washington State Department of Ecology crews contained the spill without casualties. This spill was the largest since the 1999 Bellingham pipeline explosion.⁵⁵⁸

Major Incidents before 1997

Historically, Seattle’s most deadly disasters, aside from the 1919 influenza pandemic, were transportation accidents. While safety standards have vastly improved since these events, they illustrate the potential for high loss of life for transportation hazards.

November 18, 1906. Maritime. The passenger ferry Dix sank two miles off Alki. 42 fatalities.⁵⁵⁹

February 18, 1943. Aviation. A B-29 Superfortress crashed near Boeing Field. It struck the Frye slaughterhouse at 2101 Airport Way South. Eleven crew members, one firefighter and 20 people on the ground were killed. The crash caused a large explosion and cut major cross-town powerlines.⁵⁶⁰

July 19, 1949. Aviation. A C-46 cargo plane crashed shortly after take-off, cutting power lines over a wide area, and striking two buildings in Georgetown. After coming to rest, it caught fire. Five houses were significantly damaged. Five people on the ground and two passengers were killed. Thirty-three people were injured.⁵⁶¹

August 13, 1951. Aviation. A B-50 bomber struck Sick’s Brewing and Malting at 3100 Airport Way (the old Rainier Brewing building) and then cartwheeled into the Lester Apartments, destroying one third of the building. The crash killed six people in the plane and five on the ground.⁵⁶²

December 4, 1975. Motor Vehicle. In this incident, a fuel tanker overturned. 3,700 gallons of gasoline caught fire. Remarkably no one was seriously hurt. It helped that the incident happened at 1:00 am. Despite the late hour, many people, including police officers and bar patrons below the burning tanker, had close calls. The fire burned through power lines cutting power to City of Seattle offices, including the Seattle Police Department headquarters. Power restoration was delayed due to a strike by City Light crews.⁵⁶³ Prior to this accident, Seattle City Council had authorized fuel trucks to use the viaduct at non-peak hours over the Fire Department’s objections to facilitate fuel delivery across Seattle.

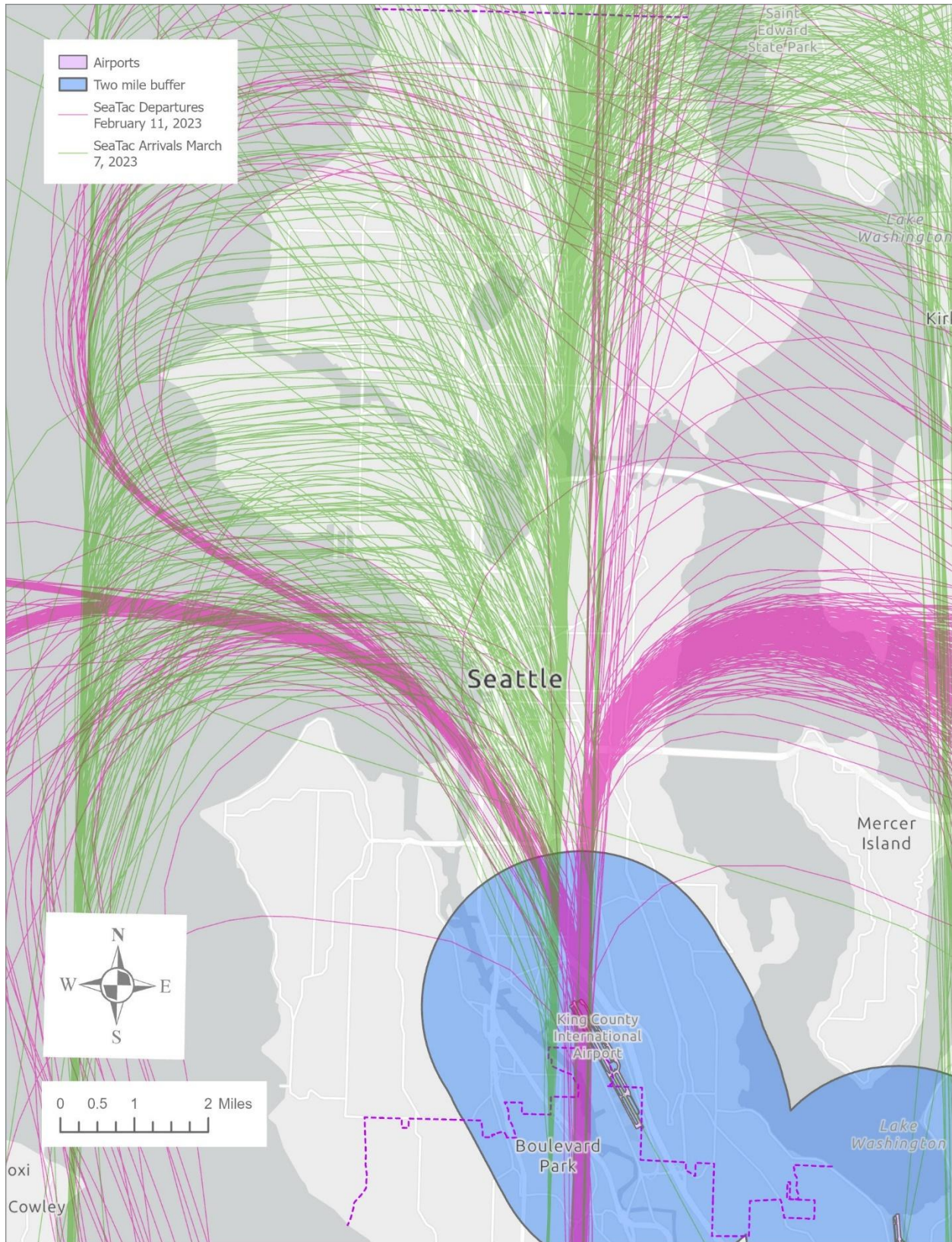
June 11, 1978. Maritime. The freighter Chavez struck the West Seattle bridge severely damaging it. The bridge was closed to traffic for six years and led to the construction of the current high-rise bridge.⁵⁶⁴

Vulnerability

Transportation accidents endanger passengers, bystanders, and infrastructure near accident sites. Vulnerabilities for passengers and bystanders can be different. For example, in a traffic accident, a larger vehicle makes its occupants less vulnerable, but those around it more vulnerable.

Vehicle and vessel occupants are densely packed into vehicles or vessels and then moved at high speed across environments in which they could not often survive without help. Safety systems have improved for most transportation modes, but occupants are exposed to a hazard by virtue of being onboard.

Figure 53. SeaTac Flight Corridors and Areas Within Two Miles of All Airports



City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

The people and infrastructure near transportation corridors are more exposed to transportation accidents. These corridors include waterways, freeways and major arterials, rail lines, pipeline right of way, flight paths, and areas close to airports. [Figure 13](#) shows these areas.

Transportation systems themselves are vulnerable to transportation incidents. Urban transportation systems are vital to cities. They are interconnected, interdependent, and intermodal. Disruptions in one area can ripple across the whole system. Cities without sufficient reserve capacity are more sensitive to disruptions. An analysis of Seattle’s transportation system is well beyond the scope of this analysis. A copy of the Mayor’s recommended [Seattle Transportation Plan](#) has more detailed information about the state of Seattle’s transportation system. Most of the analysis is in the Technical Report.

Aviation Exposure and Sensitivity

Although approach and landing are noted in accident data as flight phases with a higher risk of accident. The Federal Aviation Administration’s Airport Emergency Plan Advisory Circular requires airports to plan for Water Rescues within two miles from the end of a runway. We used this requirement as a rough indicator for increased exposure. [Figure 53](#) includes a two-mile buffer around King County International Airport to show this exposure. The entire airport is buffered, but the areas under flightpaths are more exposed. Only Seattle’s most southern sections—White Center, South Park, Dunlop, and Rainier Beach—are within two miles of SeaTac, but many planes take flight paths over the southern half of the city.

Both Lake Union and Lake Washington are used by Kenmore Air for air operations. Both lakes are heavily used for recreational boating and commercial maritime activities. The dual uses create the potential for space conflicts.

Maritime Exposure and Sensitivity

Port facilities, ferry docks, and bridges across major waterways all faced increased exposure to maritime accidents. In Seattle these include most of the Port of Seattle, ferry docks in Downtown and in West Seattle, the cruise ship terminal at Bell St Pier, the Ballard Locks, and the Duwamish waterway. As noted above, the first West Seattle Bridge, a moveable bridge, was damaged to the point of needing a replacement in 1978 by a vessel strike.

Railway Exposure and Sensitivity

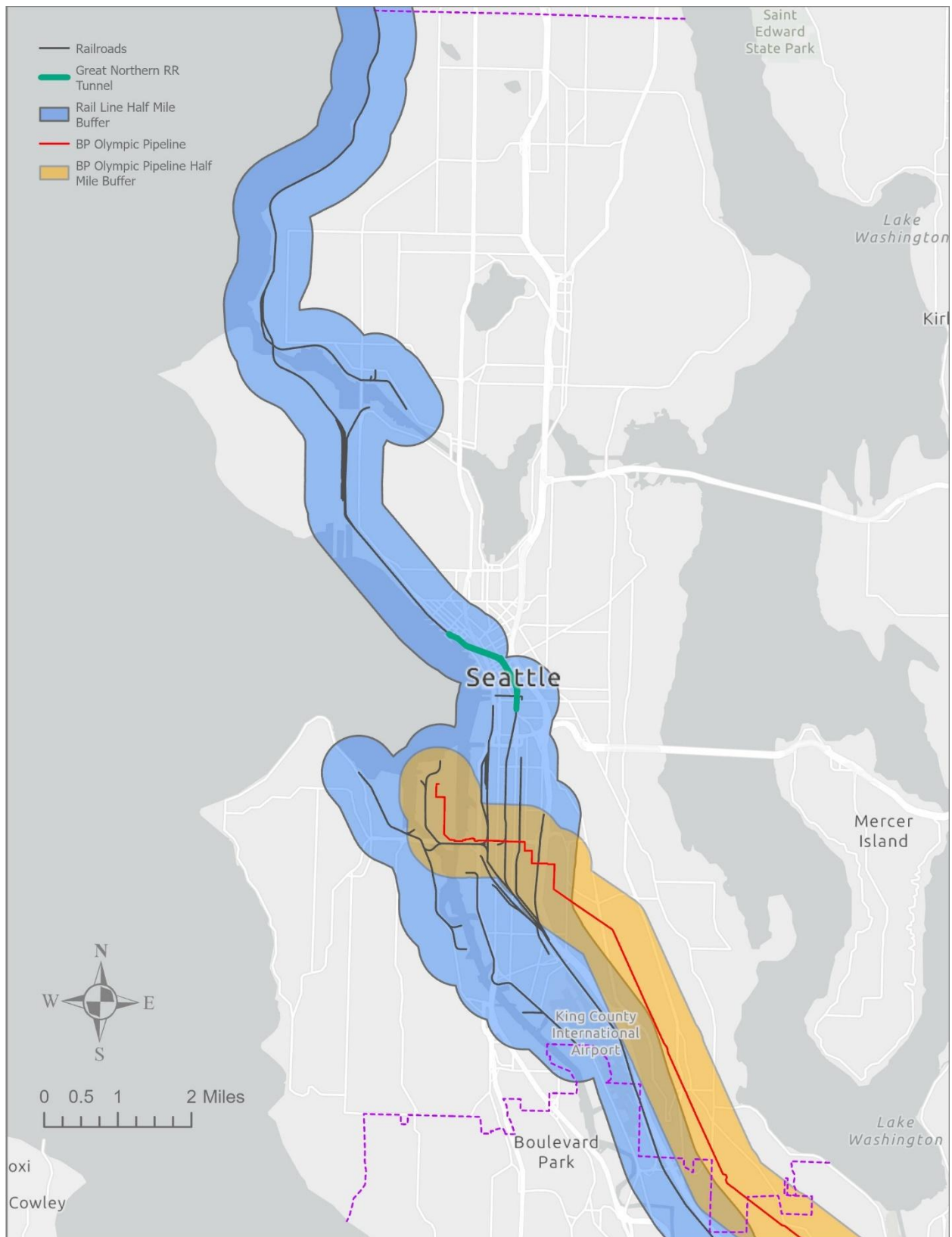
Seattle’s biggest railway exposure is for Bakken crude oil. The [2024 Emergency Response Guide](#) from the United States Department of Transportation directs first responders to isolate for a half mile in the event of a rail tank car fire involving flammable liquids, including Bakken crude oil.⁵⁶⁵ (See guide 128). Areas within half a mile of a rail line are shown in [Figure 54](#). The areas shown are probably an overstatement of the exposure because not all rail lines carry Bakken crude oil, but they give a rough cut of overall exposure. Appendix A lists the land uses, demographics, and critical facilities in these areas.

One of the areas of greatest vulnerability is the Great Northern Tunnel. Access to the tunnel is difficult and dangerous for first responders. It lacks modern safety features including escape routes and fire suppression equipment. Despite the lack of safety features, it is used by passenger trains. One of the only advantages to the tunnel is that it is poorly ventilated, making fire ignition more difficult.

Pipeline Exposure

The BP Olympic pipeline, like the railroads, carries flammable liquids. It has the same half mile standoff distance. The pipeline runs from Harbor Island to SoDo then southeast along the easement for City Light transmission lines. The pipeline and the area within one half mile of it are shown in [Figure 54](#). [Appendix A](#) has a breakdown of the exposures in this area along explosion hazards from oil trains.

Figure 54. Areas Within a Half Mile of Railways and Pipelines



City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Roadway Accident Exposure

Traffic accidents account for over 95% of transportation related fatalities nationally and the vast majority locally. Only a small percentage of these accidents become major disasters, but so many happen that two of the seven major incidents highlighted in the history section above happened on the road. Freeways and highways combining high speed and potentially dangerous driving conditions have the highest exposure to high consequence accidents. Seattle is a city of bridges. Freeway bridges like the Ship Canal Bridge, the Aurora Bridge, and the West Seattle Bridge are places where the road network is especially sensitive to disruption. The multi-year outage of the West Seattle Bridge was not caused by a transportation accident but revealed the vulnerability to bridge closures.

Consequences

Before looking at the consequences of individual, large transportation incidents, it needs to be noted that transportation accidents that happen frequently have a cumulative impact on the lives of the people of Seattle. The Seattle Department of Transportation's yearly [traffic reports](#), offers detailed statistics on city arterial streets excluding limited access State Highways and Interstates. Readers are encouraged to consult these reports. The [2023 report](#) shows an increasing collision rate in 2020 and 2021 during COVID despite a significant drop in traffic. The rate dropped significantly in 2022. Unfortunately, the number of serious injury accidents is increasing, rising from 145 in 2020 to 226 in 2022. The number of fatalities is also rising from 23 in 2020 to 30 in 2021 and 2022.⁵⁶⁶ The Washington State Department of Transportation has a [data portal](#) that includes all fatal and suspected serious injury accidents in Seattle including State Highways and Interstates. Its data shows a sharp spike in fatalities in 2021 followed by a decrease in 2022.⁵⁶⁷

Even large transportation incidents can usually be handled with day-to-day resources. Most of the incidents that require the City of Seattle to activate its emergency management system have some complexities or cascading impacts that complicate the work of first responders. These can include damage to infrastructure, extended closures of key transportation corridors, high casualties, hazardous materials incidents, and jurisdictional questions. The 2015 Duck-bus crash is an example of this type of incident. It caused five fatalities and dozens of injuries, drew large amounts of resources from the police and fire departments, tied up a major transportation route, and had extenuating conditions like the high number of international victims that complicated the response.

Potential consequences for transportation incident most likely to trigger emergency management involvement include:

- A high likelihood of fatalities. Unlike most other hazards, incidents that are most likely to trigger emergency management involvement are more likely to have heavy property damage than casualties.
 - Blockage of major transportation routes and utility damage.
 - Circumstances that prolong the duration of the incident.
 - Neighboring buildings and the people in them will probably be affected to some degree, but most of the casualties will be among those on the vehicle or vessel.
 - Maritime accidents tend to involve more property damage, especially when ships collide with bridges and other infrastructure.
 - There is a high likelihood of secondary hazards, especially fires and hazardous material spills.
- Transportation incidents can also be secondary hazards themselves.

Most of these incidents will be short, but intense. Unless there is major infrastructure damage (i.e., to a bridge) the recovery is likely to be quick and complete.

More rarely do transportation incidents have greater and more lasting consequences. Possible scenarios include an oil train explosion in the heart of the city, a major maritime accident, a pipeline explosion, or a commercial airline accident in the city. These incidents would entail high loss of life, extend over a large area, involve significant infrastructure and property damage, release of hazardous materials, and take months to years to recover from.

The 9-11 attackers used airplanes as weapons. While there has not been another attack of that magnitude in the United States, the risk remains if the potential for harm exists.

Outlook

Transportation accidents happen every day, but very few become city-scale emergencies. Safety for most transportation modes has been improving, suggesting the likelihood of a transportation disaster has also decreased, but this assumption could be problematic. The number of freight and passenger trips has greatly increased, creating more opportunities for accidents. Vehicles and vessels have gotten bigger, putting more people at risk and increasing the damage to infrastructure in collisions. Much of Seattle's transportation network lacks reserve capacity. With increasing dependence of fragile supply chains, an accident at a critical point can disrupt lives and businesses far from the accident site, especially if the accident triggers a secondary hazard like a hazardous materials incident or infrastructure failure. It is possible that the number and severity of smaller transportation incidents improve but the number of larger, more impactful incidents remains steady due to the increasing size of transportation vehicles and vessels and the increasing complexity of our transportation network.

Conclusions

Transportation safety has improved dramatically since the early days of motorized and air travel, but transportation accidents hold the potential to produce very high casualty counts. As the volume of trips across all modes increases, the total number of serious incidents may also increase despite safety improvements, especially as transportation networks become saturated and lose reserve capacity.

The possibility of terrorist attacking or using transport modes as weapons greatly increases the risks associated with larger events. The most likely events remain accidents that cause mass casualties among passengers and limited damage to surrounding infrastructure with the major caveat that damage to infrastructure, bridge, or overpass structures can cause long-lasting impacts.

10. STRUCTURE FIRES

In 2003, the Station Nightclub in West Warwick, Rhode Island burned down, resulting in 100 fatalities. In 2020, during the 2020 civil disorder following George Floyd's murder, 160 buildings burned in Minneapolis. During the 1970's, the Bronx suffered a wave of fires that destroyed 80% of its housing stock. Each of these different scenarios illustrate the extreme danger structure fires pose for cities.

The Seattle Fire Department maintains robust capabilities and can manage very severe fires with its own resources or with mutual aid from neighboring departments. Despite its capabilities, fires that have significant secondary hazards, extreme consequences, or complex circumstances that may require use of the emergency management system. Some examples of the kinds of fires that are most likely to require a complex response are fires involving a large number of structures, high-rise fires, ship fires, fires following explosions, and fires that have a significant hazardous materials component.

Fires are a major secondary hazard for other hazards included in this document and overlap with several other hazards covered here. Recently, the worst urban fires have been in cities with a large urban-wildland interface (WUI). Seattle has a limited WUI. While this chapter covers brush fires in the city, wildfires are much more of a threat to the watersheds that supply Seattle's water and power and are covered in the [wildfire](#) chapter. Explosions are a fire related hazard and are covered in [Hazardous Materials Incidents](#), but fires

caused by explosions are included here. Electrical fires contained within the power system are a special category that is covered under the [power outage](#) chapter.

Urban fires can cause high casualties, massive property destruction, and extensive environmental degradation, especially as a secondary hazard when fire suppression is degraded. More people died during the fires following the 1906 San Francisco and 1995 Kobe earthquakes than did in the precipitating shake.

During the 19th and early 20th centuries, huge urban fires were a top threat for cities. Many cities and towns, including Seattle, suffered fires that destroyed large parts of their downtowns. This threat led to the development of the modern fire service and fire codes. The result was a major success. Large urban

Key Points

- ❖ *Lead Agency – Seattle Fire Department*
- ❖ *The Fires chapter includes a broad range of incidents from large single structure fires, multi-structure fires, ship fires, industrial fires, brush fires, and vehicle-related fires. Wildfires are included in their own chapter.*
- ❖ *Seattle has experienced large fires, including the 1889 fire that destroyed downtown and the 1970 Ozark Hotel fire that killed 20 people. Both fires occurred under different historical circumstances than those that exist today. The 1889 fire occurred before a modern fire code and the Ozark Fire happened when Seattle had many multi-unit dwellings without sprinklers.*
- ❖ *The 1970 Ozark fire led to legislation mandating that safety systems, such as sprinklers, be retrofitted into older buildings*
- ❖ *Fires have been a deadly secondary impact of earthquakes and civil disorders. In the 1995 Kobe and 1906 San Francisco earthquakes, more people died from fire than building collapse. Following the 1992 Rodney King verdict, multiple fires were set in Seattle, taxing Fire Department resources.*
- ❖ *Fires in underground electrical vaults have caused prolonged outages in downtown and other dense areas where power has been placed underground. The effects of these power outages are covered in the chapter on power outages.*

conflagrations like the 1889 Seattle fire largely became a thing of the past. Fires along the wildland urban interface are the major exception for some cities.

Despite this major success, fires remain a deadly threat. Nationally, over 4000 people died in fires in 2021 at a rate of 13 people per million which is an increase of 18% since 2012. The increase has been especially steep since 2019.⁵⁶⁸ Some of this rise could be related to COVID because most fire deaths happen in the home. More people spending more time at home means more exposure to potential fires. A US Fire Administration dataset of residential fires shows a rise in fire deaths in 2021 and 2022 followed by a decline in 2023, supporting the COVID hypothesis.⁵⁶⁹

Economic losses due to fire have increased in the past decade along with fatalities. Inflation adjusted dollar losses have increased by over 20%. Residential losses jumped from \$8.6 billion in 2013 to \$10.8 billion in 2022 and non-residential losses went from \$3.1 billion in 2013 to \$3.6 billion in 2022. The increase in non-residential losses hides a spike during 2020 and 2021 before falling in 2022. It is not clear if this bump is COVID related.⁵⁷⁰

The large catastrophic fires considered here are the result of factors impeding fire suppression. The best fire suppression is a fire that never happens. The [Seattle Fire Code](#) specifies standards for buildings, activities, and hazardous processes. It is enforced by the Seattle Fire Department's Fire Prevention Division and aided by public engagement to enlist the help of the community to prevent fires.

Once a fire starts, successful fire suppression depends on speed. In enclosed spaces, avoiding flashover, the near simultaneous ignition of all combustible objects and surfaces in the space, is critical. The time to flashover can vary greatly depending on the materials in the space, construction materials, and automated fire suppression technologies like sprinklers. The increasing use of synthetic materials and open floor plans in residential construction has greatly decreased flashover times from 30 minutes with natural materials to typically 5 to 10 minutes.⁵⁷¹

Firefighters have the best chance to respond effectively when they can detect a fire and reach it quickly in overwhelming numbers. Water application is the primary extinguishment tactic, in addition to isolating the fire to prevent it from spreading. Fires escape control when they spread too quickly to be contained, when automated suppression systems do not work properly, or when they occur in places that are difficult to reach like some outdoor spaces.

Anything that inhibits automated suppression and firefighter access increases the probability that a fire will grow to significant size. Because hazards like earthquakes and civil unrest can both cause fires and inhibit their suppression, fire is an especially dangerous secondary hazard. Damage to transportation infrastructure or poor security can result in firefighters being unable to reach fires quickly or in adequate strength. An earthquake may damage the water distribution system, lowering water pressure at hydrants, or could cause complete failure of watermain leading to no available water for fire suppression. In these circumstances, unattended fires could grow and threaten large areas. From 1900 to 2014 there have been 11 large fires following earthquakes, including Kobe, Japan. They can be extremely devastating. The 1906 San Francisco fire destroyed 28,000 buildings. Civil unrest presents the other major fire risk. Arson fires are commonly set during civil disorders. The 1992 LA riots produced large fires that engulfed whole city blocks. Some of these fires were left to burn after firefighters were assaulted. More recently, in 2020, over 160 structures were burned in Minneapolis in the unrest following George Floyd's death.⁵⁷²

History

Seattle has experienced major fires, including ones that have required extended multi-agency response, but it has not yet activated its Emergency Operations Center (EOC) for a fire. Most of these fires were

large apartment fires that displaced multiple residents. Adding to the overall fire risk has been a sharp increase in the number of fires in vacant buildings, rising from 77 in 2021 to 130 in 2023. Three people were killed in vacant building fires in 2023. Fires in vacant and derelict buildings present many unknowns, from questions about structural integrity and hazardous contents, to the possibility of people sheltering inside. [Figure 57](#) shows the increase in vacant building fires since 2021.

Going far back to Seattle's early history, fire played an important role in shaping Seattle. The catastrophic Great Seattle Fire of 1889 consumed 100 acres of downtown Seattle just as the city was poised to become Washington State's leading urban center.⁵⁷³ Amazingly, it caused no fatalities or major injuries. Equally impressive was the speedy and complete recovery. Seattle was able to totally rebuild its downtown area within eighteen months, doing so with masonry instead of wood. Ironically, the attempt to mitigate fire vulnerability introduced a new, and at the time, unknown vulnerability to earthquakes. In 2024, Seattle's seismic risk is directly related to the fire 135 years ago. Seattle's quick recovery is due, in large part, to gold being discovered in the Yukon shortly after the fire. Seattle profited as the major point of departure for prospectors. Their spending fueled the fastest growth in Seattle's history.

The list of fires below is broken out into those after 1990 and those before 1990 to emphasize more recent fires. The pre-1990 list starts with some very old events starting with the Great Seattle Fire. While early events do not directly reflect today's hazard environment, they do show how Seattle has been shaped by major fires.

Significant Fires since 1990

September 16, 1991. F/V. Omnisea. A five-alarm fire involving a fish processor moored at Pier 91. Importantly, this location is not a shipyard (shipyards have more fire control resources). The US Coast Guard assisted in the response. The fire was caused by a welding torch while maintenance was taking place. The vessel contained significant amounts of ammonia, a hazardous material. None of the ammonia was released into the environment.⁵⁷⁴ The fire required the use of 75% of Seattle Fire's on-duty personnel, and significant amount of mutual aid to backfill Seattle's fire stations. Seattle Fire units were on site for five days.⁵⁷⁵

September 21, 1991. Villa Plaza Apartment Fire. This major apartment fire underscores the link between equity and hazard vulnerability. The multi-building complex was being used as low-income housing. The fire was caused by a candle being used in a unit in which power had been shut off for non-payment. The complex did not have sprinklers. It was grandfathered into ordinance requiring sprinkler systems in Seattle. The fire spread rapidly along the exterior cedar siding. There were no deaths, but 8 people were injured, 232 people were displaced, and 66 of 96 units were destroyed.⁵⁷⁶

January 5, 1995. Mary Pang Fire. This International District arson fire marked the worst day in the Seattle Fire Department's history when four firefighters perished after they fell through a floor into a burning basement. Several factors combined to make this a very dangerous fire for responders. The arsonist, Martin Pang, used accelerants to make the fire spread quickly. The building was old, with many undocumented additions causing fire fighters to lack situational awareness. Responders had to fight the fire from multiple sides which introduced communications challenges. Finally, incident commanders lacked sufficient support staff, causing them to become overwhelmed. These factors caused SFD personnel to enter a floor thought to be safe. They did not know the fire had moved to the basement and that the floor was not supported by heavy timber but by a more lightly constructed 'pony wall'. The pony wall collapsed, sending the four firefighters to their deaths. This fire caused significant changes to the Seattle Fire Department's operations.⁵⁷⁷

May 21, 2001. UW Center for Urban Horticulture. An arson fire set by the Earth Liberation Front, eco-terrorists, at Merrill Hall. The fire was set at night. It caused no casualties, caused \$4.1 million in

damage, and destroyed years of research.⁵⁷⁸ This incident is also listed under [Terrorism and Targeted Violence](#).

June to November 2009. A serial arsonist set 10 fires in the Greenwood neighborhood and one in Shoreline. The fires caused \$2 million in damage and severely injured one person.⁵⁷⁹

March 9, 2016. Greenwood Gas Explosion. Human-caused damage to a natural gas pipe caused an explosion that destroyed one building and three businesses. Eight firefighters and one chief officer were injured and transported to Harborview Medical Center. 54 surrounding businesses suffered damage, causing closures of up to several months. Residents of a neighboring apartment had to be temporarily relocated while their building underwent repairs. United Command was established with six City departments. The City's Department of Neighborhoods and Office of Economic Development acted as liaisons with the community. The Phinney Neighborhood Association managed financial assistance.⁵⁸⁰ The fire caused an estimated \$5 million in total damage.

Significant Fires before 1990

This list starts with the Great Seattle Fire then continues based on records of all multiple alarm fires since 1912 maintained by Seattle Fire Department personnel.

June 6, 1889. The Great Seattle Fire. The fire caused no casualties, but it burned nearly the entire downtown.

July 30, 1914. Colman Dock Fire. Colman Dock stood at the site of the current ferry dock in downtown Seattle. The dock was the largest on the west coast. Five people were killed and 29 were injured. Wooden docks, often treated with creosote as a preservative, are very vulnerable to fire.

June 30, 1916. Bell Street Pier. This fire at an army ammunition depot exploded, including artillery shells. A bystander, a young boy, was killed by one of them.

April 20, 1920. Lincoln Hotel Fire. A large hotel in downtown Seattle burned completely, resulting in four deaths.

April 30, 1935. City Light South Lake Union Steam Plant. The fire caused a power outage and severe traffic disruption but no deaths.

February 18, 1943. B-29 Crash and Fire. This fire, detailed above in transportation incidents, resulted in 32 deaths.

September 9, 1945. St. Vincent de Paul Fire. An arson fire set by a homeless man destroyed a whole block of property and caused four deaths.

July 6, 1948. Lyle Branchflower Explosion. An explosion and fire at a Ballard fish oil producer killed three workers and blew a car off the Ballard Bridge.

May 20, 1958. Seattle Cedar Lumber. Another major fire near the north end of the Ballard bridge resulted in no deaths.

March 20, 1970. Ozark Hotel. This arson fire killed 21 people and had a major impact on Seattle's older neighborhoods. The Ozark was a single room occupancy (SRO) hotel, a type of housing that commonly served homeless and seasonal workers. It was a known fire risk. The fire department had inspected it often, but it was still vulnerable. It was in disrepair, had no sprinklers, and a poor escape route.⁵⁸¹

April 25, 1971. Seventh Avenue Hotel. A little over one year after the Ozark fire, another SRO burned, killing 12. Following these fires, stringent new fire ordinances were passed, including requiring buildings to be retrofitted with sprinklers and smoke detectors. Most building owners found it was not financially viable to retrofit upper floors and chose to abandon them.

December 4, 1975. Fuel Tanker Explosion/Fire on Alaskan Way Viaduct. (Also listed under [Transportation Incidents](#) and [Hazardous Materials Incidents](#)). A gasoline tanker truck crashed. Gasoline leaking from the truck caught fire, causing extensive damage to surrounding buildings. The fire caused a major downtown power outage when it burned through a power trunk line.

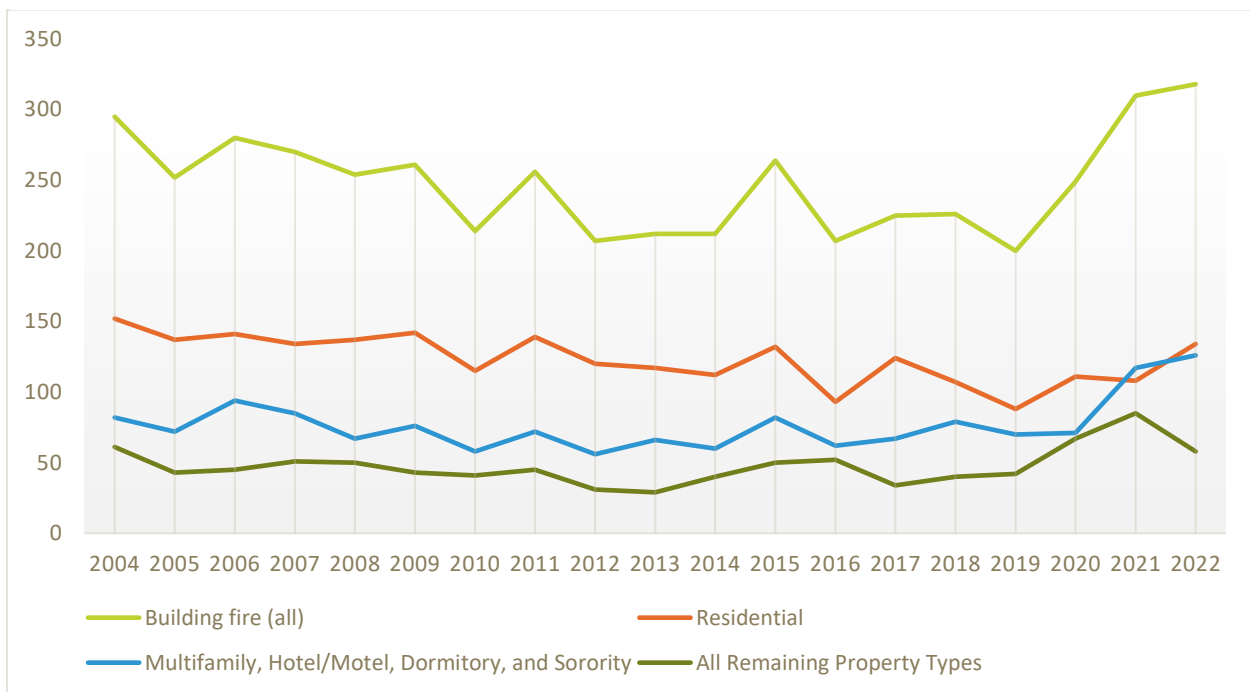
December 22, 1976. Pike Place Market. An apparent arson fire burned the Economy Market Building at 89-99 Pike St.

March 4, 1985. Health Sciences Center. A complex fire occurred on the 13th story of a 17-story building housing an infectious disease lab and trace amounts of radioactive material.

May 9, 1989. M.V. Golden Alaska. A 340-foot seafood processor caught fire below decks, initiating a complex incident requiring days to fully extinguish.

September 9, 1989. Blackstock Lumber. An arson fire at a lumberyard caused the death of one firefighter and severely injured another.

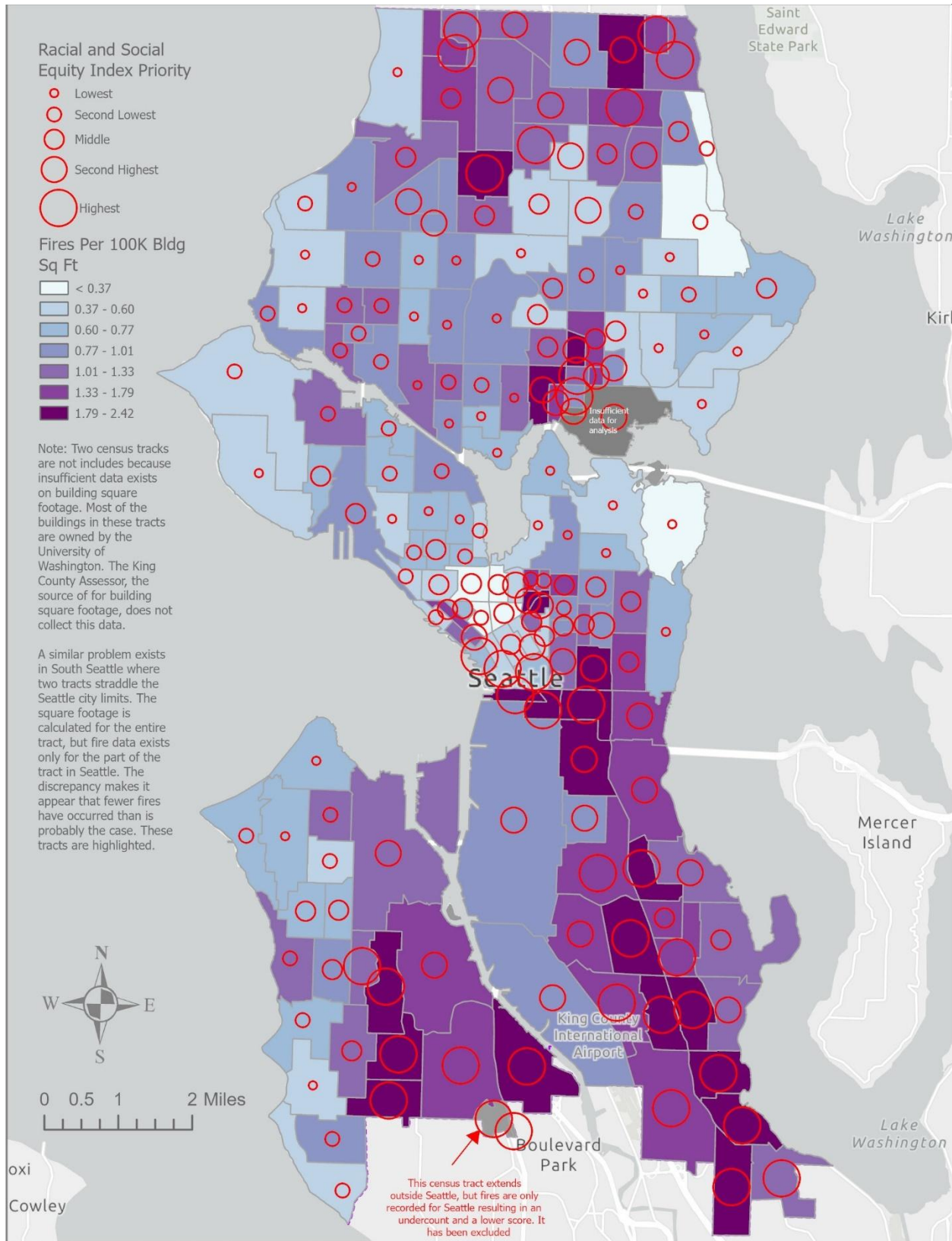
Figure 55. Structure Fires in Seattle 2004 to 2022



Vulnerability

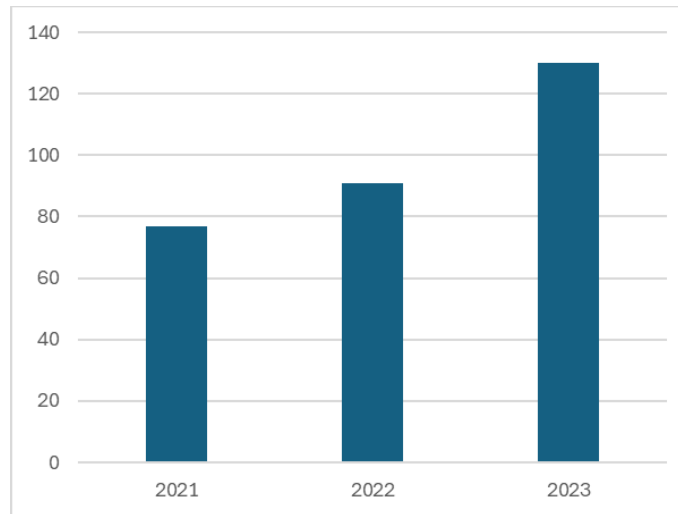
This section evaluates which locations and people are most exposed to potentially catastrophic fires. It is important to note that small fires that do not require emergency management involvement have a significant cumulative impact. [Figure 56](#) shows the number of fires per 100,000 square feet of building space from 2004 – 2022. The areas with more fires per 100,000 square feet have a historically higher exposure to fires. The data does not indicate the severity of the fires, but a higher exposure to fires can mean a higher exposure to *significant* fires. It is important to note that three of the most significant fires since 1990 did not happen in areas with a historically high rate of fires.

Figure 56. Structure Fires 2004 to 2023 per 100,000 square feet of building space with equity index



City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Figure 57. Vacant Building Fires 2021 to 2023



Some of the building characteristics that affect vulnerability include:

- High occupancy buildings are inherently more vulnerable because they expose more people to the hazard. They include sporting and entertainment venues, hotels, prisons, and multi-family buildings.
- Building contents have a large impact on vulnerability. Sites that store large amounts of flammable or hazardous materials are more vulnerable.
- Maintenance and upkeep can reduce vulnerability while a lack increases it. The lack of maintenance is a major factor making vacant buildings dangerous as many are structurally unsound.
- The National Fire Protection Administration identifies construction characteristics that bear on fire vulnerability: structural construction type, size, height, non-structural elements, ventilation, and fire protection systems.
- Construction types broadly fall into five bins: wood frame, 'ordinary' (i.e., masonry and wood), heavy timber, non-combustible (concrete and fire-resistive coated steel), and fire resistant (steel).
- Size or the overall volume of the building. Large buildings present more challenges for firefighters.
- Height. High-rise buildings can be very challenging for firefighters. Automated suppression is very important.
- Non-structural elements. Finishes, cladding, and related items can increase the likelihood that a fire will spread quickly. The acoustical tiles played a significant role in the 2003 Station Nightclub fire that killed 100 people.
- Ventilation. Openings, voids, and HVAC systems can allow fires to move more freely within a structure.
- Fire protection systems. On-site, automated fire protection systems like sprinklers are very effective. Recent research found they reduced deaths by 90%.⁵⁸²

Marine vessel fires are challenging. They are enclosed spaces making approaching the fire extremely dangerous. Ships have large amounts of flammable fuel onboard and, if they are passenger vessels, high occupancy.

The wildland-urban interface is vulnerable to wildfire. Seattle does not have direct connection with Western Washington's major wildlands, but it has large parks giving a small wildland-urban interface, but this area is smaller compared with areas on the edge of the metropolitan area. The Washington State Department of Natural Resources mapped the wildland-urban interface in 2019 and will implement codes for it. As of 2025, Seattle's implementation has been delayed allowing for refinement of the mapping data used to support the code.

Fire department response time is a key vulnerability metric. The National Fire Protection Association has determined that a "room and contents" fire will flashover to a structure fire within 5 to 10 minutes.⁵⁸³ The longer a fire burns without response the more likely it will spread to additional structures. Therefore, a response time under five minutes is considered good. The Seattle Fire Department has set their own standard for the first fire engine to arrive on scene within 4 minutes 90% of the time and a first-full alarm response (meaning the standard bundle of fire apparatus and firefighters) within 8 minutes 90% of the time. In 2023 the first engine met this standard 77% of the time and the first-full alarm met the standard 99% of the time.⁵⁸⁴ Between 2013-2017, the first unit standard was met 83% of the time.⁵⁸⁵

Building architecture, which is governed by building and fire codes, is another critical factor in reducing fire risk. Many high-population areas are now made from fireproof materials like brick, steel, and concrete that reduce the risk of fire spread. However, most of the city's residential structures are wood. In these structures, the key variables are early detection, spacing between structures to isolate a large fire and easy access for fire trucks. Most multi-family structures being built now are wood frame, because wood is an inexpensive and abundant local material. This is the general trend along the West Coast.⁵⁸⁶ There have also been recent moves to allow large multi-family structures to use wood and cross-laminated timber in their construction. In 2018, the Seattle City Council approved an ordinance allowing six floors of wood construction on top of two floors of concrete.⁵⁸⁷ These new building ordinances could increase the density of wood frame structures in the city, in turn increasing fire vulnerability. Seattle requires smoke detectors in all new and existing residential buildings and most other types as well. This law improves the chances that the Fire Department will detect fires early, decreasing the probability of a fire getting out of control. Due to these factors, the older neighborhoods, where the houses are closer together and the streets are narrower, are probably more vulnerable to multi-structure fires than new areas.

Seattle has the densest residential areas between San Francisco and Vancouver, B.C. and its density is increasing. More people are working and living in large structures. Density has many positive aspects but exposes more people to fire risk. The densest residential areas include Belltown, Capitol Hill, First Hill, and University District neighborhoods, with over 100 people per acre in many blocks and over 200 in some.⁵⁸⁸ Seattle's deadliest fire, the 1970 Ozark Hotel fire, occurred on the edge of downtown in the Denny Triangle area at 7th Avenue and Westlake in a dense neighborhood with many poorly maintained buildings. Although this fire happened over 50 years ago when fire codes and enforcement were weaker, the recent increase in vacant building fires shows that the combination of high occupancy and poorly maintained buildings is still a vulnerability.

In large buildings, the most critical factor is the functioning of passive and automatic systems. In tall buildings, the upper floors are impossible to reach from the outside. Moreover, HVAC and elevator shafts create corridors to spread a fire throughout the whole structure. Compartmentalized refuge areas, detectors and excellent sprinkler systems are the most effective means to deal with this type of fire. Seattle's codes employ all these devices. The most vulnerable area, as measured by the size of the exposed population, is Downtown. Fortunately, most of the high-rise buildings in Downtown were built after 1970, when fire codes mandated sprinklers or have undergone a substantial alteration that required the installation of sprinklers or other automatic fire suppression systems.

Structure fires can occur as a secondary impact from other hazards, most notably civil disorder or earthquakes. The Seattle Fire Department has prepared plans for triaging incidents in this situation. This planning emphasizes first performing windshield surveys to grasp the extent of the problem, then responding to the most critical situations. If fire resources are unable to combat all incidents, some fires may be left to burn or only enough resources will be committed to prevent the fire from spreading to adjacent structures. Additionally, during civil disorders, conditions may be too dangerous for fire crews to suppress some fires. If fires are left to burn, the risk of a major multi-structure fire increases.

Seattle has experienced brush fires, especially along transportation corridors, but has been able to contain them quickly largely due to the easy access that the city's street network provides. For more complete information on wildfires see the Wildfire chapter below. Wildfires have been put into their own [chapter](#) because they present a much different hazard profile for Seattle than structure fires. Seattle has few areas left with heavy vegetation, most of which are parks, but owns watersheds and dams in the Cascades that are surrounded by wildlands.

Consequences

Fires are a serious hazard with the potential to kill dozens of people in a single incident, injure many more, cause millions of dollars of damage, and lead to long term impacts on the community. A 2016 Oakland nightclub fire cost 36 lives. It highlights fires as a significant hazard for emergency management. Fire impacts can be complex with consequences extending beyond the scope of a fire department. They include displacement of people and businesses, damage to critical infrastructure, extended transportation closures, and release of hazardous materials. Fires in large, multifamily buildings are especially challenging. If building systems like elevators are damaged, residents on upper floors are often displaced until the infrastructure is repaired, which can take weeks or months.

The cumulative effects of 'normal' fires have been devastating in some communities across the US. During the 1970s and 1980s the Bronx lost 80% of its housing stock and 250,000 people were displaced.⁵⁸⁹ Despite situations like the one that plagued the Bronx and other US cities during the 1970's, fire prevention and response has been a major historical success. During the 19th century and early 20th century, many US cities, including Seattle, regularly suffered huge conflagrations that destroyed large parts of them. The focus on fire safety over one hundred years ago is an example of how hazards can be mitigated. Despite this general success, the urban fires in Los Angeles in January 2025 and Lahaina, Hawaii in 2023 demonstrate the ability for hot, windy weather to cause rapid, uncontrolled wildfire to spread to urban areas.

One of the more likely disastrous fire scenarios is a large fire in a vulnerable structure with high occupancy. Tragic recent examples include nightclubs like the Oakland fire mentioned above, or the 2003 Station nightclub that killed 100 people. Both involved management engaging in unsafe actions that violated local fire codes and highlight the importance of good code enforcement. Apartment and hotel fires can also be extremely dangerous but can be mitigated with a strong fire code and enforcement. If the code has significant gaps, tragedy can result. The 2017 Grenfell fire in London killed 70 people in a low-income high-rise apartment. The building employed construction techniques and materials that exacerbated the fire. Conditions in the building were dangerous as well. Many of these problems were noticed before the fire. While conditions in Britain and the US are not the same, this fire highlights the danger posed by older, unsafe building practices with poor fire safety practices. It highlights the need to be aware of conditions of the building stock, especially those serving vulnerable populations.

Explosions are included here as part of the fire hazard. The Lac-Mégantic rail explosion in 2013 killed 47 people and destroyed 40 buildings. The commodity, Bakken Crude, that caused this disaster runs through Seattle close to Lumen Field and T-Mobile Park then through the one-mile-long Great Northern

Tunnel under downtown Seattle. A 2019 study by the Washington State Department of Ecology on rail transportation safety found that areas within 411 feet of a train are at highest risk from an explosion. It lists the spill severity in Seattle as ‘Very High’ with 74,685 carloads of Bakken Crude shipped through Seattle annually.⁵⁹⁰ The City of Seattle does not have the authority to prevent shipment of dangerous rail cargo through Seattle. The worst-case scenario is an oil train exploding during a sporting event. While the probability is very low, the consequences include potentially hundreds of deaths and injuries.

Outlook

The types of incidents covered under this analysis are those that exceed the normal operating capacity of responding departments. Seattle has suffered many major and tragic fires, but since the advent of modern fire codes in the 1970s, none have exceeded the capacity of the Seattle Fire Department to manage on its own. Recently, City emergency managers have become involved with coordinating actions to mitigate the consequences of fires such as displaced people and disrupted businesses. Based on these parameters, what this section really considers is the likelihood that Seattle will experience a fire so impactful that it will exceed Seattle Fire’s resource capacity and require extended multi-department coordination to deal with its consequences.

Without extenuating circumstances, fire is unlikely to grow severe enough to become a disaster triggering activation of the City’s emergency operation center (EOC). Supporting this assessment is the Seattle Fire Department’s 2022 elevation to a Protection Class 1 rating. Only 1% of departments in the US have this rating and the rating recognizes the strength of Seattle Fire’s response metrics. Its strong response capabilities include being able to respond quickly and strongly to prevent fires from becoming large enough to threaten large numbers of people and property.⁵⁹¹

Fire is much more likely to become a disaster if it is associated with another hazard like an explosion, hazardous materials incident, earthquake, or civil unrest. A [study](#) conducted by SUNY Buffalo and Princeton that looked at fire following earthquake in Seattle’s downtown core. It found a high likelihood of fires in Belltown and along the waterfront based on age and type of building stock, probable damage to water systems, and roadway damage impeding access to fire crews.

The cumulative effect of smaller fires is important. [Figure 54](#) shows the annual number of fires in Seattle. It had been on a gradual decreasing trend that was noted in the 2019 SHIVA. This trend reversed during COVID. The biggest jump was in multi-family buildings, which is worrisome from a safety perspective as many people are exposed to the hazard. In a related trend, the number of vacant building fires had soared since 2021. In 2024, the City of Seattle enacted legislation to make it easier for the City of Seattle to take action to abate these structures, including demolition if necessary. These fires are related to a rise in the number of unhoused persons, the opioid and meth epidemics, and a mental health epidemic.

More small fires do not necessarily mean a higher chance of a catastrophic fire. Even with fewer fires overall, it is possible for a unique set of circumstances to cause a big fire. One indicator, albeit subjective, is the number of fires the Seattle Fire Department includes as significant in its annual report. This number recently has ranged from a low of 5 in 2018 to 13 in 2021. As a percentage of the overall number of building fires they range from a low of 2.2% in 2018 to a high of 4.4% in 2020. None of these fires caused the City’s EOC to activate. 63 fires have been deemed important enough to be included in the Seattle Fire Department annual report since 2017. While inclusion is a subjective measure, it is reasonable to presume these fires were the most impactful and challenging for the fire department. It is also reasonable to presume that the likelihood of a fire becoming catastrophic (meaning requiring the EOC to activate) is less than 1 in 63 per year. If we assume 1 in 100 significant fires is catastrophic, that means the changes of a catastrophic fire is about 0.02% to 0.04% per year.

Conclusions

Disastrous structure fires and explosions are rare in the modern United States but remain a potentially severe hazard. Isolated structure fires explosions are not the sole hazard, as fires are frequently a secondary hazard. When fire occurs as a secondary hazard, such as after an earthquake, challenging conditions can impede response and make fires more likely to spread. Long duration fire disasters like the New York fire epidemic are possible. The causes of the fire epidemic are complex but generally connect to New York's dire financial condition and triaging of fires. Seattle is not in immediate danger of this situation.

With many high-occupancy buildings and densely populated areas, Seattle has high exposure to fire risk. The risk this exposure entails has been reduced by measures to decrease the frequency and mitigate the effects of disastrous fires. They include the adoption of stringent Fire and Building Codes and the maintenance of a four-minute Fire Department response time.

11. HAZARDOUS MATERIALS INCIDENTS

This chapter analyzes hazardous materials releases that pose an immediate, acute danger to human safety and the environment. This analysis follows the National Fire Protection Association’s breakdown of hazardous materials into two categories: those with physical hazards and those with health hazards.⁵⁹² Physical hazards include materials that are explosive and flammable. Health hazards include materials that are toxic and corrosive, but this analysis expands that to those that are carcinogenic or pose a biological health risk. These definitions make this chapter overlap with the [Structure Fires](#), [Transportation Incidents](#), and [Infectious Disease and Biological Hazards](#) chapters. The Seattle Fire Department is the lead department for hazardous materials incidents. Natural gas incidents are analyzed here but are closely connected to structure fires.

Public awareness of hazardous materials threat rose in 1984 when the Union Carbide plant in Bhopal, India released large amounts of the pesticide, methyl isocyanate, into the area surrounding the plant. Over 500,000 people were exposed to the chemical, thousands died, and tens of thousands suffered major injuries. The disaster shocked the world and spurred legislation in the US.

More recently and closer to home, a Norfolk Southern freight train derailed near East Palestine, Ohio on February 3, 2023. Hazardous chemicals, including vinyl chloride, ethylene glycol, ethylhexyl acrylate, butyl acrylate, and isobutylene, were released into the environment as eight train cars burned. No deaths or injuries resulted from the immediate incident.⁵⁹³ Approximately 200 households had to be relocated during the recovery. Norfolk Southern has spent \$800 million to remediate the damage. The EPA reports the air and water are safe as of early 2024, but some residents remain concerned about long term.⁵⁹⁴

Despite incidents like these, much of the human cost in the United States result from long term chemical exposures. They are managed through a large infrastructure involving federal, state, and local government agencies in conjunction with the public health system. They are long-term community stressors and can be an important factor in long-term recovery after disasters.

The federal government plays a large role in all phases of hazardous materials management. Title III of the 1986 Superfund Amendments and Reauthorization Act (SARA), passed in the wake of the Bhopal

Key Points

- ❖ *Lead Agency – Seattle Fire Department*
- ❖ *This chapter focuses on acute hazardous materials threats that arise suddenly and require an immediate multi-agency effort to contain.*
- ❖ *Crude oil explosions are Seattle’s most significant acute hazardous materials threat.*
- ❖ *Natural gas calls have increased 60% from 2019 to 2023. Gasoline spills doubled in the same period.*
- ❖ *Prolonged exposure to hazardous materials contributes to disease burden particularly in areas in the Duwamish Valley and Central Seattle. See King County’s [Environmental Pollution Index](#) for more information.*
- ❖ *While significant hazardous materials incidents have occurred in Seattle, they have never caused an activation of Seattle emergency management system.*
- ❖ *Hazardous materials incidents are a frequent secondary hazard. In other words, a disaster can trigger hazardous materials incidents.*
- ❖ *Widespread concern amount hazardous materials incidents started with the 1984 disaster in Bhopal, India that killed over 2,200. It led to the 1986 Emergency Planning and Community Right-to-Know Act or SARA Title III. This law led to a lot of new planning and response infrastructure.*

disaster, and the Clean Air Act of 1990, mandate “cradle to grave” tracking of designated hazardous materials by requiring users to report what chemicals they are using and releasing into the air, and how they will respond to an emergency. Under the act, the federal government delegates implementation to the states. Washington State has passed the responsibility to local districts known as Local Emergency Planning Committees (LEPC). Seattle maintains its own LEPC managed by the Seattle Fire Department. The reporting requirements mandated by these acts have produced a rich data set of chemicals in the community.

In Seattle, the majority (60-70%) of hazardous material incidents occur on private property such as small businesses and residential units. The remaining 5-10% take place in storage facilities, 10-20% in industrial settings, and 15-20% from transportation incidents.⁵⁹⁵ Facilities that commonly house hazardous materials in the Seattle area include hospitals, metal plating and finishing, aircraft manufacturing, public utilities, cold storage companies, fuel facilities, communications facilities, chemical distributors, research facilities, and high technology firms.⁵⁹⁶ Illegal drug labs or dumping can also pose a risk.

Transport incidents are typically more difficult to manage because they often happen in uncontained settings and/or populated areas. Responders to transportation accidents do not have detailed site plans nor chemical inventories. A recent concern is the increasing transportation of Bakken crude oil, which is lighter and more flammable than traditional crude. In 2013, a train carrying Bakken derailed and exploded just outside of the U.S. in Quebec, Canada, killing 47 people and destroying 30 buildings. An oil train carrying Bakken derailed in Seattle under the Magnolia bridge in July 2014. Fortunately, no oil was spilled, and the incident was not catastrophic like the Quebec explosion, but it illuminated the risk of transporting highly flammable materials through dense, urban areas.

The Fire Prevention Division of the Seattle Fire Department (SFD) provides the leadership and inspection services to help prevent fires, explosions, and release of hazardous materials and to assure fire and life safety for Seattle’s residents, workers, and visitors. The Hazardous Materials Section provides inspection services for the storage and use of flammable and combustible liquids and other hazardous materials and processes as required by the Seattle Fire Code and Administrative Rules. SFD also has a 56-person Hazardous Materials Unit, established in 1980, that is thoroughly trained to respond to all hazmat scenarios and frequently provides guidance to operational companies.

The Seattle Fire Department is supported by private and governmental resources. On the private side, large companies often have response teams, and the Chemical Manufacturers Association has created an organization, CHEMTREC, which runs a 24-hour hotline for emergencies that happen in transit. Additionally, several private companies specialize in responding to chemical emergencies. At the federal level, the EPA, Coast Guard, and the US Department of Transportation’s Bureau of Explosives have strike teams that assist local responders in special situations. Washington State provides teams from the Department of Ecology and the Department of Natural Resources that play a leading role in spill response, especially those involving water bodies.

The Seattle Local Emergency Planning Committee (LEPC) was set up in 2002 to foster a working relationship between private industry and public agencies in addressing hazardous materials issues. In addition to promoting public awareness and industry reporting, the LEPC takes a cooperative approach toward the prevention and preparation for hazardous materials releases. LEPC membership includes City personnel, members of the SFD Hazmat Team, representatives from the Washington State DOT, Washington State Department of Ecology, Seattle/King County Public Health, Harborview Hospital, Port of Seattle, Boeing, BNSF Railway, Bank of America, and a member of the public.

The number of chemicals in use today makes it critical to know which ones are at a particular site. The Occupational Safety and Health Administration (OSHA) lists 28,000 toxic chemicals and each of them has a unique way of interacting with their environment and with other chemicals, including the ones used to

clean up spills. Untrained responders can make matters worse by applying a material that will react adversely with the spilled chemical, highlighting the importance of well-trained Hazmat responders.

The possible use of chemical, radioactive, and biological material increases the risk hazardous materials pose, but thankfully the use of these materials is rare. Manufacturing sufficient amounts of chemicals is a challenge for individuals and groups planning terrorist attacks. The most significant to date is the 1995 Tokyo Gas Attack that killed 12 and injured thousands. The use of radiological devices is also rare. Radiological attacks are not nuclear bombs. Rather, they use a variety of means, including conventional explosives, to disperse radioactive substances. There is a debate about the effectiveness of these devices, however. The two examples of actual attacks using radiological devices come from Russia and Chechnya. Neither bomb exploded. The US Department of Homeland Security believes the most likely use of a radiological attack would be to contaminate facilities where people live and work to disrupt their livelihoods, or to cause anxiety in people who believe they may have been exposed. A Fact Sheet by the US Department of Homeland Security stated that it would be difficult to build a device “that would deliver radiation doses high enough to cause immediate health effects or fatalities in a large number of people.”⁵⁹⁷ The use of biological agents is covered in the chapter on [Infectious Disease and Biological Hazards](#).

History

Although hazardous materials incidents can have grave consequences as explained below, Seattle has never activated its Emergency Operations Center (EOC) for a hazardous materials incident. Most significant incident historically is the 2016 Greenwood Gas Explosion which required an extended recovery operation overseen by an incident management team.

Major Incidents

December 4, 1975. Fuel Tanker Explosion/Fire on Alaskan Way Viaduct. (This incident is also listed under [Structure Fires](#) and [Transportation Incidents](#)). A gasoline tanker truck crashed. Leaking gasoline caught fire, causing extensive damage to surrounding buildings. The fire caused a major downtown power outage when it burned through a power trunk line.⁵⁹⁸

June 10, 1999. Bellingham Pipeline Explosion. Although this incident did not occur in Seattle, it focused attention regionally on pipeline safety. Three people died and Bellingham’s water treatment facility was severely damaged. Seattle has a spur of the same pipeline that runs from Harbor Island to Renton. It transports mostly gasoline.⁵⁹⁹

March 25, 2014. Over 4000 containers of improperly stored dangerous chemicals were discovered at a private residence in Seattle’s Greenlake neighborhood. A response was mounted that involved the Seattle Fire Department, the King County Hazardous Waste Program, and the US Environmental Protection Agency. No injuries were reported.⁶⁰⁰

July 14, 2014. Two cars of a Bakken crude oil train derailed in the Interbay area of Seattle. No spill occurred.⁶⁰¹

March 9, 2016. Greenwood Gas Explosion. An uncapped natural gas pipe caused an explosion that destroyed one building and three businesses. 54 surrounding businesses suffered damage, causing closures of up to several months. Residents of a neighboring apartment had to be temporarily relocated while their building underwent repairs. Unified Command was established with six City departments. The City’s Department of Neighborhoods and Office of Economic Development acted as liaisons with the community. The Phinney Neighborhood Association managed financial assistance.⁶⁰²

February 27, 2017. A 10,000-gallon propane truck overturned on I-5 near downtown Seattle. Seattle Fire crews were able to transfer the propane successfully to another truck.⁶⁰³

June 26, 2018. Fire at the Seattle Iron and Metals (SIM) recycling facility along the Duwamish River. The burning material included hazardous substances raising concerns about chemicals in smoke from the fire and discharges into the Duwamish, a Superfund cleanup site. This fire was preceded by other incidents and fires that threatened the community.⁶⁰⁴ In 2013, the Puget Soundkeeper Alliance sued SIM. In 2019, SIM and the Alliance agreed to a settlement stipulating that SIM make \$1 million in safety improvements.⁶⁰⁵

May 2, 2019. Thirteen people treated from radiation exposure after a breach of Cesium-137 at the Harborview Medical Center Research and Training Building.⁶⁰⁶ The leak was serious enough to warrant a Federal Department of Energy report. Only a small amount of the 2900 curies of material was released (curies are a measure of the intensity of radioactivity in material). There is no simple way to convert curies into a measure of an absorbed dose by a person because it depends on the specifics of the exposure. Cesium-137 is the same material involved in the Chernobyl accident. The Cesium-137 was in the process of being removed by a federal contractor as part of a nuclear waste removal project aimed at removing radioactive material from medical facilities where it is used in medical treatments. Some experts worry that radioactive material from medical facilities could be used to make a dirty bomb.⁶⁰⁷ The building had to be closed, cleaned, and remediated before reopening nearly two years later on April 29, 2021.⁶⁰⁸

July 28, 2022. Firefighters shut down both directions of I-5 between the Lakeview and Mercer Street exits due to a fire involving a truck carrying tanks of oxygen, argon, acetylene and propane. Several tanks exploded, causing a second fire at a nearby construction site. The Hazardous Materials unit was deployed, and, fortunately, no injuries were reported.⁶⁰⁹

Seattle Fire Department Data

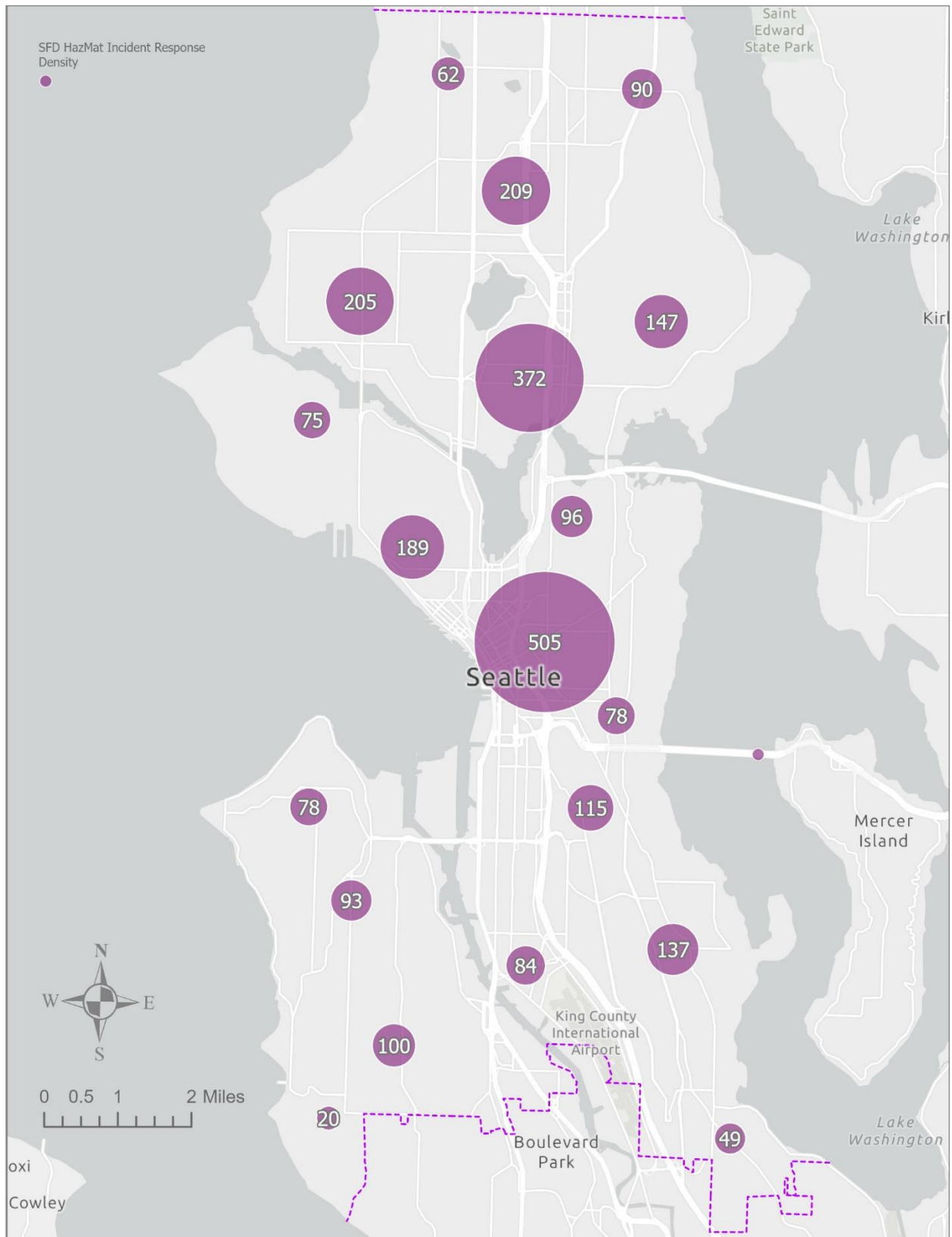
The Seattle Fire Department (SFD) reports hazardous materials incidents to the [National Fire Incident Reporting System](#) (NFIRS). Between the beginning of 2019 and the end of 2023, SFD responded to 4739 hazardous materials calls as defined by NFIRS, however, NFIRS includes electrical hazards, building collapses, and vehicle accidents as hazardous materials responses. 2709 incidents remain if these codes are excluded, with only codes related to chemical, radiological, and biological substances left.

Nearly half of the responses have been for natural gas leaks (42%) followed by carbon monoxide (19%), and gasoline and other flammable liquids (17%). There has been a 60% increase in the number of hazardous materials responses from 2020 driven by a 60% increase in the number of natural gas responses and a 90% (near doubling) increase of gasoline and flammable liquid responses. See [Figure 58](#), [Figure 61](#), and [Table 17](#) for details.

National Trends

Reviewing historical data at a national scale is helpful because Seattle has a limited history with very big hazardous materials incidents. Unfortunately, systematic data across all 50 states does not exist. The largest, easily accessible database is from the [National Toxic Substance Incidents Program](#) created by the Center for Disease Control from 2010 to 2014. It collected data from nine states on significant hazardous materials releases with public health impacts. Washington was not part of the program, so we do not have data on Seattle specifically and must assume that Seattle's incidents do not differ significantly from the participating states. It is also important to note that most of the incidents reported are smaller than the kinds of incidents of concern in this analysis and that characteristics of these smaller incidents may be different than those of very large incidents. With these assumptions and

Figure 58. Density of Hazmat Incidents 2019 to 2023



WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

caveats acknowledged, the data allows us to answer some important questions. Percentages have been rounded.

Percentage of incidents causing at least one fatality? 1.5%

Percentage of incidents causing more than 30 injuries (including fatal injuries)? 0.08%, or just 12 of the 13,529 reported incidents.

Where do incidents occur? The program found that 64% of hazardous materials incidents occur at fixed sites such as factories and storage facilities and the remaining 36% occur during transportation.

Which chemicals are most commonly involved? For fixed facilities it is natural gas (14%), carbon monoxide (8%), illegal meth (7%), and ammonia (7%). For transportation it is alkaline hydroxides (10%), sulfuric acid (5%), hydrochloric acid (5%), and natural gas (3%).

What is the release mode? For fixed facilities it is volatilization (vaporizing) (47%), spills (38%), explosions (1%), and multiple modes (12%). For transportation it is spills (82%), volatilization (9%), and multiple modes (5%). Explosions in transportation accounted for only 0.1% and fires for only 0.2% of incidents. Volatilization is involved in 54% of all injuries and 45% of the deaths.⁶¹⁰

Local Considerations

Facilities that commonly house hazardous materials in the Seattle area include hospitals, metal plating and finishing, aircraft manufacturing, public utilities, cold storage companies, fuel facilities, communications facilities, chemical distributors, research facilities, and high technology firms.⁶¹¹ Illegal drug labs or dumping also pose significant risks.

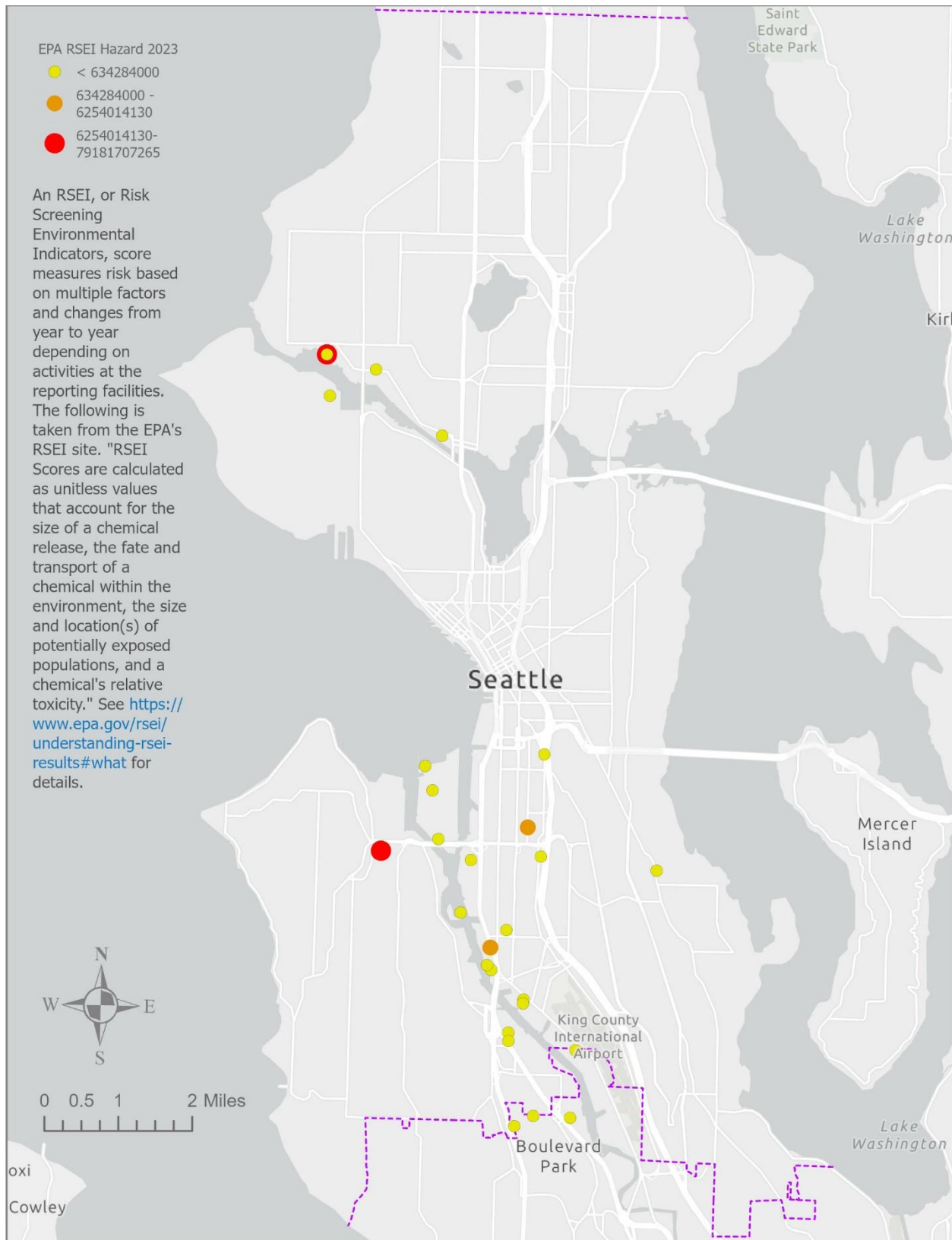
After a train transporting Bakken crude oil exploded in Lac-Mégantic, Quebec in 2013 killing 47 people and destroying 40 buildings, Seattle became aware of the risks posed by the same Bakken crude oil trains running through the city. The rail lines run north to south close to Lumen Field and T-Mobile Park before going through the one-mile-long Great Northern Tunnel under downtown Seattle. These shipments began in 2012. A study by the Washington State Department of Ecology on rail transportation safety found that 74,685 carloads of Bakken Crude were shipped through Seattle annually or over 1,400 cars per week by 2021.⁶¹²

The federal Environmental Protection Agency's [Toxic Release Inventory](#) (TRI) program tracks releases from facilities. It requires facilities in certain sectors (manufacturing, mining, power generation, etc.) who have over 10 employees and produce, process, or use chemicals to report the amounts that were released each year on and off their facility.⁶¹³ They monitor chemicals that are either harmful to public health or the environment. Because chemicals can vary widely in their toxicity, just listing the amount of a chemical released does not tell the true picture of risk. To deal with this problem the EPA made the Risk-Screening Environmental Indicators (RSEI) model. The results below include both pounds emitted in Seattle and RSEI scores. The chemicals in the inventory are likely to pose long-term, chronic hazards.

In 2023, 29 Seattle facilities reported releasing 216,207 pounds of toxic chemicals into the air.⁶¹⁴ Additionally, roughly 560,416 pounds of toxic chemicals were released by Seattle facilities to off-site locations. Off-site storage is included in the RSEI database. The majority of manganese is off-site storage from the Nucor plant in West Seattle. The most harmful chemical released in Seattle is chromium used in South Park by Seattle Propeller. The chromium is also disposed of off-site.

See [Figure 59](#) for facilities that release toxic chemicals. A release does not indicate a hazardous materials incident. Rather, it means that a chemical was emitted into the air or water or placed in a type of land disposal.⁶¹⁵ These numbers reveal the amount of chemicals that are being used in the city and could potentially pose a risk to public health if handled improperly or uncontrollably released as a secondary hazard from another hazard like an earthquake.

Figure 59. EPA Toxic Release Inventory, Risk Screening Environmental Indicators (RSEI) data for 2023



The chemicals released into the air include:

- 1-Bromopropane (107,829 pounds) – Industrial solvent. Reasonably anticipated to be a human carcinogen
- Toluene (40,484 pounds) – Solvent for paints, adhesive, and thinners and a gasoline additive
- Xylene (26,664 pounds) – Petrochemical. Solvent used in printing. Related to toluene
- Methyl Isobutyl ketone (9,919 pounds) – Solvent

US Department of Transportation Data for Seattle

The United States Department of Transportation collects data concerning hazardous materials incidents that occur during transportation. 911 incidents occurred in Seattle between 2000 and 2024. Most of them were minor and were resolved without the need for a Seattle Fire Department response. The number of incidents ranges from a low of 18 in 2020 to a high of 57 in 2001. Overall, the pattern suggests a downward trend, but enough variation exists year-to-year to make a firm conclusion impossible. Only 13 incidents, or 1.4%, were listed as serious, and only 5 required evacuations. Of the 13, 11 involved flammable liquids or gas. Of all incidents, most (61%) involved the highway transportation mode, followed by air (26%), rail (11%), and water (1%). None of the reported incidents caused injuries or fatalities. The database only includes actual releases so the June 14, 2014, Bakken crude oil rail derailment is not included because no release occurred.⁶¹⁶

Local Superfund Sites

In late 2024, the newest phase of the Duwamish River Superfund Site cleanup began on the Lower Duwamish River between the South Park Bridge and the West Seattle Bridge. The goal of the project is to lower the amounts of PCBs in river sediment by 90%.⁶¹⁷

Vulnerability

For all incidents, including smaller ones, the most exposed areas are sites that use hazardous materials, areas near to them, or downwind from them. Following this are transportation routes used for freight and the properties adjacent to them. Active or abandoned landfills are also potential sites, but Seattle has no active landfills. It has abandoned landfills, but most are either [old](#) or have been [remediated](#). One that has not finished remediation is the South Park Landfill near SR 509 and SR99. The Washington State Department of Ecology is [finalizing a plan](#) to finish the cleanup of the site as of 2024.

While all incidents, including minor incidents, show higher exposure at industrial sites and along transportation routes, the major incidents included in the history section show more varied exposure. The six major incidents since 2014 include a hospital and two neighborhood locations. Going back further, the list includes another hospital and a University of Washington lab. Transportation accidents account for 40% of all major incidents listed in the History section. Transportation exposure includes pipelines. The Williams pipeline runs from Harbor Island to Renton along Beacon Hill. The areas adjacent to the BNSF rail lines are exposed to Bakken crude oil explosions and other hazardous materials transported by rail. The City of Seattle does not have the authority to prevent shipment of dangerous rail cargo through Seattle. Although industrial sites have only experienced one major incident, large amounts of fuel are stored on Harbor Island, a location with heightened sensitivity to seismic shaking and exposure to storm surge.

Hazardous materials that enter the sewer or stormwater system can lead to an increased complexity and overall footprint to hazardous materials incidents. About 60% of the stormwater conveyance system discharges directly to a waterbody (river, streams, lakes, ponds, and marine waters). Hazardous materials discharged into these areas can have an adverse impact on the environment in these areas.

While hazardous materials discharges to the sewer or combined sewer system can also have a detrimental impact on the treatment processes and infrastructure.

Seattle has a strong hazardous response capability led by the Seattle Fire Department Hazardous Materials Response Team, which currently has 59 members. Adding to this capability is the EPA's cache of hazmat equipment in Seattle's South Park neighborhood where it can be quickly deployed.

Consequences

Hazardous materials cause explosions, fires, biohazards, radiological exposures, and toxic chemical releases. Seattle has experienced all these consequences from previous incidents. They can disperse through the air or water and can enter the body through the lungs, digestive system, or skin. Some will react with water and other common agents that firefighters use. Every chemical has a unique set of properties that pose a unique set of dangers and call for a unique response. In most cases, a fire will multiply the threat of direct contact either by causing the material to explode and/or dispersing it.

Explosions pose the most immediate danger to human lives and property. The timing of the Greenwood gas main explosion in 2016 was very lucky. If the incident had happened during the day, it is possible civilians would have been killed or injured. The 47 lives lost in Quebec underline the potential for loss of life. Explosions cause extreme property damage. The Greenwood explosion destroyed two structures and damaged dozens more, displacing dozens of residents and several businesses.

Explosions are largely single site events, although they do have the potential to initiate other explosive reactions. The consequences depend on where they happen as well as when they occur, and how powerful they are. All of Seattle is covered by the Puget Sound Energy gas system. Gas explosions could happen anywhere. The consequences would be greatest in the denser areas of the city during the day. Bakken crude oil explosions are limited to areas near the BNSF tracks shown in [Figure 59](#).

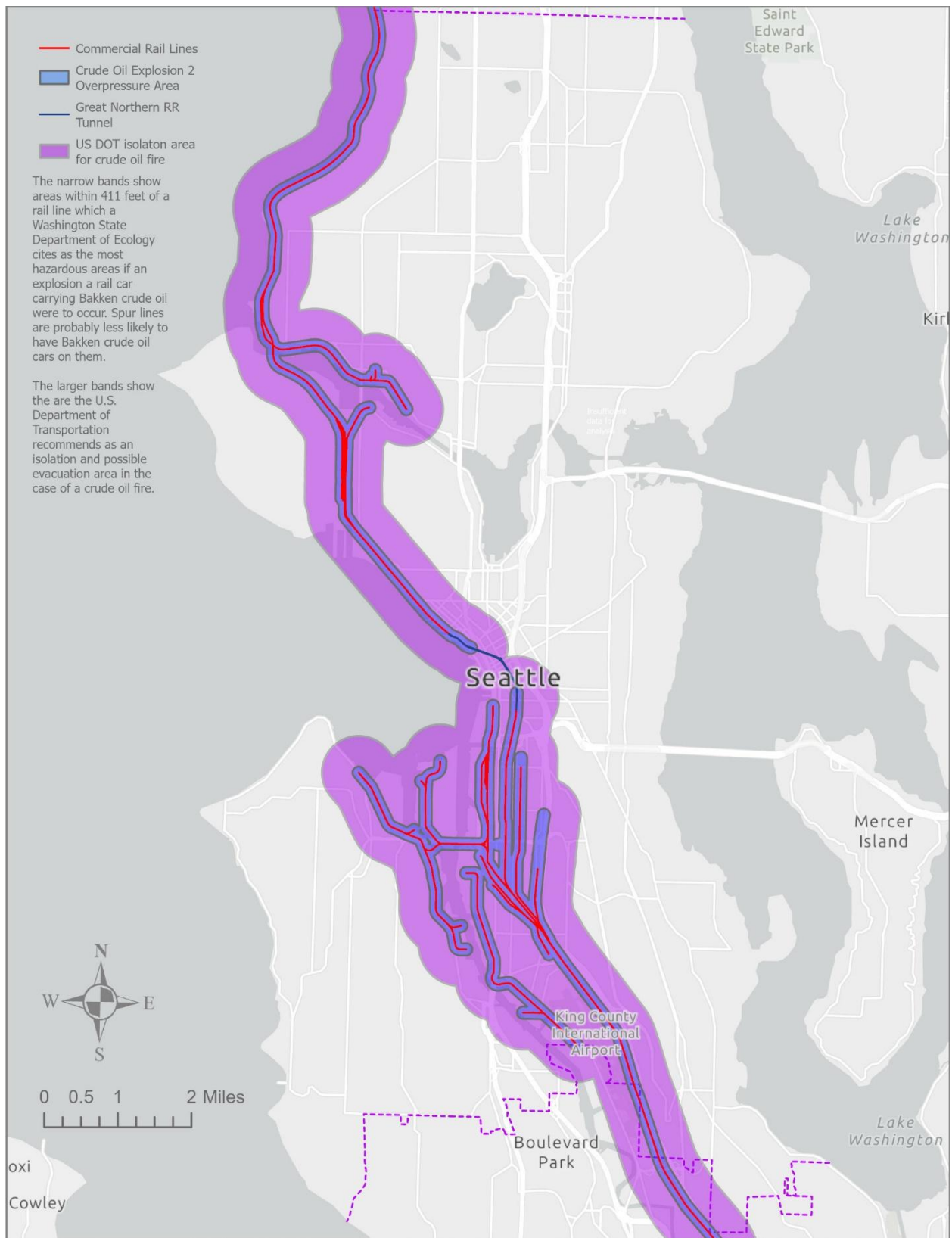
Toxic releases, like the one in East Palestine, can sicken people within the exposure plume and deposit chemicals that can stay in the environment for a long time unless remediated. The number of immediate deaths is often low compared to the number of injuries, with respiratory injuries being the most common. In most cases, a responsible party is identified and is responsible for cleanup costs. Environmental monitoring is required to define the area needing cleanup. Even with cleanup and monitoring, many people living near a toxic release site will understandably have concerns about their long-term health. Government and the responsible party will have to work with communities over a long period of time to regain trust.

Toxic releases can also cause extreme environmental damage, especially if chemicals enter the water or sewer systems where they can spread and leach into groundwater or discharge into bodies of water. Many large maritime vessels are capable of leaking thousands of gallons of oil into the Puget Sound. If dangerous gases escape in large quantities, or if chemicals enter the water system through a Combined Sewer Overflow or direct runoff, an accident could escalate from a localized emergency to a wider environmental disaster.

The consequences of biological incidents are covered in [Infectious Disease and Biological Hazards](#). Radiological hazards like the 2019 Harborview incident are contained on the site where they occur. Those sites are unusable for months or years while cleanup happens.

Incidents caused by a terrorist attack would be serious because of the deliberate intent to harm. Dangerous substances could be released in locations that would impact many people, such as transit systems or entertainment venues. The 1995 nerve gas attack on the Tokyo subway killed 12 people and injured about 500. It caused 5,500 to seek medical evaluations.⁶¹⁸ In the extremely rare chance that Seattle was the target of a radiological attack, such as a dirty bomb which mixes radioactive material with conventional explosives, only people close to the device would receive enough radiation to get seriously ill. People would be more likely to be physically harmed by the explosion.⁶¹⁹

Figure 60. Bakken Crude Exposure

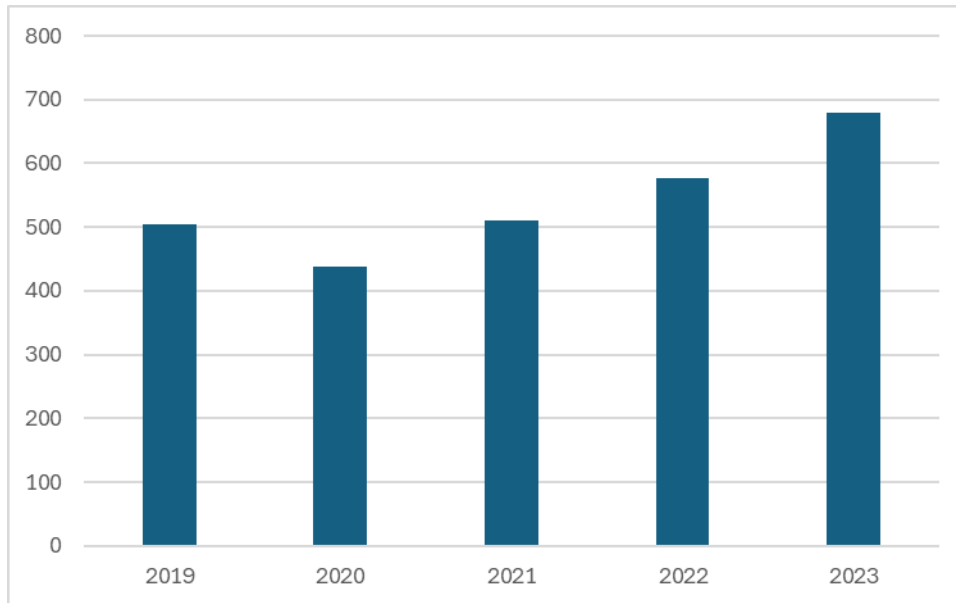


WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

In a scenario where numerous hazardous materials releases occur as a secondary impact to another hazard (e.g., earthquake), response capacity would be diminished. In past events, bystanders have been injured because people were not removed quickly enough or were allowed to return early during a prolonged evacuation.⁶²⁰

Hazardous materials are present in Seattle’s environment posing chronic health hazards to those exposed. These are long-term exposures spread out over many years. They are important hazards to recognize and remediate, but their consequences are evaluated not evaluated here. Public Health – Seattle King County has an [environmental health](#) program to evaluate and mitigate harmful substances.

Figure 61. Seattle Fire Department Hazardous Materials Dispatches 2019 to 2023



Outlook

Seattle has had 6 major hazardous materials incidents since 2000. That’s one every four years, but for each major incident there are dozens or hundreds of smaller incidents. Since 2019, the Seattle Fire Department has logged over 2700 hazardous materials calls. The United States Department of Transportation records 911 incidents in Seattle from 2000 to 2024, but only 13, or 1.4%, were recorded as ‘serious’.

Despite the low ratio between all incidents and major incidents, some observations can be made. The increase in natural gas leaks could be tied to Seattle’s construction boom. Additionally, the rise in gasoline theft could increase the chance of a major gasoline related hazardous materials incident. The increase since 2013 in the amount of Bakken oil being transported by rail through the city may increase Seattle’s likelihood of a disastrous incident. Many of the railcars that carry Bakken oil in the state were not made to carry oil and have been known to puncture upon impact.⁶²¹

The increasing number of lithium-ion batteries, especially in vehicles, poses an increased hazardous materials risk. The problem is serious enough that the United States Department of Transportation convened a stakeholder meeting in 2024 to address battery safety. Participants noted dozens of battery fires after Hurricane Ian in 2022. Battery fires require more water to extinguish, and the runoff is more acidic with a pH of 2.7. Even with a fire under control, damaged batteries pose a risk because they can ignite long after the damage occurs.⁶²²

Hazardous materials incidents cross over with terrorism. Seattle has never experienced a chemical or radiological attack. The difficulty of obtaining or manufacturing chemicals makes an attack very unlikely,

though not impossible. In 1995, sarin gas was used to attack the Tokyo subways. A few terrorists have expressed interest and intent on using radiological attacks, but none have been successful.

Five-Year Outlook

Major hazardous materials incidents, like the ones outlined in the History section, have a roughly 25% chance of happening each year. Cumulatively, that's roughly a 75% chance over five years. These previous incidents were not big enough to trigger the use of the City's Emergency Operations Center, but the continuous shipment of Bakken Crude through Seattle remains a concern. The trains pack a lot of destructive potential and pass near sensitive areas like Seattle stadium district. Hazardous materials incident remain a common secondary hazard of the other hazards analyzed here. The increasing number of lithium-ion batteries is increasing this secondary hazard, at least until new safety standards can be developed.

Table 17. Seattle Fire Department Hazardous Materials Dispatches Code by Year

NFIRS Code 	2019	2020	2021	2022	2023	Grand Total
400 - Hazardous condition, other	64	51	68	41	50	274
410 - Combustible/flammable gas/liquid condition, other	24	22	27	22	34	129
411 - Gasoline or other flammable liquid spill	70	64	59	126	133	452
412 - Gas leak (natural gas or LPG)	186	193	244	218	301	1142
413 - Oil or other combustible liquid spill	14	5	10	9	5	43
420 - Toxic condition, other	8	4	5	7	14	38
421 - Chemical hazard (no spill or leak)	6	4	5	5	11	31
422 - Chemical spill or leak	11	9	8	11	13	52
423 - Refrigeration leak	3	3	1	3	2	12
424 - Carbon monoxide incident	93	76	81	135	129	514
430 - Radioactive condition, other	3				1	4
431 - Radiation leak, radioactive material	1					1
451 - Biological hazard, confirmed or suspected	5	6	2		4	17
Grand Total	488	437	510	577	697	2709

Conclusions

Minor hazardous materials incidents are common, making them high probability events that typically do not involve emergency management. More serious incidents that require an extensive response, but not a full Emergency Operations Center (EOC) activation arise with a roughly 25% chance per year. The City of Seattle has not had to activate its EOC for a hazardous materials incident and has a well-trained team within SFD who handle response. The highest hazard is the risk of explosions caused by natural gas and Bakken crude oil shipped through Seattle by rail. Other significant sources of hazard are the Williams bulk fuel pipeline and the tank farms on Harbor Island.

12. BUILT ENVIRONMENT FAILURES

On June 24, 2021, the Champlain Towers South in Surfside, Florida collapsed killing 98 people. The structural failure was a stark reminder of the deadly potential posed by engineering and construction failures, the need for strong building codes, and excellent adherence to those codes. This chapter explores our local experience with failures in the built environment, our exposure to failures, and potential consequences with an emphasis on systems owned and/or maintained by the City of Seattle. It includes buildings and infrastructure like bridges, dams, and utilities. Many hazards cause structural failures. We created a standalone chapter for engineering failures because some failures are not caused by other hazards, rather the structure itself is the hazard.

Failures of the built environment cause two main dangers: physical collapse and service disruption. A sudden catastrophic collapse can lead to devastating consequences, including injuries and fatalities resulting from falling debris or the loss of structural integrity. The collapse may cause secondary hazards such as flash floods in a dam failure or the release of toxic chemicals. Structures and the infrastructure connected to them produce services for the community. Losing them causes hardship. A structure does not have to collapse to impose hardships on the public. If engineers discover sufficient cause for potential failure, they may need to close a structure for repair.

When active crack propagation was discovered in the West Seattle Bridge in 2020, it was closed due to the potential for catastrophic failure. Despite the hardship, the closure was a success because it avoided potential tragedy.

Given the size of our built environment, collapses like the one at Surfside are very rare. In addition to being secondary effects from other hazards like earthquakes, failure can be caused by design flaws, poor construction, unnoticed environmental factors like moisture or corrosion, and inadequate maintenance.

Nationally, age combined with inadequate maintenance plays a role in weakening structures. In many regions, pipelines, bridges, and other structures exceed 100 years in age. Some systems in Seattle are approaching or are past this age. The Fremont and Ballard bridges, as well as the Hiram M. Chittenden Locks, were all 108 years old as of 2025. The spending gap between what is currently allocated for infrastructure and what is needed nationally to ensure structures are sound is \$3.7 trillion according to the American Society of Civil Engineers (ASCE), which also assigned an overall C- grade to the nation's infrastructure. [Washington's infrastructure](#) received a C grade from ASCE, with stormwater system rating lowest (D+) and dams rating highest (B-).⁶²³ Congress passed the 2021 Infrastructure Investment and Jobs Act (IIJA) and 2022 Inflation Reduction Act (IRA), which included more than \$580 billion in new

Key Points

- ❖ *Lead Agency – Depends on failure and impacts. Seattle Fire, Seattle Public Utilities, Seattle Transportation, Seattle City Light*
- ❖ *Building, bridge, and dam failures are of greatest concern due to potential for high loss of life and economic consequences.*
- ❖ *This chapter covers large, complex infrastructure failures that are not triggered by some other hazard (e.g., an earthquake). Failures to digital and communications infrastructure is discussed in the cyber incidents*
- ❖ *Infrastructure can be damaged during construction, such as a contractor breaking a water main; or fail after construction due to a design flaw, such as the collapse of the Tacoma Narrows Bridge in 1940.*
- ❖ *Occasionally, our understanding of a threat to infrastructure becomes clear only after we build it. This has occurred with many bridges built in the early 20th century before Seattle was aware of its earthquake risk.*

infrastructure spending from 2022-2026. If the level of funding is maintained the spending gap will drop to \$2.9 trillion.⁶²⁴

The City of Seattle is responsible for much of Seattle’s infrastructure and for enforcing building and fire codes. The City of Seattle owns and maintains the drinking water distribution system, the drainage system, the power grid, solid waste, most roadways, and most bridges. Private companies maintain the natural gas system and communications systems (except for public safety radio, PSERN). Sound Transit owns and maintains Link light rail infrastructure. Heavy rail that runs through the City of Seattle is owned and maintained by Union Pacific Railroad and Burlington Northern Santa Fe Railway.

Seattle’s drinking water, drainage systems, and solid waste systems are funded by Seattle Public Utilities ratepayers. The power grid is funded by Seattle City Light customers. Transportation systems are paid for through public levies. The 2015 Transportation Levy to Move Seattle included funds to seismically upgrade 16 bridges.⁶²⁵ In 2024, voters approved a \$1.55 billion Transportation Levy to replace the 2015 levy. It includes \$634 million for street maintenance and modernization, bridges, and structures.

As old infrastructure is replaced and new infrastructure is built, advanced computer technology is becoming more integrated with the maintenance and operations of the infrastructure. Most complex infrastructure is now controlled with computer systems (called Supervisory Control and Data Acquisition or SCADA systems). While SCADA system failure can lead to infrastructure failure, it is covered in the [Cyber Disruption](#) chapter.

History

The Seattle region has experienced some large failures, but none included major loss of life. This is a list of the major infrastructure failures in Seattle.

Since 2000

December 14, 2006. Drainage System. (Also covered in [Flooding](#)). Extreme rainfall overwhelmed the drainage system along Madison Street. Water built up in a low point in the street. It overtopped the curbs and rushed downhill, flooding a home, and killing one person. The flooding was made worse because the drainage pipe under Madison Street, installed in the early 20th century, was not able to quickly drain the upstream area and caused regular flooding at this site.⁶²⁶ The City of Seattle activated its Emergency Operations Center for this event and the wider storm event.

May 2, 2007. Water Main Break Under University Bridge. A 24-inch main installed in 1912 broke, causing a large sinkhole and concerns regarding the integrity of the bridge abutment. The incident also damaged an 8-inch gas main and a conduit housing fiber-optic trunk lines. The bridge was not damaged, but water and gas service in the area had to be temporarily terminated for most of the day until repairs to the gas main could be made. A road under the bridge that is the only access for several houseboats was blocked.⁶²⁷ The City of Seattle activated its Emergency Operations Center for this event.

January 19, 2009. Howard Hanson Dam. Potential catastrophic flooding was avoided in the Kent Valley after engineers noted that one of the dam’s abutments had a void. To reduce the chance of failure, dam operators had to maintain lower water levels in the reservoir, increasing the chance of flooding in the Kent valley until repairs were completed.⁶²⁸ Repairs were completed in 2012 before dam failure occurred and flooding downstream was avoided.

February 9, 2017. West Point Treatment Plant. Heavy rains and high tides caused flooding at the wastewater treatment plant, which caused significant damage to an electrical circuit shutting down operating systems that control plant operations.⁶²⁹ 235 million gallons of untreated waste were released into Puget Sound.⁶³⁰

April 5, 2019. Power Infrastructure. A storm with high winds caused 26 utility poles to come down on East Marginal Way in Tukwila, leaving roughly 16,500 customers without power and injuring two people.

Some of the poles were found to have rotting wood and damage from beetles that weakened their bases.

April 27, 2019. Crane Collapse. A tower crane collapsed from the roof of a building in South Lake Union onto Mercer Street causing four fatalities and injuring four others. This was not a design failure, but an error in operations. The cause was the removal of a series of bolts connecting the tower sections by a contractor while dismantling the crane. The bolt removal was not in accordance with manufacturer instructions.⁶³¹ This incident triggered an EOC activation.

March 23, 2020. West Seattle Bridge Cracks. After noticing significant changes in several long-term monitored cracks in the bridge deck, the Seattle Department of Transportation closed the bridge and began repairs. The bridge reopened on September 17, 2022. The closure caused increased congestion and travel times, disrupted freight, reduced property values, and impeded emergency services.⁶³² The Mayor issued a Proclamation of Civil Emergency acknowledging the significant impacts of removing 84,000 daily trips from the West Seattle Bridge on residents, businesses, the Port of Seattle, and the surrounding communities.

September 13, 2020. Pier 58 Collapse. The pier collapsed during an emergency demolition. The pilings supporting Pier 58, part of Waterfront Park, had been deteriorating for years and were being monitored. Following an inspection, the pier was closed to the public and an emergency demolition scheduled. The structure collapsed during the demolition injuring two workers.⁶³³

Prior to 2000

November 7, 1940. Tacoma Narrows Bridge Collapse. This collapse did not happen in Seattle but is noted because of its use in engineering schools as a classic example of design flaws leading to catastrophic failure.⁶³⁴ One of the most famous infrastructure failures in the world occurred when a 42-mph wind caused the bridge to twist until its cables snapped. There were no casualties.

November 11, 1957. Sinkhole. One of Seattle's largest sewer lines collapsed, causing a massive sinkhole under Ravenna Boulevard. The line was built in 1910-11 in unstable ground. The hole was 120 by 200 feet and 145 feet deep. Ten families had to be evacuated. The break caused an 11-day sewer outage in a 13 square mile area affecting 43,000 people. The system took two years to repair and at a cost of \$22 million (in 2024 dollars).⁶³⁵

June 11, 1978. Maritime. The freighter Chavez struck the West Seattle bridge, severely damaging it. The bridge was closed to traffic for six years and led to the construction of the current high-rise bridge.⁶³⁶

February 25, 1987. Husky Stadium Collapse. An addition to the northern deck collapsed during construction. The cause was the premature removal of six temporary wire supports that allowed the structure to sway too much. Workers noticed a support buckling and had time to vacate the site, so there were no casualties.⁶³⁷

November 25, 1990. Old I-90 Bridge Sinking. The old I-90 bridge was under construction and not being used. The old bridge sank following a major storm. The pontoons that support the bridge had been opened to temporarily store water. The openings allowed additional storm water to enter and subsequently caused the bridge to sink. The sinking bridge snapped cables anchoring the new bridge, which was open and in use. The bridge was closed to traffic. Tugboats were used to keep the bridge from floating away while new cables were installed.⁶³⁸

July 19, 1994. Kingdome Ceiling Tiles and Crane Failure. Hours before a baseball game, four large tiles peeled from the ceiling and plunged into the seats. The cause was water damage that caused the tiles to delaminate.⁶³⁹ Had a game been in progress the result should have been tragic. All 40,000 tiles had to be replaced. Two construction workers died during repairs when the basket on top of a crane broke loose and fell 250 feet.

Vulnerability

Seattle is exposed to structural and infrastructure failures because it has the highest concentration of infrastructure in the Pacific Northwest and, as one of the oldest municipalities in Washington, has a large amount of older infrastructure. Aging infrastructure increases the risk of failures, example of which include water main breaks, pipeline ruptures, and bridge collapses. Strong building codes, good design practices, active maintenance, and strong capital improvement programs can all mitigate this vulnerability. The recent adoption of the 2021 International Building Code (for new buildings) and Existing Building Code (for renovations of existing buildings) means Seattle is using the most current standards for its buildings. For structures outside the range of prescriptive building codes, Seattle uses an engineering peer review process to better understand risks and vulnerabilities.

The City of Seattle also owns infrastructure outside Seattle, including dams used for water supply, power generation, and flood control. In these locations, the City of Seattle is responsible for safely operating infrastructure with potential impacts on public safety. These include dams on the Skagit, Pend Orielle, South Fork Tolt, and Cedar rivers. The [National Inventory of Dams](#) maps these dams and others including dams in the City of Seattle. It also includes inundation areas that would be flooded in the case of dam failure. The areas exposed to flooding in a worst case Howard Hanson dam failure are shown in [Figure 61](#).

Incorporating new standards for new infrastructure and rehabilitating existing infrastructures is one major step in the right direction towards reducing risk and vulnerability to the City's older existing infrastructure. Continued funding is another major component in risk and vulnerability reduction. Seattle's Capital Improvement Program is strong but faces some challenges such as volatility in funding sources like the Real Estate Excise Tax (REET) and the need for utility rates to keep pace with infrastructure costs. For example, per capita water consumption has decreased 30% since its peak in 1981 while the served population has grown.⁶⁴⁰ The recently adopted [Shape our Water](#) plan and the [2024 Levy to Move Seattle](#) both address these challenges.

Virtually every part of Seattle is vulnerable to one type of failure or another because of the ubiquity and dependence of every social and economic function on working infrastructure. However, some places are more sensitive than others. These include locations where multiple facilities or pipelines are co-located or areas that lack utility and transportation redundancy. For example, West Seattle residents faced significant delays leaving West Seattle because alternative routes lacked the West Seattle bridge's capacity. [Figure 13](#) and [Figure 14](#) show major transportation and utility infrastructure networks.

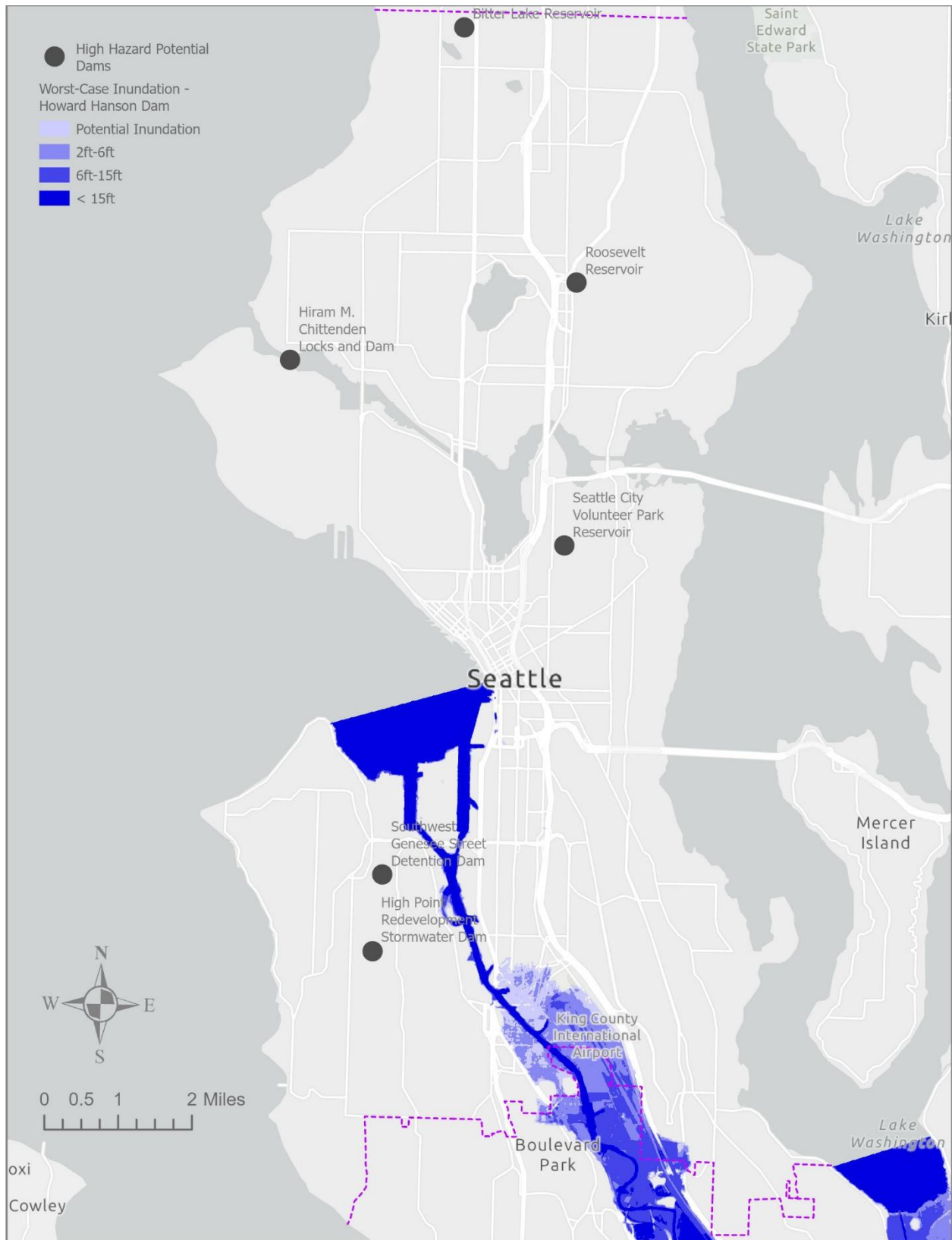
The most vulnerable periods in the life of a structure are during construction, right after it is built, and as it nears or exceeds its expected operational life. Most of Seattle's larger-scale failures occurred during one of these phases. Many times, visible signs that are present before a failure allow people time to escape. Warning signs are the major reason there were no casualties during the collapses of the Tacoma Narrows Bridge, Husky Stadium, and the I-90 floating bridge.

Seattle's growing population increases its vulnerability to infrastructure failure. An expanded built environment and more people offer more opportunities for accidents and puts more people in harm's way, but this vulnerability can be mitigated through analysis, planning, policy, funding, and enforcement. As an example, Seattle Public Utilities identifies and maps large diameter pipes serving critical facilities like hospitals.

Consequences

With a growing population, aging infrastructure, and uncertain federal funding, managing Seattle's infrastructure environment is becoming increasingly complex. Infrastructure and structural failures have caused fatalities, injuries, utility outages, and economic losses in Seattle. Future incidents are likely to

Figure 62. High Hazard Potential Dams in Seattle and Worst-Case Howard Hanson Dam Inundation



WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

cause the same. Consequences are often limited to the failure site, but if failure involves infrastructure serving a broad area the effects can be widespread. The 1957 Ravenna sinkhole left 43,000 Seattleites without sewer service for 11 days and the West Seattle Bridge repairs caused over two years of traffic delays.

If Seattle were to experience a major structural failure, such as a bridge or building collapse, there would probably be fatalities and injuries. The Surfside condo collapse was the deadliest building failure in U.S. history with 98 fatalities. It serves as a realistic upper bound for thinking about potential failures. Bridge collapses have also caused fatalities with the deadliest bridge collapses in the U.S. causing between 3 and 114 fatalities.⁶⁴¹ If a major road, such as I-5 or SR-99, is damaged or disrupted from the incident, there would be prolonged increases in traffic as vehicles would have to take alternate routes until the road was repaired or cleared. The economic cost of the traffic impacts in the Minneapolis I-35 bridge collapse was an estimated \$70 million-dollar reduction in economic output (about 0.01% of the state economic output).⁶⁴² The economic cost of the Baltimore's Key Bridge collapse has not been formally estimated but will be in the billions. Closer to Seattle, the May 23, 2013, collapse of the I-5 Skagit River bridge led to major economic and public consequences until a permanent replacement bridge opened on September 15, 2013.

Utility infrastructure failures can also cause fatalities, especially dam failures, pipeline explosions, and steam explosions. Fatalities can be delayed due to impacts on health from a utility failure. In Flint, Michigan, 12 people died and 90 became ill from legionella bacteria in the municipal water system.⁶⁴³ Additionally, prolonged power outages have led to deaths from carbon monoxide poisoning. There are also cascading impacts. Water leaks can cause landslides if they are able to saturate slopes, and gas pipe ruptures or failures of waste treatment facilities can lead to hazardous materials incidents.

Outlook

The balance between an improved post-pandemic economic environment and improving Washington state infrastructure score from ACSE on one side and increasing extreme weather events, continued local funding challenges, increased construction costs, and the number of incidents since 2000 suggest a moderate increase in the chance of a large-scale structural or infrastructure failure. Moreover, Seattle's increasing population means more people are exposed to infrastructure failures.

The history section shows an increased major incident frequency after 2000 suggesting that large scale failures are becoming more common, but this amounts to an educated guess. Two incidents, the Hanson Dam void and the West Seattle Bridge cracks, were the proactive addressing of problems. Finding problems before they become catastrophic collapses is a good thing. Better safety standards and improved inspections are identifying potential problems earlier. Even with improved local management, the combined effects of increasing extreme weather events, decreased federal support, and age are stresses on Seattle's infrastructure and increase the likelihood of large-scale incidents.

The City of Seattle owns and maintains a large portion of Seattle's infrastructure through its [Capital Improvement Program](#). It outlines priorities and projects. Importantly, it emphasizes that asset vulnerability reduction is a priority in replacing and upgrading infrastructure. It also specifies funding challenges including declines in some revenue streams and increasing construction costs. Departments indicate they can meet critical needs, but their ability to do so is threatened by funding challenges.⁶⁴⁴ A recent example is the collapse of Pier 58 and the removal of Pier 63. Pier 58 was closed to the public in 2020 following years of deterioration and collapsed while undergoing an emergency removal.⁶⁴⁵ Pier 63 was managed by Seattle Parks and Recreation. The pier's pilings were determined to be unsafe and posed a catastrophic failure risk. The Real Estate Excise Tax, which would have funded its replacement, declined during the post-pandemic economic environment, making replacement challenging.⁶⁴⁶

Overall, the City of Seattle faces a challenge balancing the need to replace aging infrastructure vulnerable to seismic and extreme weather events against increasing construction costs and declines in revenue. In September 2024, the Seattle City Council approved [power](#) and [water](#) rate increases through 2030 to cover increased costs.

Other local governments and private sector infrastructure owners face many of the same challenges, especially the need to adapt aging infrastructure to climate change and recently discovered seismic vulnerabilities after a period of high inflation and increasing interest rates increased construction costs. Puget Sound Energy has increased rates for gas customers as gas energy use has decreased while costs have increased.⁶⁴⁷ Recently Seattle's construction costs have risen faster than the national average.⁶⁴⁸ The costs of addressing these gaps will be substantial and will likely run into the billions.

Strong building codes and their enforcement are essential for maintaining a resilient building stock. Seattle has recently updated its building code to the 2021 International Building Code. Developments in building code standards make newly constructed infrastructure more resilient to hazards and ensure older buildings undergoing substantial alterations are brought up to code.

The most vulnerable buildings in Seattle are older unreinforced masonry buildings constructed of brick or concrete blocks without rebar. They are highly vulnerable to seismic shaking. The City of Seattle is in the process of adopting codes for voluntary retrofits of these buildings and is moving towards a mandatory retrofit requirement.⁶⁴⁹

The 1950s and 60s saw many of the nation's large infrastructure projects, including many of our national interstate highways.⁶⁵⁰ Experts believe that many of these systems are now reaching the end of their lifespan and require upgrades. The good news is investments are being made. The 2021 Infrastructure Investment and Jobs Act invests \$1.2 trillion in infrastructure. This investment may be part of the reason the American Society of Civil Engineers upgraded its assessment of the state of American infrastructure to its highest level in twenty years.⁶⁵¹ It is still not known how much of this investment will reach Seattle, especially with recent cuts in federal funding.

Climate change will stress infrastructure over the long term. More infrastructure will be exposed to increases in temperatures and intensified extreme weather events and at the same time demand for their services will increase. Even if the stresses do not cause catastrophic failures like the Surfside collapse, they will reduce the structure lifespan if action is not taken. Increasing temperatures, humidity, and precipitation can degrade building infrastructure materials at a faster rate.⁶⁵² For example, a study on pavement found increases in cracking and rutting after 20 years across all U.S. climate zones.⁶⁵³

Conclusions

The built environment, encompassing buildings and the infrastructure that comprises the utility and transportation systems, make life in dense urban areas possible. When these systems fail, they endanger lives, destroy property, degrade the environment, slow the economy, and decrease quality of life. Many of the hazards covered in this analysis, like earthquakes, cause structural and infrastructure failure. They are discussed in the appropriate chapters. This chapter covers instances where the failure itself is the primary hazard.

Seattle infrastructure has become increasingly complex with increasing maintenance costs. Since the 1990's, Seattle has grown rapidly, putting additional strain on its infrastructure. Systems built in the early to mid-20th century met the demands of their time but may be challenged to meet today's demands. Utility owners have implemented plans to upgrade systems, but costs are high, and budgets limited. Examples include drainage systems that were not built to handle increasingly intense precipitation and the increasing weight and volume of traffic on the West Seattle Bridge that may have contributed to the cracks that caused its closure.⁶⁵⁴

Large-scale infrastructure projects to repair or replace old infrastructure often span multiple years from planning to completion. This is due to range of factors, such as need for detailed planning, design, permitting, securing funding, procuring contracts, and construction itself. Regulatory changes or supply chain disruptions can extend the timelines further. These projects require long-term commitment and patience, sometimes spanning decades.

The consequences of structural and infrastructure failures vary greatly. Building, bridge, and dam failures have the potential to endanger many lives. Bridge failures can have a long and lasting effect on local economies and quality of life. Wastewater failures can degrade water quality. These effects can last from months to years while infrastructure is repaired.

The outlook for structural and infrastructure failures is mixed. It is impossible to predict catastrophic failures, but underlying causes are possible to identify. Seattle faces challenges in maintaining structures and infrastructure built in the early to mid-20th century. Climate change and seismic hazards often exceed what these systems were designed for. Funding challenges like volatility in funding sources, decreased federal support, and the need for rate increases make system upgrades more difficult. On the positive side, inspection programs have caught problems like cracking in the West Seattle Bridge before they endangered the public. The public has supported increased funding for infrastructure and infrastructure owners have invested in plans to prioritize future capital improvements.

13. POWER OUTAGES

On August 14, 2003, a large part of the upper Midwest, East Coast, and Ontario, Canada went dark. The power outage affected 50 million people. Some parts of the United States waited four days for the power to be restored. Estimated losses ranged from \$4 billion to \$10 billion. The outage highlighted widespread infrastructure problems in the power grid, and the complexity and consequences of widespread power outages.⁶⁵⁵

Power is an essential component of modern society and is immediately noticeable when absent. The 2003 outage caused other areas of the country to look at their own networks to analyze the chances of a similar incident and its potential effects on their own networks.

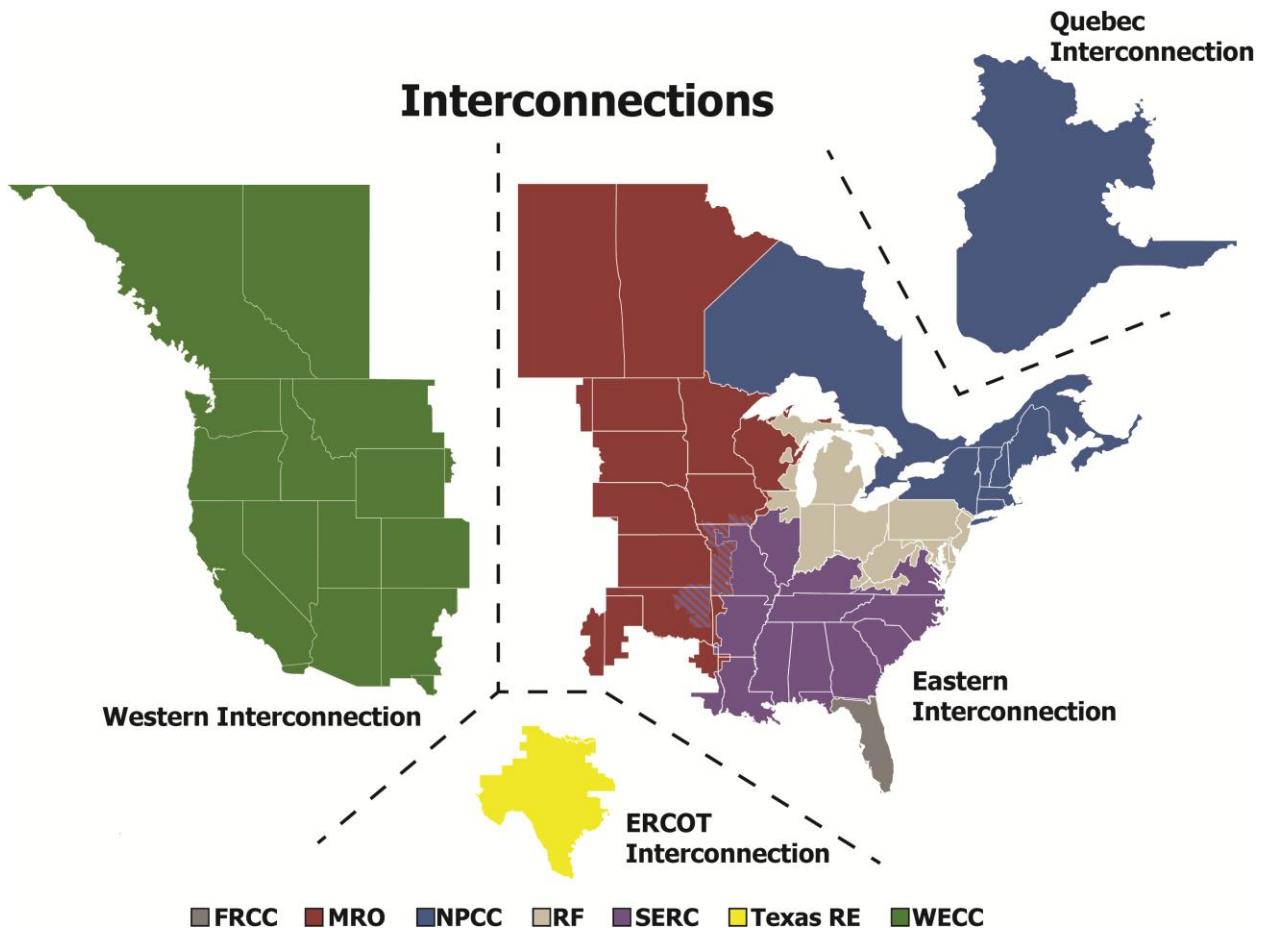
A power outage can affect an isolated area or be widespread. A total loss of power would be considered a “blackout.” A “brownout” occurs when the voltage level is below the normal minimum level specified for the system. A brownout may be done intentionally to prevent a full power outage. “Load shedding” or “rolling blackout” is a common term for a controlled way of rotating available generation capacity between various districts or customers, avoiding total, widespread blackouts.

The City of Seattle owns its own generating capacity, transmission lines, and distribution system. It is operated by the city’s public power utility, Seattle City Light (SCL), and is connected to the Bonneville Power Administration (BPA) network, which is part of the Western Interconnection, an electricity network made up of 11 western states, two Canadian provinces and northern Baja California, and Mexico (see [Figure 63](#)). The Western Interconnection has more Balancing Authorities (organizations that make sure that the supply and demand flows of electricity are balanced) than any other U.S. network but is served by only one Reliability Coordinator (an organization that provides situational awareness and real-time monitoring for the grid).⁶⁵⁶

Key Points

- ❖ *Lead Agency – Seattle City Light*
- ❖ *Seattle’s power infrastructure is linked to the Western Interconnection, a network of public and private power generators and distributors that serve over 80 million people in the Western U.S., from Mexico to Canada.*
- ❖ *Almost 90% of Seattle’s power comes from hydroelectric power; 40% of the power Seattle consumes is purchased.*
- ❖ *About half of Seattle City Light’s unplanned power outages are caused by falling trees or branches.*
- ❖ *Seattle could face power outages due to electrical vault fires, windstorms, or an issue in the regional grid. Seattle can isolate itself from the grid but cannot supply enough electricity for the city on its own.*
- ❖ *The largest impacts of an extended power outage would be economic because most businesses in the affected area would likely shut down.*
- ❖ *Seattle’s power depends on the health of generating facilities that lay far outside the municipal boundaries, on snow and rain that are the “fuel” for hydroelectric power and finally on the health of the transmission and distribution lines that move the power.*
- ❖ *Expected climate and hydrologic changes will likely alter the annual patterns of hydroelectric supply, lowering supply during the summer and increasing supply during the winter.*
- ❖ *Increased demand from electric vehicles, population growth, and building electrification will require SCL to increase their supply in the years to come.*

Figure 63. United States Electrical Interconnections



Source: Interconnections. North America Electric Reliability Corporation. Retrieved August 23, 2018, from <https://www.nerc.com/AboutNERC/keyplayers/PublishingImages/Interconnections%2024JUL18.jpg>

The high voltage transmission system is near capacity in many parts of the West, including the Pacific Northwest. A seasonal power exchange in this system takes advantage of the seasonal diversity between the Northwest's winter peaking and the Southwest's summer peaking loads. Utilities can transfer their firm's power from north to south during the Southwest's summer load season and from south to north during the Northwest's winter load season, allowing both regions to maintain less generating capacity than would otherwise be necessary. SCL's existing portfolio includes a seasonal exchange with utilities in Northern California.

SCL serves nearly 500,000 customers, reaching approximately 961,000 people in its service area, and is the ninth largest public electric utility in the country in terms of customers served. SCL owns seven dams, mostly on the Skagit and Pend Oreille Rivers. Almost 90% of Seattle's power comes from hydroelectric power, both from its own dams and those of the BPA.⁶⁵⁷ The remaining 10% comes from a variety of sources such as nuclear, wind, and coal. SCL owns no coal or nuclear generation, but a portion of the power SCL purchases from BPA is generated by these sources. SCL purchases about 40% of the power that Seattle consumes.⁶⁵⁸ Seattle's power depends on the health of generating facilities that lay far outside the municipal boundaries, on snow and rain levels that are needed for hydroelectric power generation, and finally on the health of the transmission and distribution lines that move the power. Seattle has powerlines underground in Downtown and other dense areas of the city. More information on Seattle's power supply can be found in the [Community Profile](#) section.

History

All power systems experience unplanned outages. Most are small, resolved within a few hours and do no lasting damage. Larger outages occasionally occur. These outages are usually secondary events caused by other hazards, e.g., winter storms or freezing rain. Some larger outages, such as the 2003 outage, demonstrated that power outages can be a primary incident. Two local examples are two fires in underground vaults serving the downtown areas that caused lengthy outages. This section lists major outages in Seattle and several regional events that did not directly affect Seattle but highlight issues with the Western power grid.

1958. Seattle. Wind related outages. Loss of power in many areas of the city, especially in West Seattle and Magnolia.

1962. Seattle. Columbus Day Storm. Biggest storm to hit the Pacific Northwest. It affected utilities throughout the region.

1988. Downtown Seattle Vault fire. Six electrical cables were damaged resulting in a four-day loss of power to a 50-block area downtown. The area included the Westin Hotel and the Pike Place Market. The cause was a contractor driving a steel piling through a buried cable. Businesses that lost power sued the City and the contractor. Newspaper reports that the City paid more than \$1.5 million to settle claims.

1993. Downtown Seattle Vault fire on October 5th. 1,800 customers in about 270 buildings were out of power for up to three days in a 37-block area. Eight large generators were brought in to help the population. Fire destroyed huge underground cables that had to be replaced.

1996. Western Interconnection. Two major outages struck the Western power grid in 1996. On July 2, a localized outage caused by a tree in Idaho led to a cascading regional outage that resulted in 10% of the consumers in the western U.S. losing their power for at least a few minutes. The next month, on August 10, more than 7 million people across the West lost power. Areas were affected intermittently for up to several hours. While the outages weren't long, they highlighted the fragility of the network.

1997. Western Interconnection. Two separate disturbances in the Western grid that interconnects with Seattle City Light's system. Both outages had minor customer impact but could have been worse.

2000 – 2001. California. Rolling blackouts plagued much of California. The Northwest was involved as a power supplier. This event placed strain on transmission lines in the Northwest and caused two major outages during peak demand periods. The energy crisis cost California \$40 billion in added energy costs, and customers saw their energy bills double or triple during that time.⁶⁵⁹

2006. Seattle. Hanukkah Eve Windstorm. Seattle City Light suffered its most extensive outages in the utility's history as a result of a severe regional windstorm. More than 49% of customers lost power. Some customers were without power for more than a week. Neighboring utilities also suffered major damage.

July 2009. Western Washington. While Seattle avoided power outages during record heat, Tacoma and Monroe did not. Typically, summer is a low demand time for Pacific Northwest power but the increasing number of HVAC systems in the area can lead to high energy demands. This event demonstrated that Seattle is also vulnerable to demand spikes during the summer.

August 2015. North Cascades. Goodell Creek Fire. Lightning in the North Cascades National Park started a wildland fire that forced Seattle City Light to shut off transmission lines from its Skagit hydroelectric project.⁶⁶⁰ The loss of transmission capacity cost the utility an estimated \$100,000 per day. While the threatened dams and powerhouses typically produced 20% of Seattle City Light power, no outages occurred from the fire.

November 2021. Skagit Flood. An atmospheric river brought heavy rainfall and winds to Western Washington, causing extensive flooding and landslides that prompted a full closure I-5. More than

158,000 customers were without power during the height of the storm, including 7,300 SCL customers.⁶⁶¹

August 2023. Sourdough Fire. A large wildfire in the North Cascades threatened the SCL-owned and operated Diablo, Ross, and Gorge dams on the Skagit River. The three dams provide roughly a third of Seattle’s electricity. Out of caution, SCL took the Diablo and Ross dams offline to provide safe access to firefighting crews and protect infrastructure. SCL officials boosted hydropower production at Boundary Dam in Washington’s northeast corner and purchased more wind, solar, and hydropower to fill the gap left by the dam closures.⁶⁶²

November 2024. Western Washington. A bomb cyclone intensified rapidly in the Pacific, with gale warnings issued throughout Washington, Oregon, and California. Nearly half a million people in Western Washington lost power, as much of the state was pelted with wind, mountain snow, and heavy rain. The east side of the cascade crest was hit particularly hard, with power restoration taking several days. According to Puget Sound Energy, the storm caused the region’s largest power outage since 2006.⁶⁶³

Vulnerability

Power lines are underground in the downtown core and other dense areas. They are vulnerable to vault fires but extremely resistant to wind damage. Locally, more power has been going underground. The underground system is less likely to fail but can be more time-consuming and expensive to repair when it does fail. In the rest of the city, wind damage is linked to the number of trees close to power lines. In 2015, SCL began piloting “self-healing” power lines.⁶⁶⁴ The technology can detect an outage and isolate the section of the circuit being affected. Power is then restored to areas that are not directly affected by the isolated section. Self-healing lines reduce the number of customers without power as well as pinpoint the outage location more precisely, so workers can respond faster.

SCL relies on BPA mainly for its transmission lines, which are on steel towers that are very resistant to storms. However, an earthquake or wildland fire has the potential to disrupt these lines. Not only can a transmission tower be damaged due to fire, but soot from fires can build up on line insulators and cause electric arcing. Several dams that generate power for Seattle are located many miles outside the city and are vulnerable to wildland fire. Even before the Goodell Creek Fire in 2015, SCL had made fire protection upgrades at its vulnerable dams.⁶⁶⁵

Earthquake vulnerability is not evenly distributed throughout the power system. Historically, transmission towers and lines have fared better in earthquakes than operation centers and substations.⁶⁶⁶ SCL has attempted to mitigate this vulnerability by building seismic isolation technology into high voltage transformers.

Communities with older high-rise and commercial buildings are generally more vulnerable to an outage because they often lack backup generators. During the 2006 storms and power outages, it was discovered that many nursing homes lacked back-up power. With many residents dependent on electrical equipment, these facilities are highly vulnerable to outages.

Hospitals are even more sensitive than nursing homes. However, hospitals have emergency power generators that are typically powered by diesel fuel and configured to start automatically as soon as a power failure occurs. During Hurricane Katrina, hospital patients began experiencing life-threatening conditions within hours of power loss. Seattle is the major concentration of hospitals in the region. Other life-critical systems such as telecommunications are also required to have emergency power. All Seattle fire stations have emergency generators.

General economic health and social climate have a significant effect on what happens during a blackout. The 1978 New York blackout occurred during a time of political instability and discontent. As a result,

there was widespread looting. In the 2003 Northeast Blackout, there was none. The social climate is an important external variable in a widespread outage.

Almost all businesses depend on reliable power. Businesses with perishable inventory, like grocery stores and restaurants, stand to take permanent losses during extended outages. When the power is out only in one community, the retail stores in that community lose customers to neighboring communities. If the outage is short but widespread, then retail stores do not suffer because post-incident sales trend to accelerate and make up for the downtime.

Washington's market for electric vehicles is expanding rapidly, providing another significant vulnerability in the face of a severe power outage. Washington state saw a record year for the sale of electric and plug-in hybrid vehicles in 2023, which accounted for roughly 20% of all vehicle sales in the state.⁶⁶⁷ This was double the national average of 9.5%. Washington has audacious zero-emissions goals; by 2035, 100% of all new passenger vehicles and light-duty trucks sold in Washington must meet zero-emission requirements. In addition, the city has seen a large population growth and a faster than expected electrification of building heating and cooling mechanisms, all increasing power demand.

With this substantial increase in demand, SCL is looking to increase power supply. Whereas the 2022 load projections estimated a supply increase of 400 megawatts by 2033, SCL's 2024 updates identified a need for an additional 1,825 megawatts in this same timeframe.⁶⁶⁸ With droughts expected to increase in Washington due to climate change, the city's power producing dams may be underproducing its normal supply at certain times of the year. City Light projections will require additional resources to meet the increased demand, such as solar, geothermal, and wind.⁶⁶⁹

Consequences

The December 2006 windstorm demonstrated the importance of power. Some parts of the city were without power for nearly a week during very cold weather. The outages led to several fatalities outside the City of Seattle. The response was the second costliest in the City's history after the Nisqually Earthquake.

The largest impacts of an extended power outage would be to the economy as most businesses are likely to shut down in an extended outage. During the 2006 power outages, City financial records indicate that more than \$6.9 million was spent repairing and replacing wires, transformers, and poles. Local transportation networks collapse when traffic signals are out. In 2006, 150 traffic signals went dark.

The transition to electric vehicles and building electrification will exacerbate the impacts of any significant power outages in the city, leaving some unable to use their vehicles or heat and cool their homes during an outage. EVs and plug-in hybrids still only make up roughly 3% of cars on the road as of 2024, but this figure is expected to continue to increase as zero-emission requirements come into effect.

The maximum credible scenario would probably be some sort of "perfect storm" of disparate elements coming together to create a huge problem. This would likely include a regional outage involving the Western Interconnection during a period of peak power demand in Seattle. Even if Seattle could successfully island its infrastructure, it might not be able to meet all the demand. Since extreme demand tends to be driven by extreme weather, it is likely that Seattle would be facing either very hot or very cold temperatures at the same time. Currently, Seattle's social climate seems stable, but if it is not, that could be one more potential element in the mix.

Climate Change

Climate change presents future challenges for the power system. While warming temperatures may increase power demand for cooling purposes, overall energy efficiency is expected to offset this increase in demand. Projected changes in snowpack and streamflow will likely have the biggest impacts on the

power system. Hydropower generation in the Columba River Basin is projected to increase 5% in winter and decrease 12 to 15% in summer by the 2040s (relative to 1970-1999).⁶⁷⁰ The same seasonal pattern of change is expected to occur in the Skagit watershed, though the exact amount of change is not well known. If SCL cannot meet demand in the summer due to the decrease in power generation, they may have to purchase additional power. More impacts are discussed in the climate change chapter.

Outlook

Seattle has never suffered a catastrophic blackout like the Northeast, nor has it had rolling blackouts like California experienced during 2000 and 2001, however several events on the Western grid have come close to affecting the city. Seattle has experienced three large unplanned and multi-day outages in the past 30 years. The most likely sources are underground vault fires, regional windstorms, or an issue in the regional power grid.

A regional cascading blackout is a possibility in this region. A problem could originate outside the SCL system because of its interconnectedness with the BPA system. Seattle has the ability to isolate itself but, because the city can only generate a portion of its power, “islanding” could cause short-term, supply-related rolling blackouts.

Wind will continue to be a hazard to power distribution. Although it has fewer trees than the rest of King County, Seattle has successfully been re-growing its tree canopy. About half of SCL’s unplanned power outages are caused by trees or branches falling. SCL has implemented a vegetation management program to trim trees that may grow into or fall on power lines.⁶⁷¹ Vegetation management specialists work with arborists year-round to trim back trees from lines. The whole system is trimmed every four years.

Improvements have been made to underground electrical vaults, including automatic fire suppression and remote vault monitoring capabilities.⁶⁷² These improvements have reduced the likelihood and duration of outages. Nevertheless, there have been 20 electrical vault fires in Seattle since 2016. A recent vault fire in the Green Lake neighborhood caused outages for about 5,000 customers, but only for a few hours.⁶⁷³

Improvements have also been made to Magnolia’s West Point Treatment Plant, which processes roughly 90 million gallons of wastewater daily. In September 2024, King County completed construction of a \$165 million high-voltage battery system that can provide emergency power to the plant in case of a power outage.⁶⁷⁴ An outage in 2017 caused a release of 235 million gallons of stormwater and raw sewage into Puget Sound, underscoring the impacts of power loss for critical wastewater processing facilities. The battery system upgrade is expected to increase the plant’s resilience to future storms.

In recent years, power utilities across the country have seen increased occurrences of attacks on infrastructure by foreign adversaries and domestic extremist groups. In 2023, two men, one from Ohio and another from Texas, were sentenced to federal prison for “[plotting] to attack the country’s energy infrastructure, damage the economy, and stoke division in American society in the name of white supremacy”.⁶⁷⁵ The plot included damaging infrastructure in several regions throughout the US.

Domestic terrorism occurrences impacting power infrastructure are expected to increase in frequency as the US energy sector undergoes significant transformation and expands electrification efforts. Seattle is included in this effort; demand for electricity in the region is growing faster than previously expected. The demand is coming from the adoption of electric vehicles, population growth, and the shift towards electrifying buildings for heating and cooling.⁶⁷⁶ As the City moves towards increased electrification, risk for power outages—and the impact they will have—will inherently grow.

Conclusions

Seattle's energy landscape is changing quickly and demand for power is increasing. To plan for the acquisition of new resources, which can take many years, SCL forecasts future power consumption or load in its service area 20 years into the future. Load is only expected to grow due to economic and population growth alongside transportation and building electrification. Additionally, some of the power purchase contracts will expire. This growth will require adding wind, solar, geothermal, and battery storage.

14. EXTREME HEAT

On June 28, 2021, the temperature reached 108° at SeaTac airport, setting an all-time record. This heat event, known as the “2021 Heat Dome”, occurred between June 26 and July 2, 2021. Seattle had daily highs over 100° for three days. This event resulted in over 400 excess deaths in Washington State, with over 150 of those coming as a direct result of the heat.⁶⁷⁷ This heat event was considered very rare, estimated to occur roughly every 1 in 1000 years. However, climate scientists predict such an event could occur every 5-10 years with 3.6 degrees of global warming.⁶⁷⁸ Heat events like this are particularly dangerous hazard for Seattle, where the famously mild climate makes it difficult for the community to acclimate to extreme heat when it occurs, and buildings have historically not been constructed to insulate from high outdoor temperatures.

An extreme heat event (EHE), or heat wave, is a weather pattern that is substantially hotter and/or more humid than average for a location at that time of year. EHE’s can cause dehydration, heat cramps, heat exhaustion, heat stroke, and even death. Seattle’s proximity to the Pacific Ocean generally results in mild summers with low humidity. Onshore air flows off the cool Pacific Ocean act as a natural air conditioner for the region. However, when high pressure persists over the Pacific Northwest during the summer, drier conditions develop. In addition, air sinks along the western slopes of the Cascade Mountains, and further escalates warming, this is known as downslope flow. In the summer, when the sun is the strongest, Seattle experiences EHEs when onshore flows off of the Pacific decrease and there is an occurrence of downslope flow on the western slopes of the Cascade mountains. The duration of an EHE is dependent on when onshore flow resumes allowing for increasing cooler air off the Pacific.

Onshore flow initially brings cooler air from the Pacific along the coast before reaching Puget Sound.⁶⁷⁹

Meteorologists can accurately forecast EHE development and the severity of the associated conditions with several days of lead time. Meteorologists are also able to identify a larger scale weather pattern, which may lead to EHE, as early as 10 days before the EHE begins. The National Weather Service (NWS)

Key Points

- ❖ *Lead Agency- Seattle OEM*
- ❖ *A heat disaster doesn’t often result in physical damage, and deaths from heat tend to occur in private dwellings, making heat a “quiet killer”.*
- ❖ *The season, humidity, duration and availability of cooling systems all strongly influence the impact of extreme heat events.*
- ❖ *Seattle’s typically mild summers result in a population that is less acclimatized to extreme heat compared with that of many other cities in the United States. Seattle is among the cities with the highest heat sensitivity in the country.*
- ❖ *Many Seattle homes and businesses lack cooling systems, increasing our vulnerability.*
- ❖ *The most vulnerable people in heat events are the elderly, infants, the homeless, the poor, and people who are socially isolated.*
- ❖ *Heat cramps, heat exhaustion, and heat stroke are examples of negative health effects associated with both average warmer summer temperatures and temperature extremes.*
- ❖ *In Seattle, most fatalities are indirectly caused by heat, e.g., heart attacks, strokes, and respiratory illness.*
- ❖ *Climate research shows that extreme heat events have become more severe in the Pacific Northwest in recent decades. Experts project that temperatures on the hottest days in the Puget Sound area will increase by 6.5°F on average by 2050. Nighttime low temperatures are also increasing, limiting nighttime heat relief.*

developed the [HeatRisk](#) service to put extreme heat into an actionable, impacts-based context to support decision making at a local level. HeatRisk considers a number of critical factors including the local climatology, time of year, forecast maximum and minimum temperatures, and event duration. It then uses CDC heat health thresholds to create a tiered risk index that identifies at-risk populations and actions for each level of heat. The NWS uses this system as a basis for Extreme Heat Watches, Extreme Heat Warnings, and Heat Advisories. Furthermore, the NWS partnered with Public Health Seattle-King County after the 2021 Heat Dome event to align public health recommendations for heat with the NWS HeatRisk service.

Extreme heat is the deadliest weather event in the United States. In 2023, the 30-year average for annual heat deaths was 183. This is up from the previous 30-year average of 134 annual heat deaths captured in 2018.⁶⁸⁰ Between June 26-August 20, 2021 alone there were 157 people in Washington State died as a direct result of heat.⁶⁸¹ Heat-related deaths in America's hottest city, Phoenix, Arizona, have increased 1000% in the past decade.⁶⁸² The past decade (2014-2023) has seen the ten warmest years in historical record.⁶⁸³

The human body cools down primarily through sweating, where water evaporates from the skin. During extreme heat, or when the body cannot compensate for fluids and salt lost through perspiration, the temperature of the body's inner core begins to rise and damage to the brain and other vital organs can occur. Heat-related illnesses, such as heat exhaustion and heat stroke, can occur when the body is not able to properly cool itself.

Once the air temperature exceeds skin temperature, convective cooling from the skin is no longer possible. The effects of ventilation or wind reverse, adding heat to the body. This is a dangerous scenario that causes individuals in hot rooms with fans on to accelerate deterioration under hot conditions. Some decedents in a severe Chicago heat wave were found in indoor spaces with the fan on and are believed to have died as a result of this mechanism.

Statistical analysis of King County mortality data by David Hondula found that adverse health effects for heat begin to rise at 25.9°C (78.6°F). This is several degrees lower than other cities in the United States. The research studied day-to-day baseline conditions and non-extreme events.⁶⁸⁴ Understanding our increased vulnerability to high temperatures, researchers have recently examined whether extreme heat days increase the risk of Emergency Medical Service (EMS) demand, hospitalizations, and mortality in King County. Calkins and colleagues found that on extreme heat days, there was an 8% increase in Basic Life Support (BLS) calls and a 14% increase in Advanced life Support (ALS) calls (over a 6-year study period). The risk of these EMS calls increases with each unit increase of the humidity index.⁶⁸⁵

Isaksen and colleagues analyzed hospital admissions and mortality associated with EHE in King County over a 30-year period. They report a 2% increase in hospitalizations and a 10% increase in risk of death on EHE days, with risk increasing as heat increases.⁶⁸⁶ Both researchers identified the elderly as an especially vulnerable population. More surprisingly, however, their studies revealed an increased risk on EHE days for EMS calls, diabetes-related mortality, kidney disorders, acute renal failure, natural heat exposure, and asthma hospitalizations for young and middle-aged adults, a population generally thought to be more resilient to heat.⁶⁸⁷ This may be attributed at least partially to Seattle's built environment. Air conditioning is the primary intervention for reducing heat-related mortality, and Seattle lacks the widespread air conditioning and cooled spaces many other cities have. Additionally, historical regional architecture trends prioritized heat retention over passive cooling, making spaces difficult to cool down passively.

The Washington Climate Impacts Group (CIG) projects that EHEs in the northwest will become more severe in the future. They project that the hottest days in the Puget Sound area will increase by 6.5°F, on average, by the 2050s.⁶⁸⁸ Models predict between 17 and 27 extreme heat days on average for western

Washington by 2050, with that nearly doubling to 20 to 48 extreme heat days by the 2080s. Based on current models, EHEs are expected to increase in frequency due to climate change.

History

While good meteorological records exist for Seattle, heat waves are more complex than just high temperatures. Other factors like time of year, humidity, duration, extent of nighttime cooling, and the availability of cooling systems all strongly influence the effect. Because of these factors and the recognition of EHEs as a type of disaster only recently, records are marginal.

1981. A heat wave lasted several days in the upper 90s.

1992. A record 15 heat warnings were issued by the National Weather Service for the Seattle area. An estimated 50 – 60 people died because of the heat⁶⁸⁹.

1994. A citywide heat extreme is set, recorded at 100 degrees.

2009. A new all-time record set when the maximum temperature reached 103 degrees. Humidity was unusually high.⁶⁹⁰ Two deaths in Western Washington are directly attributable to the heat.

2015. Seattle's hottest summer on record. The average high temperature was 80.2 degrees Fahrenheit. July had 10 days with high temperatures in the 90s.⁶⁹¹

2021. Record shattering heat wave across the Pacific Northwest June 26 to 28. Highs reached 108 degrees. Over 34 people died in King County making this our most deadly climate-related event in history.⁶⁹² Over 150 people died directly as a result of heat state-wide. A study of the event by climate scientists concluded that this was a rare event, but it was made possible by climate change and that similar events are much more likely if climate change cannot be slowed.

2022. Seattle sees 6 consecutive days of 90 degrees or above, setting an all-time record going back 77 years.⁶⁹³ The heat wave saw three days of 95 degrees for the fifth time, tying the record.

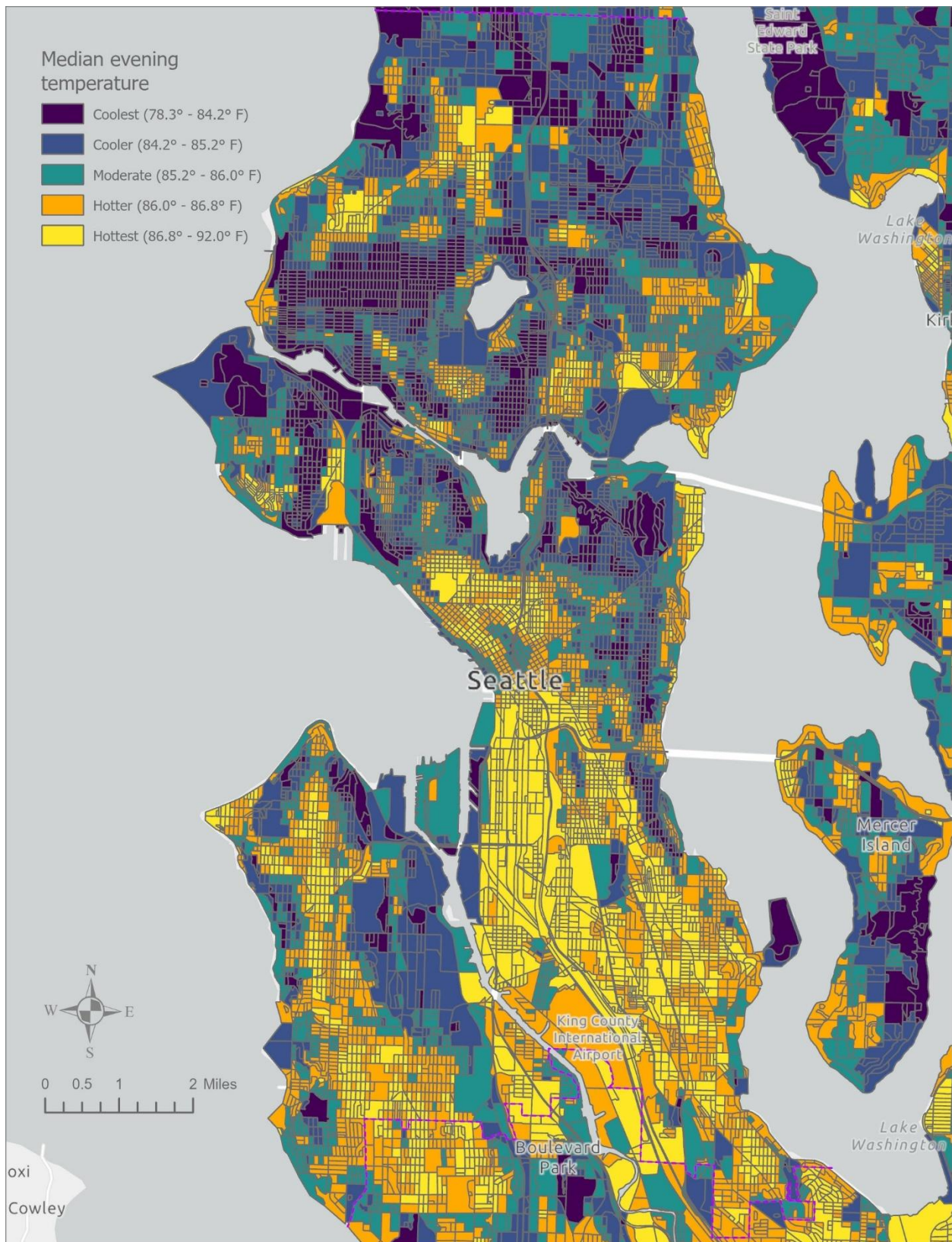
Vulnerability

Underlying health conditions, certain medications and drug use, and individual factors and determinants such as age, employment, housing status, and outdoor activity levels may increase an individual's vulnerability to heat-related illness. Those more sensitive to heat include children and older adults; outdoor workers; individuals experiencing homelessness or living unsheltered; households without access to cooling resources; athletes and people who exercise outdoors; and people with chronic health conditions, including mental health conditions.⁶⁹⁴

Environmental factors can also increase health risks from extreme heat. Many residents lack efficient cooling systems in their homes or businesses and remain unaware how to protect themselves. Based on American Housing Survey data, 53.4% of homes in 2021 have AC, making Seattle the second least air-conditioned city of the top 15 biggest metropolitan areas.⁶⁹⁵ Central air conditioning is becoming more commonplace in single family homes, and the city has seen a large increase in apartment buildings offering air conditioning.⁶⁹⁶ Despite this, lower income households in Seattle, along with older residents, are less likely to have access to AC, making AC access an important equity issue.

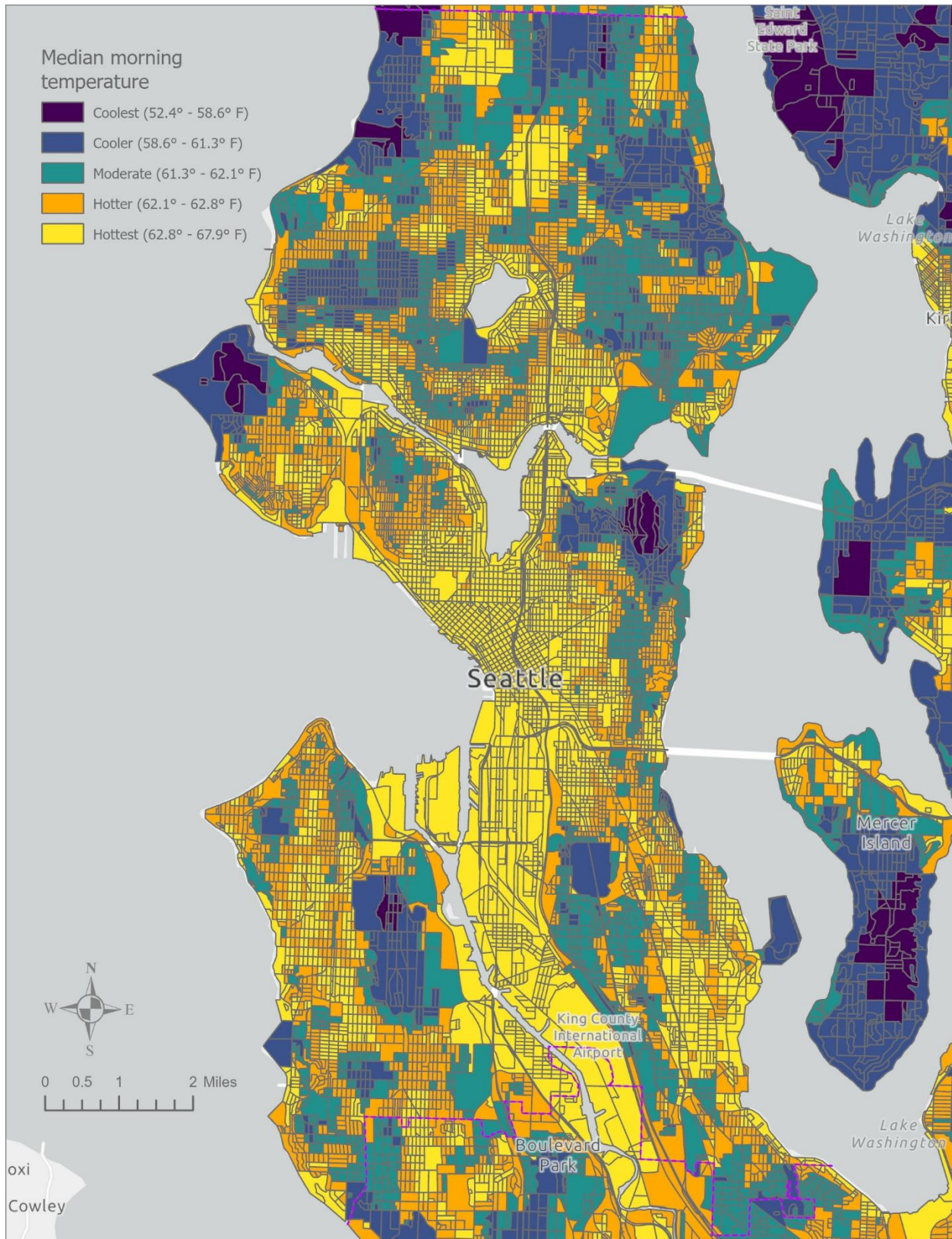
Seattle's population is accustomed to mild summer temperatures and is thus not physically acclimated to extreme heat. Drastic changes in temperature can have large impacts on any population, but what is considered "drastic" is relative to a geographic area and its temperature trends. For Seattle, certain temperatures can be categorized as extreme heat at much lower thresholds than other areas that experience high temperatures or large temperature fluctuations. This makes Seattle's population more vulnerable to heat events.

Figure 64. Heat Island Evening⁶⁹⁷



WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Figure 65. Heat Island Morning⁶⁹⁸



WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

Land use plays a large role in overall vulnerability to heat. Urban areas can also have reduced air flow because of tall buildings, as well as increased amounts of heat generated from vehicles, factories, and air conditioners. When vegetation in urban areas is replaced with buildings, especially those with dark roofs, and dark paving materials, the heat absorbed during the day increases and cooling from shade and evaporation of water from soil and leaves is lost. These factors can contribute to the development of an urban heat island with higher daytime maximum temperatures and less nighttime cooling than surrounding rural areas. In Seattle, many neighborhoods with the highest equity priority have low tree canopy cover and high percentages of impervious surfaces. These built environment characteristics translate to increased vulnerability to heat events for folks already made vulnerable due to other social and economic factors such as systemic racism.

These effects have been observed in real time. In July of 2020, the Corrective and Preventive Actions (CAPA) Heat Watch program, NOAA, and a handful of other partners and volunteers conducted a heat island study across Seattle, tracking temperature and humidity at various locations throughout the day. The results give clear visualization of the temperature differences between urban heat islands and areas with more vegetation. Study results can be observed in [Figure 64](#) and [Figure 65](#).

Social and economic factors play a role in the community's heat risk. Social isolation is a particularly dangerous factor in Seattle, where solo dwellers make up almost 43% of households according to 2023 census data, up from 38% in 2019.⁶⁹⁹ Data from Chicago's 1995 heatwave, the Pacific Northwest's heat dome in 2021, and Europe's summer 2022 record heat all point to living alone as a critical factor for heat-related illness and death, especially those who are older and those without a strong social network to check on their wellbeing.⁷⁰⁰ This may be due to the fact that recognizing the symptoms of heat-related illness can be difficult to self-assess, and those living alone may not know when to call for help.

A 2009 study found that Seattle is on par with Chicago for heat vulnerability, which was the site of a 1995 EHE that killed over 700 people. The study uses a Heat Vulnerability Index, driven by four factors: social isolation, lack of air conditioning, the proportion of the population with chronic medical conditions, and social vulnerability (race, poverty, age, and housing conditions).⁷⁰¹ Results can be seen in [Figure 66](#). A study in 2015 showed that the risk of mortality from EHEs is not equitably distributed across cities. For Seattle, postal code areas that have higher percentages of elderly (65+) residents and Pacific Islander residents are associated with a higher risk of heat-related death during EHEs.⁷⁰²

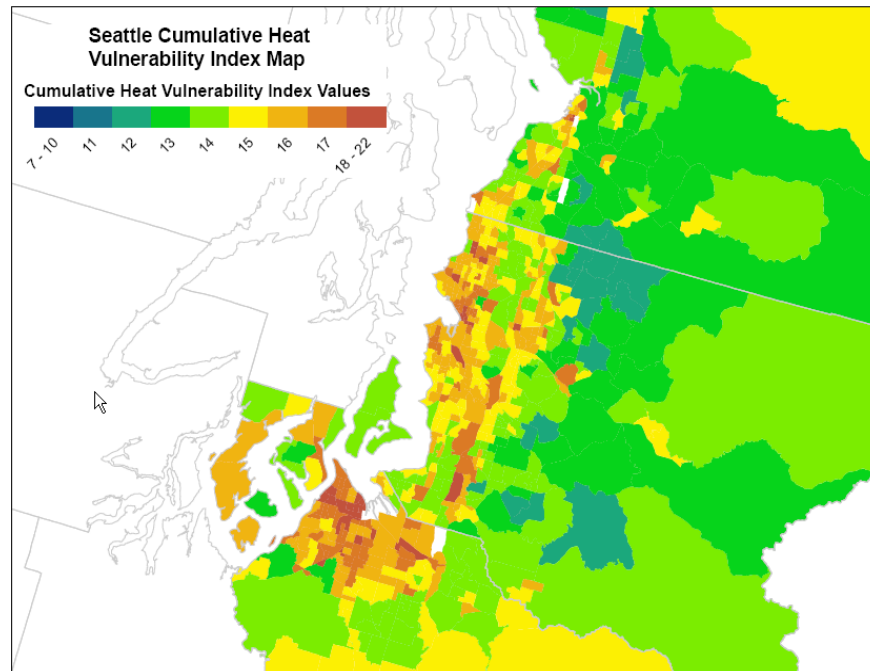
EHEs can be particularly dangerous for people experiencing homelessness due to their prolonged and direct exposure to the heat and limited access to cooling resources, such as water fountains, emergency sheltering, and AC environments. Locating and finding transportation to cooling centers can be a significant barrier. For people living in tents, many seek out tent coverings to provide shade and relief from direct sun. A study demonstrated tent coverings increase the ambient temperature inside the tent, which increases risk for heat-related illness for this population.⁷⁰³ With a large population of unsheltered individuals in Seattle, it is critical that the City's heat response equitably prioritizes the needs of people who may be living outside.

Consequences

Since the mid-1970s, on average of three or four fatalities occur in the Seattle area each summer.⁷⁰⁴ During excessively warm summers, such as 1992, an estimated 50 to 60 deaths occurred in Seattle due to heat. According to the Washington State Department of Health, Washington saw on average 45 heat-related illness hospitalizations annually between 2000 and 2020, with a peak of 437 in 2021.⁷⁰⁵ In Seattle, most fatalities are indirectly caused by heat, such as heart attacks, strokes and respiratory illness. These factors, along with research suggesting increases in the demand of healthcare services during EHEs, could indicate that Seattle's EMS and healthcare institutions could be impacted during a severe EHE.

Hot, dry temperatures can lead to poor air quality, which in turn is linked to respiratory disease and acute respiratory impacts.⁷⁰⁶ In addition to causing climate change, high carbon dioxide concentrations in the atmosphere is associated with production of allergens such as ragweed pollen that can, in turn, contribute to asthma cases by combining with fossil fuel pollutants, especially diesel exhaust.

Figure 66. Seattle Metro Area Heat Vulnerability Index



Source: Colleen Reid, personal communication. 2009.

There are also non-health consequences of heat. Stretches of hot, dry weather can increase the risk of brush fires and wildfires as vegetation dries.⁷⁰⁷ In July 2018, fire fighters in King County responded to 20 brush fires in one weekend alone.⁷⁰⁸ Brush fires can threaten adjacent property and cause traffic delays on major roads. High heat can also cause steel to expand, threatening the function of certain infrastructure like draw bridges. In 2018, firefighters in Chicago had to hose down a steel bridge that would not open to boat traffic due to heat expansion.⁷⁰⁹ Seattle has 7 bridges that must open to marine traffic.⁷¹⁰ Furthermore, the increase of brush fires and wildfires may also coincide with an increase in smoke, resulting in potential air quality degradations for Seattle. A reduction in air quality may further exacerbate EHEs due to the health complications of opening windows to reduce heat in residence, which would lower air quality in homes.

EHEs can lead to power outages due to increased demand on the energy infrastructure. While the number of homes with air conditioning has increased in the area, most implementations are energy efficient and energy demand has not yet impacted the energy system locally. However, if Seattle were to increase its air conditioning consumption to national levels, around 75%, it could overload the system to the point where outages could occur.⁷¹¹ In 2018, Los Angeles experienced unprecedented energy demand levels during a heat wave, causing over 25,000 residents to lose power, some for as long as three days.⁷¹² About 73% of households have air conditioning in Los Angeles.⁷¹³

Additionally, EHEs that coincide with a drought or low snow-pack year for Seattle's watersheds could result in a water shortage. If Seattle's water reserves are already low, high demand during hot days could lead the City of Seattle to impose water usage curtailments.

Climate research suggests an increase in EHE severity as the century progresses, which is discussed further in the chapter on [climate change](#).

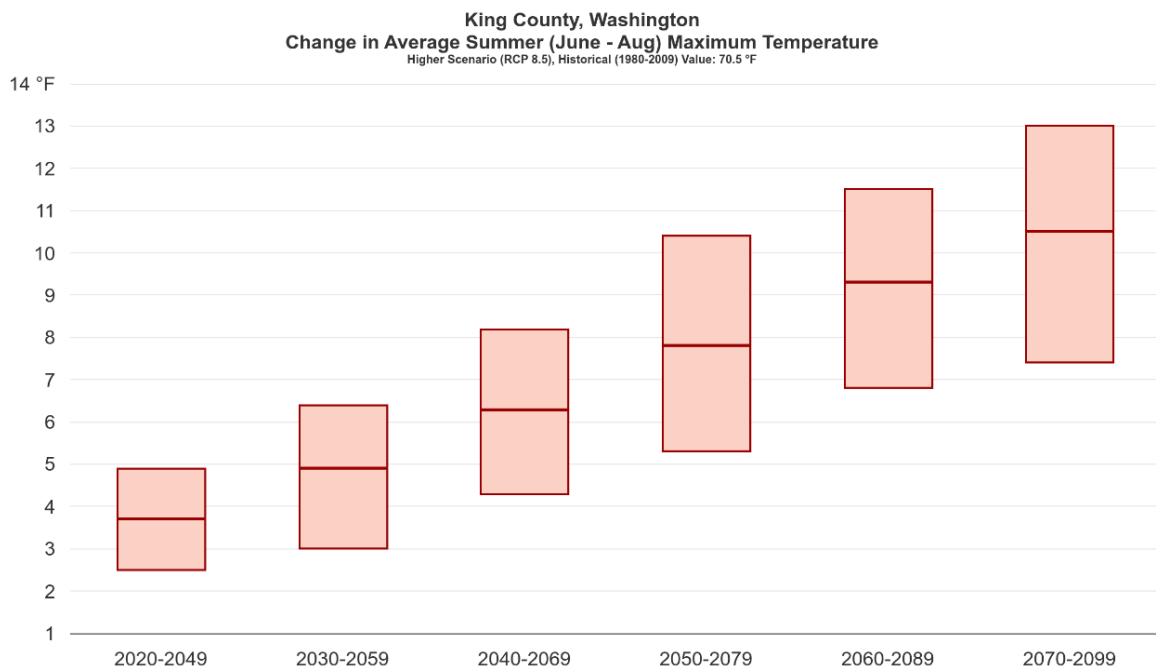
Outlook

Seattle is already seeing longer and more frequent extreme heat events. According to the National Oceanic and Atmospheric Administration, Seattle’s average number of heat events per year has increased from 2.2 in the 1960s to 6.3 in the 2020s. Furthermore, the average duration of heatwaves has increased 2.1 days from the 1960s.⁷¹⁴

Climate data for the Puget Sound area from 1901 to 2009 reveals a trend towards daily low temperatures increasing at a higher rate than daily high temperatures.⁷¹⁵ In other words, nighttime temperatures are rising, meaning there could be less cooling at night during future EHE’s. This is particularly dangerous as many households rely on the region’s lower overnight temperatures to cool down their homes, which were historically designed to retain heat.

The Washington Climate Change Impacts Assessment assessed the likelihood of future extreme heat events. It used three different scenarios of summer warming—low, moderate and high—and developed estimates for the number of heat events. In every scenario, they predict a rise. In the worst case scenario, Seattle could have an average of ten heat events per year with a maximum duration of 57 days by 2085.

Figure 67. Change in Average Summer Maximum Temperature



The graph shows the change in summer (June-August) average maximum temperature in a county for future 30-year periods compared to the 1980-2009 average. For example, a value of 4.0 means that the average summer maximum temperature is expected to increase by 4.0 degrees Fahrenheit for the county. The change in average summer maximum temperature is an indicator of heat stress for people, ecosystems and infrastructure.

Source: Climate Mapping for a Resilient Washington, 2022.

Conclusions

Extreme heat events are increasing in regularity and severity in the Pacific Northwest. Due to Seattle’s historically temperate climate and poor acclimatization to high temperatures, it doesn’t take much additional heat to increase our risk of heat-related illnesses and cause other health impacts. This is exacerbated by the urban heat island effect and Seattle’s built environment, where many buildings do not have AC and were built to retain heat. Underlying health conditions, certain medications and drug use, and individual factors and determinants such as age, employment, housing status, and outdoor activity levels may increase an individual’s vulnerability to heat-related illness.

15. FLOODING

In December 2006, heavy rain overwhelmed the City’s drainage systems and water backed up at the top of an embankment in the Madison Valley area. It overtopped the embankment, rushed downhill, slammed into a home and caused one fatality. This event raised awareness about the seriousness of Seattle’s flood hazard.

Seattle has over 200 miles of waterfront, making coastal and riverine flooding a natural concern in the area. It is surrounded by Puget Sound and Lake Washington and contains the Duwamish River, a ship canal, and several streams. Moreover, flooding outside Seattle can affect the city. For example, flooding along the Cedar River can decrease water quality to the point where it cannot be diverted for drinking water supply and water stored in Lake Youngs needs to be used instead.

Flooding in Seattle falls into four types:

- **Riverine flooding** – Heavy precipitation causes a river or stream to overflow its banks into the adjoining floodplain, also known as fluvial flooding. This is the classic flood. Seattle’s creeks, especially Thornton and Longfellow, have flooded more often than the Duwamish River, which is managed by the Howard Hanson Dam. Failure of the Howard Hanson dam or the release of large volumes of water from the dam could cause flooding of the Duwamish River.
- **Coastal flooding** – Associated with storms. High tides and wind can push water into coastal areas. Coastal flooding can erode the toes of bluffs and are one factor in

Key Points

- ❖ *Lead Agency – Seattle Public Utilities*
- ❖ *Nationally, floods are the most costly and destructive disasters. Most of the damage caused by Hurricane Katrina was caused by flooding.*
- ❖ *Western Washington is very prone to flooding, and Seattle’s flood profile is different from the rest of the state. Seattle has four flooding hazards: riverine flooding, coastal flooding, urban flooding, and compound flooding, where two or more types happen simultaneously. Urban and riverine flooding are most common.*
- ❖ *Climate change is projected to cause sea level rise and increase the frequency of heavy rain events, heightening Seattle’s future risk of urban and coastal flooding. Seattle is already planning to adapt to these future changes.*
- ❖ *The area in the 100-year floodplains covers parts of South Park and areas along Thornton and Longfellow Creeks. Flood control structures have been built in flood prone areas. Small segments of two high-volume arterials cross the flood plain: SR99 crosses the South Park floodplain and SR 522 cross along three segments of Thornton Creek.*
- ❖ *Federal Emergency Management Agency (FEMA) data reveals that Seattle has 12 buildings (including residential) that have had more than one flood loss.*

landslides. Some areas, like South Park, can experience drainage problems under the same conditions.

- **Urban flooding** – Happens when intense rain overwhelms the capacity of the drainage system and is also known as pluvial flooding. Low lying, bowl-shaped areas like Madison Valley and Midvale are the most likely to flood.
- **Compound flooding** – This is the result of two or more flooding sources occurring simultaneously or within a short period of time. The most common type is a combination of storm surge and riverine flooding, which can result in longer and more widespread flooding than anticipated.

The key factors determining the amount of damage in a flood are the depth and velocity of the water, and the amount of time the water stays above flood level. To project the expected amount of damage, the frequency of high water in a particular area needs to be computed. Usually, this is done by the Federal Emergency Management Agency (FEMA). An area that has a 1% chance of flooding in any given year is called a 100-year floodplain. Similarly, a 500-year flood has a 0.2% chance of occurring each year. The elevation and shape of these floodplains, as well as historical and geological records, suggest probable flood depths and velocity.

Riverine floods often develop slowly and give floodplain residents ample time to evacuate. Casualties occur when people cannot or will not leave or try to drive across flooded roadways. Flash floods or dam failures are more dangerous than typical riverine floods because people have less time to escape and are more likely to get trapped. These types are rare in Western Washington. Even small floods can cause heavy structural damage by rotting wooden frames and undermining foundations. More frequently they destroy moveable property and commercial stock. Further information about dam failures can be found in the [Built Environment Failures](#) chapter.

Riverine floods can also affect city infrastructure when high water cuts transportation routes or powerlines. These lifeline losses can impact people beyond the immediate floodplain. If floodwaters inundate hazardous waste sites or buildings where dangerous chemicals are housed, they also generate secondary incidents such as hazardous material exposures. In New Orleans, flooding from Hurricane Katrina caused a release of 25,000 barrels of crude oil into a neighborhood adjacent to a refinery. 6,500 homes were affected.⁷¹⁶ During the Duwamish River flood event of December 2022, water that entered people's homes was that of the Duwamish Superfund site, which is known to contain hazardous chemicals such as polychlorinated biphenyls (PCBs), arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), dioxins and furans.

The Puget Sound is not considered to have an "open" coastline, where coastal flooding is usually more violent. Storms extend the reach of waves creating floods along the coasts. Storm surges as high as 23 feet have been reported in conjunction with tropical storms. Since they accompany storms, storm surges have enormous destructive potential as winds drive waves ashore at high velocities. Few non-engineered buildings can survive a strong storm surge, especially those constructed of wood. Even stronger structures like port facilities, warehouses, and bridges are vulnerable to coastal floods. Surges are worse when they occur at high tide or king tides, which are extremely high tide events that occur a few times per year when the moon is closest to the earth.

Urban Flooding in Seattle typically occurs during a weather event called an atmospheric river, or colloquially, a "Pineapple Express." An influx of warm air from the tropics or subtropics rapidly raises winter temperatures. The mix of raised freezing levels and increased water vapor can produce heavy precipitation, causing urban flooding.⁷¹⁷ This type of flooding can be exacerbated by high tidal events, such as King Tides, as was seen in the December 2022 Duwamish River flood event. These events typically happen in winter but can occur in late fall and early spring as well.

Research has also shown that urban areas can exacerbate rainfall, referred to as the “urban wet island effect”. Akin to the more commonly known “heat islands”, wherein cities reach hotter temperatures due to heat-trapping infrastructure components, the urban wet island effect can cause more rain to fall in urban areas than rural ones. Large buildings can physically slow the passing of storms, exhaust from cars and other pollution can produce “seed clouds” that release precipitation, and radiated heat from asphalt and other materials can increase convection in the atmosphere, leading to more rain in cities.⁷¹⁸ This phenomenon has been observed globally.

Regulations exist at the local, state, and federal level to reduce flood risk, including structural and non-structural means. In the past, structural methods such as the construction of dams, levees and bulkheads were the most common means used. During the 1950s and 1960s, the emphasis began to shift because these structures failed to completely solve the flood problem. Catastrophic flooding, like that on the Mississippi in 1993, led federal authorities to emphasize a suite of non-structural mitigation strategies, such as flood insurance, government buyouts, and more restrictive land use planning.

Lastly, heavy rain that causes flooding can also cause landslides. More information about Seattle’s landslide risk can be found in the [Landslide](#) chapter.

History

Early in Seattle’s history, low-lying areas near downtown and at the mouth of the Duwamish flooded. This prompted the construction of landfills and a drainage system downtown and the channeling of the Duwamish. Because of these changes, listing very early events is irrelevant.

Areas along the city’s streams experience periodic, localized flooding, typically limited to the blocks or neighborhoods immediately adjacent to the streams. These streams include Longfellow and Thornton Creeks. The depth and current velocity of the floodwaters have been low, and they generally cause only localized structural damage and bank erosion.⁷¹⁹ The record of flooding in these areas is limited, but FEMA data shows problems in November 1978 and January 1986. Limited urban flooding also occurred in the residential area near Thornton Creek during the winter storms of 1996/1997, and again in October 2003.

The rivers in eastern King County are prone to severe flooding. Only a few floods in the area have affected Seattle directly, the most significant being on the Cedar River. Major flooding of the Cedar River occurred in 1975, 1990, 1995 and 1996. The flooding led to water quality issues but occurred in the winter when demand for water is lower, minimizing impact to customers. Filtration was added to the Tolt system in 2001, so the impact of floods on water supply is no longer a serious concern for that portion of the system.

Other notable flooding events include:

December 14-15, 2006. Intense rainfall (roughly 2.17 inches in 24 hours) led to the flooding of approximately 300 homes, six landslides of various sizes, overwhelmed storm water facilities, and one death. Usually, rainfall in Seattle is a few hundredths of an inch per hour. The peak of this storm was a band that ran through the middle of Seattle and produced an inch of rain in one hour. The City of Seattle activated its Emergency Operations Center for this event.

December 1-3, 2007. Three storms came through the Pacific Northwest, with the last being particularly intense.⁷²⁰ 4.5 to 5.5 inches of rain fell in north and west Seattle in 24 hours, setting an all-time record. Seattle experienced flooded roads, sinkholes, and landslides, and led Seattle Public Utilities to activate their debris management plan for the first time. While this storm brought more rain than the 2006 event, it was spread out over a longer period. Unusually dry weather in the previous month also helped mitigate the risk of landslides.⁷²¹ The City of Seattle activated its Emergency Operations Center for this event.

December 27, 2022. Flooding occurred in the South Park neighborhood when the Duwamish River overtopped its banks. This event was caused by annual winter King Tides (large tidal exchanges producing extremely high tides) that exceeded their predicted tide height due to the presence of an extreme low-pressure weather system. Additional flooding factors included runoff from rain, melting snow, and ice from previous winter storm events earlier in December. Over 45 homes and businesses were impacted, and more than 60 residents were displaced, with many buildings requiring extensive demolition, remediation, and inspection efforts before they could be safely reinhabited. The South Park Neighborhood is more ethnically and racially diverse, has a greater percentage of residents living below the poverty line, and has more residents for whom English is not their primary spoken language than the city as a whole. The event highlighted the pressing issue of environmental justice within the City.

Vulnerability

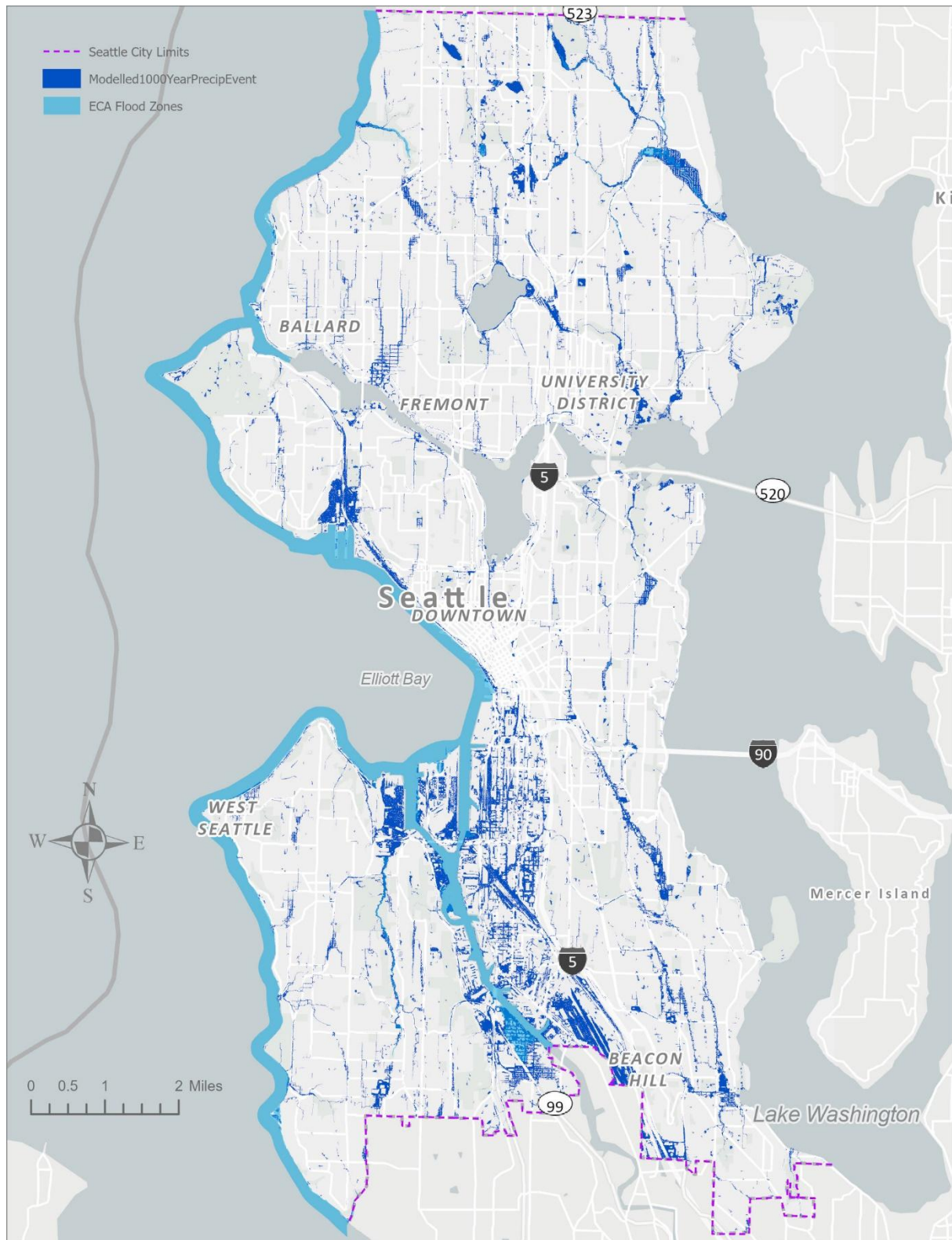
The National Flood Insurance Rate Maps and the U.S. Army Corps of Engineers [inundation maps](#) indicate areas prone to flooding in Seattle. The latter shows the area affected by a potential break of the Howard Hanson Dam. These maps show that the locations prone to flooding are quite limited. These areas are most vulnerable from November to February when the city receives most of its rain. The City of Seattle has adopted a variety of structural controls to prevent flooding. It placed a diversion on Thornton Creek and a storm water detention basin on Longfellow Creek. However, each has its limits. The Thornton Creek diversion is effective up to a 100-year flood; the Longfellow basin was only partially effective during the January 1986 flood.⁷²² In 2014, SPU completed a restoration project along a flood-prone portion of Thornton Creek, which widened the creek channel to handle greater water capacity and enlarged a main culvert.⁷²³

The Howard Hanson Dam regulates the only large river in the city, the Duwamish. There are two concerns regarding flooding: 1) a flood event in the upper Green River that causes the dam to be over capacity; or 2) a breach or complete failure of the dam. The dam's reservoir can usually contain the runoff from winter storms and spring snow melt. An extremely heavy rain event during the winter months could cause the dam to reach or exceed its design capacity, requiring water to be released. The Army Corps of Engineers has modeled a 500-year flood event (a flood with a 0.02% chance of occurring per year) in the upper Green River. A flood of this magnitude has not occurred since record keeping began. The modeling shows water flows of 25,000 cubic feet per second that would flood parts of the Green River Valley, including Kent.⁷²⁴ However, by the time the water flow reaches the lower Duwamish in Seattle, flooding is not expected as tidal effects will govern.⁷²⁵

The other potential flood scenario would be from a breach or failure of the dam. The Army Corps of Engineers has modeled two scenarios of a dam break. One models a dam break when the reservoir is 10% full, and the other models a dam break when the reservoir is 100% full. In the 10% scenario, the flood could have a large impact upriver, where most of the water would spill over into the Green River Valley.⁷²⁶ This upriver flooding would relieve pressure on downstream areas like Seattle. In the 100% full scenario, the model shows that flooding could occur in the South Park neighborhood.⁷²⁷ However, this is a worst-case scenario, and any flooding event will depend on the exact nature of the breach and the water storage level. Dam failure is also discussed in [Built Environment Failures](#). [Figure 62](#) shows a map of estimated inundation from a worst-case failure of the Howard Hanson Dam.

In 2009, a void was discovered in the Howard Hanson Dam. Concerns about its strength led to temporary repairs and a reduction in capacity of the reservoir. This means that more water would have to be released from the dam in a heavy storm. At the time, the Army Corps of Engineers, the dam's operator, estimated a 1 in 33 chance of flooding due to releases. Permanent repairs were made to the dam, including a seepage barrier and installation of drains that direct seepage into a drainage tunnel.⁷²⁸ Other flood control measures include log booms that prevent debris from blocking the spillway and rock

Figure 68. Areas with Heightened Flood Risk



City of Seattle, Enterprise Data

This map visualizes two types of flooding risks; areas along rivers and streams that can overflow their banks, as well as urban flood areas that have a higher likelihood of ponding during extreme precipitation when drainage systems are overwhelmed.

installations that prevent erosion of the dam. The Army Corps states that the dam can control water up to a 140-year flood event.⁷²⁹

The failure of levees just outside the city limits could produce localized flooding at Boeing Field and SCL facilities, but the Army Corps of Engineers reports that these levees are in good repair.

The Cedar River system, which provides 70% of Seattle's water supply, is also vulnerable to flooding. Because of the lack of filtration on the Cedar, diversions from the river are shut down when the water is turbid.⁷³⁰ When this occurs, Seattle Public Utilities is able to use water stored in Lake Youngs, a reservoir of water downstream of the Cedar, for our water supply instead. Because flooding on the Cedar occurs in the fall or winter when demand for water is at its lowest, water from Lake Youngs and the Tolt River system can meet the full needs for water supply.

Both Seattle City Light (SCL) and Seattle Public Utilities (SPU) own and operate facilities located outside of the city limits on the Cedar River, the Tolt River, the Skagit River, and the Pend Oreille River. This includes dams, treatment plants, and reservoirs. Flooding can be a concern in these areas during times of heavy rain and extraordinary snowpack, especially in the Tolt Watershed due to its steep slopes that were heavily logged several decades ago.⁷³¹ In both the Cedar and Tolt Watersheds, heavy runoff can damage culverts, roads, and bridges, some of which support transmission pipelines and are important for hydropower production.

In Seattle, riverine flooding can occur on the Duwamish River and on Thornton and Longfellow Creeks. The city also sees urban flooding, caused by excessive rain overwhelming the drainage system. This most frequently happens in low-lying and bowl-shaped areas, such as Madison Valley, and is generally concentrated in specific areas rather than widespread. Detailed maps showing drainage system capacity risk areas can be found in [SPU's Drainage System Capacity Risk Area Prioritization Analysis](#).

One area of particularly vulnerable to flooding is the South Park neighborhood. The neighborhood lies at a low elevation along the Duwamish and is prone to flooding due to backups in the drainage system, leading to compound flooding. During major storms, runoff can drain directly into the Duwamish. Because the Duwamish is a tidal river, its elevation rises with the high tide. High stream flow combined with a high tide can push water to overtop the riverbanks, as was seen in the December 2022 event further described above. To address this issue, SPU built the South Park Pump Station, which sends stormwater runoff to the Duwamish Waterway during high tide events when the storm drain system cannot drain by gravity. This was done in tandem with drainage and roadway improvements to mitigate neighborhood flooding.

Coastal problems are another vulnerability. The National Flood Insurance Rate Maps show a coastal flooding hazard directly along the coast but not extending inland. Coastal flooding has occurred in West Seattle and South Park when winter storms coincide with king tides. This combination of events occurred during the South Park flooding event of 2022, leaving many without homes due to extensive flooding damage. In response to the flood event, SPU created a South Park Emergency Response Plan. The plan does not use a single threshold (tide height) to determine activation but rather monitors the Elliot Bay tide gauge as well as actual rainfall, snowmelt, wind, and atmospheric pressure. Close monitoring of these variables determines the use of precautionary measures such as closing off intersections, providing sandbags, and notifying the community about potential impacts.

As previously stated, sea-level rise will make coastal flooding worse. The projected amount of sea-level rise in Seattle is 4 to 56 inches by 2100, depending on the amount of vertical land movement (land in Western Washington has been rising after being compacted in last glaciation).⁷³² Areas that may be at risk for future sea level rise flooding include Brace Point, Harbor Island, Duwamish Waterway south of Harbor Island, South Park, Georgetown, Interbay, Smith Cove, West Point Lighthouse, and Meadow Point as Golden Gardens Park.⁷³³

Many of the low-lying coastline areas, especially the more heavily used parts of the waterfront, are protected by seawalls. In 2017, the City of Seattle completed major repairs to its aging downtown seawall. The repaired wall is expected to last more than 75 years. The city estimates that the top of the downtown seawall will still be 3 ft above the new water level projections for 2100.⁷³⁴ Other seawalls could be overtopped if they are not modified or replaced.

Much of Seattle's coastline consists of bluffs with homes built at the top. Coastal storms can erode the toe of these sea cliffs and are a factor in landslides. In parts of West Seattle and Magnolia, homes are built along the shore. These properties are most vulnerable to coastal storm damage.

Consequences

Western Washington is most vulnerable to riverine flooding due to the short, steep rivers coming from the Cascade mountains.⁷³⁵ Despite this, Seattle's riverine flooding risk has been historically low. The situation may be changing, however, with climate change projections signaling that urban flooding may become a larger threat. Climate researchers project that Seattle will experience more extreme precipitation events, although there is a large amount of uncertainty in their predictions. In response, Seattle's drainage system is being retrofitted to add surge capacity.

Areas near streams and in natural bowls are at risk of localized ponding. The main risk is to property, the majority of which is residential. During periods of excessive rain, the volume of water entering the combined sewer system may exceed capacity. When this happens, sewage may back up from the SPU system into homes and buildings through private side sewers. Sewer backups can create a health hazard and cause significant damage to building structures and the items within. Repairs from both sewer backups and flood damage can be expensive and disruptive. Furthermore, owners and renters in flood prone areas are often low-income, and flood insurance can be prohibitively expensive.

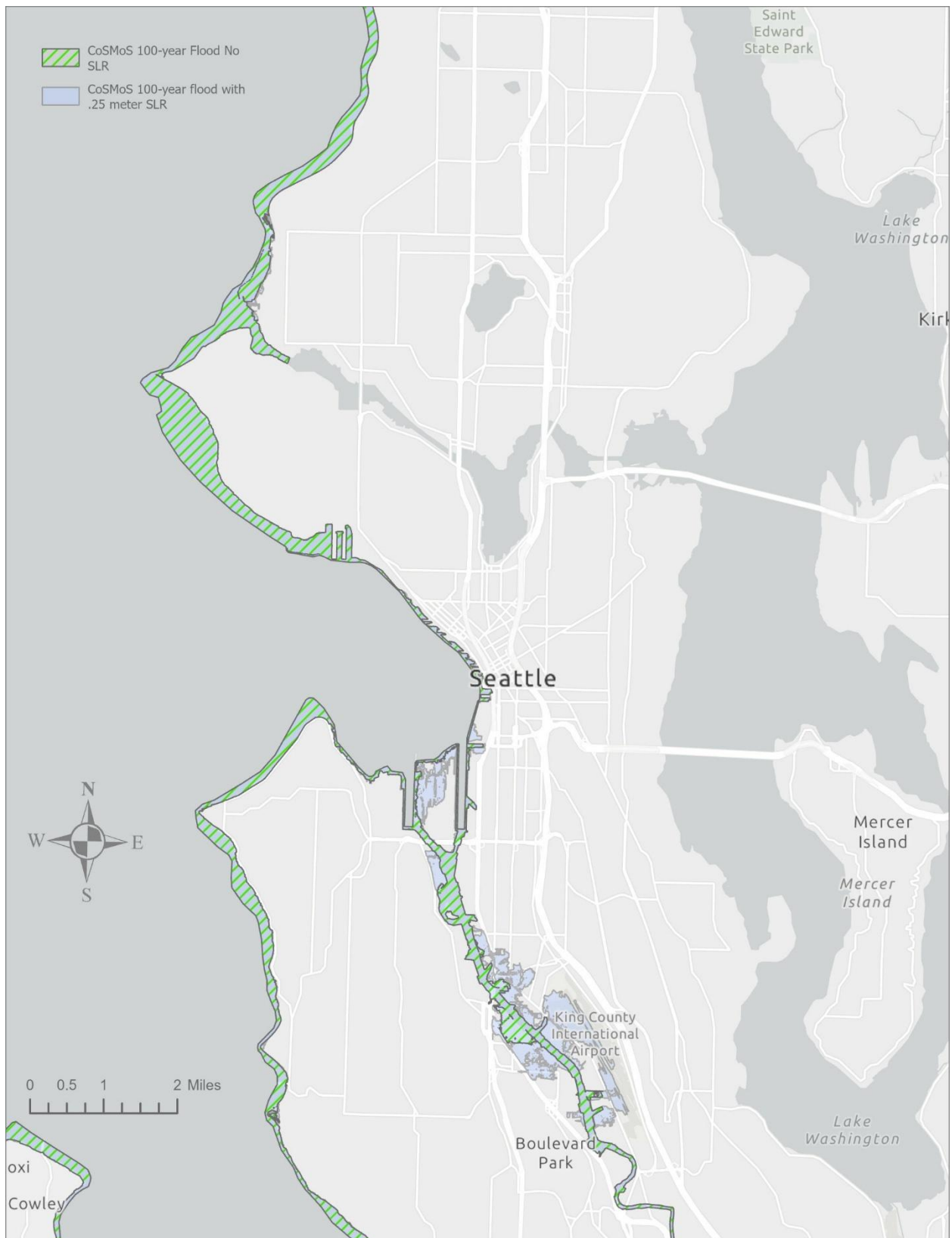
Intense rainfall can also lead to combined sewer overflows (CSOs), which occur when pipe capacity is overwhelmed in a combined sewer system due to stormwater influx. During these events, a mix of stormwater and wastewater is discharged at designated relief points to avoid sewage backups on private property and in the right of way. CSOs pose a substantial risk to the area's environmental health by carrying raw sewage, industrial wastewater, herbicides and pesticides into water bodies in the event of heavy rainfall.

Coastal flooding in Puget Sound could damage a large area. The most common land use near the shore is residential, but the Port of Seattle and the BNSF Railway might also be affected because of their proximity to the water. Flooding in the Duwamish Valley is another concern, as the dominant land use in the Duwamish Valley is industrial and houses many hazardous materials. A flood in this area would cause a severe disruption of the local economy, leading to a decline in tax revenue and a loss of jobs. If firms relocate following a flood, the city could lose some of this income permanently. Furthermore, some neighborhoods along the Duwamish River are at risk for compound flooding, which can occur when heavy rainfall and high tides coexist, causing the river to overtop. Protecting residential areas from future river overtopping would likely entail a large infrastructure project such as a berm.

Other severe scenarios include coast erosion caused by coastal flooding extended by sea-level rise. Such events could endanger people living along the shore or near coastal bluffs. The main danger is landslides, which in extreme cases can generate tsunamis.

Lives can also be at risk during flood events, as demonstrated by the fatality that occurred in Madison Valley during the 2006 storm. While that case had unique circumstances, with an extra high curb structure along Madison Street acting like a small dam, it is possible for a similar set of circumstances to arise again and put lives in danger.

Figure 69. Compound Flood Models with .25 Meter Sea Level Rise



WSU Facilities Services GIS, City of Seattle, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, FPA, NPS, IISDA, IISFWS

Outlook

Seattle will experience flooding in the future. The principal unknown factor is the severity of future events. Several studies point towards relatively small changes in annual and seasonal precipitation, but an increase in heavy precipitation events. Local meteorology expert, Cliff Mass, analyzed rainfall intensity data and discovered that events like the one on December 14, 2006, have a 1% to 2% chance of occurring each year. These observations are in alignment with the University of Washington's Climate Impacts Group (CIG), which projects that the number of days with more than 1 inch of rain will increase by 6% to 20% by the 2050s.⁷³⁶ Additionally, CIG projects that coastal flooding will increase due to sea level rise extending the reach of waves in a storm surge.⁷³⁷ A study by Warner et al. found that the frequency of the heaviest rainfall days (above the historical 99th percentile) could increase by 290% by 2100.⁷³⁸

Data from Seattle Public Utilities is so far aligning with these predictions. A 2017 study by Tetra Tech of SPU's rain gage records discovered a small but statistically significant trend towards short-duration, high-intensity events.⁷³⁹ SPU is working towards upgrading the city's drainage system in critical areas in attempts to mitigate risks this poses to the city. As part of this effort, SPU modelled a 1000-year urban flood event. The areas that are estimated to be inundated are shown in [Figure 68](#).

[USGS Coastal Storm Modeling System \(CoSMoS\)](#) produces models of compound flooding, which is defined as flooding caused by multiple drivers: precipitation, stream flows, tides, and sea level rise. CoSMoS released new modelling for King County in December 2025. They show the current 100-year flood exposure as largely the same as shown in the ECA Flood Zones shown in [Figure 68](#). These areas are the FEMA identified 100-year flood zones. The CoSMoS models highlight Seattle's exposure to sea level rise. With .25 meters or 10 inches of sea level rise, large parts of Harbor Island, South Park, and areas adjacent to King County International Airport would become susceptible to 100-year floods (see [Figure 69](#)). USGS has made a [web mapping tool](#) to allow the public to explore the data.

Conclusions

Changes in the landscape, like the dredging and filling along the Duwamish, have reduced the city's risk to flooding. The Howard Hanson Dam maintains further structural protection, and smaller controls work on Longfellow and Thornton Creeks. These structural solutions are backed up by the city's membership in the National Flood Insurance Program which requires buildings within the floodplain to have flood insurance. All of these factors make flooding one of the most well-studied and funded mitigation efforts in the city. Nevertheless, urban flooding incidents and future climate projections point to a hazard that is shifting and exposing new vulnerabilities.

16. SEVERE WINTER WEATHER

Seattle's winter weather is shaped by the Cascade mountains, Olympic mountains, and the Pacific Ocean. Our region's maritime climate usually keeps Seattle warm in the winter. The prevailing westerly winds that blow in from the Pacific keep cold arctic air from reaching the Puget Lowlands most of the time. Occasionally, an arctic front develops in which cold air from the Yukon moves south into British Columbia and through a gap in the Cascade Mountains, northeast of Bellingham. If this push of cold air is met with moist warm air from the Pacific, snow is often the result. Usually, the snow starts near Bellingham and moves south. Such fronts account for roughly 80% of Puget Sound snow.⁷⁴⁰

Seattle sits within the Puget Sound Convergence Zone, an area of colliding wind currents that can cause lower temperatures and higher precipitation, typically between Everett and North Seattle. The convergence zone can mean that in the winter, Seattle can experience snowfall while areas a few miles north and south of the zone do not, or, that Seattle experiences variability in snowfall between its own neighborhoods.⁷⁴¹ Seattle's steep topography can also create localized events. It is not uncommon for snow to fall at high elevation areas, such as Capitol Hill or Queen Anne Hill, while areas closer to sea level remain snow-free.⁷⁴²

Because Seattle does not see routine snow events, the City does not have the same clearance capacity that cities in the upper Midwest and Northeast have. Seattle's steep topography and narrow streets also complicate snow removal. During major snow storms the transportation system shuts down, sometimes trapping people at home or work. The Seattle Department of Transportation (SDOT) removes snow from arterial streets within 12 hours of a lull in a snowstorm and works 24/7 to treat roads before and during storms.⁷⁴³ Residents and business owners are responsible for plowing their own property and adjacent sidewalks. Vehicle accidents rise among those who attempt to drive. In 2015, snowy or icy roads contributed to 3% of traffic collisions in Washington State.⁷⁴⁴

Access to emergency services can be impaired during severe winter weather. During exceptional storms, structures can be damaged. This happened in the 1996/97 storm when several roofs collapsed. Energy

Key Points

- ❖ *Lead Agency – Seattle Department of Transportation (SDOT)*
- ❖ *Seattle's weather is regulated by the Pacific Ocean, which remains relatively constant in temperature throughout the year. Occasionally, cold air from the interior of the continent pushes into the Puget Sound region and causes dramatic cold spells, ice, and snow.*
- ❖ *Snow and ice can impede transportation routes, public safety response, utility operations, and cause economic loss.*
- ❖ *Seattle does not have dedicated snowplows. Trucks must be outfitted with snow removal equipment when snow threatens. There are not enough of these trucks to plow every street in the city.*
- ❖ *Due to Seattle's steep topography, some streets are too steep to keep open during snow and ice events.*
- ❖ *During snow and extreme cold, Public Health – Seattle & King County issues public warnings about the dangers of carbon monoxide poisoning. A regional "Take Winter by Storm" campaign also helps educate on winter preparedness and safety.*
- ❖ *Occasionally, rapidly melting snow can contribute to saturating the ground and becomes a factor in triggering landslides. The last time this happened was in the winter of 1996/97.*

use skyrockets due to increased heating use, placing a demand on power generation and distribution systems. Elsewhere in the nation, energy demand spikes have reached crisis levels. An extreme winter storm in Texas in 2021 led to a loss in power to more than 4.5 million homes, causing at least 57 deaths.⁷⁴⁵ Those who did have power experienced massive surge pricing, making utility bills unaffordable for many. In some cases, those with low or fixed incomes cannot afford the extra expense and must suffer through the cold.⁷⁴⁶

SDOT carefully monitors winter weather conditions. They use a forecasting tool called [SnowWatch](#) to predict the consequences of storms at the neighborhood-level. When possible, SDOT will treat major roads and bridges with salt brine before a storm to prevent ice formation. When one inch of snow has accumulated, SDOT begins plowing roads. Routes that are critical for major institutions and emergency services, such as those near police precincts, fire stations, and medical facilities, are prioritized, as well as those leading to Seattle's major employers.⁷⁴⁷ SDOT also works closely with King County Metro to keep buses and street cars running and has daily check-ins with Seattle Public Schools when a winter storm happens while school is in session.

While it's difficult to link snow events directly to economic activity, some evidence suggests that widespread, lingering snow can negatively impact the overall economy. Economists believe that severe snowstorms across the United States from 2013-2014 contributed to the economy declining 2.1% in the first quarter of 2014, mainly due to interruptions in supply chains.⁷⁴⁸ Another account claims that Massachusetts alone lost around \$1 billion in wages and profits due to snow during the 2014-2015 winter season.⁷⁴⁹

One study that analyzed vehicle accidents caused by winter weather (snow, ice, or sleet) between 1975 and 2011 reported that an average of nearly 900 fatalities occur nationally each year.⁷⁵⁰ Additionally, researchers have found that indirect effects of storms have resulted in fatalities, from traffic accidents, sledding accidents, exposure to cold, falls, and carbon monoxide poisoning.

Research by the National Weather Service related to winter weather has found that:

- Ice is deadlier than snow
- About 70% of deaths occur in automobiles
- About 25% of deaths are people caught outside
- 50% of hypothermia cases are over 60 years old, 75% are male and 20% occur at home

The cold that often lingers after a snowstorm can produce its own dangers, especially when accompanied by power outages. The primary danger in this situation is hypothermia. Those most vulnerable populations are people experiencing homelessness, those without heat, the elderly, and people who are socially isolated.

History

Seattle's unofficial record for the most snow in one winter is 64 inches in 1880. The single-day record is 21.5 inches in 1916.⁷⁵¹ Other historical records that extend back beyond modern record keeping indicate that Seattle was colder and snowier in the past.

Official snowfall records at SeaTac Airport have been kept since 1948, measuring an average of just 6.3 inches per year.⁷⁵² Several winters have received considerably more snowfall. Events have occurred as early as November and as late as March.

December 1861. Very cold, with an unofficial record temperature of -4 degrees Fahrenheit. Newspapers mentioned ice skating on Lake Union was covered in six inches of ice.

Winter 1880. Estimated to be the snowiest winter in Seattle. 64 inches of snow fell during the season. Snow drifted three to five feet at the waterfront, possibly indicating even bigger drifts at higher elevations. Most significantly, roofs collapsed throughout the city.

January 1893. 45.5 inches fell in less than two weeks.

February 1, 1916. Single-day snow record set at 21.5 inches. The roof of the St. James Cathedral collapsed. Snow drifts were up to five feet.

January 1920. A sledding accident on Queen Anne killed four children and injured five more.

February 1923. 16 inches of snow.

January 1943. A total of 18.4 inches of snow over one week closed schools and caused power outages.

January 13, 1950. Near record one-day snowfall of 21.4 inches at SeaTac accompanied by 25-40 mile per hour winds. 57.2 inches fell the entire month at SeaTac. This storm claimed 13 lives in the Puget Sound area. The winter of 1949-50 was the coldest since official records began.

Winter 1956. 23 days of measurable snowfall.

December 1964. Eight inches of snow.

December 1968 Ten inches of snow fell on New Year's Eve.

January 1969. 19 inches of snow accumulated at SeaTac on the 28th. Nearly 46 inches fell during the month.

January 1972. Intense cold. Nine inches of snow fell at SeaTac. Schools closed. This storm was connected to landslides later that year.

December 1974. Nearly ten inches of snow fell as the power went out in many parts of the city.

November 1985. Eight inches of snow fell on Thanksgiving Day.

December 1991. Snow closed SeaTac and brought traffic to a halt.

December 1996 Near-record snow fell the day after Christmas. Metro halted service completely for the first time in its history. Freeze and snowmelt contributed to flooding and landslides during the following week. The landslides are covered in the [Landslides](#) chapter.

December 2008. Seattle experienced a rare, extended period of lingering snow with some areas of the city receiving 3-6 inches. The temperature dropped to a record-tying 14 degrees Fahrenheit. King County Metro had fewer than half of their usual bus routes running, and Amtrak trains stopped running altogether. Seattle officials did not salt city streets, making driving difficult. At SeaTac, passengers were stranded for several days due to flight cancelations.⁷⁵³

November 2010. Seattle received 1-2 inches of snow, causing dangerous road conditions. A cargo plane skidded off the runway at SeaTac airport, causing flight delays. Three fatalities were attributed to accidents caused by the icy road conditions. High winds caused power outages as temperatures dropped into the 20s.⁷⁵⁴

January 2012. 3-9 inches of snow fell throughout the area with subsequent freezing rain. King County Metro reduced service by 30%. 6,500 Seattle City Light customers experienced power outages.

February 2017. SeaTac airport records 7.1 inches of snow.⁷⁵⁵ Power outages occurred, affecting 110,000 Puget Sound Energy customers and 11,000 Seattle City Light customers.

February 2019. Over a period of ten days, 20.2 inches of snow accumulated, making it the snowiest month in 50 years. It was the second snowiest February on record and was the seventh snowiest month recorded in Seattle history.⁷⁵⁶

December 2022. The worst ice storm in over two decades hit Seattle, coating the city with a quarter of an inch of freezing rain. While short-lived, the ice forced runway closures at SeaTac Airport, shut down stretches of I-90, and cancelled all King County Metro bus service.⁷⁵⁷ The Seattle Fire Department responded to over 200 calls for people slipping on ice. Roughly 13,000 were without power across Washington.

Vulnerability

Seattle's geology and climate increase the city's vulnerability to snowstorms. The hilly topography makes many areas of the city impassable even after a light snowfall. Queen Anne Hill, Beacon Hill, parts of West Seattle, and areas facing Lake Washington and Puget Sound seem especially prone to isolation during storms because of the many steeply graded and narrow streets that serve them. SDOT works during and after snowfall to keep arterial roads safe and passable but does not clear residential streets. Cities that plow residential streets have significantly more resources devoted to snow response, dedicated policies around street parking during winter weather events, as well as fewer challenges relating to steep and narrow streets.

Those experiencing homelessness are the most vulnerable to winter weather and are a growing population in Seattle. Although attempts are made to find extra space in shelters during winter, many people remain on the streets in harsh conditions. In 2022, King County was ranked third in the United States for the number of people who are unsheltered, making winter storms particularly dangerous for many in Seattle. The city's low-income and aging residents typically bear the most consequences of winter storms. People without back-up sources of heat may suffer from the cold during outages as well. In 2006, several incidents of carbon monoxide poisoning occurred when people attempted to burn charcoal indoors to maintain heat.

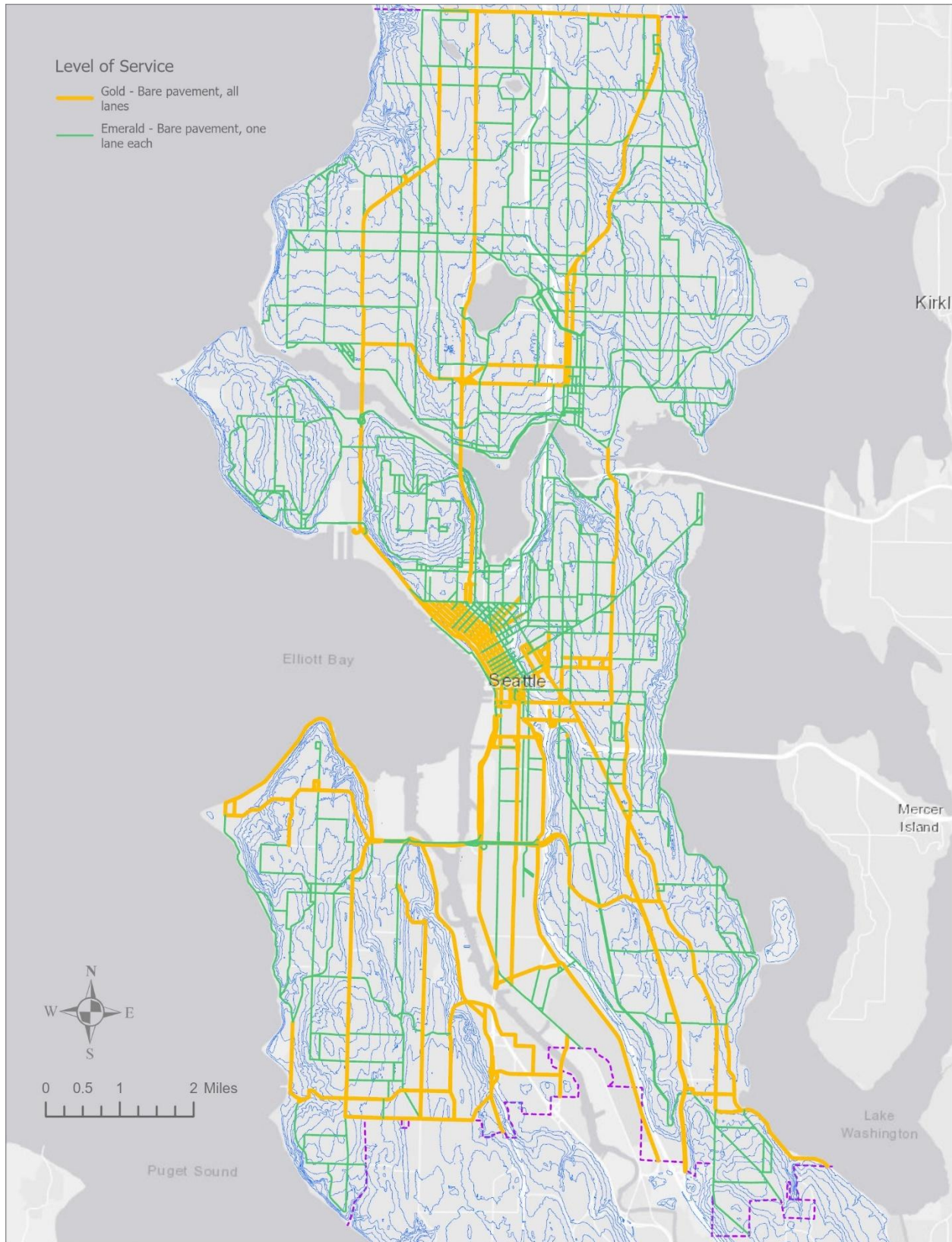
Anyone requiring medical care is vulnerable when the transportation system is impaired. Aging residents are indirectly affected since they require medical care most frequently and snow can make it difficult for them to receive it. When critical outpatient services cannot be accessed, medical needs may escalate. Patients may deteriorate and require ambulance transport and emergency department care and admission. This places an additional burden on the healthcare system in King County. To mitigate impacts, SDOT works closely with Public Health Seattle King County and other medical organizations such as [Hopelink](#) to provide private transit providers to residents with critical medical appointments. Children are another vulnerable population during winter storms because they often play on dangerous, icy streets. Several children have been killed in sledding accidents.

Seattle retailers are vulnerable because a major part of the snow season overlaps the holiday shopping season. The loss of sales at this time can be critical. Seasonal, temporary, contract, and other workers who lack paid time off can lose income during snowstorms if they cannot get to work or their employer closes due to weather conditions.

Consequences

The two biggest direct impacts of snow and ice are cold temperatures and immobility. These drive the main secondary impacts, which get worse the longer the snow and ice remain on the ground. As the February 2019 winter weather event demonstrated, snow and ice can linger for weeks in Seattle and the city government, residents, workers and business must be prepared for this situation. Seattle faces transportation impairments while snow is falling and up to eight hours after it has stopped along most snow routes. Arterials that are too steep to plow, minor arterials, and residential streets face longer impairments. Additionally, power outages during snowstorms and the cold weather that often accompanies them remain a serious threat. Hypothermia and carbon monoxide poisoning from makeshift heat sources continue to pose health and safety risks.

Figure 70. Snow and Ice Routes by Service Level



City of Seattle, Bureau of Land Management, Esri, HERE, Garmin, USGS, EPA, NPS, Esri, HERE, NPS

A snowstorm may slow the local economy. Hourly workers may lose wages, plane flights may be cancelled, and retail stores and restaurants may lose revenue. However, there is a debate about whether these slowdowns cause permanent revenue losses. Productivity and sales may decline temporarily but often accelerate after a storm. People who cannot make a purchase due to snow will likely still make that purchase later. More permanent effects may occur if Seattle faces a localized snow event (i.e. convergence zone snow). For example, holiday shoppers may go to Bellevue to buy Christmas presents if they cannot get to Seattle stores.

For local governments, responding to a snowstorm can be a major unbudgeted expense. Many cities have spent more than their original snow-removal budgets when faced with unexpected or unusually large storms. In 2011, a blizzard that hit New York City cost over \$68 million, \$30 million more than their yearly snow-removal budget.⁷⁵⁸ The same could happen in Seattle, especially during winters with multiple winter storms. Since snow and ice are common occurrences, it can be very difficult to get an official disaster declaration for snow events and therefore difficult to receive federal aid.

Climate change may introduce new challenges. Frigid weather places increased demands on power systems as people try to heat their homes. In the past, demand peaks have not reached the point of crisis and there have been no cases of power rationing as in other parts of the country. However, if projections are correct and future snowpack is reduced, Seattle City Light may have to purchase additional power from external sources to meet winter demand.

Secondary hazards of snowstorms can be flooding and landslides as the snow melts. In heavy snowstorms, structural damage is likely. During the 1996 snowstorm, over 80 roofs suffered damage. These failures are always a danger since the Seattle area is prone to wet, heavy, and sticky snow.

Outlook

Climate change may be decreasing the frequency of snow events. The University of Washington Climate Impacts Group projects that greater Puget Sound area will see less winter precipitation falling as snow by the 2040s. This change will be most significant in mid-elevation basins that typically receive a mix of snow and rain in the winter. Mountain snowpack is projected to decline 42-55% by 2070, as more precipitation falls as rain rather than snow.⁷⁵⁹ A climate change study on snowpack in the Puget Sound lowlands has not yet been conducted.

Other global weather patterns will continue to overlay climate change. These include the El Niño Southern Oscillation (ENSO) that alternately brings El Niño and La Niña to the Pacific Northwest. El Niño is characterized by warmer, somewhat dryer winters; La Niña is characterized by wetter, cooler, and snowier winters. The Pacific Decadal Oscillation (PDO) can also bring climate variability. The PDO is a 20 to 30-year cycle of cooling or warming in the sea-surface temperatures and winds over the Pacific Ocean. It appears the PDO has been in a warming phase since the mid-1970s.⁷⁶⁰

Conclusions

Despite a relatively mild climate, Seattle is a northern city, so it can and does receive heavy snowstorms. This creates a dilemma for the government and the population. Extensive preparations become very costly if snow fails to materialize; if snow does come and the city is not prepared, significant transportation problems can arise.

17. WATER SHORTAGES

Water shortages develop when the supply of water cannot meet demand. The cause can be either a decrease in supply, a rise in demand, or a combination of both. Water shortages are not the same as droughts, which are prolonged periods without precipitation. Shortages often develop as a result of drought, but can also be caused by overconsumption, or structural failures such as pipeline breaks. The latter are covered in [Built Environment Failures](#).

Seattle uses water for direct consumption (e.g., drinking, washing, and watering lawns) and to generate electricity. Both types of consumption are cyclic. Water use peaks in the summer with demand determined by the heat and dryness of the weather. Power consumption peaks during the winter, when the demand for heating and illumination increases. The extent of its demand also depends on the weather. The colder the winter, the more power required.

SPU currently serves 1.6 million retail and wholesale customers in King and Snohomish counties. The utility manages reservoirs in the Cascade Mountains to supply water for consumption and fisheries, and to provide flood mitigation and hydropower generation.

During the spring, SPU captures rainfall and runoff from melting water from the winter snowpack and stores the water in city-owned reservoirs. Water remains there until the demand increases, requiring releases from storage. During peak demand, water is drawn from the reservoirs at a greater rate than it is being replaced. This yearly cycle of recharge and drawdowns is the city's "water budget."

For Seattle's drinking water supplies, the end of the yearly drawdown cycle is dependent on the timing of fall rains, which is uncertain and cannot be not forecasted well in advance. If the water budget is not renewed each year, Seattle could face a water shortage.

SPU draws most of its water for direct consumption from two watersheds in the Cascade Mountains — the South Fork of the Tolt River and the Cedar River—and from well fields in the Highline area. The

Key Points

- ❖ *Lead Agency – Seattle Public Utilities*
- ❖ *A water shortage occurs when the demand for water exceeds supply. It can be caused by the onset of a drought or sudden infrastructure failure, such as a major pipeline failure or treatment plant shutdown.*
- ❖ *Peak demand for water for people and businesses occurs in the summer. Replenishment of the city's reservoirs does not occur until the spring, when snow accumulated during the winter melts and runoff from rains is stored. Low winter snow accumulation followed by hot summer weather or later-than-normal return of fall rains can cause a shortage.*
- ❖ *It is extremely unlikely that Seattle would run out of water. To avoid failure of the water supply, a series of increasingly severe usage curtailments would be enacted to ensure that Seattle would have enough water for essential functions.*
- ❖ *While the curtailments would mitigate a greater disaster, they would have increasingly severe impacts on residents and businesses.*
- ❖ *The City of Seattle depends on its two Cascade watersheds, the South Fork Tolt and Cedar Rivers, for its water supply. Both reservoirs are managed for instream flows for fish.*
- ❖ *Decreasing demand has mitigated the pressure on the water supply. Total water consumption has gone down despite increases in population in the area served by SPU. Maintaining public health is the highest priority in managing a water shortage.*

Cedar supplies roughly 70% of the drinking water to the greater Seattle area, while the South Fork of the Tolt supplies one-third. The amount of water in these rivers is dependent on the yearly levels of snowpack in the mountains. Alternative water supplies available in an emergency or shortage include the Seattle Wellfield, three wells located near Sea-Tac airport.⁷⁶¹ This water is delivered to Seattle's retail customers and SPU's wholesale customers through large diameter pipes. Unlike an electric utility that is connected to a regional and national power grid, Seattle must rely on its own watershed resources. There is no "water grid" that can provide water from outside sources in a shortage.

Water shortages can lead to decreases in power production. Roughly 40% of the city's power comes from dams Seattle City Light owns and operates on the Skagit and Pend Oreille Rivers. The remaining power is generated from a mix of power sources purchased from the Bonneville Power Administration (BPA) and other renewable sources. When the amount of water in the reservoirs drops, SCL cannot generate as much power. When peak demand exceeds supply, SCL buys power from other sources, mostly the Bonneville Power Administration.⁷⁶² Most of these demand peaks are anticipated so the utility can buy power ahead of time or swap power with another utility. The real costs occur when water shortages are unforeseen, and the City of Seattle must make emergency purchases.

Droughts are slow-onset, or "creeping" disasters because their effects accumulate slowly over time. Even with modern forecasting tools, there is always some uncertainty about when to adopt water restriction measures. Water resource managers are never sure if they are overreacting whenever usage restrictions are requested preemptively. This doubt can cause managers to delay action until a drought is well underway. There are three different types of droughts that affect the Seattle regional water supply. Winter/spring drought from low accumulations of snow in the mountains, summer drought from dry conditions and hot temperatures, and fall/early winter drought from delayed fall rains.⁷⁶³ SPU and SCL, with real-time information about snowpack, can typically forecast water supply for the summer and manage resources accordingly. They cannot, however, predict the end of the drawdown cycle and timing of fall rains.

To respond to a water shortage, SPU uses four levels of water use curtailments: advisories, voluntary restrictions, mandatory restrictions, and emergency curtailments. As a shortage worsens, SPU enacts progressively stringent restrictions.⁷⁶⁴

SPU uses several data and forecasting tools to monitor water resources.⁷⁶⁵ They work with USGS to monitor stream flows and the Natural Resources Conservation Service (NRCS) to monitor snow levels. Additionally, SPU monitors daily weather forecasts and 30- and 90-day multi-season climate outlooks and tracks El Niño/La Niña conditions. SPU uses an in-house reservoir management and stream flow forecast model which is updated hourly with meteorological and hydrological data. It can simulate the current snowpack, soil moisture, aquifer storage, and stream flows of the watersheds, allowing SPU to analyze future reservoir operating scenarios.

Nationally, per capita water use has decreased by nearly 30% since 1975 despite a growing population and economy.⁷⁶⁶ Within Seattle, water demand leveled off during the 1980s then dropped off sharply in 1992 after a severe drought and mandatory curtailment measures. Since then, the combined effects of higher water rates, the 1993 state plumbing code, conservation programs, and improved system operations have kept both billed and total consumption significantly below pre-drought levels. Water consumption further declined between 2000 and 2005 due to additional conservation efforts represented by the regional 1% Conservation Program. Despite a population increase in Seattle of 44% since 1990, total water demand has declined 27%.⁷⁶⁷

Peak water demand has fallen dramatically since the 1980s. In the 1980s, hot summer weather could produce peak consumption of over 325 million gallons per day (MGD), compared with only 270 MGD in 1994 when temperatures reached 100 degrees. Ten years later, during the two very hot, dry summers of 2003 and 2004, peak day consumption reduced further, barely reaching 250 MGD. Between 2005 and

2010, average peak day consumption has been around 200 MGD. Peak day consumption through 2035 is estimated to remain around 200 million gallons a day.⁷⁶⁸

Droughts do not necessarily cause water shortages. However, they can contribute to shortages. The most common measure of drought intensity is the Palmer Drought Index that describes dryness. The values usually range from -4 (extremely dry) to +4 (extremely wet). The values are a function of precipitation and temperature that are obtained by comparing current local scores with average scores for the area. One significant drawback is that it underestimates the role of water stored in snowpack.⁷⁶⁹

Breaks in the pipeline distribution system or events that force SPU to shut down the water system preemptively, such as a failure at one of the water treatment facilities, can also cause shortages. Pipeline breaks or other infrastructure failure often result from other disasters like earthquakes, floods and explosions, but they also can occur as a result of mechanical failure or human error. More information on water pipe breaks can be found in the section on infrastructure failures. Lastly, a major contamination incident could cause a water shortage, as a detection of harmful bacteria, such as E. coli, could call for a temporary shutoff to certain affected areas.

History

Water shortages are a regular occurrence in the region's history. This section reviews the significant shortages to reveal the duration, severity, and cause. Drought conditions are cited as an indirect and imperfect measure of the shortage. Some short-term shortages were caused by pipeline breaks, none of which precipitated an immediate health danger in the city or prompted water rationing.

1919. A hot, dry summer.

1928/29. Rain was 20% of normal. This was the longest recorded drought in Washington at that time. It exacerbated the 1930 drought.

1930/31. Moderately dry weather occurred in Western Washington. The [Palmer Drought Severity Index](#) hovered in the -3 range.

1938. A record dry growing season in Western Washington at the time. The state studied the minimum stream flows necessary to preserve fish life. Stream flows are still an issue and complicate the regulation of reservoir levels.

1941-1945. During March and April 1941, the Palmer Drought Index was -4, then hovered between -3 and -1.5. Temperatures west of the Cascades were usually above normal.

1952/53. Puget Sound was hit with dry weather beginning in January and continuing through April 1953. The worst came during the winter when the Palmer Drought Index reached -4. The state ordered power cuts for hydroelectric dams.

1965/66. King County recorded Palmer Indices of roughly -1.5 from June 1965 to December 1966.

1967. The summer was dry with no significant rain from the third week in June to the first week in September.

1976/77. Precipitation was 57% of normal in Seattle. For three months, the Palmer Drought Index was in the -4 range. Hydroelectric power generation dropped 47%. City Light had to make emergency power purchases at highly inflated prices. As a result, it had to increase its debt and put a surcharge on electric bills.⁷⁷⁰

1987. Hot, dry summer weather increased water demand, causing a rapid drop in reservoir levels. Mandatory restrictions were adopted. Consumption dropped by 10%.

November 1987. The Tolt pipeline broke, temporarily dropping the supply reaching customers by 30%. This impacted 10,000 customers, but only for several hours. Water was rerouted through the Cedar

River pipeline, placing additional demands on the Cedar River Reservoir. Voluntary restrictions dropped consumption by 5%. Luckily, November had low demand, and the Cedar River pipeline was able to completely supply the city.

1988. The level of Cedar River Reservoir fell below its outlet. The Seattle Water Department responded by installing emergency pumps to extract water. The pumps were left at the site and used again in 1992.

August 1988. The Tolt pipeline broke during a period of peak use, threatening 100 suburban customers with loss of service or low water pressure. The public was asked to curtail all unnecessary water use. The goal was a 30% reduction, but only 18% was achieved. The outage lasted several days.

1992. Scarce winter rains prompted emergency measures to avoid severe reservoir depletion. Enforced mandatory restrictions reduced water consumption by 25- 30%. Additional emergency pumps installed in 1988 at Cedar River Reservoir were used. The silver lining to the 1992 shortage is that per capita water consumption remained low even after the shortage ended.

2001. Snowpack appeared to be very similar to that of 1992. Water supply forecasts made through the end of the year looked dire until a late snowfall occurred in March.⁷⁷¹ Snowpack in SPU's watersheds ended up peaking at 75% of normal and reservoirs were full or nearly full by June. Nonetheless, with a state-wide drought emergency in effect, SPU asked customers starting in early April to voluntarily reduce water use by 10%.

2002. Fall rains came later than normal. SPU had to mobilize pumps on Chester Morse Lake. SPU entered into the voluntary curtailment stage and warned customers that water restrictions could occur if the weather continued to be dry. No further restrictions were imposed.

2005. The worst snowpack in 60 years at SPU's watersheds, causing SPU to enter into the advisory stage. Effective reservoir management and some late spring/early summer rainfall brought reservoirs back to near normal levels. By early July, the advisory was lifted.

2015. A new record-low snowpack occurred in the state, with a historic hot and dry summer. The Governor declared a state-wide drought emergency by mid-May. Even though reservoirs were operated to store more than their typical capacity in anticipation of the drought, SPU entered into the voluntary curtailment stage, asking their customers to decrease water consumption by 10% (which was achieved). Regional water supply conditions returned to normal in November.

Based on significant past events, shortages seem to occur once every five to ten years. In most cases, water shortage response actions were implemented prior to or during the summer. The extent of losses is difficult to determine. The most severe shortages were the result of either low snowpack or dry fall conditions.

2017. Seattle went 55 days without rain, breaking a record set in 1951.

2023: An unusually dry summer followed by a delay in sustained autumn rain led SPU to ask customers to voluntarily use less water for the first time since 2015. By December 2023, supply had bounced back to normal levels.

Vulnerability

The main direct vulnerability for urban areas in a water shortage is financial, as water restrictions and/or price increases are put in place to lower demand and protect supply. This applies to both drinking water and power. However, it is unlikely that restrictions and price increases would become so severe that there would be public health or public safety impacts. Water is still a cheap commodity in the U.S. and only about 10% is used for direct human consumption.

The history of water shortages shows that the power and water supply systems have different vulnerabilities to drought. Their water demands differ, and Seattle's reservoirs are located far enough

apart that precipitation can be significantly different at each location.⁷⁷² Often, only one system is affected by dry weather. Overall, the city's water system would be more impacted by a severe water shortage; whereas SCL's power system is connected to the regional power supply, water outside the SPU system generally cannot be added to supplement SPU's water supply.

The heaviest water users are affected the most by water shortages. Commercial customers have traditionally been the biggest consumers, but many have succeeded in sharply reducing consumption. Some heavy users remain, such as landscapers and greenhouses, as well as households with larger lots and those with more members.

Maintaining stream flows for salmon is a challenge for the utilities during droughts. To create these flows, SPU and SCL must let water bypass their facilities during the spring when the reservoirs are most easily replenished and, in the fall, when water is being drawn from storage. During dry years, the amount of water they release can cause water reserves to drop significantly.

Wildland fire is becoming a more prominent threat to the water system. Climate change is projected to increase wildland fire risk west of the Cascades where most of Seattle's reservoirs are located.⁷⁷³ Fires that occur near the watersheds can degrade surface water supplies by increasing turbidity, impacting aquatic species, and reducing reservoir storage.⁷⁷⁴ SPU maintains a wildland fire crew that works with the Washington Department of Natural Resources to protect Seattle's watersheds from fire. This is particularly important for the Cedar River, which SPU does not filter. Seattle City Light was awarded a Hazard Mitigation Grant in 2023 for a defensible space project to protect the Cedar River Watershed. This is the first wildfire mitigation grant approved for FEMA funding on the west side of the Cascades in Washington State.

SPU and SCL are publicly owned utilities, and any increased costs from water shortages are often transferred to their customers in the form of higher rates. SPU water rates are projected to increase at 3.4% annually through 2026.⁷⁷⁵ Seattle's low- and fixed-income residents will be the most vulnerable to rate increases.

A water shortage could indirectly expose Seattle residents to harm if it contributes to power failures, if low stream flows suppress power production at a time of peak demand, or to fires if water pressure is low or vegetation is dry.

Consequences

Seattle has a water shortage risk that is likely to increase with climate change; however, an even bigger driver will be demand for water. With good planning, it will be possible to boost supply or enact conservation measures to address demand increases. Climate change impacts can be mitigated through system adaptations and good reservoir management.

While Seattle will certainly face water shortages in the future, these will probably be on the same order of magnitude as previous shortages. Seattle's water supplies seem secure. On the power generation side, the situation seems more challenging, but the likelihood that a water shortage will cause rolling blackouts seems remote. It is more likely that power rates will increase.

With the effects of climate change on top of regular yearly and decadal fluctuations, a severe multiyear drought could have serious consequences for Seattle and extend beyond economic impacts into the public safety and health spheres. Most of these effects are likely to stem from indirect factors such as wildland fire, power failure, and heat exposure risk. Even under the maximum credible scenario, Seattle is better off than some cities that are truly facing a crisis as their entire supply is threatened.

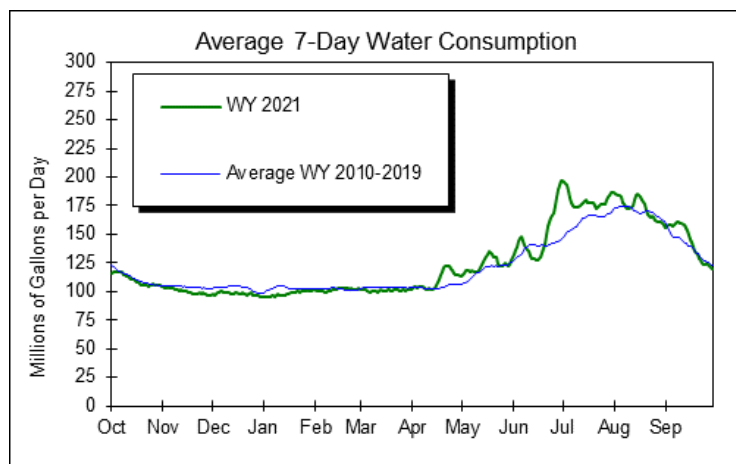
Outlook

In the long term, climate change has the potential to affect the water supply system but is not the only factor that could contribute to future hydrologic changes. Land use, land cover, and reservoir

management can all affect streamflow and water availability. The University of Washington Climate Impacts Group (CIG) projects that average spring snowpack in the Cascade Mountains will continue to decline by 42% to 55% during the time between 2070 to 2099.⁷⁷⁶ They also project that decreased snowpack and early spring melting will contribute to peak streamflow occurring earlier in the year. Summer streamflow is projected to decrease by at least 24% by 2080.⁷⁷⁷ The main implications will be that Seattle’s water resources will be more reliant on variable rain than mountain snowpack, and SPU may face more frequent temperature-driven droughts due to low snowpack and/or early snowmelt leading to an extended summer dry season.⁷⁷⁸

Demand is the critical variable. Total consumption and demand are falling despite population growth, but consumption can still spike, especially in summer months during periods of high heat. These periods are predicted to increase with climate change. If a low snow year is followed by a hot summer, Seattle’s water supply could face at least a short-term challenge. During the 2021 Heat Dome event, water usage spiked to 222.4 million gallons per day (MDG), with the ten-year average sitting at 143.7 MDG. This can be visualized in [Figure 71](#).

Figure 71. 2021 Water Use in Millions of Gallons per Day



SPU forecasts that demand will increase gradually to 147 MGD by 2039, and then decline to stay relatively flat at 132 MGD through 2060.⁷⁷⁹ The Utility is actively working to increase operational resilience by using climate modeling and assessment, as well as by making improvements to the natural and built environment.⁷⁸⁰ SPU states there is less than a 10% probability that Seattle will need a new water supply source before 2060.⁷⁸¹

The challenges are different for SCL. The University of Washington Climate Impacts Group forecasted changes to hydropower in the Columbia Basin, where Seattle gets most of its power. It projects that annual production will decline slightly, with increases in the winter offset by declines in the summer.⁷⁸² SCL is looking to increase power supply. Whereas the 2022 load projections estimated a supply increase of 400 megawatts by 2033, SCL’s 2024 updates identified a need for an additional 1,825 megawatts in this same timeframe.⁷⁸³ The authors caution that, in the near term, annual production will be more influenced by other factors, like El Niño and La Niña events, rather than climate change.

Historically, SCL’s peak demand is in the winter when stream flows are also at their peak. Demand in the summer has typically been checked by the low market penetration of air conditioning systems locally. However, based on American Housing Survey data, the percentage of homes with AC has increased from only 31% in 2013 to a 53.4% in 2021, no longer making Seattle the least air-conditioned city of the top 15 biggest metropolitan areas.⁷⁸⁴ Central and mini-split air-conditioning is becoming more commonplace in newly constructed apartments, and the city has seen a fourfold increase in apartments offering air

conditioning over the past decade.⁷⁸⁵ Population increases will lead to a growth in demand for heating, even as per capita demand goes down due to warming winter temperatures. Taken together, these projections suggest that adaptation to climate change will be easier in the winter than the summer.

Conclusions

Experience suggests that Seattle Public Utilities and Seattle City Light can manage shortages effectively. Since droughts require little in the way of emergency equipment, pose little immediate danger to public health, and have a crisis period that lasts for weeks or months, there has been little reason to activate the Emergency Operations Center. As with other “creeping” hazards, the City of Seattle does not presently have a system in place for prolonged multi-department emergency management. Nevertheless, the current system could be used for interdepartmental city involvement to assist the utilities in managing a severe shortage emergency caused by infrastructure failures.

18. WILDFIRE AND SMOKE

Wildfire is a natural part of a forest's lifecycle. The hazard of wildfire for Seattle is two-pronged; it threatens many assets the City of Seattle owns in the Cascade Mountains, and the Seattle residents are vulnerable to the smoke that wildfire produces. This analysis will include the threat of both of these components of wildfire.

Wildfires in the Pacific Northwest are not a novel phenomenon. Research indicates that the Western Cascades have experienced large "stand-replacing" fires roughly every 200 to 600 years, meaning the majority of trees in the forest are burned.⁷⁸⁶ The eastern Cascades tend to see more frequent, less severe fires. These differences can be observed in [Figure 72](#).

Wildfire influences which tree species grow and where, as well as contributing to nutrient cycling and nitrogen fixation. Indigenous Peoples in the Pacific Northwest furthermore used small-scale controlled burns to remove undergrowth, making space for new plants and wildlife, as well as to promote the growth of edible plants and preserve cultural traditions.⁷⁸⁷ These cultural burns also reduced fire risk later in the summer as conditions become drier, as they minimized burnable ground fuels. The arrival of European colonizers brought an era of industrial logging to the region that removed much of the native old growth forests and an end to this practice, leaving forests today to be made of younger trees dense with undergrowth and ladder fuels that can fuel rapid fire growth.

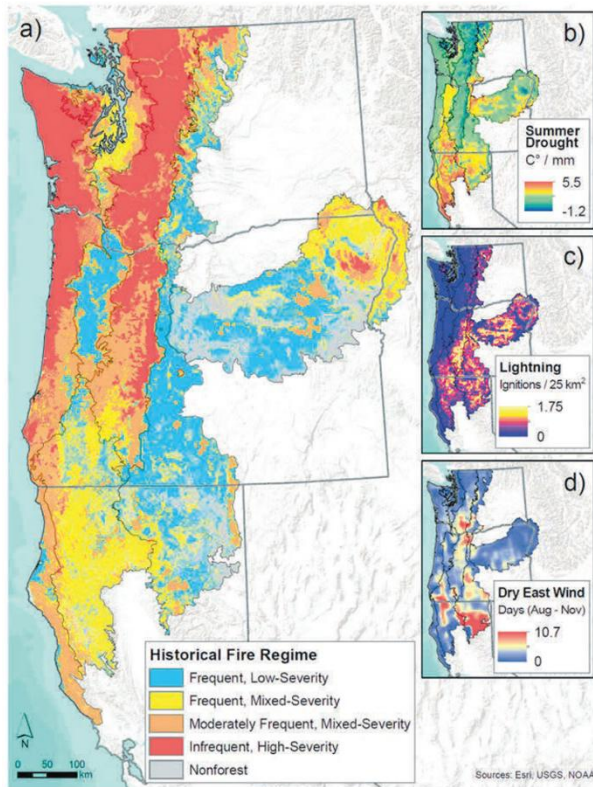
Climate change is expected to exacerbate the risk of wildfire. Insect outbreaks and tree diseases that can harm tree and ecosystem health are projected to increase in occurrence and intensity, making forests more vulnerable to natural disturbances such as wildfire.⁷⁸⁸ Furthermore, projected decreases in summer precipitation, warming, and earlier snowmelt are expected to both lengthen fire season and create drier, more combustible fuels, increasing chances for wildfire.⁷⁸⁹ These

Key Points

- ❖ *Lead Agency – depends on location and impacts. For fires in watersheds: Seattle Public Utilities or Seattle City Light. For smoke: Seattle/King County Public Health*
- ❖ *Wildfires are new hazard in this analysis. Given the increasing number of fires throughout the West that threaten City assets outside the City proper (e.g., City Light and Public Utilities owned dams) and smoke from wildfires that can drift into Seattle, the importance of wildfires in Seattle's risk profile has grown.*
- ❖ *Wildfire risk is dependent on a variety of factors, including vegetation, temperature, soil moisture, relative humidity, wind, fuel density, and forest management practices.*
- ❖ *The area burned in US wildland fires doubled from 1984 to 2015, with studies attributing higher temperatures and changing precipitation patterns from climate change responsible for at least half of this increase.*
- ❖ *The average area burned annually in the Pacific Northwest is expected to triple by the 2040s given current greenhouse gas emission rates.*
- ❖ *Warmer temperatures, lower snowpack, and changes in precipitation will lead to increased fire risk in the western cascades.*
- ❖ *While Seattle has a very limited wildland urban interface, the City owns assets such as dams, watersheds, buildings, and worker housing that is directly vulnerable to wildfire. Thus, Seattle is indirectly vulnerable because wildfire puts power generation and water supply at risk.*
- ❖ *Wildfires contribute to carbon emissions, have the potential to degrade air quality in the city, and can be expensive to suppress.*

changes increase the dryness of fuels and lengthen the fire season, creating conditions more favorable for fire over a longer period of time. This includes an expanded window of time when conditions are more suitable for large fires.⁷⁹⁰

Figure 72. Historical fire regimes in the Pacific Northwest. Map from *Fire Ecology and Management in Pacific Northwest Forests*.



The wildland urban interface (WUI) is the area where the urban development and wildland meet on at least one side. Seattle’s primary risk, though limited, is from areas defined as the wildland urban intermix. Intermix is found between the interface and the wildlands or in low-density pockets of urban areas. Development in the WUI is particularly vulnerable to damage from wildfire considering structural proximity to flammable debris. The University of Wisconsin identified WUI areas globally. [Figure 73](#) identifies these areas in Seattle.

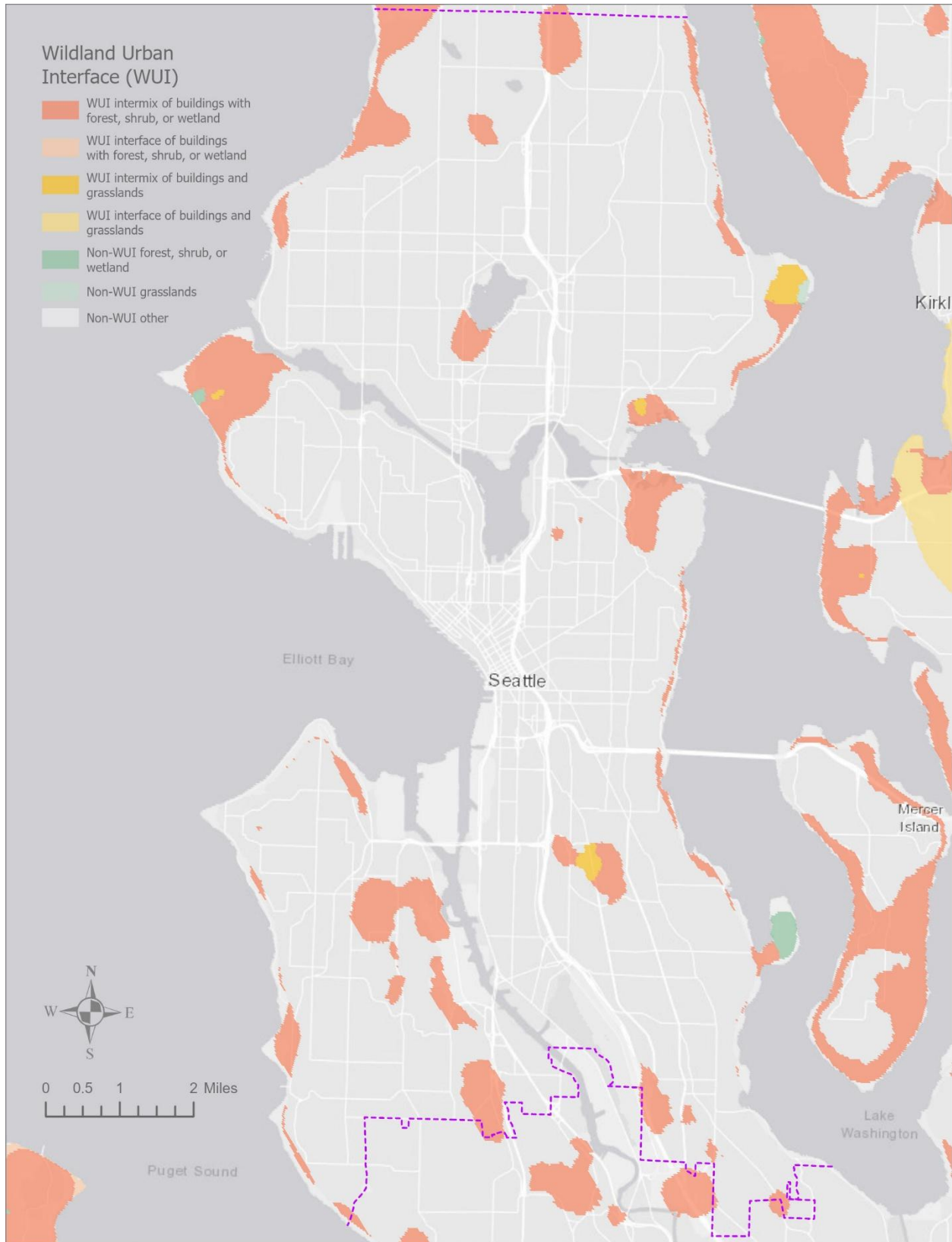
As of 2025, Washington State is currently in the process of establishing building codes for new construction or remodeling within the WUI. The Washington Department of Natural Resources is working to create maps illustrating both WUI hazards and WUI risk. Once mapping is complete, only areas deemed high and very high risk will be required to use certain fire-resistant materials and to limit trees and other vegetation around structure. It’s unlikely that Seattle will have any areas with this risk designation. Despite low risk for large costly fires spread largely through natural vegetation including grass, brush, and mature trees within the city, brush fires burning mostly in grass and low-lying brush along roadways are a common

occurrence and pose a threat to homes and businesses.

Although wildfire risk is low within city limits, the City of Seattle owns and operates assets that are vulnerable to wildfire risk, including the South Fork Tolt and Cedar River Municipal Watersheds owned by Seattle Public Utilities, as well as several hydroelectric dams owned by Seattle City Light. As these assets are critical for providing safe drinking water and a stable electricity supply for Seattle residents, their risk poses a significant hazard for the city. SPU has a Wildland Fire Crew that is trained to provide immediate response to wildfire threats within the South Fork Tolt and Cedar River watersheds.

Smoke from wildfires presents a direct hazard to Seattle and poses a significant concern to public health. Wildfire smoke is comprised of a complex mixture of pollutants, including particulate matter, carbon monoxide, nitrogen oxides, volatile organic compounds (VOCs), as well as many other toxics and trace elements. The fine particles composing wildfire smoke, referred to as Particulate Matter 2.5 or PM2.5, are the primary pollutant of concern and can be six-times smaller than the width of a human hair. These particles are respiratory irritants and can be inhaled into the deepest part of the lungs and can enter the bloodstream.⁷⁹¹ Wildfire smoke exposure can range from short-term symptoms such as headache to sore throat, coughing, burning eyes, dizziness, and wheezing. More serious health complications include asthma, cardiovascular complications, stroke, kidney failure, and premature death.⁷⁹² Those with

Figure 73. Seattle Wildland Urban Interface



City of Seattle, Bureau of Land Management, Esri, HERE, Garmin, USGS, EPA, NPS, Esri, HERE, NPS

existing respiratory, cardiovascular, or kidney diseases, pregnant people, the elderly, and children are more vulnerable to the effects of wildfire smoke. People working outdoors and populations living unsheltered face a greater risk of exposure to wildfire smoke, also making them more vulnerable to the effects of wildfire smoke.⁷⁹³

Figure 74. Air Quality Index Levels as Defined by EPA.

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

Wildfire smoke severity is measured by the Air Quality Index (AQI), which is determined by the concentration of PM2.5 in the air. The AQI runs from 0 to 500, with a higher AQI indicating a greater level of air pollution and greater health concerns. Each level of the AQI scale comes with different recommendations for exposure, such as limiting time outdoors or certain activities.⁷⁹⁴

The presence of wildfire smoke in the Seattle area is largely dependent on the location of a wildfire and prevailing wind direction. During the early summer months, winds typically prevail from the southwest or west in Seattle. With most fires in Washington state occurring to the east of Seattle, oftentimes westerly winds will push smoke further east into the United States and Canada. While occurring less frequently, a major wildfire occurring on the Olympic Peninsula could result in significant levels of wildfire smoke in the metropolitan area. Later in the summer and through the early fall, the prevailing wind direction can change when a strong high-pressure system is located east of the Cascade Crest, causing very dry winds to flow from east to west over the mountains. The air then becomes compressed as it sinks, causing it to rise in temperature. This hot, dry wind increases the risk for local wildfire activity and can push smoke from any fires in East of the Cascades into the metropolitan area.⁷⁹⁵

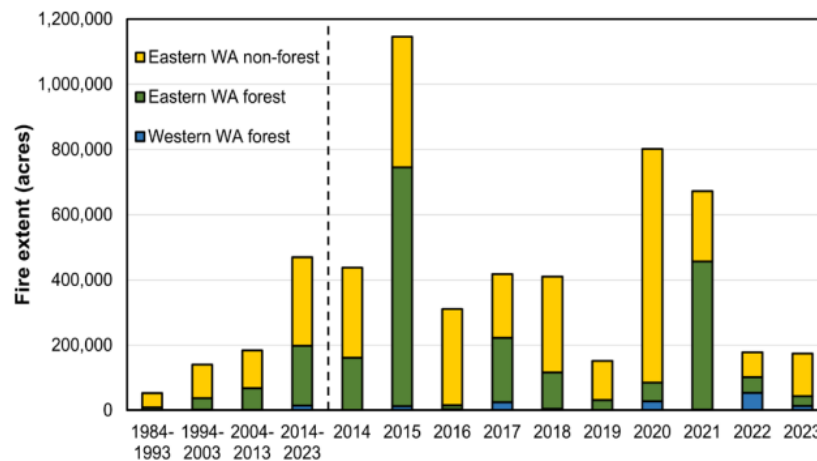
History

Climate change is increasing frequency and severity of wildfires, fire intensity and resulting in an increase in the number of acres burned throughout the western United States and Canada, which in turn is increasing the frequency duration in which of smoke is capable of impacting air quality in our area. The earliest written accounts of fires and smoky conditions in Seattle go back to the 19th century, with reports of fires started by lightning strikes, coal-burning steam engines, and campfires. There are numerous reports of thick smoke choking the city, including one by Mark Twain in 1895. These accounts,

summarized in an article by CrossCut, suggest that the impacts were severe.⁷⁹⁶ The last decade has seen unprecedented smoke, with 2020 having the highest fine particle levels since the Puget Sound Clean Air Agency started monitoring levels in 1999.⁷⁹⁷

It is important to note that the relationship between air quality in Seattle and the severity of fires in Washington is complicated; a relatively calm fire season can still mean many days of poor air quality in Seattle, depending on the smoke's origin. For example, in the graph in [Figure 75](#), 2017 was a calm year in acres burned. Despite this, Seattle saw 16 days of smoke-impacted days due to smoke from fires in British Columbia.

Figure 75. Total Fire Acreage Burned Across Washington State since 1984.⁷⁹⁸



2012. A wildfire in Siberia produced a smoke plume that affected the air quality in the Pacific Northwest from July 6-10, illustrating that wildfires far removed in geographic locations can impact local air quality.⁷⁹⁹

2015. The worst fire season in Washington's recorded history, with 1.6 million acres, or 1,562 square miles, burned from June to September. Air quality in the region was particularly impacted on August 22nd and 23rd, as easterly winds brought wildfire smoke into the Seattle and Portland metropolitan areas, degrading the air to Unhealthy level. Fire suppression cost the state more than \$560 million.⁸⁰⁰

2016. A calmer season compared to 2016, with 293,717 reported acres burned.⁸⁰¹ There are no reports of diminished air quality in Seattle due to smoke.

2017. A more active fire season in 2016, with 404,223 acres reported burned. Despite a relatively active fire season, the deteriorated air quality events in Seattle were largely due to smoke moving into the area from fires north in British Columbia. Overall, King County experienced 16 smoke-impacted days in 2017.⁸⁰² (Cliff Mass - [Cliff Mass Weather Blog: Smoke Pushes Into Washington State](#)).

2018. Seattle experienced nine days of deteriorated air quality due to wildfire smoke, all of which occurred in August. Parts of the city recorded an AQI of 220, considered unhealthy for all populations.

Washington saw a total of 434,834 acres burned in the 2018 fire season.⁸⁰³ The Seattle EOC did not activate.

2019. A mild year across the state. Seattle did not see any days of wildfire smoke pushing the air quality into the unhealthy for sensitive group category. Across Washington, total acres burned was much lower than the ten year average (320,469), with 169,742 acres reported burned.⁸⁰⁴

2020. Seattle saw the highest July-September maximum daily fine particulate levels recorded by the Puget Sound Clean Air Agency. Seattle experienced 4 very unhealthy levels of air quality, 4 days of unhealthy air, and 6 days unhealthy for sensitive groups. 12 of these days occurred during a major smoke event from 9/8-9/18, which was fueled by hot and dry easterly winds. Of note, a combination of smoke and clouds on September 12th diminished solar radiation to such an extent that the high temperature (61°F) was 11 degrees lower than forecasted (72 °F).⁸⁰⁵ Overall the Pacific Northwest region saw 223% of the ten-year average for acres burned, 90% of which burned in the month of September. It was the most active fire season since 2015, with a total of 842,358 acres burned in the state of Washington.⁸⁰⁶

2021. Another above average fire year in Washington State, with 674,249 burned acres.⁸⁰⁷ Despite this, smoke events in Seattle in 2021 were limited, with only 1 day reaching an AQI unhealthy for sensitive groups, and 2 days designated unhealthy.⁸⁰⁸ Of note, a smoke event in August coincided with an extreme heat warning, as temperatures crept above 90°F.

2022. This was a comparatively calm wildfire season, with acres burned across the state totaling 173,662, falling below the 10 year-average of 472,881.⁸⁰⁹ The Bolt Creek Fire, burning just 1.5 miles north of the town of Skykomish on the Western slopes of the cascades, burned nearly 15,000 acres and led to the declaration of several evacuation orders. While a mild fire in scale, easterly winds pushed smoke into the western part of the state, leading to a smoky fall in Seattle. In total, Seattle saw 21 days impacted by air quality (AQI > 100) in September and well into October.⁸¹⁰

2023. Another relatively calm year for Washington state. Large fires, defined as events larger than 100 acres, burned a total of 174,300 acres across Washington in 2023, nearly 44,000 of which were forested areas.⁸¹¹ Of particular note for the City of Seattle, the Sourdough wildfire threatened the Seattle City Light-owned Skagit Hydroelectric Project, at its peak reaching over 7,000 acres. Two of the three dams were twice taken offline, reducing the City's power supply and requiring SCL to purchase other sources of energy.

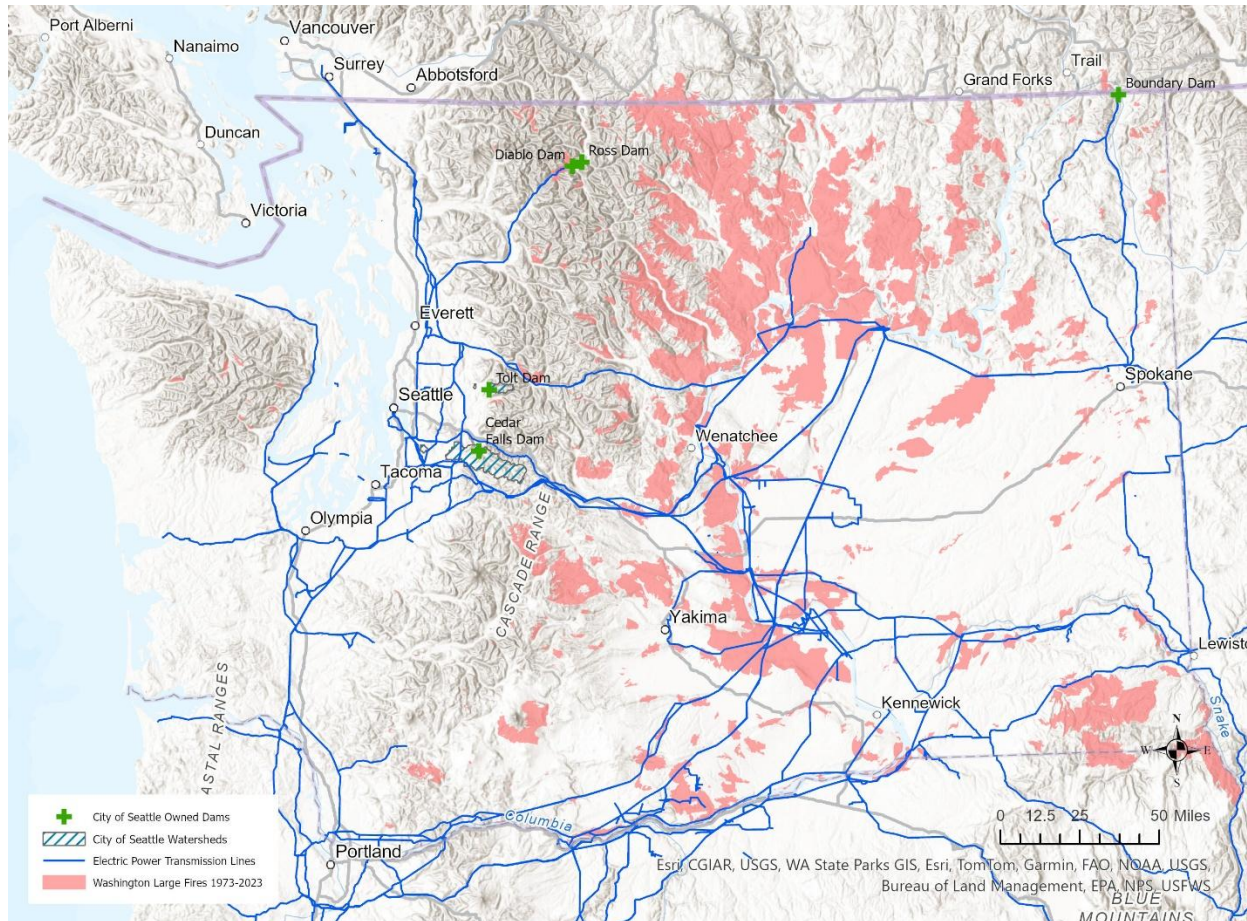
Vulnerability

Seattle has a very limited wildland-urban interface and therefore has limited exposure to wildfire within the city limits. However, the City of Seattle owns water supply and power generation assets in the Cascades and in northeastern Washington that are exposed to wildfire risks. Fires affecting these assets put the personnel working at them and the services that they provide at risk.

For Seattle City Light, risk is highest where transmission lines cross through forests and at generation sites that are the most remote. Managing wildfire risk is not new for Seattle City Light. In 2005, a hiker started a fire off Highway 20 between the SCL-owned company towns of Newhalem and Diablo, which burned into the right-of-way below SCL's transmission towers. In 2015, lightning ignited the Goodell Creek Fire, which burned thousands of acres, caused the evacuation of Newhalem and Diablo and temporarily shut off the transmission lines from the Skagit Hydroelectric Project. A map of large wildfires across Washington from 1973-2023 and their proximity to electrical infrastructure can be seen in [Figure 76](#). As these fires can threaten the energy supply the city relies on, SCL created a

comprehensive [Wildfire Risk Reduction Strategy](#). Released in 2023, the plan uses several strategies to identify, manage, and mitigate the risk to their assets and personnel. Although SCL’s power infrastructure is predominantly on the western side of the cascade slopes, which sees less frequent fire than the eastern side, the risk of fire impacting their assets grows as climate change progresses and development of the WUI expands.

Figure 76. Washington Wildfires in Relation to City of Seattle Owned Infrastructure



Seattle Public Utilities faces their own set of risks and vulnerabilities to wildfires. The utility manages two watersheds, the Cedar River and South Fork Tolt River Municipal Watersheds, as well as the Lake Youngs Reservation. All three locations are closed to the public and development, although Lake Youngs is surrounded by suburban development. The restricted access to these areas is somewhat protective against fires, as most fires are ignited by human activity, although some human activity does take place in/around the property boundaries.⁸¹² While on the wetter side of the cascade crest, both watersheds are vulnerable to the hot, dry easterly winds that can fuel fires. Seattle Public Utilities is in the process of developing a Wildfire Management Strategy to plan for and mitigate risks of wildfires in the municipal watersheds.

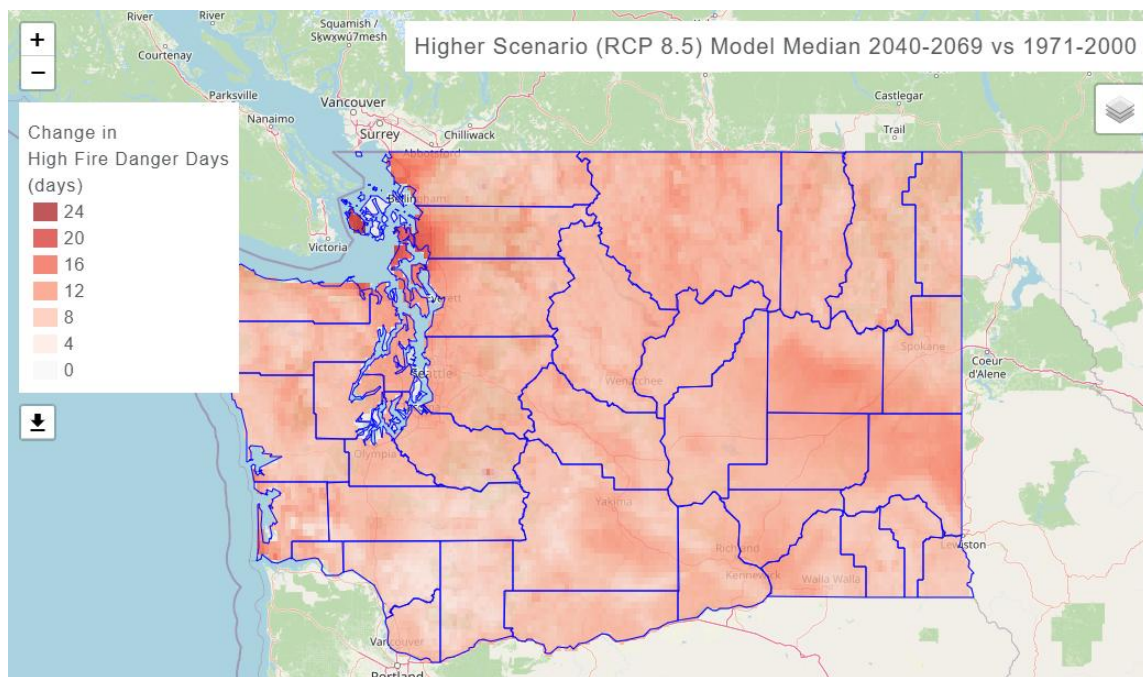
In recent years, smoke from fires outside our immediate region has made its way into the Puget Sound region via long-range transport winds. In 2020, wildfires across Oregon were fueled from hot and dry easterly winds, creating a “super-massive” smoke plume as large as the state itself. When the wind pattern shifted, the smoke plume was pushed into Washington, choking the region with unhealthy air for over a week.⁸¹³ This event highlights the difficulty of pinpointing locational vulnerability to wildfire smoke, as smoke can drift hundreds, if not thousands, of miles from the fire where it is being produced.

This makes Seattle not only vulnerable to smoke from wildfire events in Washington, but also those in outside locations such as Oregon, California, Canada, and as far away as Siberia, such as the smoke the Pacific Northwest saw in 2012.

Within the city, outdoor workers are particularly vulnerable to the impacts of wildfire smoke exposure. In 2019, this totaled approximately 26,000 people, or 4.4%, of people who work in Seattle.⁸¹⁴ This estimate includes the industries of agriculture, forestry, fishing and hunting, and construction. In December 2023, the Washington Department of Labor & Industries (L&I) permanently adopted [protective rules](#) for outdoor workers, which applies to all employers with employees who work outdoors. The rules require employers to be prepared for the impact of wildfire smoke may have on their workers by creating response plans, providing training, monitoring smoke levels, implementing communications systems, and ensuring employees have access to personal protective equipment for voluntary use and prompt medical treatment if necessary. The rules set trigger points for employers to take specific actions when the particulate matter in the air reaches certain levels.

Wildfire smoke can be particularly dangerous to those without access to indoor areas with filtered air, such as those experiencing homelessness. Despite the dangers of poor air quality exposure, emergency cleaner air shelters in Seattle haven't seen high numbers of attendance in the smoke events of recent years.⁸¹⁵ Compared to the hazards of extreme heat or cold that can cause illness or death more rapidly, the effects of smoke exposure are more nuanced and can appear slowly over the days spanning an event and up to 5-days following smoke exposure. This can diminish a sense of urgency to seek clean air, especially for people who may already need shelter, food, and water. While consequences of both extreme heat and wildfire smoke require further study, research suggests heat and smoke together can be particularly dangerous, causing oxidative stress and inflammatory impacts in the human brain.⁸¹⁶

Figure 77. Likelihood of Climate and Fuel Conditions for Wildfire in King County



The map shows the change in annual high fire danger days compared to the 1971-2000 average. A high fire danger day is a day in which 100-hour fuel moisture is less than the historical 20th percentile. For example, a location with a value of 2 means that there are 2 additional days in which 100-hour fuel moisture is less than the 20th percentile. An increase in high fire danger days indicates greater potential for wildfire danger to damage

infrastructure, interrupt businesses, and affect public health and well-being. Source: [Climate Mapping for a Resilient Washington](#), CIG 2022.

Consequences

There are several consequences for power infrastructure exposed to wildfire. Repairing damaged infrastructure can be costly; Goodell Creek fire cost SCL \$2.2 million in damages, response, and labor. A reduction in power supply is a potential impact, although SCL's infrastructure is interconnected with Bonneville Power Administration's (BPA) transmission lines, providing redundancy in the event a transmission or distribution lines are impacted by wildfire. Additional energy purchased from BPA may add to overall costs of the event.

In recent years, several electric utilities around the country have implemented Public Safety Power Shutoffs (PSPS). This is a last resort mitigation tool initiated by utilities to deenergize specific powerlines in high-risk areas experiencing hazardous weather such as extremely hot, dry, and windy conditions. PSPS thus reduces the risk of electrical system ignition of wildfires. PSPS are different than "rolling blackouts" or outages associated with utility failure. While SCL has not yet implemented PSPS, several other local utilities in Washington State have created PSPS policies to enhance wildfire response.

A wildfire impacting the Cedar River or South Fork Tolt Municipal Watersheds may have severe consequences for Seattle, especially regarding water quality. Ash from fires can destabilize soil structure, leading to increased erosion. Areas with burned vegetation can see a reduction in water absorption and retention in the soil, critical for watershed health. These factors can cause increased sediment input and turbidity in streams and rivers within the watershed, as well as reduce reservoir capacity.⁸¹⁷

In addition to turbidity, wildfires can cause chemical contamination of water. Burning infrastructure can release metals such as copper, nickel, lead, and arsenic into the water supply. Fire retardants themselves often contain per- and polyfluorinated alkyl substances (PFAs, or "forever chemicals), which are notoriously difficult and expensive to remove from the water supply, further contaminating water sources. A study on the water quality following the Camp Fire in Paradise, California in 2018 revealed that runoff from fire debris elevated toxic metal chemicals. Chromium, cadmium, Nickel, Lead, and Zinc saw a 200-fold increase in concentration compared to pre-fire values.⁸¹⁸ These metals are not only harmful to human health but also pose a significant threat to aquatic species such as fish, birds, and amphibians as well.

The Tolt Water Treatment Plant Facility has water filtering capabilities, but the Cedar Water Treatment Plant Facility does not. As the unfiltered Cedar River Municipal Watershed supplies roughly 2/3rds of the City's water supply, this means that a wildfire impacting the Cedar River Watershed could degrade a significant portion of the city's water. It is also possible that a fire in the South Fork Tolt River Watershed could result in sediment inputs that exceed the capabilities of the Tolt Water Treatment Facility's water filtration system. Post-wildfire water quality impacts for large wildfires could be recurring, chronic, and/or relatively long-lasting. These impacts are currently in the process of being studied and modeled. Increased erosion and less stable soils can lead to increased landslide risk. This is particularly concerning for the South Fork Tolt River Watershed, which has very steep slopes. Steep slopes can also make it difficult to fight fire.

Outlook

Wildfires will likely increase in number and size due to climate change in addition to a variety of other factors, including increasing development in the wildland-urban interface. Fire season itself is expected to lengthen in duration due to higher average temperatures and predicted diminished snowpack. This will

lead to drier soils and vegetation, enabling fire spread and growth. Climate change is also predicted to alter the historic range and spread of insects and pests, such as the mountain pine beetle, that can weaken trees and plants, making them more vulnerable to burning. High temperatures and increased wildfires across the country may limit and/or exhaust local fire suppression capabilities, leading to weakened response and further fire spread.

Wildfire risk in the Cascades differs between the western and eastern slopes and these differences have implications for future wildfire occurrences. Whereas the western forest is wet, dense, and filled with older-growth trees, the eastern slope has drier, hotter summers, alongside a less dense canopy. Historically, wildfires on the eastern side of the state are more frequent and less severe, with high amounts of underbrush burning and larger, fire-resistant trees surviving. However, centuries of strict fire suppression have led to an accumulation of undergrowth in the eastern forests, posing a greater risk for larger fires on the eastern slopes. Fire suppression policies may not have as much of an impact on future wildfire risk in the historically dense western slopes, but climactic changes, an expected increase in development of the wildland/urban interface (WUI), and population growth are expected to increase risk overall on the west side of the Cascades.⁸¹⁹

Across the state of Washington, the number of high fire danger days is expected to increase. This may lead to closed recreation areas, interrupt timber operations, as well as require increased enactment and enforcement of burn bans, and require more frequent response to wildfire activity.

Conclusions

Wildfires are a natural part of ecosystems here in the Pacific Northwest, but climate change is altering seasonal fire trends, with fire season predicted to increase in duration and fire activity anticipated to increase in severity as the century progresses. This is due to changes in temperature, precipitation patterns, and snowpack, as well as other ecosystem changes such as invasive species and historic burn practices. While Seattle only has a limited direct wildfire risk, the city owns many assets in the Cascade Mountain Range that are susceptible to wildfire. The largest risk wildfire poses to Seattleites is the smoke it produces, which can cause a variety of health issues. Smoke is particularly dangerous for youth, the elderly, those with preexisting health conditions, those who work outdoors, and people experiencing homelessness.

19. WIND

The Pacific Northwest experiences windstorms that can reach hurricane strength. Wind strength is measured in terms of sustained winds and gusts. Sustained winds are the speeds averaged over one minute near the surface of the earth. Gusts are the three to five second peaks that are often more than 25 – 50% stronger than the sustained winds.

Gusts are often what cause the greatest damage. The El Niño / La Niña cycle influences the development of major windstorms. El Niño periods bring warmer, drier winters to the Pacific Northwest, while La Niña brings wetter, cooler, and snowier winters. The cycle between these periods, called El Niño Southern Oscillation (ENSO), is typically three to seven years. It appears that the Pacific Northwest sees more frequent windstorms in the “neutral” years between the two extremes.⁸²⁰ Because these transitions can be predicted three to six months ahead of time, meteorologists can give communities a general warning that the threat of windstorms is elevated.

Mid-Latitude Cyclones

Pacific Northwest windstorms that can reach hurricane strength are called mid-latitude cyclones. The mid-latitudes, from 30° to 60° north, experience a large difference in temperature between the tropics to the south and the arctic to the north. These temperature differences provide the energy source for the storms. The mixing of cold and warm air can create an area of low pressure as a cold front overtakes a warm front. Mid-latitude cyclones are larger than tropical cyclones and maintain their strength over land more effectively. This means they are typically larger and can reach further inland than tropical storms.

Tropical cyclones can become mid-latitude cyclones when they push into the mid-latitudes (30° - 40°) through a process called *extratropical transition* (ET). The western North Pacific has the greatest number of these events in the world. Current meteorological models often fail to anticipate these events. The largest recorded storm to strike the Pacific Northwest, the 1962 “Columbus Day Storm,” was a mid-latitude cyclone.⁸²¹

Key Points

- ❖ *Lead Agency – Seattle Fire*
- ❖ *The Puget Sound region experiences strong windstorms, including ones with hurricane force winds known as mid-latitude cyclones. These storms are wider than tropical storms. The moderating effects of the Pacific Ocean prevent hurricanes.*
- ❖ *Puget Sound is sheltered compared to the Washington Coast, but it can still receive sustained winds of 60-70 mph and gusts up to 90mph. Local terrain has a strong effect on wind speeds. Winds speed up as they move over hills and ridges.*
- ❖ *Pineapple Express storms also pack strong winds, but these storms are known more for their rain than wind. They occur when the jet stream dips into the tropical regions and up into our area. Wind is just one component of these events that also can include flooding, landslides, and power outages.*
- ❖ *Tornadoes are very rare in the Puget Sound region. Washington ranks 43rd in tornado frequency.*
- ❖ *Power outages are the most wide-spread problem caused by windstorms. Structural damage is the costliest consequence of windstorms. Much of the damage comes from falling trees. Floating bridges are particularly vulnerable to wind and wind-driven waves.*
- ❖ *Large windstorms are regional events. The more heavily forested suburban areas are often hit harder than Seattle is. The result is that resources to aid in recovery can be hard to find.*

Atmospheric Rivers or “Pineapple Express”

Atmospheric Rivers or “Pineapple Express” storms in the Northwest have much weaker, although still considerable, winds and often much more precipitation. They occur when the jet stream funnels warm, moist air up from the tropics to Pacific Northwest. These more common storms cause more flooding and landslides than mid-latitude cyclones. When storms occur outside winter they hit the trees in full leaf. The leaves act as sails causing more stress on the tree.

Western Washington experiences several other kinds of wind that are more localized. They typically do not threaten Seattle but can be damaging to communities near Seattle. They are mentioned here to distinguish them from mid-latitude cyclones and Atmospheric Rivers.

Strait of Juan de Fuca Wind Surges

The Strait of Juan de Fuca can act as a wind funnel in the right conditions. In the winter, a strong surge can push sustained wind speeds to 50 – 70 mph and gusts to 70 – 80 mph.⁸²² These events usually occur in north Puget Sound with damage occurring as far south as Mukilteo. Two significant events of this type occurred on December 17, 1990, and October 28, 2003.

Cascade Downslope Winds

These storms are caused by a build-up of high pressure east of the Cascades. When a low-pressure system moves into the Puget Lowlands, the dammed-up air east of the mountains comes surging through the lower passes.⁸²³ Stampede Pass is the lowest pass in the region and the area immediately below it, Enumclaw, routinely sees strong winds as a result. Occasionally, these winds push all the way to Puget Sound, south of Seattle. During one of these events, Fife and Federal Way can be experiencing winds of 50-60 mph while in Seattle the wind speed is close to zero.

Tornadoes

Tornadoes are unusual events in the Pacific Northwest but can and do develop in the region.⁸²⁴ There have been several recorded in the Puget Lowlands. Tornadoes are ranked on the Fujita Scale from 0 to 5. They are an estimate of wind speed based on the damage pattern. The largest tornado that has occurred in the Puget Sound area was an F3. Between 1950 and 2024, there have been 138 tornadoes in Washington, the majority of which were F0 or F1.⁸²⁵ Those in the Puget Lowland were mostly associated with the Puget Sound Convergence Zone.

History

The Pacific Northwest is periodically hit by mid-latitude cyclones and other more localized wind events. Most storms happen in late fall and winter. Of the ten major storms to hit Seattle since 1962, seven have occurred in winter. The other three occurred in March, August, and September.

1943. An April windstorm saw gusts up to 65-69 mph. The storm is reported to have destroyed 6 houses, torn houseboats from their moorings, damaged power lines, disrupted ferry traffic, and resulted in at least one death.⁸²⁶

9/28/1962. An F1 tornado damaged eight homes in the Sand Point/View Ridge area before travelling across Lake Washington and damaging homes in the Juanita area of Kirkland.⁸²⁷

10/12/1962. The “Columbus Day Storm” had 85 mph sustained winds equal to hurricane speed. Higher wind speeds of 150 mph on the coast demonstrated the protection that the Olympic Mountains give the region.⁸²⁸ Nevertheless, the damage was widespread. Throughout the region, 46 people died, over 300 required hospitalization, 53,000 houses were damaged, and the power went out in many areas of Washington.⁸²⁹ It is not clear how much of this damage was in Seattle. Parts of the power transmission system in Portland were destroyed.

12/12/1969. An F3 tornado struck the Kent Valley. The storm caused 1 injury. It damaged a billboard and a farm.⁸³⁰

3/26/1971. Sixty mph winds forced the closure of the Evergreen Point Bridge. The wind also ripped panels off the Safeco Plaza building, forcing the Downtown Library to close. Two people died.

2/13/1979. The Hood Canal Bridge broke apart in a violent storm. The western part of the bridge sank into the canal.⁸³¹

2/19/1981. Wind and lightning damaged at least one home and left 100,000 without power in Seattle and King County. This storm began as a tropical cyclone.

11/13/1981. Two major storms caused power outages, closed bridges, and damaged buildings.⁸³²

11/24/1983. The “Thanksgiving Day Storm.” Downed trees were a leading cause of outages that left 270,000 without power across the region.⁸³³ The wind also damaged roofs and broke boats loose from their moorings. The storm was not predicted, increasing the damage.

11/25/1990. The Old Mercer Island Bridge sank in a storm. The sinking was caused in part by construction waste in the floats under the bridge (Also see [Built Environment Failures](#)).⁸³⁴

11/16/1991. 400,000 were left without power in the Seattle area after the worst storm since the Thanksgiving Day Storm of 1983.⁸³⁵

1/20/1993. “The Inauguration Day Storm” caused massive outages in Seattle, although the power was out the longest in the suburbs. Debris littered the roads, and traffic came to a stop as traffic lights failed. Winds gusts in the Puget Sound were 60-70 mph. Six people died in the state.⁸³⁶

12/14/2006. Unusually intense levels of rainfall in a very short period of time were immediately followed by very heavy winds up to 69 miles per hour that felled power poles and large, mature, healthy trees. Three-fourths of an inch of rain fell in less than 45 minutes in some areas of the city. As a result, more than 1.3 million customers were without power throughout western Washington, some for longer than a week.⁸³⁷ Making the situation worse, a late-afternoon Seahawk game in Seattle meant many more motorists attending the game were further delayed from getting home because of the storm.

8/29/2015. The strongest August windstorm on record hit Western Washington, with winds of 50-60 mph (46 mph at SeaTac). Almost half a million people lost power, two people died from falling trees, two people died from carbon monoxide poisoning, and four people were injured.⁸³⁸ The damage was increased because the trees were in leaf. The North Puget Sound and coastal areas received the strongest winds.

10/24/2021. A mid-latitude ‘bomb cyclone’ hit Western Washington, bringing heavy rain and wind gusts of up to 60 mph to the Seattle area. The storm had the lowest pressure recorded since reliable measurements began in 1974, reaching 942.5 hPa (hPa measures atmospheric pressure). More than 100,000 in the Puget Sound region lost power.⁸³⁹

11/19/2024. A storm akin to the bomb cyclone of 2021 hit Western Washington, with peak winds reaching 74mph in the lowlands. Over 640,000 customers in the region lost power, 114,000 of which were Seattle City Light customers. It was the Seattle’s largest power outage since 2006.⁸⁴⁰

Vulnerability

Tree density and wet soils are the biggest factors in the amount of damage produced from windstorms in the Pacific Northwest. Tall conifers often have shallow roots and are prone to being uprooted, especially when the ground is saturated with water. The ground is often saturated in late fall and winter when the majority of these powerful storms occur. Seattle has fewer trees than suburban and rural areas, but it still has a substantial amount and has been actively working to regrow its tree canopy.

Structural damage is the costliest consequence of windstorms. Falling trees and branches can snag power, cable television, and telephone lines, bringing them down and causing outages. When they fall across roads, they interrupt transportation. A downed tree can usually be cleared quickly; when accompanied by downed power lines, the job takes much longer.

Damage can occur at wind speeds as low as 32 mph and destroy wood frame structures at speeds around 100 mph. Seattle has adopted the 2021 International Building Code, which requires new structures to withstand 85 mph for three seconds (with modifications to be made for location), but Seattle also has many older buildings that were built to a weaker standard. Almost 90,000 homes in Seattle were built before 1939. Furthermore, Seattle's coast and hills affect this load. Winds are stronger over water and along hillsides. Areas on [Figure 78](#) that are shown in red are prone to stronger winds. The higher the number, the stronger the wind. Wind Exposure C Areas denote coastal wind hazard. During a windstorm on December 12, 1995, a ship just outside of Elliott Bay reported a gust of 90 mph, exceeding the design threshold.

Wind causes both direct and indirect health hazards. People have died from falling trees and branches. Because many windstorms happen in winter and many residents are dependent on electricity for heat, cold-related health problems are a hazard. Several people were killed in King County while heating their homes with charcoal fires during the power outages following the 2006 storm.

Areas with limited access, such as Magnolia, can become isolated if trees fall on the few roads that lead into them. North and West Seattle, which are the most heavily forested, may have a higher vulnerability of property damage than the rest of the city.

Wind-driven waves are another hazard for the city. Large waves can endanger the I-90 and SR 520 floating bridges. The SR 520 bridge, which was rebuilt in 2012, can withstand wind gusts up to 89 mph. On average, more than 200,000 vehicles move over these bridges daily. Sound Transit is currently building tracks for the Link light rail to travel over the I-90 bridge, adding another 50,000 daily passengers to its load.⁸⁴¹ This traffic gives them enormous socioeconomic importance. Their inherent exposure to wind and their value to the local economy make them vulnerabilities for Seattle.

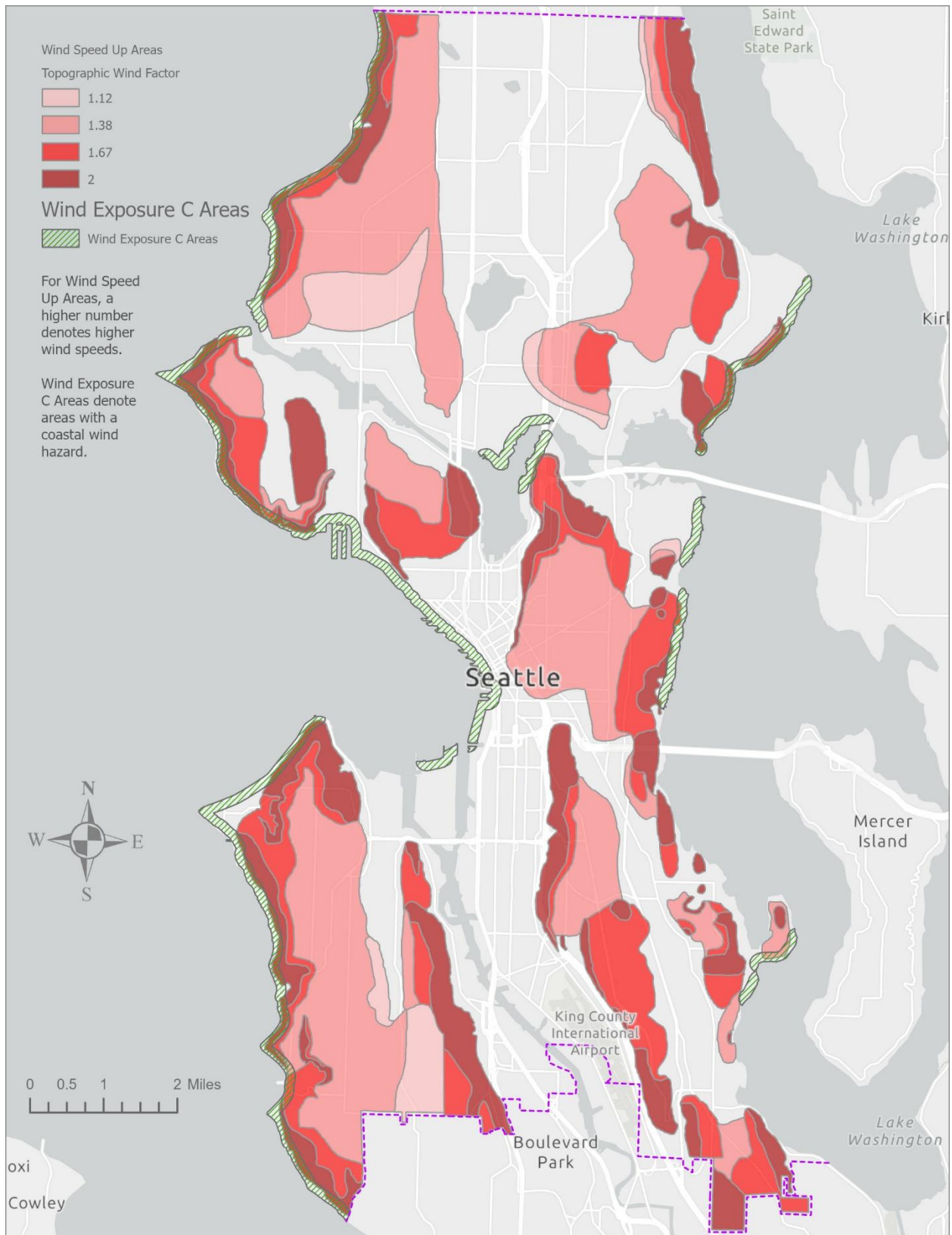
During the 1993 Inauguration Day Storm, trees falling on buildings, power and telephone lines, and on roads caused most of the damage. In addition, falling trees and limbs damaged hundreds of homes, and fires, started by fallen power lines, damaged several buildings. Some major public structures suffered damage. For example, both floating bridges across Lake Washington, I-90 and SR 520, had damage to pontoons that keep the bridges afloat.⁸⁴² Extensive damage occurred from uprooted trees and brittle trees that broke, or whose branches broke off and fell onto power lines, buildings, and roadways.

If windstorms are accompanied by heavy rain or followed by extreme cold, the effects of the windstorm are multiplied. As detailed in other chapters, rain can lead to urban flooding and landslides while extreme cold will increase the hardship caused by power outages.

Consequences

Windstorms are a regular part of Pacific Northwest weather as are rain-driven flooding and snow. Wind causes direct physical damage to structures, power and telecommunications infrastructure, and coastal bluffs. Wind causes trees to fall posing risks to people, structures, and infrastructure. Windstorms cause indirect damage to the economy through power outages and inhibiting the transportation system. Many people cannot or choose not to come to work because they fear long drives or must take care of damage at home. For local governments, debris removal can place a strain on budgets. Despite these costs, the biggest economic problem from windstorms is property damage. Families can incur major expenses even from light damage to roofing or siding. The 2006 record intensity storm of torrential rains and high-velocity winds took a toll on Seattle's residents and their property. Scores of city residents

Figure 78. Wind Speed-Up Areas



WSU Facilities Services GIS, City of Seattle, King County, WA State Parks GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS

experienced thousands of dollars in damage to their homes and businesses from downed trees falling onto house roofs and cars, flooding inside homes and businesses, and severe roof and siding damage. Wind is a major expense for local government. The 2006 storm caused \$16 million in damage to City property and infrastructure.⁸⁴³

Even moderate wind speed can damage buildings. Wind speeds as low as 32 mph can drive objects through walls.⁸⁴⁴ Other research shows that wood-frame and unreinforced masonry structures can be damaged or even destroyed at speeds less than 100 mph and that a home constructed according to any of the major codes in the U.S. will lose its roof in winds from 80 to 120 mph.⁸⁴⁵ Winds have exceeded this threshold in Seattle, especially in areas where the topography increases wind speeds, demonstrating that widespread structural failures are possible.

Power outages are the major secondary hazard of wind. The consequences of a power outage resulting from a windstorm can be worse than the direct damage caused by the wind itself. The [Power Outages](#) chapter goes into detail on these consequences. These include the economic costs of business shutdowns, loss of perishable foods, risks to people dependent on medical devices, exposure to cold or heat, and impairment of transportation.

Wind causes major transportation problems. In the 2006 windstorm, over 300 trees blocked roadways in King County,⁸⁴⁶ including dozens of arterials in Seattle.⁸⁴⁷ Wind driven power outages cause traffic lights to go dark, making driving a long and difficult process. The floating bridges pose another safety risk. If a windstorm develops suddenly, as in 1983, the State Department of Transportation may not be able close the bridges before waves begin spilling onto the bridge decks.

Seattle can expect storms up to the magnitude of the Columbus Day storm. While the hazard intensity may not change, Seattle has grown, and our economy has become more time dependent. This increase in vulnerability means that the damage from windstorms is more likely to be higher than in past storms. While windstorms have caused fatalities, their main effect has been economic.

Outlook

Western Washington will continue to experience periodic strong windstorms. A storm with 40-50 mph wind gusts is expected at least once per year, with larger storms (60-80 mph wind gusts) expected every decade or so. Advancements in meteorological technology will increase the likelihood that these events will be forecasted before they occur. More research is needed on how climate change will affect the frequency and intensity of future windstorms in the Puget Sound region. One study, conducted by Seattle City Light (SCL) and the University of Washington, found that most regional climate models predict a slight decrease in the number of windstorms between August and October where winds exceed 30, 40, and 50mph wind gusts in the 2030s and 2050s.⁸⁴⁸

Conclusions

The Pacific Northwest experiences windstorms periodically and is prone to severe storms about once per decade. The population growth happening in Seattle means that future windstorms will likely cause more damage, mostly to private property. While regional climate models predict a slight decrease in windstorms in the coming decades, they remain a significant hazard to infrastructure and safety.

APPENDIX A: EXPOSURE ANALYSIS

This section analyzes patterns of hazard exposure where hazardous areas can be clearly mapped. Not all hazards have a readily mappable component.

Earthquake Hazard Exposures

For earthquakes, one of the major hazards is liquefaction which occurs when certain soils liquify when shaken. These soils can be identified and mapped. Seattle’s liquefaction prone areas have been mapped as shown in [Figure 23](#). The tables and charts below summarize what is in these zones.

Table 18. Land Use in Liquefaction Prone Areas

Area	Acres	% of Seattle	% of Area
Seattle	53178.37	100%	
Liquefaction Prone Areas	9880.67	18.6%	100%
Property in Areas	7547.74	14.2%	76%
<i>Commercial/Mixed-Use</i>	914.000	2%	9%
<i>Easement</i>	0.64	0%	0%
<i>Industrial</i>	3144.09	6%	32%
<i>Major Institution and Public Facilities/Utilities</i>	732.51	1%	7%
<i>Multi-Family</i>	380.65	1%	4%
<i>Parks/Open Space/Cemeteries</i>	765.13	1%	8%
<i>Reservoirs/Water Bodies</i>	57.96	0%	1%
<i>Single Family</i>	813.13	2%	8%
<i>Unknown</i>	3.53	0%	0%
<i>Vacant</i>	736.10	1%	7%
Right of Way	2332.93	4%	24%

Table 19. Estimated Structures, Exposures, and Assessed Value in Liquefaction Prone Areas

Item	Estimated
Number of Buildings	17,236
Number of Single-Family Units	8,632
Number of Multi-Family Units	27,199
Gross Sq. Footage	137,388,888
Residential Gross Sq. Footage	57,439,144
Commercial Gross Sq. Footage	135,704,417
Total Assessed Value	\$92,141,839,369
Estimated persons exposed (daytime)	212,858
Estimated persons exposed (nighttime)	55,526

Table 20. FEMA Community Lifelines in Liquefaction Prone Areas

Lifeline Type	Count
Communications	8
Energy	53
Food, Hydration, Shelter	62
Hazardous Materials	22
Health and Medical	6
Safety and Security	30
Shelter	2
Transportation	35
Water System	32
Total	250

Table 21. Locally Defined Critical Facilities in Liquefaction Areas

Critical Facilities Type	Count
Catastrophic Incident Recovery Asset	94
Education (Schools)	21
Essential Business	2
Human Services	7
Infrastructure	1
Logistics	1
Vulnerable Population	21
Total	147

Table 22. Racial and Social Equity Index Areas in Liquefaction Prone Areas

	Acres	% Seattle	% Area
Total Liquefaction Prone Area in Census Tracts	9815.12*	18.46%	
Highest Equity Priority	1807.57	3.40%	18.42%
Second Highest	5118.03	9.62%	52.14%
Middle	1196.21	2.25%	12.19%
Second Lowest	814.22	1.53%	8.30%
Lowest	879.09	1.65%	8.96%

*Total area of liquefaction prone areas in census tracts is slightly lower than total liquefaction prone areas in the city, as some liquefaction prone areas lie outside of census tracts

Table 23. Wildlife Areas in Liquefaction Prone Areas

	Acres	% Seattle
Seattle	53178	100%
Liquefaction Prone Area	9880.67	18.6%
All Wildlife Habitat Areas	3749.60	7.05%
<i>Wildlife Habitat in Liquefaction Prone Areas</i>	407.82	0.77%

Landslide Hazard Exposures

The major exposures in landslide prone areas are to single family zones and rights of way (roads). One third of all landslide prone areas are single family zones. A quarter are rights of way and another quarter are vacant areas (e.g., greenbelts).

Table 24. Land Use in Landslide Prone Areas

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Landslide Prone Area	4471.43	8%	100%
Property in Area	3338.66	6%	75%
<i>Commercial/Mixed-Use</i>	48.14	0%	1%
<i>Easement</i>	0.03	0%	0%
<i>Industrial</i>	62.93	0%	1%
<i>Major Institution and Public Facilities/Utilities</i>	79.74	0%	2%
<i>Multi-Family</i>	261.26	0%	6%
<i>Parks/Open Space/Cemeteries</i>	1075.98	2%	24%
<i>Reservoirs/Water Bodies</i>	1.91	0%	0%
<i>Single Family</i>	1495.55	3%	31%
<i>Unknown</i>	0.62	0%	0%
<i>Vacant</i>	402.52	1%	9%
Right of Way in Area	1132.77	2%	25%

Table 25. Estimated Structures and Assessed Value in Landslide Prone Area

Item	Estimate
Number of Buildings	14,046
Number of Single-Family Units	10,370
Number of Multi-Family Units	11,837
Gross Sq. Footage	55,516,339
Residential Gross Sq. Footage	42,389,970
Commercial Gross Sq. Footage	6,161,633
Total Assessed Value	\$29,960,960,118
Estimated persons exposed (daytime)	15,837
Estimated persons exposed (nighttime)	37,287

Table 26. FEMA Community Lifelines in Potential Slide Areas

Lifeline Type	Count
Communications	1
Energy	0
Food, Hydration, Shelter	2
Hazardous Materials	0
Health and Medical	0
Safety and Security	0
Shelter	0
Transportation	0
Water System	7
Total	10

Table 27. Locally Defined Critical Facilities in Potential Slide Areas

Critical Facilities Type	Count
Catastrophic Incident Recovery Asset	6
Education (Schools)	2
Essential Business	0
Human Services	0
Infrastructure	0
Logistics	0
Vulnerable Population	8
Total	16

Table 28. Social Vulnerability Index in Slide Prone Areas

	Acres	% Seattle	% Area
Total Slide Prone Area in Census Tracts	4462.49*	8.39%	
Highest Equity Priority	716.54	1.35%	16.06%
Second Highest	916.97	1.72%	20.55%
Middle	337.96	0.64%	7.57%
Second Lowest	1173.47	2.21%	26.30%
Lowest	1317.54	2.48%	29.52%

*Total area of slide prone areas in census tracts is slightly lower than total slide prone areas in the city by 1.39 acres

Table 29. Wildlife Areas in Landslide Prone Areas

	Acres	% Seattle
Seattle	53178	100%
Landslide Prone Area	4471.43	8%
All Wildlife Habitat Areas	3749.89	7.05%
<i>Wildlife Habitat in Landslide Prone Areas</i>	1473.51	2.77%

Volcano Hazards Exposures

The entire city is exposed to ashfall but only the low-lying areas along the Duwamish are exposed to lahars or more likely, post-lahar sedimentation. Below is a summary of exposures in this area.

Table 30. Land Use in Post-Lahar Sedimentation Area

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Post-Lahar Sedimentation Area	2899.33	5.45%	100.00%
Parcel area in area	2369.99	4.45%	81.74%
<i>Commercial/Mixed-Use</i>	93.42	0.18%	3.22%
<i>Easement</i>	0.36	0.00%	0.01%
<i>Industrial</i>	1828.91	3.44%	63.08%
<i>Major Institution and Public Facilities/Utilities</i>	86.91	0.16%	3.00%
<i>Multi-Family</i>	35.26	0.07%	1.22%
<i>Parks/Open Space/Cemeteries</i>	21.46	0.04%	0.74%
<i>Reservoirs/Water Bodies</i>	3.12	0.01%	0.11%
<i>Single Family</i>	103.63	0.19%	3.57%
<i>Unknown</i>	0.00	0.00%	0.00%
<i>Vacant</i>	196.88	0.37%	6.79%
Right of Way in area	529.34	1.00%	18.26%

Table 31. Estimated Structures and Assessed Value in Post-Lahar Sedimentation Area

Item	Estimate
Number of Buildings	2,712
Number of Single-Family Units	926
Number of Multi-Family Units	726
Residential Gross Sq Footage	2,575,077
Commercial Gross Sq Footage	24,006,422
Total Assessed Value	\$8,278,003,095
Estimated persons exposed (daytime)	46,600
Estimated persons exposed (nighttime)	5,577

Table 32. FEMA Community Lifelines in Post-Lahar Sedimentation Areas

Lifeline Type	Count
Communications	0
Energy	11
Food, Hydration, Shelter	7
Hazardous Materials	15
Health and Medical	0
Safety and Security	4
Shelter	0
Transportation	4
Water System	6
Total	47

Table 33. Locally Defined Critical Facilities in Post-Lahar Sedimentation Areas

Critical Facilities Type	Count
Catastrophic Incident Recovery Asset	8
Education (Schools)	1
Essential Business	12
Government	1
Hazard	15
Human Services	7
Health	0
Public Safety	3
Infrastructure	7
Transportation	4
Vulnerable Population	0
Total	58

Table 34. Social Vulnerability Index in Post Lahar Sedimentation Areas

	Acres	% Seattle	% Area
Total Liquefaction Prone Area in Census Tracts	2898.21	5.45 %	
Highest Equity Priority	601.25	1.13%	20.75%
Second Highest	2296.96	4.32%	79.25%
Middle	0	0%	0%
Second Lowest	0	0%	0%
Lowest	0	0%	0%

Table 35. Wildlife Areas in Post-Lahar Sedimentation Area

	Acres	% Seattle
Seattle	53178	100%
Post-Lahar Sedimentation Zone	3463.73	6.51%
Wildlife Habitat Areas	3749.89	7.05%
<i>Wildlife Habitat in Post-Lahar Sedimentation Zone</i>	23.22	0.04%

Tsunami and Seiche Exposures

Tsunamis pose the biggest danger to the area around Elliott Bay while seiches threaten all areas along enclosed bodies of water. Unlike tsunamis, seiches do not travel far inland so the only exposures are to structures over the water or immediately adjacent to it.

Table 36. Land Use in Worst Case Tsunami Inundation Area

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Worst Case Tsunami Inundation Area	2261.54	4.25%	100%
Parcel area in Area	1844.88	3.47%	81.58%
<i>Commercial/Mixed-Use</i>	238.89	0.45%	10.56%
<i>Easement</i>	0.00	0.00%	0.00%
<i>Industrial</i>	1095.95	2.06%	48.46%
<i>Major Institutions</i>	78.26	0.15%	3.46%
<i>Multi-Family</i>	41.74	0.08%	1.85%
<i>Parks/Open Space/Cemeteries</i>	75.84	0.14%	3.35%
<i>Reservoirs/Water Bodies</i>	33.19	0.06%	1.47%
<i>Single Family</i>	56.88	0.11%	2.52%
<i>Unknown</i>	2.28	0.00%	0.10%
<i>Vacant</i>	221.83	0.42%	9.81%
Right of Way in Area	416.67	0.78%	18.42%

Table 37. Estimated Structures and Assessed Value in Worst Case Tsunami Inundation Area

Item	Estimate
Number of Buildings	3,778
Number of Single-Family Units	1,411
Number of Multi-Family Units	5,050
Gross Sq. Footage	103,001,936
Residential Gross Sq. Footage	15,849,021
Commercial Gross Sq. Footage	69,920,797
Total Assessed Value	\$44,607,343,685
Estimated persons exposed (daytime)	62,302
Estimated persons exposed (nighttime)	5,496

Table 38. FEMA Community Lifelines in Worst Case Tsunami Inundation Area

Lifeline Type	Count
Communications	2
Energy	6
Food, Hydration, Shelter	9
Hazardous Materials	7
Health and Medical	0
Safety and Security	4
Shelter	1
Transportation	8
Water System	10
Total	47

Table 39. Locally Defined Critical Facilities in Worst Case Tsunami Inundation Area

Critical Facilities Type	Count
Catastrophic Incident Recovery Asset	18
Education (Schools)	0
Essential Business	1
Government	0
Hazard	0
Human Services	2
Health	0
Public Safety	0
Infrastructure	0
Transportation	0
Vulnerable Population	5
Total	26

Table 40. Social Vulnerability Index in Worst Case Tsunami Inundation Areas

	Acres	% Seattle
Total Tsunami Inundation Area in Census Tracts	2255.75	4.24%
Highest Equity Priority	91.14	0.17%
Second Highest	1417.89	2.67%
Middle	392.19	0.74%
Second Lowest	209.93	0.39%
Lowest	144.59	0.27%

Table 41. Wildlife Areas in Worst Case Tsunami Inundation Area

	Acres	% Seattle
Seattle	53178	100%
Tsunami Inundation Area	2261.54	4.25%
Wildlife Habitat Areas	3749.89	7.05%
<i>Wildlife Habitat in Tsunami Inundation Area</i>	60.94	0.11%

Table 42. Land Use in Lake Union Seiche Area

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Lake Union Seiche Area	145.34	0.00%	100%
Property in area	145.34	0.27%	100%
<i>Commercial/Mixed-Use</i>	91.16	0.17%	62.72%
<i>Easement</i>	0.00	0.00%	0.00%
<i>Industrial</i>	18.37	0.03%	12.64%
<i>Major Institutions</i>	0.36	0.00%	0.24%
<i>Multi-Family</i>	0.89	0.00%	0.61%
<i>Parks/Open Space/Cemeteries</i>	6.14	0.01%	4.22%
<i>Reservoirs/Water Bodies</i>	1.58	0.00%	1.09%
<i>Single Family</i>	19.24	0.04%	13.24%
<i>Unknown</i>	0.00	0.00%	0.00%
<i>Vacant</i>	7.62	0.01%	5.24%
Right of Way in area	0.00	0.00%	0.00%

Table 43. Estimated Structures and Assessed Value in Lake Union Seiche Area

Item	Estimate
Number of Buildings	153
Number of Single-Family Units	81
Number of Multi-Family Units	80
Gross Sq. Footage	2,368,506
Residential Gross Sq. Footage	253,127
Commercial Gross Sq. Footage	1,683,223
Total Assessed Value	\$1,465,828,050
Estimated persons exposed (daytime)	6,057
Estimated persons exposed (nighttime)	584

Table 44. FEMA Community Lifelines in Lake Union Seiche Area

Lifeline Type	Count
Communications	0
Energy	1
Food, Hydration, Shelter	0
Hazardous Materials	0
Health and Medical	0
Safety and Security	1
Shelter	0
Transportation	1
Water System	0
Total	3

Table 45. Locally Defined Critical Facilities in Lake Union Seiche Area

Critical Facilities Type	Count
Catastrophic Incident Recovery Asset	0
Education (Schools)	0

Essential Business	0
Government	0
Hazard	0
Human Services	0
Health	0
Public Safety	0
Infrastructure	0
Transportation	0
Vulnerable Population	0
Total	0

Table 46. Wildlife Areas in Lake Union Seiche Area

	Acres	% Seattle
Seattle	53178	100%
Lake Union Seiche Area	145.34	0.27%
Wildlife Habitat Areas	3749.89	7.05%
Wildlife Habitat in Seiche Area	0	0.00%

Flooding Exposures

Seattle has two distinct, but related flood hazards, each with their own high exposure areas. The first are areas along rivers and streams that can overflow their banks. These areas comprise the first set of tables and figures. The second are urban flood areas that have a higher likelihood of ponding during extreme precipitation when drainage systems are overwhelmed. These areas comprise the second set.

Table 47. Land Use in Flood Prone Areas

	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Flood Area (FEMA 100-year flood)	518.38	0.97%	100.00%
Property in area	464.94	0.87%	89.69%
<i>Commercial/Mixed-Use</i>	20.47	0.04%	3.95%
<i>Easement</i>	0.00	0.00%	0.00%
<i>Industrial</i>	153.80	0.29%	29.67%
<i>Major Institutions</i>	36.25	0.07%	6.99%
<i>Multi-Family</i>	17.49	0.03%	3.77%
<i>Parks/Open Space</i>	98.74	0.19%	19.05%
<i>Reservoirs</i>	22.46	0.04%	4.33%
<i>Single Family</i>	76.75	0.14%	14.81%
<i>Unknown</i>	0.25	0.00%	0.05%
<i>Vacant</i>	38.72	0.07%	7.47%
Right of Way in Area	53.44	0.10%	10.31%

Table 48. Estimated Buildings and Assessed Value in Flood Prone areas

Item	Estimate
Number of Buildings	4579
Number of Single-Family Units	3,103
Number of Multi-Family Units	4,827
Gross Sq Footage	36,467,362
Residential Gross Sq Footage	12,635,211
Commercial Gross Sq Footage	23,154,312
Total Assessed Value	\$22,517,859,600
Estimated persons exposed (daytime)	8,594
Estimated persons exposed (nighttime)	2,212

Table 49. FEMA Community Lifelines in Flood Prone Areas

Lifeline Type	Count
Communications	0
Energy	0
Food, Hydration, Shelter	0
Hazardous Materials	0
Health and Medical	0
Safety and Security	3
Shelter	0
Transportation	4
Water System	4
Total	11

Table 50. Locally Defined Critical Facilities in Flood Prone Areas

Critical Facilities Type	Count
Catastrophic Incident Recovery Asset	2
Education (Schools)	1
Essential Business	0

Government	0
Hazard	0
Human Services	0
Health	0
Public Safety	0
Infrastructure	0
Transportation	0
Vulnerable Population	2
Total	5

Table 51. Social Vulnerability Index in Flood Prone Areas

	Acres	% Seattle	% Area
Total Flood Prone Area in Census Tracts	512.59	0.96%	
Highest Equity Priority	150.77	0.28%	29.41%
Second Highest	124.41	0.23%	7.81%
Middle	79.09	0.15%	15.43%
Second Lowest	118.31	0.22%	24.27%
Lowest	40.01	0.08%	23.08%

Table 52. Wildlife Areas in Flood Prone Areas

	Acres	% Seattle
Seattle	53178	100%
Flood Area (FEMA 100-year flood)	518.38	0.97%
Wildlife Habitat Areas	3749.60	7.05%
<i>Wildlife Habitat in Flood Prone Areas</i>	75.91	0.14%

Table 53. Land Use in Urban Flood Areas (1000-year storm)

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Urban Flood Prone Areas	4431.07	8.33%	100.00%
<i>Property in Area</i>	2890.02	5.43%	65.22%
<i>Commercial/Mixed-Use</i>	290.90	0.55%	6.56%
<i>Easement</i>	0.58	0.00%	0.01%
<i>Industrial</i>	1053.60	1.98%	23.78%
<i>Major Institutions</i>	295.59	0.56%	6.67%
<i>Multi-Family</i>	159.27	0.30%	3.59%
<i>Parks/Open Space/Cemeteries</i>	351.03	0.66%	7.92%
<i>Reservoirs</i>	9.97	0.02%	0.22%
<i>Single Family</i>	424.53	0.80%	9.58%
<i>Unknown</i>	1.42	0.00%	0.03%
<i>Vacant</i>	303.13	0.57%	6.84%
<i>Right of Way</i>	1541.05	2.90%	34.78%

Table 54. Estimated Buildings and Assessed Value in Urban Flood Prone Areas

<i>Item</i>	Estimate
Number of Buildings	22,020
Number of Single Family Units	11,555
Number of Multi-Family Units	38,090
Residential Gross Sq Footage	76,507,492
Commercial Gross Sq Footage	110,553,184
Total Assessed Value	\$1,352,399,845,138
Estimated persons exposed (daytime)	65,667
Estimated persons exposed (nighttime)	33,217

Table 55. FEMA Community Lifelines in Urban Flood Prone Areas

Lifeline Type	Count
Communications	2
Energy	3
Food, Hydration, Shelter	4
Hazardous Materials	2
Health and Medical	1
Safety and Security	1
Shelter	0
Transportation	2
Water System	9
Total	24

Table 56. Locally Defined Critical Facilities in Urban Flood Prone Areas

Critical Facilities Type	Count
Catastrophic Incident Recovery Asset	25
Education (Schools)	2
Essential Business	0
Government	0
Hazard	0
Human Services	3
Health	0

Public Safety	0
Infrastructure	1
Transportation	0
Vulnerable Population	2
Total	33

Table 57. Social Vulnerability Index in Urban Flood Prone Areas

	Acres	% Seattle	% Area
Total Urban Flood Prone Area in Census Tracts	4420.39	8.31%	
Highest Equity Priority	937.99	1.76%	21.22%
Second Highest	1977.55	3.72%	10.43%
Middle	618.27	1.16%	13.99%
Second Lowest	425.73	0.80%	44.74%
Lowest	460.85	0.87%	9.63%

Table 58. Wildlife Areas in Urban Flood Prone Areas

	Acres	% Seattle
Seattle	53178	100%
Flood Area (1000-year flood)	4420.39	8.31%
Wildlife Habitat Areas	3749.6	7.05%
<i>Wildlife Habitat in Urban Flood Prone Areas</i>	224.99	0.42%

Explosive Exposures

Seattle has two large sources of potential explosive hazards; the BP pipeline and the railroad that runs through downtown and along the Puget Sound shoreline. Both of these sources could cause explosions reaching half a mile beyond the source. Because of this, both hazards were mapped and analyzed together as one unified potential explosive hazard.

Table 59. Land Use in Explosion Risk Zone

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Urban Flood Prone Areas	4431.07	8.33%	100.00%
Property in Area	11474.36	21.58%	73.76%
<i>Commercial/Mixed-Use</i>	1096.29	2.06%	7.05%
<i>Easement</i>	1.07	0.00%	0.01%
<i>Industrial</i>	3210.45	6.04%	20.64%
<i>Major Institutions</i>	751.56	1.41%	4.83%
<i>Multi-Family</i>	718.00	1.35%	4.62%
<i>Parks/Open Space/Cemeteries</i>	1063.21	2.00%	6.83%
<i>Reservoirs</i>	7.40	0.01%	0.05%
<i>Single Family</i>	3452.93	6.49%	22.20%
<i>Unknown</i>	6.49	0.01%	0.04%
<i>Vacant</i>	1166.95	2.19%	7.50%
Right of Way	4081.53	7.68%	26.24%

Table 60. Estimated Buildings and Assessed Value in Explosion Risk Zone

Item	Estimate
Number of Buildings	36,693
Number of Single Family Units	23,934
Number of Multi-Family Units	46,380
Residential Gross Sq Footage	125,811,288
Commercial Gross Sq Footage	146,480,621
Total Assessed Value	\$112,528,315,765
Estimated persons exposed (daytime)	453,969
Estimated persons exposed (nighttime)	149,045

Table 61. FEMA Community Lifelines in Explosion Risk Zone

Lifeline Type	Count
Communications	8
Energy	63
Food, Hydration, Shelter	120
Hazardous Materials	21
Health and Medical	9
Safety and Security	40
Shelter	1
Transportation	46
Water System	37
Total	345

Table 62. Locally Defined Critical Facilities in Explosion Risk Zone

Critical Facilities Type	Count
Catastrophic Incident Recovery Asset	84
Education (Schools)	25
Essential Business	4
Government	0
Hazard	0
Human Services	13
Health	0
Public Safety	0
Infrastructure	0
Transportation	0
Logistics	4
Vulnerable Population	74
Total	204

Table 63. Social Vulnerability Index in Explosion Risk Zone

	Acres	% Seattle	% Area
Total Urban Flood Prone Area in Census Tracts	15541.01	29.22%	
Highest Equity Priority	4067.55	7.65%	26.17%
Second Highest	5936.68	11.16%	38.20%
Middle	1245.79	2.34%	8.02%
Second Lowest	2414.75	4.54%	15.54%
Lowest	1876.24	3.53%	12.07%

Table 64. Wildlife Areas in Explosion Risk Zone

	Acres	% Seattle
Seattle	53178	100%
Flood Area (1000-year flood)	15555.89	29.25%
Wildlife Habitat Areas	3749.6	7.05%
<i>Wildlife Habitat in Urban Flood Prone Areas</i>	1564.76	2.94%

APPENDIX B: HAZARD SCENARIOS

This section provides two scenarios for each hazard: a Most Likely and a Credible Worst-Case. The purpose of a scenario is to provide City emergency manager with concrete planning targets based on research contained in this analysis. Real events will differ from the scenarios, but the intent is that the scenarios are representative. The scenarios also help summarize the hazard for those who do not have time to read the entire SHIVA document. Finally, the scenarios are the basis for the hazard ranking. Each scenario includes a description and a table detailing impacts across multiple parameters.

Earthquakes

Most Likely Scenario

Magnitude 6.8 Deep Earthquake

A magnitude 6.8 deep earthquake occurs during business hours. The earthquake is similar to the 2001 Nisqually Earthquake. The epicenter is closer to Seattle causing more intense shaking. Ten unreinforced masonry buildings collapse in the Pioneer Square and SODO areas resulting in fatalities, injuries, and entrapment. An additional 200 buildings loss of load bearing capacity and need to be red tagged and more 1000 need to be yellow tagged. The ground is saturated with water causing widespread liquefaction, lateral spread, and landslides.

Secondary Hazards Triggered:

- Landslides
- Hazardous Material Incidents
- Built Environment Failures
- Structural Fires
- Power Outages

Category	Impact 1 = low 5 = high	Narrative
Frequency	4	Events in 1949, 1965 and 2001. Seismologists estimate a 1 in 50 chance (2%) per year.
Geographic Scope	5	Most of the Central Puget Sound Region including all of Seattle
Duration	2	Widespread disruption lasts 3 days but damaged structures and impacted households, businesses and organizations experience effects for weeks to months.
Health Effects, Deaths, and Injuries	2	Fatalities in the low single digits. Injuries in the double digits.
Displacement and Suffering	2	About 70 households displaced for several months. About half find rental housing. The other half requires help. Several hundred vulnerable persons lose access to services that support them (for example, a homeless shelter has to close due to damage).
Economy	2	Damage amounts to approximately \$500 million in Seattle. Isolated businesses are severely impacted. Some close, but overall economy is quick to recover.
Environment	2	Earthquake generates hazardous materials incidents. Responders are not able to get to them as quickly as they normally would. As a result, environmental quality suffers prolonged but temporary degradation.
Built Environment	3	200 buildings, mostly older and small commercial buildings are 'red tagged' meaning they need to be replaced or massively repaired before they can be re-occupied. 1000 buildings need moderate repairs. Several utilities affected for 2-3 weeks.

Transportation	3	All areas of Seattle remain accessible, but road and bridge damage cause delays in reaching several areas.
Critical Services and Utilities	2	One critical service (e.g., fire, police, and hospitals) is not able to perform at full level for 2-3 weeks.
Confidence in Government	1	The public's opinion of the government's ability is unchanged.
Cascading Effects	4	The earthquake triggers several large secondary incidents. For example, improperly stored hazardous materials spill and catch fire. Due to complications from the earthquake, the Fire Department is not able to bring the normal level of resources to bear. Several landslides have also been triggered, destroying several homes and damaging 10-20 apartment buildings and businesses.

Credible Worst-Case Scenario

Magnitude 7.2 Seattle Fault Earthquake

A M7.2 Seattle fault earthquake strikes during the weekday while the Sounders are playing a game. The ground is saturated due to heavy rain during the previous two weeks. Over the next few days, the temperatures are expected to drop into the upper 30's and the steady rain transitions to showers. The earthquake generates a 16ft tsunami, triggers thousands of landslides, tens of fire ignitions, and releases tons of hazardous materials.

Secondary Hazards Triggered:

- Tsunami
- Landslides
- Hazardous Material Incidents
- Built Environment Failures
- Structural Fires
- Power Outages

Category	Impact (1- 5)	Effects
Frequency	1	One event known in 900 AD. Evidence of earlier events. Seismologists estimate 1 in 1000 chance per year for a magnitude over 6.5 and 1 in 5000 for a magnitude 7.5, but there is uncertainty in this estimate due to lack of data.
Geographic Scope	5	This earthquake will affect all communities along the fault zone (an area extending through Bremerton, Seattle, Mercer Island, Bellevue and Issaquah). The Kent Valley will also be heavily affected due to the soft soils in the river valley. Very Strong (MMI VII) shaking extends north to Edmonds and south to Tacoma.
Duration	5	This event devastates the Central Puget Sound region. Immediate recovery (e.g., service restoration) takes a month. Full recovery takes years. Main routes into the area require major repairs. Resources must be pulled in from around the country.
Health Effects, Deaths, and Injuries	5	Structural collapses, landslides, fires and a tsunami combine to cause 1,200 deaths and 15,000 severe to critical injuries.
Displacement and Suffering	5	25,000 households are displaced due to damage to their homes. 4,000 will be displaced for more than 6 months. Fans in the stadium and tourists are stranded in Seattle.
Economy	5	The earthquake causes \$20 billion in damage and indirect losses. The industrial area along the Duwamish Waterway is especially hard hit. It will take years for the area to recover. The Port is heavily damaged and seeks to recover as soon as possible to avoid losing customers permanently.

Category	Impact (1- 5)	Effects
Environment	5	Major marine environmental damage is caused by secondary effects, especially hazardous materials releases and fires. Tank farms on Harbor Island rupture spilling fuel into Puget Sound. The BP pipeline breaks due to movement of the fault zone. Damage to wastewater mains pollutes the marine areas along the shoreline. The earthquake has triggered a tsunami and landslides. These secondary hazards have scoured sensitive coastal eco-systems.
Built Environment	5	6,000 buildings are destroyed; 21,000 are severely damaged and unsafe to occupy and 80,000 are moderately damaged. Damage is heaviest south of the Ship Canal, but older sections of Ballard, Wallingford and the U-District also have concentrations of damage. Pioneer Square, the International District, Sodo, and the northern area of West Seattle are especially hard hit.
Transportation	5	Damage to surface, air and marine transportation systems is extreme. All major surface routes into the city are damaged and impassable. Retrofitting of bridges ensures that critical bridges do not fail, but they suffer major damage and 12 will need to be replaced. 14 minor bridges and overpasses collapse. Both major airports have extensive damage to runways. SeaTac is able to use one runway. Port of Seattle facilities are located at the epicenter and are devastated.
Critical Services and Utilities	5	Large parts of the city lose water pressure, power, and communications. Public safety responders are overwhelmed.
Confidence in Government	5	Recovery from the earthquake is slow and complex. The pace of recovery becomes a source of frustration which is directed at government.
Cascading Effects	5	The earthquake causes multiple secondary hazards, each of which is a major disaster in its own right. It triggers a tsunami, numerous massive landslides, hazardous materials spills and over 80 large fires.

Alternate Scenario

Magnitude 9.0 Cascadia Subduction Zone Earthquake

Because earthquakes are so complex, it is impossible to convey the earthquake hazard consequences without including Cascadia Subduction Zone earthquakes. Shaking would be rated as ‘Very Strong’ (MMI VII) on the Modified Mercalli Intensity scale and would last several minutes. Well-engineered structures would survive with minimal damage but outdated and poorly designed or maintained structures would suffer extensive damage or collapse. Average structures would have slight to moderate damage. A megathrust earthquake is also likely to generate a powerful seiche on Lake Union and possibly in other waterbodies as well. As bad as this earthquake would be for Seattle, it would be much worse on the coast where the shaking would be much stronger and where a tsunami would be triggered that could devastate the entire coastal area. Seattle would be in the position of having to help coastal communities even as it struggles with huge losses.

Landslides

Most Likely Scenario

Hundreds of shallow landslides over several days

The most likely scenario is an event like the 1996/7 landslide event. 227 mostly shallow landslides occur over a three-day period. Most occur on undeveloped property, causing little or no damage. 52 cause significant property damage, mostly non-structural. 11 cause major structural damage. Mostly residential areas affected. Some commercial properties are damaged. A few major roads are blocked. Several roads are undermined. Some water, gas and sewer lines are severed. Mitigation measures protect Aurora from a major landslide.

Category	Impact 1 = low 5 = high	Narrative
Frequency	5	We expect this type of event every 10 - 50 years.
Geographic Scope	4	Landslides occur throughout the city but happen mostly in the 8% of the city previously mapped as prone to landslides.
Duration	3	The landslides occur over a period of three days, but response and clean-up take another two days.
Health Effects, Deaths, and Injuries	2	The landslides cause no deaths. Tension cracks appear at the top of most slopes before they fail allowing residents and businesses to escape before the slides occur. Ten slides occur without warning and strike structures, injuring 15 people.
Displacement and Suffering	2	75 people in 32 households are displaced. All except three households are able to find their own shelter with friends and family.
Economy	1	Although 72 buildings are affected and the property owners incur severe losses, the losses do affect the greater Seattle economy in a measurable way.
Environment	2	The landslides create scars on hillsides increasing the potential for erosion. A sewer line is undermined and breaks spilling untreated sewage, but the damage is cleaned and repaired quickly.
Built Environment	2	28 buildings are red tagged including 1 childcare center. The latter was unoccupied when the landslide struck it. 60 buildings are yellow tagged.
Transportation	3	2 bridges are struck and suffer damage that restricts usage to emergency vehicles only. Previous mitigation prevents the Magnolia bridge from being closed completely. Several non-arterial roads are undermined. Mitigation barrier along Aurora stops a slide from blocking it. Several smaller arterials are covered in debris that is removed within 24 hours. Amtrak and Sounder passenger service is stopped for 48 hours.
Critical Services and Utilities	1	Several slides break water and sewer lines. A high pressure gas line is undermined but doesn't break. This damage causes localized outages

Category	Impact 1 = low 5 = high	Narrative
Confidence in Government	1	The public sees the landslides as natural events. Services are restored quickly. The government is able to maintain the confidence of the public.
Cascading Effects	1	Forecasting of a heightened likelihood of landslides reduced the chance for this incident to trigger secondary hazards. No significant secondary hazards occur.

Credible Worst-Case Scenario

Deep-seated landslides affecting critical facilities and populations with many shallow landslides

3 large deep-seated landslides occur within 3 hours during a storm along with hundreds of smaller landslides. The landslides occur at night without warning. They destroy multiple structures, destroy roads, start fires and release hazardous materials. A Seattle City Light transmission tower coming into Seattle from the south slides. Many lives are lost as the landslides crush homes in the night. Massive landslides into Puget Sound and Lake Washington cause tsunamis. A landslide derails a train carrying Bakken crude-oil. Three cars explode.

Category	Impact 1 = low 5 = high	Narrative
Frequency	2	This scenario is considered 1 in 1000 event.
Geographic Scope	4	Almost all of the areas identified as landslide prone are affected (8% of the Seattle's landmass), but scatter throughout the city.
Duration	3	The slides occur over a 3-hour period. Seattle spends the following 5 days actively responding and many more days in recovery.
Health Effects, Deaths, and Injuries	3	42 people are killed and 35 are injured when 20 houses are crushed
Displacement and Suffering	3	240 people are displaced from their homes. Of these 54 need shelter.
Economy	3	Multiple businesses are affected with concentrations of damage in two areas. Freight trains and Amtrak service is halted for three weeks as the tracks are repaired. The overall City economy suffers minor impacts, but the effects on freight transport and at the neighborhood level are more severe.
Environment	3	The landslides strip hundreds of acres of hillsides of vegetation, break numerous sewer lines and knock a train carrying flammable oil into Puget Sound.
Built Environment	3	165 buildings are red tagged; 430 are yellow tagged. Several major arterials are undermined; the Magnolia bridge has to be closed when its piers are knocked away.
Transportation	4	Due to bridge and arterial outages, emergency services are delayed reaching Magnolia and parts of West Seattle. Commuters experience long delays. Sounder and Amtrak train service is stopped for three weeks.
Critical Services and Utilities	2	A large landslide in South Seattle topples a City Light transmission line. Bonneville Power Administration (BPA) transmissions lines outside the city are affected too. The loss causes a widespread outage lasting 36 hours.
Confidence in Government	3	The incident's magnitude surprises the public. The response takes longer than it expects. As a result, it becomes impatient with the pace of response.
Cascading Effects	4	The landslides have caused a major hazardous materials release incident, an explosion, and triggered a tsunami.

Volcano Hazards

Most Likely Scenario

Post-lahar sedimentation clogs the Duwamish Waterway and floods low-lying areas

Post-lahar sedimentation following an eruption of Mt. Rainier clogs the Duwamish Waterway and overflows its banks. A Mt. Rainier lahar devastates the Puyallup, Carbon, and White River valleys stopping at Auburn. In the next few weeks massive amounts of debris begin flushing out the Duwamish blocking the waterway and overflowing the banks of the river in South Park and Georgetown. Major distribution and transportation hubs south of the city are destroyed causing localized food shortages. Land transportation routes from Seattle southward are severely impeded.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	The type of lahar envisioned in this scenario is a 'Case I' flow as categorized by the Cascades Volcano Observatory. Case I lahars are estimated to happen about once every 500 to 1000 years.
Geographic Scope	3	The only area affected in Seattle itself is the Duwamish Waterway, but the Kent Valley south of Seattle will be severely impacted.
Duration	5	Lahar deposits wash down the Duwamish River for weeks. The regional transportation system will be disrupted for weeks. Many people who live in South King County but work in Seattle are displaced. Seattle residents who work in South King County lose their workplaces.
Health Effects, Deaths, and Injuries	1	The incident causes no deaths or injuries in Seattle.
Displacement and Suffering	4	200 households in South Park and Georgetown are displaced, and Seattle hosts many people who are displaced from South King County.
Economy	3	The Duwamish waterway must be dredged. This work impacts Port of Seattle and other shipping operations. Transportation routes and distribution centers south of the city are severely impacted. Workers living south of Seattle have longer commutes.
Environment	2	The lahar debris causes extension damage in the Green River and Duwamish waterway as extensive efforts are underway to restore it. The lahar sediments contain hazardous materials from destroyed buildings upstream.
Built Environment	3	100 structures along the Duwamish Waterway are damaged. The lahar debris moves slowly and floods buildings with heavy sludge.
Transportation	2	Transportation routes in Seattle itself are not affected, but those to the south are severely impacted. Bridges, highways and rail lines are heavily damaged.
Critical Services and Utilities	3	The lahar from Mt. Rainier has heavily damaged multiple warehouses and distribution centers in the Kent Valley including food distribution centers. Seattle suffers several days of food and commodity shortages as business adjust.
Confidence in Government	1	The Seattle public is not directly impacted by the eruption and views it as a natural event. It does not hold the City of Seattle responsible for it.
Cascading Effects	2	The post-lahar sedimentation activates toxic sediment in the Duwamish River and deposits over the valley.

Credible Worst-Case Scenario

Mt. Rainier lahar reaches the Duwamish Valley while ash blankets Seattle

Mt. Rainier erupts. A lahar reaches Seattle followed by an ash cloud. The city has several hours of warning. At the same time, an unusual weather pattern blows 6" ash into Seattle. Rain moves in after the ashfall. The ash becomes hard and cement-like as it gets wet.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	1	This scenario would be an unprecedented event. No evidence has been found that a lahar has reached the mouth of the Duwamish. The Cascade Volcano Observatory estimates them as a less than 1 in 1000-year events. Multiple ash deposits have been found in several locations throughout Seattle, but the severity of these ash falls is unknown.
Geographic Scope	5	The entire Central Puget Sound region would be affected by this event. Ash blankets the region, and the Green River Valley is covered by a lahar.
Duration	5	Response and short-term recovery take 4 weeks. Long term recovery will take years. Even with a debris management plan, tapping resources to remove large amounts of ash is difficult. The lahar has also generated large amounts of debris and caused a lot of structural damage which takes time to repair.
Health Effects, Deaths, and Injuries	3	The lahar overtops the riverbank. Due to timely warning provided by the USGS and an Emergency Alert Message, most people get to safety, but the lahar causes 23 fatalities. 340 people with existing respiratory problems are hospitalized from the ash exposure.
Displacement and Suffering	4	The lahar displaces 867 people who require shelter because their homes and apartments have been red tagged due to lahar damage.
Economy	3	The ashfall interrupts commerce until it can be cleared, but the biggest stressor for the economy is the lahar which has caused extensive damage along the Duwamish waterway. The shipping and manufacturing sectors are the most heavily affected.
Environment	2	The lahar scours the Duwamish Waterway setting back restoration efforts. Ash has a short-term detrimental effect on plants but will enrich the soil long term.
Built Environment	4	215 structures along the Duwamish are red tagged. They include businesses, homes and an apartment. The wet compacted ash has a much higher density than settled snow and collapses 125 roofs. Many buildings experience damage to HVAC system. Settled snow has a density of 200-300 kg/m ³ ; wet compacted ash is 1,000 to 2,000 kg/m ³ .
Transportation	5	The ashfall brings transportation to a halt. Airspace is closed for one week. Roads are impassible and ash clogs vehicle air filters, including those on many emergency vehicles. Trains are inoperable. SDOT and SPU implement the City's debris management plan. Ash is first cleared from roadways. The work is complicated due to the ash's density.
Critical Services and Utilities	2	During the recovery of the road network, food distribution and access to medical care are difficult. Wet ash causes some power outages. Ash enters the wastewater system where it clogs pipes and damages equipment.

Category	Impacts 1 = low 5 = high	Narrative
Confidence in Government	1	The public perceives the eruption as an outlier. The City of Seattle was able to warn people living and working in the Duwamish Valley to leave before the lahar reached Seattle. SDOT is able to clear major roadways within several days allowing the City of Seattle to maintain public confidence.
Cascading Effects	3	The lahar stirs contaminated sediment in the Duwamish. Ash fall triggers some power outages when it weighs down lines and causes insulators to flashover.

Tsunamis and Seiches

Most Likely Scenario

Tsunami and seiche following Cascadia Subduction Zone earthquake.

A tsunami and seiche following a Cascadia Subduction Zone earthquake. This scenario is connected to the Earthquake Alternate Scenario. During a Cascadia Subduction Zone earthquake (see the Alternate Earthquake Scenario) the water in Lake Union begins to oscillate. Waves that move up and down begin to appear in the Lake. Soon ships, boats, houseboats and floating docks move up and down 6 feet (from wave crest to trough). Vessels and houseboats smash violently together. Power, water, sewer, gas and communications lines are severed. Lake Washington, Elliott Bay, and Greenlake also have seiches, but they are not as extreme. Two hours and twenty minutes after the earthquake, the first tsunami waves arrive. It is high tide, allowing the waves to flood beaches, but the most severe flooding is on and around Harbor Island.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	Seiches have occurred on multiple occasions in the Seattle area since the late 19 th century, most recently in 2002. Lake Union seems especially prone to seiches, probably because of its Y-like shape. Previous events have caused damage but have not been disastrous. Modelling results published in 2008 indicate that a Cascadia Subduction Zone earthquake would produce the most damaging seiche for Lake Union. Effects on Lake Washington and other water bodies are still not well understood.
Geographic Scope	3	The seiche effects Lake Union and its shoreline, and small watercraft on Elliott Bay.
Duration	2	The seiche continues for 10 minutes after the end of the ground shaking gradually becoming less and less violent. Amidst the overall earthquake response, it takes three days to stabilize response to the seiche and transition to short term recovery.
Health Effects, Deaths, and Injuries	2	1 person falls in the water and drowns and 13 are injured in falls and by debris. Most of the injuries occur to people inside ships or houseboats.
Displacement and Suffering	3	Due to extreme battering and the severing of most utilities 159 people living aboard boats and houseboats need to find temporary shelter. A few boaters and sailors are stranded in Elliott Bay and require rescue.
Economy	3	The damage from the seiches blends with that of the earthquake. Maritime businesses, especially those on Lake Union, suffer significant damage.
Environment	2	The seiche resuspends and redistributes pollutants from the sediments in local water bodies.
Built Environment	3	15 houseboats are red tagged and another 45 are yellow tagged. Many ships, boats, and seawall docks are heavily damaged.
Transportation	2	The I-90 and SR 520 floating bridges must be closed for inspection and repair. They are closed for one week. Lake Washington Blvd is damaged in two locations.
Critical Services and Utilities	1	The seiche damages utility connections to individual properties but no major lifelines are damaged.
Confidence in Government	1	Local government is able to respond to the seiche in a timely and comprehensive manner. The public retains confidence in government.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	2	The seiche undermines slopes in 12 locations causing landslides.

Credible Worst-Case Scenario

Tsunami following Seattle Fault earthquake

A tsunami following a large Seattle Fault earthquake. This scenario is connected with the Credible Worst-Case Earthquake scenario. This tsunami occurs at high tide and sends waves up to 16 feet high into the area around Elliott Bay minutes after the most powerful earthquake Seattle has ever experienced. The waves cover all Harbor Island, large parts of Sodo and Interbay, and the crowded downtown waterfront. Because the source of the earthquake is so close many people have no chance to escape. The waves destroy many buildings weakened by the earthquake.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	Tsunami deposits have been found in Seattle and Whidbey Island. They are from the Seattle Fault earthquake that occurred in 923 CE. Earthquake of this magnitude on the Seattle Fault are rare events. Currently seismologists estimate they have a 1 in 1000 chance of occurring each year.
Geographic Scope	4	The tsunami would affect the area surrounding Elliott Bay and the shoreline of West Seattle.
Duration	2	The tsunami would strike the Seattle shoreline seconds to minutes after the earthquake stops. Active response to the tsunami would take days as urban search and rescue looked for survivors in debris. Recovery would take years and would be part of the larger earthquake recovery project.
Health Effects, Deaths, and Injuries	4	175 people near the waterfront perish. The majority of deaths occur along Alki and the Downtown Waterfront. Cool rainy weather has limited the number of people outdoors.
Displacement and Suffering	5	743 people are displaced by the tsunami. Their residences along Alki, West Seattle, and Magnolia have been destroyed or severely damaged. This number is added to those displaced by the earthquake itself.
Economy	4	The tsunami devastates the critical Seattle port and manufacturing sectors. Fuel depots on Harbor Island are knocked offline. This damage has enormous multiplier effects on the rest of the Seattle economy. Many businesses in the SODO are destroyed
Environment	4	The tsunami ruptures many tanks containing hazardous materials. The biggest is a tank rupture on Harbor Island. Response to the fuel spill is complicated by the damage to Port infrastructure and the need to concentrate on life safety.
Built Environment	3	245 structures are destroyed and 1200 are yellow tagged. They are a mix of residential, commercial and industrial buildings.
Transportation	4	The tsunami severely damages roads along the waterfront and along the Duwamish waterway. Emergency personnel are slow to reach the affected area. Major downtown arterials are impassable for weeks.
Critical Services and Utilities	3	The collapse of the old viaduct breaks, wastewater, communications, electrical, steam, and gas lines. The outage causes a near lack of service in the downtown waterfront areas.
Confidence in Government	3	Response to the tsunami is complex and slow, especially when combined with the earthquake. The public wonders why more was not done to mitigate tsunami risk.

Cascading Effects	4	The tsunami causes a large hazardous material spill, fires and numerous landslides

Infectious Disease and Biological Hazards

Most Likely Scenario

Infectious disease with effects between the 2009 H1N1 virus and COVID-19

A new strain of corona virus sweeps across Seattle in December, affecting the young and healthy as well as populations more typically at risk. This scenario is in between the 2009 H1N1 pandemic and the COVID-19 pandemic. The pandemic causes hundreds of deaths, over a thousand hospitalizations, stresses hospitals, and closes schools and businesses for several weeks.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	4	Seattle experiences influenza outbreaks every year. Most can be handled by the public health and medical community, but some stand out for their complexity and severity: influenza in 1918, 1957, 1968 and 2009. The scenario here envisions an influenza epidemic between the 2009 H1N1 and the COVID-19 pandemics
Geographic Scope	5	The virus is a pandemic and affects the while city.
Duration	5	It takes 4 months for there to be no new confirmed cases of the virus in the population.
Health Effects, Deaths, and Injuries	4	Thousands become severely ill, 1200 need to be hospitalized, and 400 die.
Displacement and Suffering	3	No families are physically displaced from their homes, but schools and many businesses close for several weeks causing hardships and social conflict
Economy	3	Retail businesses feel losses during the holiday season as shoppers avoid going out in public, but the wider City economy is able to absorb the losses.
Environment	1	The environment is not directly affected by this event.
Built Environment	1	Buildings are not affected by this event.
Transportation	1	The transportation system is not affected by this event.
Critical Services and Utilities	1	Critical services and utilities are not affected by this event.
Confidence in Government	3	The public health system is able to respond quickly to the event. The public's confidence in its public health system grows.
Cascading Effects	1	Affected institutions and businesses must deal with closures, cancellations, business loss and absent workers, but they are not concentrated so they do not cause ripple effects.

Credible Worst-Case Scenario

Pandemic influenza with characteristics similar to the 1919 pandemic

A severe pandemic influenza sweeps the globe striking Seattle. Seattle has 3,600 deaths and 171,000 illnesses. The crisis lasts a month. Economic activity slows severely. Providers have difficulty maintaining service levels to vulnerable populations. Public health officials implement emergency plans to stand up alternate care facilities, deliver medication and handle remains respectfully.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	This scenario is based on planning done by the Seattle / King County Public Health. It envisions an event similar to the 1918 pandemic influenza. It is estimated as a 100-year event.
Geographic Scope	5	The disease is worldwide. It moves quickly around the globe due to air travel. Surveillance systems detect the disease a week before it reaches Seattle. Emergency responders are able to do some planning.
Duration	5	The most acute part of the outbreak lasts four weeks in Western Washington but preparations for the arrival of the disease and recovery from it keep the emergency management system busy for seven weeks.
Health Effects, Deaths, and Injuries	5	The severe influenza has enormous consequences for Seattle public's health. 170,000 people in Seattle become ill. Half (85,000) need outpatient care. 3,600 people die including many young adults. 2,809 people require ICU care and 1,404 require mechanical ventilation.
Displacement and Suffering	5	Although no households are displaced due to physical damage to their home, nearly everyone in Seattle is directly affected. Schools are closed for weeks. So many people are sick or must care for children or sick people that many businesses and government offices close. The city faces critical shortages of supplies including food.
Economy	4	The economy comes to a standstill for weeks, but surges once the illness subsides. Unfortunately, that is too late for many small businesses that cannot withstand weeks of downtime.
Environment	1	The environment would not be directly affected but would suffer indirect impacts due to staff shortages in agencies that oversee environmental protection and monitoring.
Built Environment	1	Although the disease does not destroy buildings, absenteeism affects how buildings run. The lack of support staff causes many buildings to close.
Transportation	3	The disease would not cause any direct damage to the transportation system, but high absenteeism would affect it. Public transit, shipping, and infrastructure management operate at 50% capacity. People avoid public transportation and take cars instead, causing heavy traffic on main roadways.
Critical Services and Utilities	3	Governments attempt to keep their public safety personnel healthy, but influenza affects service. Police, fire, and emergency medical services have to greatly reduce service levels. Water, power, wastewater, and communications are able to continue operations with reduced staffing but are unable to respond to outages and other problems.
Confidence in Government	3	The public understands the influenza is a severe natural event. Restrictions on public gatherings are not popular and create frustration. Some people believe they are not getting enough attention from the medical community.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	2	The disease does not directly cause secondary effects, but the staffing reductions makes the City of Seattle harder to operate. Several non-life threatening landslides occur during this time, but the City is not able to respond due to staffing shortages.

Terrorism and Targeted Violence

Most Likely Scenario

Domestic violent extremist attack on soft target

A domestic violent extremist attacks a house of worship killing 22 people. The perpetrator live streams the attack on Twitch. Before launching the attack, the perpetrator planted homemade explosives in garbage bins at a farmer’s market. The bombs explode 30 minutes for the attack on the house of worship killing 2 and injuring 12. The perpetrator flees the scene. Local law enforcement engages in a manhunt.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Seattle has experienced arson and bombing by extremists on three occasions in the past 25 years. Two planned arson/bombing attempts were prevented in the same timeframe. Most of the events that occur do not require activation of Seattle Emergency Management system.
Geographic Scope	1	One facility is attacked with consequences for the surrounding area.
Duration	1	Incident response is over in less than 24 hours, but investigation takes longer.
Health Effects, Deaths, and Injuries	2	One person is killed in the attack in the fire.
Displacement and Suffering	2	The fire spreads to surrounding buildings, one of which is an apartment. Most residents find shelter with friends and family, but four households need assistance.
Economy	2	The facility experiences unrecoverable losses of valuable research that cannot be easily replaced for any amount of money.
Environment	2	The lab contained drugs and biological samples that are released into the environment.
Built Environment	2	The research lab and the neighboring apartment are destroyed. Four other buildings are damaged.
Transportation	2	Traffic in the surrounding area is halted during response.
Critical Services and Utilities	1	The attack does not inhibit critical service delivery or utilities.
Confidence in Government	3	The public wishes the government had prevented the attack and wants facilities that are likely to be attacked out of the city.
Cascading Effects	2	The attack causes a fire that spreads to surrounding buildings.

Credible Worst-Case Scenario

Coordinated massed drone attack.

A violent terrorist organization uses weaponized drones to attack multiple locations. Areas attacked include Seattle Center during summer festival, the Pike Place Market, and the area outside T-Mobile Park before a baseball game. 20 drones are armed with conventional explosives. The attacks leave dozens dead and many more injured. Law enforcement must find the perpetrators and secure the attack site as a crime scene while operating under the threat of additional attacks.

Category	Impacts Low = 1 High = 5	Narrative
Frequency	1	This scenario is scenario has not occurred yet anywhere in the world, but the availability of drones along with the knowledge gleaned from the battlefield in ways to weaponize them make this attack scenario plausible.
Geographic Scope	4	The attack happens in three areas in or near downtown: Seattle Center, Pike Place Market, and T-Mobile Park
Duration	4	The attackers cannot be immediately identified. While the attack is over within minutes, the threat of new attacks lingers, and law enforcement needs to launch an extensive investigation. The attackers are apprehended 24 days after the attack.
Health Effects, Deaths, and Injuries	4	44 people are killed and 251 injured with 96 requiring hospitalizations.
Displacement and Suffering	3	The attack occurs in commercial areas, so no residences are affected, but people working and visiting downtown need to be moved out of the area. The threat of new attacks before the perpetrators are apprehended severely limits the public's ability to be in crowded outside areas.
Economy	2	The attack closes a big section of downtown for three days. Attacked locations suffer extensive damage. It takes these areas one month to re-open. Retail businesses located in them miss sales in peak summer.
Environment	1	The attack causes no significant damage to the environment.
Built Environment	2	No buildings are destroyed, but explosions damage structures in Pike Place Market.
Transportation	2	The Metro tunnel and surface streets throughout downtown close causing significant delays getting into and through downtown the day of the attack. Streets near the attacked areas remain closed for days. Some critical services remain difficult to reach.
Critical Services and Utilities	3	The attack severely overtaxes Seattle Police. Shifts are extended, and mutual aid is called upon, but service levels must be reduced to cope with the emergency.
Confidence in Government	3	The public is shocked by the attack. Initially the response is given high marks, but later public opinion shifts as many people begin to question security at the tree lighting ceremony.
Cascading Effects	2	The attack is extremely deadly and disruptive, but it does not cause any significant secondary incidents.

Social Unrest

Most Likely Scenario

Violent political protests similar to 2020 George Floyd event

A political protest in the downtown core escalates to violence between the protestors and counter protestors over opposing political ideologies. Nearby properties are vandalized. Anarchists join in the violence and property destruction. Around 3,000 people participate in the event. 110 police officers in riot gear intervene with tear gas and rubber bullets but cannot control the unexpectedly large crowd. One person is shot and killed by a protester in the chaos and 24 people are injured. 17 storefronts have been vandalized. Smaller groups of protestors break off from the larger group and disperse throughout the city, vandalizing more property and setting two fires.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Seattle has experienced civil disorder in every decade since the 1960's.
Geographic Scope	3	The riot begins in a localized area of downtown, but spreads to other neighborhoods of the city throughout the night.
Duration	1	The disorder starts during the evening and continues for 8 hours.
Health Effects, Deaths, and Injuries	2	One person is shot and killed when confronting a protestor. 24 people suffer injuries requiring medical attention.
Displacement and Suffering	2	Anarchists target downtown businesses and government buildings. Protesters engage in standoff with police. After objects thrown at police, tear gas is used which drifts into nearby buildings. Some bystanders caught in conflict
Economy	3	In total, 28 businesses suffer property damage and 7 are looted in the night. Tourism revenue dips in the weeks after the event.
Environment	1	There is no impact on the environment.
Built Environment	2	Two structures are destroyed in fires. 28 other buildings have property damage but are still habitable.
Transportation	2	The incident closes streets for a major portion of the downtown core. Small groups are caught dropping objects onto I-5.
Critical Services and Utilities	2	Police services are degraded in other areas of the city because many officers are needed at the site of the events.
Confidence in Government	3	Some members of the public think that the authorities should have anticipated the potential for violence and done more to prepare.
Cascading Effects	2	The event results in 2 major fires that burn commercial buildings.

Credible Worst-Case Scenario

Large scale violence between social groups

This scenario is linked to the Structure Fire Credible Worst-Case scenario.

Unforeseen political or social conflict raises tensions between social groups to an unprecedented level. An event triggers a flood of anger directed at one of these groups. The larger groups use social media to gain participants and organize attacks against the smaller groups in a deliberate manner and to terrorize them. It is difficult for law enforcement to predict attacks because of masked online communications. Government intervenes to prevent widespread violence. Houses, businesses and gathering places are set on fire (see Structure Fire Credible Worst-Case). Casualties are high due to the deliberate and premeditated targeting of people. There is no evidence to suggest any specific groups that would be party to this scenario, and it does not speculate.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	The type of disorder in which one social group attacks another in a semi-organized fashion is rarer than attacks against property or symbols of authority. In Seattle, this type of disorder has only happened once and that was in the 19th century. While contemporary culture seems more enlightened, history can always repeat itself.
Geographic Scope	5	The social conflicts imagined in this scenario are felt throughout the region, but especially strongly in Seattle. Flash points emerge in multiple locations.
Duration	3	The most serious part of the incident lasts for five days. The conflict builds over two days, with the most serious rioting on the third day. The following two days, law enforcement contains further violence.
Health Effects, Deaths, and Injuries	3	19 people are killed when they are attacked in the street or in their homes. 245 people are injured enough to require medical attention.
Displacement and Suffering	5	The attacks terrorize a community causing hundreds of households to seek safety.
Economy	3	Businesses in affected neighborhoods have to close during the incident. 5 businesses are destroyed. Afterwards, people are afraid to return to areas that experienced conflict and investors are reluctant to put their money into the areas.
Environment	1	There are no major environmental problems that arise from this incident.
Built Environment	3	34 buildings are destroyed and 275 are damaged.
Transportation	2	Transportation in and through affected neighborhoods stops. Law enforcement maintains a strong presence in many parts of the city which impedes traffic flow. There is no structural damage to the transportation system.
Critical Services and Utilities	2	Fire and emergency medical services are overburdened and must call in back-up resources from neighboring cities. Power outages occur due to fires and deliberate sabotage.
Confidence in Government	5	When some members of the public find out that the groups were communicating online, they think that the authorities should have anticipated the potential for violence and done more to prepare. Victims blame the government for allowing them to be attacked. Perpetrators and their sympathizers resent law enforcement for stopping them from doing more damage.
Cascading Effects	2	The civil disorder leads to many fires, mostly homes.

Cyber Attacks and Disruptions

Most Likely Scenario

Attack on cloud-based software used by City of Seattle shuts down critical services

Attackers compromise a trusted third-party system the City of Seattle uses to deliver critical services in fashion similar to the 2021 Colonial Pipeline attack. It focuses on financial systems that support the City of Seattle’s service delivery. Seattle is one of many local governments affected by the attack. The City of Seattle is forced to curtail key services and programs during attack including utilities, power, human services, and permitting.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	4	The Seattle Public Library experienced a severe ransomware attack in 2024. Sophisticated attacks are increasing, making a successful attack more likely. Other urban municipalities have faced ransomware attacks.
Geographic Scope	5	The attack mainly impacts city operations.
Duration	4	City of Seattle services are curtailed for two weeks until the vendor can recover and clean their system.
Health Effects, Deaths, and Injuries	1	The attack does not cause any fatalities or injuries.
Displacement and Suffering	1	The attack does not displace households, but households see billing disruptions and cancellation of programs.
Economy	2	The City of Seattle experiences revenue losses. The cancellation of services by the City of Seattle creates indirect losses in the community.
Environment	1	The attack does not damage the environment.
Built Environment	1	The attack does not damage buildings.
Transportation	1	The attack pauses permitting slowing construction projects
Critical Services and Utilities	2	Most disruptions are inconveniences. People cannot pay bills or contact about customer service concerns online. Employees are overwhelmed with the volume of calls they receive and have to work without computers, delaying services. People with court dates have to reschedule.
Confidence in Government	3	The public is frustrated with the slow response to get services back online. Customers affected in the data breach are angry that their local government did not do more to protect their information. SPU faces many lawsuits and customer complaints.
Cascading Effects	1	There are no cascading effects.

Credible Worst-Case Scenario

Attack on critical infrastructure

The U.S. has never had a major cyber-attack on its physical infrastructure, but in a first, a state-sponsored group deploys a cyber-attack on the U.S. power generation and transmission system in December, causing nation-wide outages. Operators take down computerized control systems, but manual workarounds are not as efficient as computerized systems they replace. IT staff struggle for three weeks to bring systems back online.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	1	There has been only one confirmed case of a cyberattack destroying equipment, the STUXNET attack on Iranian centrifuges. However, cyber-attacks have disrupted smaller infrastructure systems including power and water. Additionally, experts believe that an attack on U.S. infrastructure is among the likely targets for hackers in the coming years.
Geographic Scope	5	Vulnerable power utilities are affected in every state in the US.
Duration	4	Seattle City Light and Bonneville Power Administration operators lose the ability to control power management systems for three weeks causing blackouts and brownouts.
Health Effects, Deaths, and Injuries	2	5 people die in traffic accidents due to the effects of power outages. 230 people become ill from eating spoiled food. 4 people die from attempting to heat their homes with a charcoal grill.
Displacement and Suffering	5	The extended power outages displace 1000s of people living in high rise buildings because water systems lack pressure to bring water to higher floors and the lack of power shuts down elevators. 300 families with electric heating systems need shelter. The transportation system is disrupted causing some food shortages. Schools close due to lack of power. Water is out in areas that require a pump until the pumps can be connected to a generator.
Economy	4	Most businesses in Seattle are forced to suspend operations for three weeks. Retail suffers especially because the attack occurs during the holiday season. There is a surge in sales after the attack ceases, partially offsetting lost business but 25 smaller businesses cannot recover. The national economy suffers overall and unemployment increases.
Environment	3	The attacks disable King County's sewage treatment plants. Untreated sewage is discharged into Puget Sound at levels harmful to wildlife.
Built Environment	1	The attack does no damage to buildings but causes many to be temporarily inoperable.
Transportation	4	Traffic control systems are taken offline. The surface transportation system is heavily affected, and vehicle accidents increase. Air traffic control systems continue to operate as do marine navigation systems.
Critical Services and Utilities	4	Multiple utilities are inoperable due to extended power loss and a lack of generators: communications, water, and power. Public safety is operating on manual systems which reduce capacity.
Confidence in Government	5	The public is initially sympathetic to the local government but grows impatient as the outages continue. When they learn that an attack was foreseen, they become resentful of government
Cascading Effects	4	The attack causes widespread power outages. Many control systems that prevent hazardous materials releases are offline.

Transportation Incidents

Most Likely Scenario

Fuel Tanker collides with bus under the Washington State Convention Center

A fuel tanker blows a tire and collides with a Metro bus. The tanker explodes and catches fire causing multiple fatalities and injuries. The high heat from the fire threatens the Convention Center's structure. I-5 southbound is completely closed.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	Seattle has experienced multiple tanker trucks overturning and several tanker truck fires. In one 1975 case, a fuel truck caught fire which came close to spreading to a nearby nightclub. While a collision between a source of hazard and a vulnerable vehicle would be a rare occurrence there is precedent. The same logic applies to an accident occurring under a structure.
Geographic Scope	2	This is a single-site incident. It affects the immediate area plus the area under the smoke plume.
Duration	1	Firefighters are able to extinguish the blaze and transport patients within 24 hours.
Health Effects, Deaths, and Injuries	3	12 people are killed and 24 injured
Displacement and Suffering	1	No persons are displaced as a result of this accident and no people except for victims suffer major losses of quality of life.
Economy	2	The Convention Center has to curtail some operations while its support structure is evaluated. It sustains some damage causing extended loss of some areas while repairs occur.
Environment	1	The fire generates smoke, but no significant damage occurs
Built Environment	2	A major structure sustains damage.
Transportation	3	I-5 is blocked for 24 hours
Critical Services and Utilities	1	No critical services are impacted
Confidence in Government	1	Local government is able to effectively respond to this incident and is not perceived as incapable.
Cascading Effects	1	No secondary hazards occur

Credible Worst-Case Scenario

Oil Train explosion and fire

A freight train carrying crude oil derailed in the BNSF tunnel near the southern entrance. The crash ignites a fire inside the tunnel. The oil train is only partially inside the tunnel. The tunnel lacks modern fire suppression technologies. The Fire Department vents fumes from the southern end of the tunnel. The fire weakens the roof of the tunnel which collapses. The southwesterly wind blows the smoke into downtown forcing the evacuation of much of downtown including the Seattle EOC and the Seattle Municipal campus.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	Seattle has not experienced a large tunnel fire but had a fuel tanker catch fire on the viaduct in 1975.
Geographic Scope	3	The fire affects the whole tunnel, SR 99, and areas surrounding the tunnel entrances.
Duration	4	The initial response takes 1 day but stabilizing the tunnel and investigating the accident takes a week. The tunnel remains closed until the damage to tunnel infrastructure is repaired.
Health Effects, Deaths, and Injuries	4	The train conductor and a crew member are killed due to toxic smoke and heat. The lack of adequate safety infrastructure in the tunnel adds to the casualties. 230 people are injured.
Displacement and Suffering	3	143 non-Seattle residents need temporary shelter until they can leave. 34 people have friends and relatives in hospital and want to stay longer to be with them.
Economy	3	The tunnel is severely damaged and must remain closed while repairs take place. The tunnel is a major freight corridor. Trains must use alternate routes that add hours to trips. Seattle shipping and manufacturing suffers as a result.
Environment	2	Venting of smoke and fumes into downtown causes evacuation of areas near the accident site.
Built Environment	2	The tunnel collapses near the fire. The sudden failure causes the ground above to fail damaging 2 buildings on the surface.
Transportation	4	Public safety personnel cannot access parts of downtown due to toxic smoke, including routes to Harborview hospital. Surface transportation is affected by the evacuation of downtown. I-5 is closed while the plume covers it (12 hours). After the fire is out the tunnel remains closed for repairs. Surface transportation returns to normal, but rail remains severely impacted.
Critical Services and Utilities	2	Toxic smoke drifts into Harborview. Health officials must decide whether to shelter in place or evacuate. Seattle Fire must backfill with mutual aid.
Confidence in Government	5	The accident begins a new tunnel controversy, and the public blames the government for not making the tunnel safer.
Cascading Effects	4	The fire has major secondary effects. The incident causes a disastrous hazardous materials incident and a tunnel collapse.

Structure Fires

Most Likely Scenario

Gas leak, explosion, and fire

A gas leak starts in a business in a mixed-use apartment building during a cold January night. The gas accumulates in the closed first-floor business. Shortly after residents notice the smell and call 911, a spark ignites the gas in the business. The explosion destroys most of the building.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	4	Gas leaks are a common occurrence in Seattle, and several explosions have occurred, most notably the 2016 Greenwood Gas explosion. This scenario envisions a more devastating leak and explosion.
Geographic Scope	1	This is a single site incident
Duration	2	Seattle Fire is able to stabilize the incident within 24 hours, but the EOC remains activated for 3 days.
Health Effects, Deaths, and Injuries	3	The blast causes 12 fatalities and 45 injuries.
Displacement and Suffering	3	225 people are displaced from the primary affected building, but several nearby structures sustain major damage that displaces residents.
Economy	2	Many nearby businesses are unable to operate for weeks due to damage to their buildings. The contents of some businesses are damaged.
Environment	2	Asbestos and other toxic building materials are scattered across a wide area.
Built Environment	2	1 structure is destroyed, 3 sustain major damage, and 14 have windows destroyed.
Transportation	2	The neighboring street is closed for the initial response but reopens within a day.
Critical Services and Utilities	2	Gas service to the neighborhood is temporarily turned off during a cold snap causing hardship for residents.
Confidence in Government	3	Fire and hazmat response are effective. After the initial response, members of the public question why the gas leak occurred and why inspections did not reveal the problem.
Cascading Effects	1	This explosion does not cause any secondary incidents.

Credible Worst-Case Scenario

Multiple fires including multi-structure fires erupt during a riot

This scenario is an extension of the Social Unrest Credible Worst-Case scenario.

Multiple fires are set during civil unrest that pits two social groups in conflict. The fires are set first in commercial buildings, but then in following days in residential buildings. Because of the danger to firefighters, many of these fires are left to burn. The weather is windy. As a result, some spread to engulf multiple blocks.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	1	Seattle has never experienced this level of destruction during civil unrest, but other cities in the US have. During past civil unrest in Seattle, arson first have been started but did not cause extensive damage.
Geographic Scope	4	The fires are concentrated in three neighborhoods. These neighborhoods are spread through the city.
Duration	4	The civil unrest lasts three days, but extinguishing the fires and helping the survivors with immediate needs lasts three weeks.
Health Effects, Deaths, and Injuries	3	43 people are killed in the fires with 443 severely injured.
Displacement and Suffering	4	3 apartment buildings burn and 12 are damaged displacing 934 people.
Economy	4	Whole blocks of businesses are burned out and closed.
Environment	1	There are no environmental impacts.
Built Environment	3	112 buildings are red tagged. 532 are yellow tagged.
Transportation	4	Transportation throughout the city comes to a standstill during the unrest. Many streets remain closed or have lanes restricted following it.
Critical Services and Utilities	3	Utilities are shut off for areas affected. Powerlines are destroyed or damaged in affected areas and need to be replaced following the unrest.
Confidence in Government	5	Local government is seen as partially responsible for the unrest and fires.
Cascading Effects	3	The fires cause multiple hazardous materials incidents, power outages, and local water shortages.

Hazardous Materials Incident

Most Likely Scenario

Material with high concentrations of hazardous materials catch fire at a metal recycling plant

During a summer afternoon, lithium-ion batteries start a fire at an open-air recycling plant along the Duwamish. The fire escalates rapidly. The plant handles materials with hazardous chemicals. The smoke from the fire includes a mix of many chemicals including dioxins, persistent organic pollutants, volatile organic compounds, and heavy metals. Wind is from the west, blowing into the Georgetown area, the smoke blocks the runway at King County International Airport.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	4	Seattle has had several recycling plant fires. The scenario envisioned here is more severe than these past incidents.
Geographic Scope	3	The toxic smoke plume affects a wide area from the plant into Georgetown
Duration	2	Seattle Fire is able to stabilize the incident within 24 hours, but the EOC remains activated for 3 days.
Health Effects, Deaths, and Injuries	2	No fatalities, but 89 people are injured and need to be transported to hospitals.
Displacement and Suffering	3	6000 people need to evacuate the area including 3000 residents. Sever
Economy	2	Businesses close during the event. Fears persist about toxic smoke damage. Most can reopen within several days, but some require a cleaning that keeps them closed for weeks.
Environment	3	Toxic residue covers a large part of Georgetown and SODO. Ash becomes airborne when the wind blows. Material enters the drainage system and needs to be captured.
Built Environment	1	No structures are permanently damaged.
Transportation	2	City streets are closed during the incident and King County International Airport paused operations.
Critical Services and Utilities	2	Utilities around the plant are shut off during the incident.
Confidence in Government	3	Fire and hazmat response are effective. After the initial response members of the public question why the plant was permitted and allowed to operate within the city.
Cascading Effects	1	This explosion does not cause any secondary incidents.

Credible Worst-Case Scenario

Fire involving anhydrous ammonia leak from a train

The Amtrak Empire Builder and a BNSF freight train carrying mix of chemicals including anhydrous ammonia collide in the Great Northern Railway Tunnel near the south portal after the BNSF train details. Shortly after the initial crash, an explosion ignites vapors from several tank cars, and a vapor cloud begins to drift into King St. Station and the CID.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	Seattle has experienced several ammonia leaks, but none as large as envisioned by this scenario.
Geographic Scope	3	The fire affects the south tunnel portal, SR 99, and areas surrounding the tunnel entrances. An area
Duration	4	The initial response takes 1 day but stabilizing the tunnel and investigating the accident takes a week. Clean up stretches over one month
Health Effects, Deaths, and Injuries	4	12 people are killed in the initial accident and chemical spill. 769 people are injured in the CID and Pioneer Square neighborhoods.
Displacement and Suffering	4	The US Dept. of Transportation Emergency Response Guide specifies an evacuation distance of 1 mile for anhydrous ammonia in cases of fire. Approximately 138,000 people need to evacuate the area. More are workers, but 16,000 residents are affected. Seattle's EOC and Seattle Fire management resources need to be relocated, making response more difficult.
Economy	3	Businesses in the area covered by the cloud are forced to close. Many see a decline in customers after they reopen due to lingering fears about remaining chemicals. The tunnel remains closed for three weeks for cleaning and investigation.
Environment	2	Venting of smoke and fumes into downtown causes evacuation of areas near the accident site.
Built Environment	1	The incident does not physically damage structures but worry buildings have been contaminated.
Transportation	4	Public safety personnel cannot access parts of downtown due to toxic smoke, including routes to Harborview hospital. Surface transportation is affected by the evacuation of downtown. I-5 is closed while the plume covers it (12 hours). After the fire is out the tunnel remains closed for repairs. Surface transportation returns to normal, but rail remains severely impacted.
Critical Services and Utilities	2	Toxic smoke drifts into Harborview. Health officials must decide whether to shelter in place or evacuate. Seattle Fire must backfill with mutual aid.
Confidence in Government	3	The accident begins a controversy about the safety of the Great Northern Tunnel, and the public blames the government for not making the tunnel safer.
Cascading Effects	3	This incident was caused by derailment and collision, a transportation incident. It can be considered a secondary incident to the main hazardous materials incident.

Built Environment Failures

Most Likely Scenario

Ballard Bridge Struck by Barge

During an opening, the Ballard Bridge is struck by a gravel barge and heavily damaged. The bridge cannot close and requires extensive repairs. Two cyclists waiting for the bridge to close are killed. Eight people are severely injured. The 57,000 vehicles per day served by the bridge need to be detoured indefinitely. The barge sinks impeding marine traffic.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Built environment failures happen fairly frequently in Seattle including bridge failures.
Geographic Scope	2	The impacts are felt on both the north and south sides of the bridge.
Duration	2	It takes three days to stabilize the incident. The bridge will not be usable for months.
Health Effects, Deaths, and Injuries	2	Two deaths and eight serious injuries.
Displacement and Suffering	2	The main break forces widespread water shutoffs. PSE is forced to shut off gas service to many customers as well.
Economy	2	The prolonged outage hurts businesses in Ballard as many customers shift business to other locations.
Environment	1	Gravel on the barge sinks, but no lasting damage is caused by the incident
Built Environment	1	Aside from the bridge itself, no structures are damaged
Transportation	3	A major corridor is not usable for an extended period.
Critical Services and Utilities	1	No major utilities impacted. Fire Station #3 in Interbay loses access to Lake Union and Lake Washington for three days while the barge is removed.
Confidence in Government	1	The private barge operator is perceived to be at fault. The City of Seattle is credited with
Cascading Effects	1	No major cascading effects result from the incident.

Credible Worst-Case Scenario

Catastrophic failure of the Howard Hanson Dam

The Howard Hanson Dam fails suddenly during the workday while the reservoir behind the dam is nearly full. This kind of failure is a very unlikely scenario, but one that the U.S. Army Corps of Engineers models as part of the National Dam Safety Program. This dam underwent emergency repairs in 2009. The dam failure sends cubic acres of water down the Green River into the Kent and Duwamish Valleys. The worst destruction is south of Seattle. Most outside resources are used in this area making limited resources available for Seattle.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	1	The U.S. has experienced catastrophic dam failures like the 1972 Buffalo Creek disaster and the 1977 Teton Dam failure, but none has occurred locally making this an extremely rare event. The U.S. has not had a catastrophic dam failure since the creation of the National Dam Safety Program.
Geographic Scope	5	Large parts of South King County is affected even more severely than Seattle. In Seattle itself, the entire Duwamish Valley is directly affected. The whole city is indirectly affected due to transportation and utility impacts.
Duration	4	The incident unfolds over a single day, but it takes four weeks to stabilize the consequences and begin recovery. Due to the scale of the destruction, long term recovery will take years.
Health Effects, Deaths, and Injuries	3	The incident unfolds quickly. The City of Seattle issues a Wireless Emergency Alert directing people to leave the low lying areas near the Duwamish, but several hundred people are unable to do so or don't receive notification. As a result, 14 people are killed and 54 seriously injured. Long term, the spread of toxins from the Duwamish on land results in an increase in adverse health effects among the exposed population.
Displacement and Suffering	3	South Park and Georgetown are almost completely flooded. Thousands of residents need short term shelter and several hundred need long term shelter.
Economy	4	Hundreds of businesses in South Park, Georgetown, and around Boeing are impacted. Boeing is unable to use its facilities near the King County International Airport.
Environment	3	Pollution in sediments in Duwamish River superfund site are resuspended and transported onto land. This pollution spread requires long-term and expensive remediation.
Built Environment	4	Hundreds of buildings are flooded and red tagged. Dozens require demolition and the rest need extensive repairs.
Transportation	4	King County International Airport is flooded interrupting freight air and Boeing commercial air operations. BNSF and Union Pacific rail lines are damaged halting commercial rail service. Major roadways are damaged and need repair.
Critical Services and Utilities	3	Water and power infrastructure is damaged by the flood waters causing extended outages.
Confidence in Government	3	The Howard Hanson dam is not owned by the City of Seattle. The Federal government is widely faulted for not maintaining the dam properly. Locally, frustration with recovery mounts, but is tempered by the acknowledgement that the amount of damage makes recovery difficult.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	3	The flooding causes hazardous materials incidents, power outages, and water shortages, but these secondary incidents, while significant, are small compared to the severe effects of the flooding.

Power Outages

Most Likely Scenario

A strong windstorm causes widespread power outage across Puget Sound

A windstorm takes down powerlines both directly and via tree fall. 120,000 Seattle City Light customers lose power and downed trees and powerlines across the city make it difficult to repair infrastructure. Many residents of downtown high-rises are unable to walk the stairs to their apartments, and some people are unable to charge their electric cars.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Large power outages occur on a fairly regular basis. Most are associated with storms or accidents. In most cases the outages last less than a day, but occasionally the power takes days to come back.
Geographic Scope	5	Windstorms can be widespread regionally, meaning other utilities in the area may not be able to share resources.
Duration	2	Full power is restored to all customers in 4 days.
Health Effects, Deaths, and Injuries	2	No one is killed in the incident, but one Seattle City Light line worker is critically injured. 10 people contract a food borne illness when they consume non-refrigerated food. Hospitals see an influx of people into the ER to access power to charge their phones, causing overcrowding.
Displacement and Suffering	2	A Seattle Housing Authority property in North Seattle loses power. Many residents are disabled or elderly. Most have no other place to go. Altogether 65 people need shelter.
Economy	2	Many small businesses that operate on the edge of profitability are losing money each day. Several biomedical research projects are destroyed when refrigerators lose power.
Environment	2	Hundreds of trees across the city have fallen, some of which are old and provide shade to several homes in the summer months.
Built Environment	2	Many homes are damaged directly from winds and debris falling on houses.
Transportation	3	Surface transportation in the affected area is disrupted. Traffic lights are dark and operate as four way stops. Two lanes of northbound I-5 were closed from a tree falling in the road.
Critical Services and Utilities	2	Aside from the power outage itself, critical services and utility services are able to be maintained at street level.
Confidence in Government	1	The public sees local government response as timely and effective.
Cascading Effects	2	The power outage increases the incidence of food borne illness.

Credible Worst-Case Scenario

Western power grid failure during cold winter weather

The western power grid fails during December when Seattle City Light needs power from it. Cold temperatures are creating a high demand for power for heating. Seattle City Light must attempt to meet demand using only its own resources (which can supply 60% of demand) and must ration it. Several large events are planned for the time period: Seahawks and UW Husky games, and an event at Westlake mall. Holiday shopping is in full swing, and businesses are eager to maintain sales. Seattle City Light would have to implement rolling blackouts to spread the pain among customers, including vulnerable customers like nursing homes.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	Failure of the western grid, called the Western Interconnection, has not had major impact on Seattle, but there have been several close calls. Seattle City Light has its own generating and transmission capability which mitigates vulnerability to problems with the Western Interconnection, but Seattle City Light relies on its power during peak demand. As a result, this scenario is estimated to have a 1 in 100 chance of occurring each year.
Geographic Scope	5	Failure of the Western Interconnection would cause a region wide power outage.
Duration	4	Power is out for 10 days. The transmission is severely damaged in a storm. Local systems also suffer damage in the storm and due to load imbalances when the Western Interconnection is lost.
Health Effects, Deaths, and Injuries	2	Despite the best efforts of public health, a family of five dies when they attempt to heat their home with a charcoal grill. Public outreach has saved lives, however.
Displacement and Suffering	4	700 people, including 45 residents of a nursing home, require shelter from the cold. The prolonged outage reduces the capacity of food distribution centers resulting in shortages of perishable food and medicines. Medical service providers, mainly outpatient services, operate at reduced capacity.
Economy	3	All businesses in Seattle without generators are affected. There is a surge in sales after the outage. Because the outage is so large, consumers are not able to redirect their spending elsewhere. Unfortunately, the post outage surge does not cover losses. The biotech industry loses research when they cannot refuel generators.
Environment	1	The environment is not impacted by the outage.
Built Environment	2	The power outage cuts water service to high rise buildings without generators. Water pumps fail in some parts of the city.
Transportation	3	Surface transportation is disrupted throughout the region. Airports are able to remain open but have to curtail non-essential functions. Marine terminals continue to operate on generator power. Gas stations lose ability to pump gas. Traffic lights are dark in many areas of the region, causing significant slowdowns on major arterials.
Critical Services and Utilities	3	Critical services operate on generators. As fuel becomes harder to obtain, some facilities run out of power. 800 MHz sites go dark.
Confidence in Government	5	The Western Interconnection is operated by government authorities. As the outage continues past the third day, the public becomes increasingly frustrated with government.

Cascading Effects	3	The outage causes a number of secondary effects: a number of fires start due to people burning wood to stay warm. The outage leads to infrastructure failures in the water and communications systems.

Extreme Heat Events

Most Likely Scenario

6 days of 90°F with 2 days over 100°F.

Temperatures are over 90°F for six straight days with two over 100°F. Lows are over 65°F during most of this stretch. The duration of the heat causes a gradually increasing strain on the population and health systems as indoor temperatures rise over 90°F in structures without A/C.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	4	Seattle reached a record 108°F during the June 2021 Heat Dome event, which saw three consecutive days over 100°F. It is projected that Seattle's heat events will become more severe in the future due to climate change.
Geographic Scope	5	The whole region is affected during extreme heat events. Seattle has more paved area than any other city in the region and suffers from an 'urban heat island' effect.
Duration	3	The apex of this event is two days of triple digit temperatures and five more in the 90s. The consequences of heat events rise with duration, especially if temperatures do not drop significantly at night.
Health Effects, Deaths, and Injuries	3	30 people die from heat-related illness and over 200 require medical attention. One nursing home does not have adequate cooling for residents.
Displacement and Suffering	2	89 people seek overnight shelter in air-conditioned facilities. Thousands of people seek shelter in air-conditioned spaces (malls, libraries, and community centers) during the day.
Economy	2	Significant but hidden costs resulting from excess medical attention (hospitalizations, ER visits, ambulance callouts and premature deaths). The heat prompts a run on fans and air conditioners. Two major events are cancelled and energy use spikes.
Environment	2	The heat stresses plants but does not damage whole areas or ecosystems.
Built Environment	1	The heat event does not destroy any buildings.
Transportation	2	The Seattle Department of Transportation must cool the older drawbridges over the Ship Canal or risk having them become stuck and unable to open. The Ballard Bridge's leaves expand to the point they are touching. The bridge can't be opened safely. Maritime traffic is impacted. Streets and sidewalks begin to crack in the heat. None of these cracks impeded traffic, but they are a cost to local government.
Critical Services and Utilities	1	Critical services and utilities are able to be maintained, but the City of Seattle must increase staffing and seek volunteers to help at daytime cooling centers.
Confidence in Government	1	The public views the government's response to the heat as adequate.
Cascading Effects	1	The heat event does not cause significant secondary incidents.

Credible Worst-Case Scenario

8 days of 90°F with 4 consecutive days over 100°F

Seattle experiences an unprecedented heat event. Temperatures are over 90°F for 8 consecutive days with 4 consecutive days over 100°F. Temperatures do not sink below 70°F overnight for 5 consecutive nights. The heat occurs early in the season, limiting the amount of acclimation possible before the event. This early season event also overlaps with the longest period of daylight, extending the temperatures well into the evening/overnight time frame with outdoor temperatures not falling below indoor temperatures until close to midnight. Indoor temperatures rise well into the 90s during the afternoon and evenings in most structures without A/C making many indoor spaces unsafe.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	Seattle's 2021 Heat Dome brought unprecedented heat to the area, with the most extreme temperatures lasting three days. The event was bookended by temperatures in the upper 80's. A longer, more intense event would be a worst-case scenario. This heat event was considered very rare, estimated to occur roughly every 1 in 1000 years. However, climate scientists predict such an event could occur every 5-10 years with 3.6 degrees of global warming.
Geographic Scope	5	The whole region is affected during extreme heat events. Seattle has more paved area than any other city in the region and suffers from an urban heat island effect.
Duration	5	This heat wave lasts for nearly two weeks. The longer a heat wave lasts the more its consequences grow. The nighttime temperatures do not dip below 70 ° F which makes the event more dangerous as homes without AC are not able to cool down.
Health Effects, Deaths, and Injuries	4	Nearly 100 excess deaths are attributed to the heat, especially among residents in poorer areas of the city who keep their doors and windows locked and lack air conditioning. Over 1000 people seek medical attention and overwhelm emergency facilities.
Displacement and Suffering	4	854 people seek overnight shelter in spaces with air conditioning systems. Most of the general population is extremely uncomfortable.
Economy	3	The heat event costs \$50 million in excess medical expenses, premature deaths, increased energy costs, and cancelled events.
Environment	2	Air quality significantly decreases in the hot stagnant air. Many plants are stressed and some die. Snowpack and glaciers undergo rapid melting, leaving forests drier than usual and more vulnerable to wildfire.
Built Environment	1	The heat does not destroy buildings.
Transportation	3	The University and Ballard Bridges are opened to avoid having them expand and damage themselves. This causes disruption to emergency services and the general public. Streets and sidewalks crack. Aircraft coming into Sea-Tac have weight restrictions imposed. Train rails kink and impede freight and passenger traffic.
Critical Services and Utilities	3	Heat out of the area causes high demand on the power generation and transmission system. High heat causes power lines to sag causing shorts and localize outages. Water consumption spikes prompting worries about a water shortage. Fire and police are unable to use the University and Ballard Bridges. The heat does not cause the loss of any responders.

Confidence in Government	3	As the event continues, the public clamors for more assistance with cooling.
Cascading Effects	2	The heat causes power outages and is raising concerns about a water shortage.

Flooding

Most Likely Scenario

Atmospheric river causing urban flooding throughout Seattle

A powerful 'Pineapple Express' brings days of heavy rain to the area. Thornton and Longfellow creeks flood. The drainage system is overwhelmed in two spots. During the storm 8 major landslides occur. Property damage is extensive, but there are no fatalities. Several roads are undermined by sinkholes, damaging water and sewer lines.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Winter storms are regularity in Seattle during the winter. One type of system is known as an atmospheric river. It occurs when moist warm air is pulled up into the Pacific Northwest by the jet stream. Such a storm is colloquially called 'Pineapple Express.' Climate scientists project that heavy rain events will become more intense in the future and flooding will increase with sea level rise.
Geographic Scope	4	This is regional storm, but only certain areas within the city are impacted.
Duration	3	The storm lasts 4 days.
Health Effects, Deaths, and Injuries	1	No one is killed or injured during the storm.
Displacement and Suffering	2	Urban flooding displaces 25 households. Mitigation in the Madison Valley and Thornton Creek areas lessens the impact of flooding.
Economy	2	Businesses in the Midvale, South Park, and Lake City have minor to moderate flooding.
Environment	2	The storm overwhelms the City's drainage system causing Seattle's combined sewer overflow (CSO) locations to release sewage into Puget Sound, Lake Union, and Lake Washington.
Built Environment	2	No buildings are destroyed, but 9 buildings have to be evacuated because the basements and ground floors flood. Another 150 buildings have basement flooding only. These buildings can still be occupied.
Transportation	2	Aurora and the Mercer Street underpass and many residential streets fill with flood water. Buses and vehicles must reroute, causing traffic delays.
Critical Services and Utilities	1	No critical services are degraded in the flood incident.
Confidence in Government	1	Local government is able to respond quickly to localized flooding. In areas with riverine flooding (Thornton and Longfellow creeks) the City of Seattle organizes sandbagging. This effort and the success of detention ponds are credited to the City of Seattle.
Cascading Effects	1	The release of raw sewage is a significant problem but does not necessitate an immediate emergency response.

Credible Worst-Case Scenario

Strong atmospheric river combined with King Tide leads to extreme coastal, riverine, and urban flooding

An atmospheric river comes through the area, at its heaviest bringing nearly 9 inches of rain in 24 hours and periods with intense rainfall (1" in an hour). While the intense rain is short-lived, precipitation continues to fall for seven days. A king tide also occurs during this time, making water levels in rivers and along shorelines higher than usual. The South Park neighborhood experiences flooding due to its proximity to the Duwamish River which sees overtopping due to the King Tides and rain. Urban flooding occurs in 12 locations, and 20 major landslides are triggered due to increase in ground water.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	This scenario is based on a synthetic storm event generated by Seattle Public Utilities and is estimated to be a 1000-year event. The modeling for this scenario was based off historical climate data. Climate scientists predict increasingly heavy precipitation events as the century progresses. When heavy rain coincides with King Tides, flooding can be exacerbated along shorelines and major rivers. This occurred during the December 2022 South Park Flooding, which caused unprecedented flooding in the Duwamish Valley and damaged several homes and businesses.
Geographic Scope	5	This storm is a regional event. Surrounding jurisdictions would be suffering the same or worse. Area rivers would be at record flood stage. Seattle would not be able to count on assistance from within the region.
Duration	4	The rain lasts for seven days without a break longer than 24 hours.
Health Effects, Deaths, and Injuries	2	4 people are killed in a landslide and 2 people drown in flood waters.
Displacement and Suffering	4	Seattle's creeks which normally only see ponding are actively flooding. King tides drive people along the shore and in South Park from their homes. Areas in the interior of the city flood when the drainage system becomes overwhelmed. Altogether 850 people need shelter. Many people with mobility impairments have difficulty going out to get food and make medical appointments.
Economy	3	Many businesses are flooded and cannot operate. Seattle's core industries: biotech, aerospace, and software are able to continue operation with some difficulties. 800 structures suffer major uninsured losses.
Environment	3	Rain causes erosion and landslides that break 2 major sewer lines. 5 facilities housing large amounts of hazardous materials are flooded releasing chemicals into the water.
Built Environment	3	34 buildings suffer major damage from king tide flooding and must be red tagged, but the more significant problem is 100s of flooded homes. Most are able to be salvaged when the incident is over but require major work to repair.
Transportation	4	Many residential streets are flooded. Smaller neighborhoods are cut off. I-5 is cut off at Chehalis and I-90 is periodically threatened by rockslides. Rail service north of the ship canal is halted many times due to landslides. Major corridors remain open as do the airport and marine terminals.
Critical Services and Utilities	3	Public safety vehicles are unable to reach smaller neighborhoods cut off by flooding. Food distribution becomes difficult due to I-5 flooding and I-90 rockslides.

Category	Impacts 1 = low 5 = high	Narrative
Confidence in Government	3	As the flooding continues the public becomes tired of the inconvenience and wonders why more isn't being done to fix problems and obtain more aid from the federal government.
Cascading Effects	3	The storms have caused landslides and hazardous materials releases.

Severe Winter Weather

Most Likely Scenario

Snowstorm leaves a foot of snow on the ground followed by extreme cold

A major snowstorm strikes Seattle during a weekday. A combined 8-12" of snow accumulates over 24 hours. Snowfall is followed by extremely cold temperatures for four days, and moderately cold temperatures for three days. An atmospheric river arrives the morning of the 8th day allowing temperatures to then warm, creating a brief but impactful period of urban flooding due to rain on snow/ice and blocked drainages.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Heavy snowstorms do not occur every year in Seattle but are not rare events either. The most likely future severe snowstorm would be similar to those that have occurred recently (e.g. 2019, 2008). Climate scientists project that Seattle will see a decrease in winter precipitation falling as snow by the 2040s, but natural precipitation variability could still cause future snowstorms.
Geographic Scope	5	This snowstorm affects the entire Central Puget Sound region. The snow moves up from the south to the north. South Seattle receives more snow than north Seattle.
Duration	4	Snow falls for two consecutive days. For four consecutive days following precipitation, daytime high temperatures remain below 32°F and overnight lows fall to between 10-15°F. For the following 3 days, daytime highs warm to the upper 30s but overnight lows still fall into the lower 20s.
Health Effects, Deaths, and Injuries	2	On the coldest 2 nights, breezy conditions result in wind chill values ranging from -5 to 5°F, but there are no deaths that are directly attributed to the storms. Investments in public warning about using charcoal indoors and sledding on dangerous hills save lives. 15 people are injured in a bus crash, and 8 unsheltered people are hospitalized for hypothermia.
Displacement and Suffering	2	No households are displaced but many people cannot make it out to go shopping and some stores are not receiving supplies. As a result, some vulnerable people are going hungry and not receiving needed medical attention.
Economy	2	The storm hits in mid-December, hurting Christmas retail sales. Shoppers forgo purchases or shift to buying online.
Environment	1	Salt is used to melt ice, but the quantities used are not enough to do permanent damage to marine ecosystems when they wash into the wastewater system.
Built Environment	2	The snow collapses the roofs of 5 buildings causing them to be red tagged.
Transportation	2	The storm is forecasted. SDOT is able to start pre-treatment of roads and Metro is able to chain buses. These actions mitigate the effects of the storm beginning midday. The commute is very bad but could have been much worse. During the next week, daytime highs warm to the upper 30s but overnight lows still fall into the lower 20s, resulting in a freeze-thaw cycle that impacts all roads that are not able to be cleared & treated.

Critical Services and Utilities	2	The storm does not cause any large-scale infrastructure outages, but numerous small water lines freeze. Public safety vehicles have a harder time reaching some parts of the city.
Confidence in Government	1	Due to improvements in the City's Snow and Ice Plan, it meets its targets. The public experiences some hardships near the end of the storm but does not blame the government for them.
Cascading Effects	2	During the storm a tour bus slides down a hill crashing into a building injuring 15 people. 140 buildings have their pipes freeze.

Credible Worst-Case Scenario

A blizzard during a large event is followed by extreme cold and freezing rain

Heavy snow begins to fall at 1pm on a Monday afternoon. Meanwhile a Monday night Seahawks game is scheduled for 7pm. Snow not only causes a snarled commute and stranded commuters but also results in major public transportation issues for the sporting event, leaving many fans stranded around Lumen Field as temperatures plummet into the 20s. By Tuesday afternoon, a total of 12-15" of snow has fallen across the city. For the following two weeks, temperatures stay in the low 20s overnight, resulting in freeze-thaw cycles that affect all roads that are untreated. On the 11th day, a system moves in, causing 0.25-0.50" of freezing rain to accumulate across the city. An atmospheric river arrives the morning of the 12th day allowing temperatures to then warm, creating urban flooding due to rain on snow/ice and blocked drainages.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	Seattle seems to have had snowier weather in the 19th century and is projected to receive less snow in the future due to climate change but could still experience natural climate variability. Seattle saw similar, yet much shorter-lived, impacts from the December 2022 ice storm.
Geographic Scope	5	The whole Central Puget Sound region is affected by this storm.
Duration	4	The entire incident lasts two weeks from the first snowfall to the melt.
Health Effects, Deaths, and Injuries	2	9 people are killed falling off roofs, sledding, and burning charcoal indoors. 24 unsheltered people are hospitalized for hypothermia and frostbite.
Displacement and Suffering	4	The low-pressure system associated with this event also results in breezy north winds that create isolated power outages across the city as well as coastal flooding along the shores of Seattle and major flooding in the South Park area. 7 apartment buildings have roof collapses. The collapses do not injure anyone, but residents must seek shelters. Others are driven from their homes when they lose power. All told 350 people need shelter.
Economy	3	The storm hits during the December shopping season. Businesses cannot remain open. 6 close permanently due to lost revenues. Major employers have to close and non-salaried employees lose wages.
Environment	2	Major amounts of salt and sand are used to keep roads open. It washes into the drainage system and ultimately into Puget Sound.
Built Environment	3	Ice-loading on roofs that still had significant snow results in several major roof collapses for structures with flat roofs, including several major grocery stores and other critical infrastructure.
Transportation	4	Surface transportation experiences major degradation. A freeze-thaw cycle that impacts all roads that are not able to be cleared and treated. The freezing rain accumulation across the city affects all regional road transportation and stops nearly all public transportation.

Category	Impacts 1 = low 5 = high	Narrative
Critical Services and Utilities	3	Public safety personnel have difficulties reaching many parts of the city. The ice accompanying the storm brings down power lines in many areas of the city. The snow impedes power restoration. Many water pipes freeze causing businesses and residences to lose water service.
Confidence in Government	3	This fresh blanket of snow combines with rapidly falling temperatures to result in extreme cold conditions as well as the freezing of some of the flooded areas in South Park creating extremely challenging conditions for responders. The public becomes frustrated at their lack of mobility. They need help getting basic supplies and think the government should be doing more to help them.
Cascading Effects	3	The snowstorm causes many traffic accidents including a gas tanker that crashes and burns. Ice and extreme cold have caused power and water outages.

Water Shortages

Most Likely Scenario

Large water main break that affects critical infrastructure and causes a long-term water shortage for an area of the city.

A 42" watermain breaks on Beacon Hill where it crosses City Light transmission lines and the BP pipeline. The release of water undermines transmission towers, the BP pipeline, and co-located utilities (gas, sewer, and communications). There are no fatalities, but the area surrounding the collapse is impacted. Transportation corridors are affected. It impacts surrounding businesses and the environment.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Infrastructure failures happen regularly. This scenario is similar to past events but with some added complexity that demands a higher level of coordination to manage consequences.
Geographic Scope	1	This is a single site incident although some impacts are felt outside the immediate area (e.g., utility outages).
Duration	4	The damage takes 10 days to repair in total, given the complexity of the infrastructure damaged.
Health Effects, Deaths, and Injuries	1	There are no deaths or injuries as a result of the break.
Displacement and Suffering	2	Water and gas services to a school and nursing home are shut off. All 65 nursing home residents have to be moved.
Economy	2	24 businesses are forced to close due to water damage
Environment	2	The water main break undermines a sewer line, breaking it. Untreated sewage spills into Lake Washington.
Built Environment	2	The water floods 5 buildings and undermines their foundations.
Transportation	2	The nearby streets near the break must be closed, causing a temporary blockage. Fears are voiced about the effect of the water on the electrical lines.
Critical Services and Utilities	3	The breakages of the water, gas, and sewer lines force utility outages in the surrounding neighborhood. Public safety services are not affected. Fuel delivery to SeaTac is interrupted.
Confidence in Government	3	The infrastructure is owned by the government. The public believes that it could have been better maintained.
Cascading Effects	2	The initial infrastructure failure leads to others and causes hazardous material (untreated sewage) to be released.

Credible Worst-Case Scenario

Shortage leading to emergency curtailments

Several years of low snowpack, hot summers and cold winters begin to place a severe strain on watersheds. SPU must implement emergency curtailments for the first time in its history. Seattle City Light has to curtail generation to preserve salmon stream flows at a time when demand is high and the water is low. It must buy power during a summer when high demand in other parts of the country has driven prices up.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	This scenario is, like the Most Likely scenario, a weather-related drought and water shortage, but it is much more severe. Although Seattle has had other periods of dry weather, Seattle must enact emergency water curtailments for the first time in its history. Climate scientists project that snowpack will decline substantially by the end of the 21 st century, and summers will become drier.
Geographic Scope	5	The drought and water shortage are region wide.
Duration	5	The full duration of the drought is years, but the worst period is the summer following an exceptionally dry winter.
Health Effects, Deaths, and Injuries	1	Due to emergency curtailments and surcharges, water supply is adequate for public health needs. As a result, there are no deaths or injuries due to lack of potable water.
Displacement and Suffering	3	No households are displaced due to a lack of potable water, but water restrictions and surcharges are hardships for many of the general public.
Economy	3	Many businesses are impacted by curtailments and surcharges. Use of the Ballard Locks impacts commercial maritime traffic. Seattle City Light implements surcharges to offset borrowing.
Environment	3	The prolonged dry weather has placed severe stress on Seattle's urban forest. The dry conditions weaken plants, making them more susceptible to disease.
Built Environment	2	The dry conditions contribute to 2 urban wildfires that destroy 10 buildings and damage 25 others.
Transportation	1	The water shortage and drought do not have a significant impact on Seattle's transportation system.
Critical Services and Utilities	3	The water system is severely impacted by the shortage. Seattle City Light is able to maintain power without curtailments but implements surcharges. Due to prioritization water pressure remains adequate for firefighting and public health.
Confidence in Government	3	The public understands the severity of the drought and water shortage, but the increasing bite of curtailments and the implementation of surcharges is not popular. Many are convinced that government could do a better job shielding the public from the costs of the shortage.
Cascading Effects	2	The extreme dry weather contributed to a serious brush fire. The fire was not a disaster by itself.

Wildfires and Smoke

Most Likely Scenario

Wildfire smoke from surrounding areas blows into the Seattle Area during a heat event

A wildfire in Oregon burns uncontrollably, with southern winds blowing wildfire smoke into Western Washington for several days. The AQI is unhealthy for sensitive groups for three days and unhealthy for all populations for two days before wind patterns shift and bring in cleaner air from the Pacific. Temperatures are in the high 80's and low 90's for the entirety of the smoke event.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Since 2015, Seattle has regularly experienced wildfire smoke in the summer months. As smoke can travel thousands of miles, fires from a variety of locations can impact Seattle's air quality. Seattle summers are also seeing more heat events. As climate change continues to accelerate, it is likely Seattle will experience smoke events that coincide with heat.
Geographic Scope	5	The area impacted depends on the size of the smoke plume, but smoke events tend to impact the entire western Washington region. Heatwaves, too, are regional events.
Duration	3	This event lasts five days, after which the weather patterns shift, bringing in cool, clean air.
Health Effects, Deaths, and Injuries	2	Starting on day three of the event, emergency rooms see increased numbers of visits with patients in respiratory distress from smoke and symptoms of heat exhaustion. Recreational events and activities around the city are delayed or cancelled entirely due to the air quality.
Displacement and Suffering	2	People living outdoors and those experiencing homelessness seek clean air spaces on days four and five of the event. Many people are torn between opening their windows at night to let in cooler air and keeping them closed to keep out smoke. This is especially an issue for people without access to air conditioning.
Economy	1	Impacts to the economy are negligible, although some stores do see decreased foot traffic due to people choosing to stay indoors.
Environment	2	Air quality harms both people and wildlife, and the heat is hard on local flora.
Built Environment	1	Buildings are encouraged to check and change air filtration systems as needed, but the smoke and heat do not cause any lasting damage on structures or infrastructure.
Transportation	1	There are no impacts on transportation in the city or region.
Critical Services and Utilities	2	Outdoor workers must take regular breaks in accordance with Labor and Industry regulation, meaning some regular repairs and maintenance of infrastructure are delayed.
Confidence in Government	1	The City of Seattle opens clean air spaces/cooling centers for people experiencing homelessness. Many express frustrations at the lack of supplies available for indoor air filtration as many local stores are closed.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	1	There are no major cascading effects from this smoke event.

Credible Worst-Case Scenario

A wildfire spreads into the Cedar River Watershed

Hot and dry easterly winds cause an existing fire in the Cascades to rapidly spread west, threatening the Cedar River Watershed which provides nearly 2/3 of Seattle’s drinking water. Despite a quick response from wildland firefighters, the fire burns a significant area of the watershed. This scenario is unique as it is the only one described that takes place outside of city limits. Despite this, this scenario would significantly impact City of Seattle-owned infrastructure and city operations. To take into account differences between impacts on Seattle and the region as a whole, we have added two numbers (x, (x)) in the impacts column.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	Fires on the west side of the Cascade Mountains occur less frequently than those on the east side. Furthermore, SPU has a Wildland Fire Crew that is trained to provide immediate response to wildfire threats within the South Fork Tolt and Cedar River watersheds. Nevertheless, wildfire in the watershed remains a possibility.
Geographic Scope	5	Even a small fire in or near the watershed could have impacts on drinking water quality.
Duration	5	Hot and dry easterly winds have spread fire quickly, making it difficult to contain. The impacts on the watershed, and thus the drinking water for Seattle, will be long lasting.
Health Effects, Deaths, and Injuries	2 (3)	Easterly winds blow wildfire smoke into the Seattle area, degrading air quality for the duration of the event and requiring some to seek medical care for respiratory-related illness. Outside of the city, several small towns in the foothills are forced to evacuate and a few deaths are reported.
Displacement and Suffering	2 (4)	No one in Seattle is displaced, although people experiencing homelessness seek shelter. Communities further east are displaced as homes near the fire are threatened.
Economy	2	Moderate impacts to industries requiring high water usage, as general voluntary water curtailments are in place.
Environment	5	Wildfire can alter soil properties, reducing infiltration and increasing erosion. Certain elements can be elevated in runoff, such as phosphorus, nitrate, and other pollutants that can risk aquatic ecosystems and human health, with potential for eutrophication and contamination of drinking water.
Built Environment	1 (3)	There are no direct consequences to structures within the city. Outside the city, structures are directly threatened by fire.
Transportation	4	The fire burns across I-90 creating unstable slopes, causing the interstate to completely close for 4 days.
Critical Services and Utilities	3	Long term degradation of water is expected, but no supply issues and curtailments are enacted. Water quality issues are mitigated by SPU’s ability to change intake due to turbidity issues.
Confidence in Government	3	An event like this will have lasting consequences, and it is likely the population will be disgruntled about long term voluntary water curtailment orders or having to change their habits to adjust to a smaller supply of water, leading to questioning of city’s preparedness for this type of event.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	3	The wildfire burn scar could trigger landslides or floods within the fire area or minor hazmat as the fire burns through the wildland urban interface. Runoff would likely cause lasting turbidity in the water supply as well.

Wind

Most Likely Scenario

Windstorm with gusts up to 70 MPH strikes Seattle during winter holiday season

Seattle faces a storm bringing gusts of up to 70 MPH causing numerous downed trees, power outages, and structural damage. City streets are dangerous and difficult to travel. 30% of City Light customers lose power. Due to the transportation difficulties and the extent of the outages, it takes 5-7 days to completely restore the system. Despite the widespread outages, City Light's tree trimming actions have mitigated a worse situation. Prior to the storm, conditions were conducive to landslides. The wind triggers 26 landslides on saturated slopes.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	The Seattle has experienced major windstorms similar to this scenario in the past 50 years.
Geographic Scope	5	Mid-latitude cyclones are wide storms. The one in this scenario affects the entire Central Puget Sound region.
Duration	2	The storm itself lasts for eight hours. Short term response and recovery lasts for another five days.
Health Effects, Deaths, and Injuries	2	Two people are killed in the region from falling debris, and 11 people are injured by debris.
Displacement and Suffering	2	Building damage, power outages, and urban flooding drive 60 people from their homes. 30% of the city loses power.
Economy	2	Many businesses close during the storm. Retail businesses are hit the hardest, but none close permanently.
Environment	2	The storm produces major amounts of debris. Most is natural but non-compostable debris must be transferred to landfills.
Built Environment	2	Many buildings have minor roof damage, but 9 have major structural damage (roof failure) and are red tagged. 25% of the city loses power. Seattle City Light's tree trimming operations and outage isolation technology prevent more widespread outages.
Transportation	2	Debris, fallen trees, traffic light outages and downed power lines cause major traffic and transit backups. The airports and marine ports are able to resume operations quickly after the storm.
Critical Services and Utilities	2	Power and fire crews must work together to coordinate service restoration in a way that does not tie up fire units. 25% of the city loses power.
Confidence in Government	1	The public feels that the government responds quickly to the storms. Recovery happens quickly and the public's confidence in government is boosted.
Cascading Effects	3	The storm causes widespread power outages and contributes to landslides.

Credible Worst-Case Scenario

Mid-latitude cyclone strikes the Pacific Northwest with gusts up to 85 mph near Puget Sound

A mid-latitude cyclone hits the West Coast. Winds gusts are recorded at 85 mph at West Point. 55% of City Light customers lose power. The whole region is affected. Thousands of trees are downed, and millions of people are without power for multiple days. The storm is followed by a sharp drop in temperatures making the loss of power life threatening. Waves damage a floating bridge. Several piers on waterfront are affected.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	A storm this size has only occurred once in the past 100 years.
Geographic Scope	5	The storm affects much of the West Coast from Northern California to British Columbia. The Seattle shoreline receives gusts of 85 mph
Duration	2	The storm itself lasts for 6 hours. It takes public safety and infrastructure crews 36 hours to stabilize the incident. Short term recovery takes another 10 days when most services are restored, but heavily damaged areas require months to years to recover.
Health Effects, Deaths, and Injuries	2	Regionally, the storm kills 73 people and 450 are hospitalized. In Seattle itself, there are 7 fatalities and 33 people require hospitalization. Many people seek power services from hospitals, clogging ERs.
Displacement and Suffering	3	Building damage and power outages drive 180 people from their homes. 55% of the city loses power. The temperature drops after the windstorm causing cold nights for those without power.
Economy	3	Many businesses close during the storm. Retail businesses are hit the hardest. Power is out for an extended period, and some business have serious physical damage. Many lack adequate business continuity plans. 25% of the businesses without plans that are damaged fail.
Environment	2	The storm produces massive amounts of debris. Most is natural but non-compostable debris must be transferred to landfills. The storm causes some hazardous material spills from warehouses along the water.
Built Environment	3	Hundreds of buildings have roof damage. Most damage is minor, but 67 buildings are yellow tagged and 14 are red tagged. Most damage is to residential property. 75% of the city is without power. Wind and waves damage two piers downtown.
Transportation	3	Debris, fallen trees, traffic light outages and downed power lines cause major traffic and transit backups. Due to the overwhelming amount of debris, surface transportation is disrupted for a week Air and marine traffic halt during the storm but resume operations soon after it has passed. Rail traffic is stopped for multiple days due to debris along the tracks.

Category	Impacts 1 = low 5 = high	Narrative
Critical Services and Utilities	4	Power outages are major problem throughout the city. 55% of the city loses power for up to 6 days. Public safety responders have a difficult time reaching some parts of the city. City Light and Fire must work to coordinate guarding downed power lines, service restoration and fire/ems response.
Confidence in Government	3	As the power outages and transportation disruption lingers, the public becomes impatient. Many cannot understand why short-term recovery is taking so long.
Cascading Effects	3	The storm causes widespread power outages and hazardous materials incidents.

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