SEATTLE HAZARD IDENTIFICATION AND VULNERABILITY ANALYSIS

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1. EXECUTIVE SUMMARY

Seattle is a vibrant city, yet it faces hazards that threaten the very tissue of our community. Seattle can reduce hazard impacts and this document is where we start. The Seattle Hazard Identification and Vulnerability Analysis (SHIVA) identifies Seattle's hazards and examines their consequences so we can make smart decisions about how best to prepare for them.

This document is the foundation for the City of Seattle's disaster planning and preparedness activities. The City hopes the rest of the Seattle community will use it in the same manner. The Seattle Hazard Identification and Vulnerability Analysis (SHIVA) is a community document. The Office of Emergency Management is constantly collecting information from partners to update it. It is updated as needed but a major review occurs at least every four years.

1.1 Major Findings

- Earthquakes are Seattle's riskiest hazard. Seattle is susceptible earthquakes ranging from ones like the 2001 Nisqually Earthquake to the one that devastated northern Japan in 2011.
- Snow and ice storms rank second. Individually they are less damaging than a powerful earthquake, but they are much more frequent.
- Cyber Attacks and Disruptions have been broken out from infrastructure failures and added as their own hazard because of our increasing dependence on networked computers to control critical infrastructure and recent successful attacks on local government.
- A combination of resource concentration, geography and lack of reserve capacity in our transportation system will make access to critical resources a challenge in a disaster.
- Our most vulnerable people live toward the outskirts of the city and along the Rainier Valley.
- Climate change will broadly affect most of the hazards Seattle experiences.

1.2 Intended Audience and Use

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 – Hazard Rankings. Use it as a starting place.

1.3 Document Structure

The SHIVA contains hazard profiles bookended by a hazard summary, community profile and an emerging hazards section at the front and a bibliography and endnotes at the back. It starts with a hazard summary that includes the Hazard Ranking. This section is the 'one stop' for anyone who needs a quick overview. It moves on to a community profile that outlines Seattle's social, physical and built environments and acts as a common foundation for understanding specific hazards. After this comes a chapter on long-term and emerging threats. Next are the chapters on individual hazards. These chapters are grouped into sections common characteristics. Finally, there is an extensive bibliography and the endnotes.

1 3.1 Hazard Summary

This section is the dashboard. It condenses the findings into one matrix. It also 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.

1 3.2 Community Profile

This section is a lens through which to evaluate individual hazards. It describes components of the Seattle community that change the impact of any hazard. These are:

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

It finds that Seattle's population density has increased steadily as has our dependence on the transportation, utility, telecommunication and other infrastructures necessary for our safety and productivity.

1 3.3 Climate Change: Effects on Hazards

This section acknowledges that climate change, while not a direct hazard itself, exacerbates the vulnerabilities and consequences of nearly all of Seattle's hazards. Climate change is projected to effect air temperatures, sea level rise, precipitation, mountain snowpack, stream flow, and air quality for the Puget Sound area. The main hazards expected to be influenced by climate change are landslides, disease outbreaks, infrastructure failures, power outages, fires, excessive heat events, flooding, and water shortages.

1 3.4 Hazard Profiles

Chapters on Seattle's hazards follow. Seattle's hazards are grouped into five main categories, most of which have subcategories describing particular hazards. The hazard groups are:

- Geophysical hazards
  - Earthquakes
  - Landslides
  - Tsunami and seiches
  - Volcanic hazards
- Biological Hazards
  - Disease/Pandemic Influenza (including bioterrorism)
- Intentional Hazards

- Social Unrest
- Attacks
- Cyber-attack and Disruption

- Transportation and Infrastructure
  - Transportation Incidents
  - Fires
  - Hazardous Materials Incidents
  - Infrastructure Failures
  - Power Outages
- Weather Hazards
  - Excessive Heat
  - Flooding
  - Snow, Ice and Extreme Cold
  - Water Shortages
  - Windstorms

1 3.5 Bibliography

The bibliography lists the research that grounds the SHIVA. Anyone who wants to find out more about Seattle's hazards is encouraged to consult it. To keep the SHIVA as concise as possible much of the research was heavily summarized, especially the parts that provide context. The sources in the bibliography provide papers, books, and websites that cover topics much more fully that the SHIVA.

1 3.6 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 excellent way to approach the bibliography.

1.4 Hazard Chapter Summaries

Most of the SHIVA consists of individual hazard profiles. They are grouped into sections based on a set of shared characteristics.

1 4.1 Geophysical Hazards

These hazards originate in the movement of earth. They destroy the built environment over large areas and can cause huge casualties. While they are impossible to prevent there is a lot Seattle can do as a community to decrease their consequences.

Earthquakes

Earthquakes are Seattle's most significant hazard. No other hazard has the combination of likelihood and potential destructiveness. Seattle is at risk for earthquakes from three sources: 1) deep earthquakes like those that damaged the City in 1949, 1965 and 2001; 2) shallow earthquakes along the Seattle Fault; and 3) megathrust earthquakes that could reach magnitude 9.0 but would originate outside Seattle.

The Seattle Fault is Seattle's most dangerous source. The Seattle Fault last ruptured in 900AD causing a 7.2 magnitude earthquake, massive landslides and a tsunami. 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.

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. A Seattle Fault earthquake could cause massive landslides. The last one in 900 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 landsides.

Tsunamis and Seiches

Tsunamis are a rare but potentially catastrophic hazard in Seattle. They are most often caused by earthquakes and landslides. Tsunamis that originate in the Pacific Ocean do not pose a major threat to Seattle because Puget Sound's shape and complex shoreline will break them up before they reach 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. A landslide triggered a tsunami in the Tacoma Narrows in 1949.

A seiche is a standing (vertical) 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.

Seattle uses tsunami risk as a criterion in siting critical facilities, but it has not pursued additional tsunami or seiche preparedness measures because a tsunami 1) will strike the shoreline within seconds or minutes of being created, 2) will probably occur immediately after a massive earthquake and 3) happen rarely.

Volcanic Hazards

Volcanic material from Mt. Rainier washing down through the Duwamish River and ashfall are the most significant volcanic threats to Seattle.

During an eruption, Mt. Rainier's glaciers could melt, mix with volcanic debris and flow down the valleys surrounding it. These flows are called lahars. Based on geologic evidence a lahar from Mt. Rainier would bury low-lying areas west of the mountain but would stop short of Seattle. In the days that follow, rain and erosion could wash the sediment down the Duwamish creating a major navigation and environmental hazard.

Severe ashfall is unlikely in Seattle. Our area'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 an ashfall in Seattle.

Seattle will need to support more heavily impacted neighbors, cope with transportation closures and help displaced people after an eruption or lahar. Seattle has not undertaken specific volcanic mitigation measures.

1 4.2 Biological Hazards

Biological hazards occur from natural matter in our world such as bacteria, viruses, insects, or animals. The only biological hazard identified for Seattle is disease/pandemic influenza (including bioterrorism).

Disease/Pandemic Influenza (including bioterrorism)

Seattle like all other cities is facing increased exposure to new diseases. The rapid increases in personal mobility, the proximity of people to livestock and global urbanization have created conditions in which it is possible for new diseases, especially influenza, to emerge and spread around the world in days. Global outbreaks are called pandemics. When a new disease emerges, human beings have no immunity against it. This condition increases the chance individuals will get sick when they come into contact with the disease and increase the severity of their symptoms if they do.

The potential consequences of disease outbreaks include:

- Patients overwhelming local hospital and health care providers.
- Inability to request mutual aid assistance if impacts involve multiple communities.
- Contaminated water supplies.
- Threats to critical infrastructure if essential operators are absent in high numbers.
- Widespread mental health impacts.
- Closure of community services, schools and larger public events.

Public Health – Seattle & King County has developed plans to attempt to slow the spread of disease by closing public gathering places, increasing the space between people (‘social distancing’) and opening additional care facilities. Bioterrorism is the use of a biological agent as a weapon to cause fear, illness, or death. Seattle has not experienced a bioterrorist attack but being a densely populated urban hub makes it an attractive target.

1 4.3 Intentional Hazards

These are hazards that some person or group seeks to cause. Often the perpetrators want to disrupt the flow of normal community life, sometimes they want to cause property damage, and other times they want to hurt people. The adversarial nature of these hazards makes them especially unpredictable and therefore dangerous. Law enforcement is primary in the response to these hazards.

Social Unrest

Social unrest includes riots, civil disorders, strikes, and mass civil disobedience. Seattle is the central stage for political and social activity in the Puget Sound region and the hub of its social activities. This condition makes social unrest likely to occur in Seattle. Most recent incidents were caused by anarchist groups. The largest centered on the 1999 World Trade Organization (WTO) meeting. Most of Seattle’s incidents have targeted property but assaults and one death has occurred. Most incidents can be handled by the Seattle Police Department, but large ones like the WTO protests require outside assistance and can shut down large areas of the City. Most incidents occur in the downtown area and on Capitol Hill.

Attacks

Attacks can be perpetrated by many different actors with different motivations, but all use violent and destructive tactics to cause harm to people and/or property. Some actors include terrorists (domestic and international), violent extremists, and targeted violent offenders. Examples of tactics are mass shootings, bombings, arson, murder, kidnapping, hijacking, or skyjacking. Not all attacks are politically motivated, some are based on personal grievances. Most attacks happen in public gathering places or institutions, of which Seattle has many. The threat of attacks has grown with the interconnectedness of the internet and social media.

The Puget Sound region has active far-right and eco-terrorist groups, and has experienced activity related to international terrorist groups. Seattle has a heightened eco-terrorism risk. In 2001 the Earth Liberation Front (ELF) firebombed the University of Washington's Center for Urban Horticulture. The number of mass shootings in the U.S. has increased over the past decade. Seattle has experienced three mass shootings in recent history, and an active shooter situation at Seattle Pacific University. In today's security conscious, post-9/11 environment, the main threat appears to be attacks using small-scale tactics such as shootings or vehicle ramming.

Attacks are almost impossible to predict. In the aftermath of 9/11, national security focus shifted to terrorism involving chemical, biological, nuclear, radiological and explosive and cyber means. Locally, Seattle Public Schools are undertaking heightened security measures. The City has been the recipient of several federal grants to bolster local security.

Cyber-attack and Disruption

To function as a modern city, 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. SCADA systems are generally outdated and vulnerable to hacking, especially if they are connected to the internet.

The likelihood of attack and disruption is increasing as more products and services connect to the internet. The City of Seattle experiences minor hacking attempts daily but has never experienced a major cyber-attack. However, limited information technology resources make a large attack a possibility and large-scale ransomware attacks have recently halted city functions in other areas of the U.S.

1 4.4 Transportation and Infrastructure

This section comprises failures in the built environment. Their causes are mostly accidental but can be deliberate when used as a means for terrorism. Engineering advances have dramatically improved safety, but Seattle still has many older transportation and infrastructure systems that were not built to modern safety standards. These systems require extra maintenance.

Transportation Incidents

Seattle is a hub for land, sea, and air transportation giving it an inherent exposure to accidents. One of the city's deadliest disasters was a plane crash that occurred in 1943, killing 32, including people on the ground. The Sodo area is the most vulnerable because it is a hub for all major transportation modes, but our bridges and tunnels also have heightened risk. Transportation accidents are usually limited in size but can cause high fatalities, fires, hazardous materials incidents, power outages, transportation network disruptions, and infrastructure failures.

Fires

Multi-block and high-rise fires are now rare in the U.S. due to better fire code enforcement, but having a large concentration of high-rise buildings, hotels, entertainment venues and industry makes Seattle vulnerable. In the 1970's several single-room occupancy hotels burned with high fatalities. Seattle also has a large port making marine fires a danger and an underground electrical distribution network that can cause extended outages when fires occur in it. Fires are especially dangerous when they are ignited by other hazards like earthquakes and civil disorders because many fires can ignite in a short period while responders are already occupied.

Hazardous Material Incidents

Seattle is a regional industrial center and major transportation hub raising its exposure to hazardous materials incidents that release toxic chemical, combustible, nuclear, or biological agents into the environment. Seattle has not had any truly disastrous hazardous materials incidents but has had several close calls with fuel tanker explosions and a fire at a UW biology lab. There has been an increase in the transport of highly flammable crude oil through Seattle in recent years. Most incidents happen at fixed sites, but those that occur during transport are often more dangerous because they occur in uncontrolled, public spaces.

Structural Collapse and/or Failure

This chapter includes structural collapse or failure of buildings, dams, and other critical infrastructure such as bridges, and water, sewer, or power lifelines. There are no dams in Seattle, but the City owns a dam south of the city. If this dam failed, the biggest consequence would be flooding in the Duwamish Valley. Seattle is especially vulnerable to bridge collapse due to central role they play in connecting Seattle's transportation network to other areas. Western Washington has had four high profile bridge collapses since 1940. The Seattle Department of Transportation has an active bridge inspection and retrofit program.

Power Outages

Power outages are a type of infrastructure failure but are treated as a separate hazard due to the complexity of their consequences. The 2003 Northeast Blackout highlighted the fragility of the U.S. power system. Seattle experienced a week-long power outage from a winter storm in December 2006. Since the wide-spread 2006 outage, Seattle City Light (SCL) has acquired a new 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. While much of BPA's infrastructure is aging, they have been a leader in seismic upgrades to their critical infrastructure. Climate change is projected to decrease hydropower generation in the summer by mid-century.

1 4.5 Weather

Severe weather events are frequent hazards in Seattle. With the exception of flooding, they have city-wide impacts that vary from minor to debilitating. Their consequences mount the longer they go on. Forecasters are getting better at predicting these events and their severity. The extra time reduces vulnerability by allowing the public and institutions more time to prepare.

Excessive Heat Events

Excessive heat events (EHE) can be an extremely deadly hazard. More than 700 people died during the 1995 Chicago heat wave. 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, night time 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 excessive 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 the elderly, infants, the homeless, the poor, and people who are socially isolated.

Flooding

Seattle is susceptible to four flood types: coastal flooding (including king tides), riverine, urban, and dam failure. Atmospheric rivers are storms that occur 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.[1] 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. The South Park neighborhood is in a 500-year floodplain. Most of Seattle’s floodplains are very narrow.
- 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 rain storms. The City has developed mitigation measures like detention ponds to decrease the consequences of urban flooding.

The City of Seattle owns dams outside the city limits. Dam failure is mostly a hazard outside the city. The greatest risk is the Howard Hanson Dam. It discharges into the Green River and the Duwamish. Studies suggest that the likelihood of flooding on the Duwamish due to a dam failure is low.

Snow and Ice

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 like power outages. Seattle has heightened vulnerability to snow and ice storms because of its hilly topography and lack of dedicated snow removal equipment (Seattle has to re-purpose general use equipment to plow snow). The City prioritizes major roads and is not able to plow residential streets. Extended snow can lead to severe transportation challenges. Excessive cold exacerbates risks to human health and safety when electric heating sources are inoperable. In 2008 several people died in King County due to carbon monoxide poisoning when they used charcoal grills indoors to heat their homes. Snow load has caused roof collapses in Seattle and rapidly melting snow has caused urban flooding and landslides.

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 2006, Seattle Public Utilities (SPU) updated and adopted a plan to respond to and mitigate water supply problems.[2] Water shortages also have consequences for power. 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. Besides climate, 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 the caused by another hazard like an earthquake.

Windstorms

Windstorms with wind speeds equaling those of category one hurricanes can strike Seattle. Sustained winds of 85 miles per hour were recorded in the Seattle area in 1993 and 2006. Seattle's most damaging storm was the 1962's Columbus Day Storm. Windstorms cause power outages, structural damage, transportation blockages, and coastal flooding. Fall and winter is the most common time for windstorms, but the occasional out of season storms can be the most dangerous. Falling trees account for most damage. Windstorms often accompany other weather hazards producing complex emergencies the can include landslides, urban flooding, snow and extreme cold. Windstorms can damage structures with speeds as low as 32 mph. 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.

1.5 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.

1 5.1 Key Points

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

1 5.2 Context

This section explains the hazard's context and why it 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.

1 5.3 History

This section details the hazard's presence in Seattle. Most of the section is a list of events that had severe consequences. 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. Despite the lower risk, these older events are important to include because they remind us how dangerous these accidents can be.

1 5.4 Likelihood of Occurrence

This section assesses the chances a hazard will cause a disaster in Seattle within four 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.

1 5.5 Vulnerability

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 and more likely to burn that brick structures when exposed to fire. They are more vulnerable. The vulnerability section covers vulnerabilities that pertain to the hazard. Some vulnerabilities pertain to all hazards. They are included in the Community Profile.

1 5.6 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 are more likely than larger ones the SHIVA uses a "Likely" and "Maximum Credible" scenario to illustrate hazard consequences. The "Most Likely" scenario is often the upper range of the historical magnitude of past occurrences, and the "Maximum Credible" scenario is one that represents the biggest incident that has a reasonable chance of occurring.

1 5.7 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.

1.6 Definitions

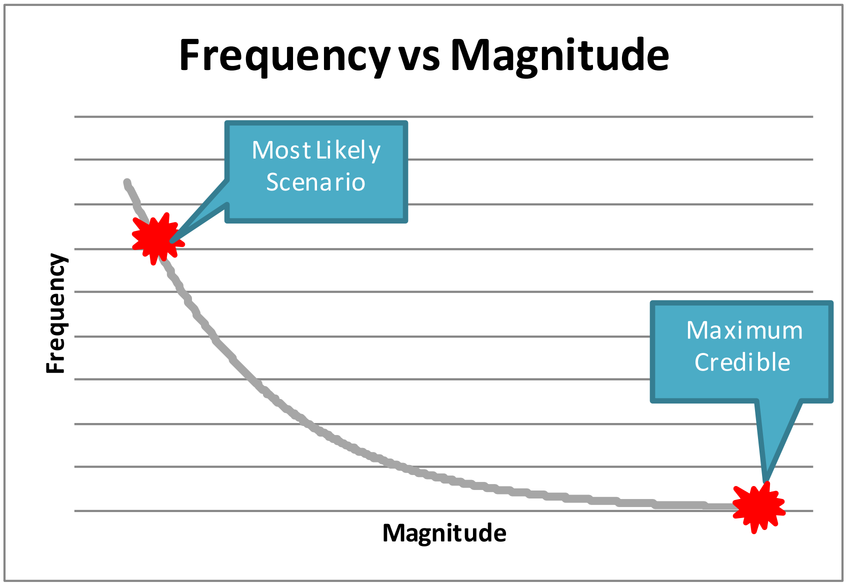
1 6.1 Hazard

A Hazard may be broadly defined as "a source of potential danger or adverse condition."[3] The definition of a hazard may be consequence based, as "something that has the potential to be the primary cause of an incident," where an incident is "an occurrence, natural or human-caused, that requires action by the emergency management program."[4] A hazard is a class of phenomena; an incident, event, or disaster is a manifestation of the hazard.

Hazards are measured by their *frequency* and *magnitude*. Frequency measures how often the hazard creates incidents. Magnitude measures incident intensity. Magnitude is *not* the severity of the consequences. To understand consequences, it is necessary to understand vulnerability. Most hazards have a power law distribution which means that magnitude increases exponentially as frequency decreases: low magnitude incidents are common and high magnitude incidents are rare.

Much of the science surrounding these hazards involves the attempt to determine the precise shape of relationship between frequency and magnitude so that rare high magnitude events can be extrapolated from the more frequent low magnitude events. The challenge for researchers is that they have very few data at the high magnitude end of the scale. Adding to that challenge is a tendency for extreme magnitude events to 'jump the tracks' and stop obeying the linear relationship.

Figure 1-1 Disaster Frequency vs Magnitude



1 6.2 Disaster

A disaster is "a severe or prolonged incident which threatens life, property, environment or critical systems."[5] Disasters require immediate community responses that are made more challenging because disasters also increase the demand for critical resources, cause logistical difficulties, communications bottlenecks and often create unique situations that require rapid policy making.

Disasters are complex events but share some things in common:

- There is often more than one hazard at work: a primary or triggering hazard and secondary hazards. Secondary hazards are also called cascading effects.
- They threaten the community's foundation.
- They threaten our sense of control.
- They often catch us by surprise.
- They overwhelm our ability to respond.

1 6.3 Vulnerability

Vulnerability is a "disaster waiting to happen". Vulnerable people and things incur more damage than those that are not when exposed to the same event. People, communities, buildings and infrastructure can all have vulnerabilities. The building material used in a house can cause vulnerabilities. Brick is more vulnerable to earthquakes than wood. Communities without strong social cohesion are more vulnerable to all disasters than those with strong social cohesion.

The vulnerabilities considered in this document are:

Physical Vulnerability

Physical factors include 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.

Social Vulnerability

A community's social vulnerability reflects the strength of a community's social ties and the collective personal vulnerability of its people.[6] The concept of social vulnerability extends beyond identifying "special needs" populations often included in disaster plans. Research has shown that a disaster's impact closely aligns with key socio-economic indicators. The Center or Disease Control has developed a model of social vulnerability that can be mapped. The result is included in the Community Profile.

Concentration

Concentrating people and assets means that more of them can be hurt in a single incident. 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.

Interdependence

Urban populations rely on and provide many services for basic survival. People can be harmed by disaster impacts even if they are not directly affected. Indirect effects can ripple through a community and are often costlier than the direct damage. Interdependence is also a benefit if undamaged communities can aid those that are damaged.

Complexity

Cities are complex systems comprised of many components. Many components mean many failures. Normally, failures are contained, but when a system is tightly interdependent failures can cascade through the system and the whole system fails. Moreover, components in complex systems often interact in unanticipated ways because their connections are poorly understood. For example, Seattle hospitals had to curtail service when a power outage closed a laundry service that supplied them with clean linens. The effects of a small power outage miles from Seattle's hospitals cascaded through the health care system.

Pace of Change

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. After Hurricane Katrina, hospital patients became critical within hours of power failure.

The Local Economy

As an area's economy and population grow and shrink, the distribution of wealth changes the location of vulnerable populations. 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 over time. Disaster can exaggerate a city's growth or decline. A declining city will decline more quickly after a disaster, while growth in a booming city can accelerate if new capital enters the city during reconstruction.[7]

State of Knowledge, the Ability to Predict and the Ability to Act on the Prediction

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 actually 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 on the basis of 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.** 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.

1.7 Summary of Document Updates

Major changes are as follows:

- Changed “Emerging Hazards” section to “Climate Change”
- Added “Cyber Attack and Disruption” chapter
- Combined the “Terrorism” and “Active Shooter Incidents” chapters into one chapter titled “Attacks”
- Renamed the “Infrastructure Failures” chapter to “Infrastructure and Structural Failures”
- Developed new scenarios for Disease/Pandemic Influenza, Social Unrest, Infrastructure and Structural Failures, and Windstorms.
- Incorporated hazard research published after 2014.
- Reassessed hazards.

1.8 Acknowledgements

The Office of Emergency Management (OEM) would like to thank Taylor Bailey for writing the 2018 update and to all of our partners for suppling the data, analysis, and review to make this document the deep look at Seattle's hazards that it is.

2. HAZARD RANKING AND METHODOLOGY

Any of the 18 hazards included in the SHIVA could cause a terrible disaster. For the purpose of prioritizing strategies to mitigate, plan, and prepare for them with limited resources, this section succinctly summarizes and ranks them. The rankings are not intended to be a precise prediction of hazard occurrence or severity. Like all models the ranking is a simplification of highly complex phenomena.

2.1 Hazard Identification Methodology

This analysis uses multiple factors to identify hazards based on best practices. A key touchstone is FEMA 386-2, Understanding Your Risks and Emergency Management Accreditation Program (EMAP) standards 4.1.1, 4.1.2 and 4.1.3.

The first step of hazard identification is defining 'hazard'. The City of Seattle Emergency Management Strategic Plan states, "*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 section 1.6.2 and the hazards that cause them in section 1.6.1. 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, 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 (e.g., cyber-attack disrupting our community on a large scale)

In the end we found over 80 types of hazards described in archives and literature. Many of these hazards demand similar capabilities to prepare for, mitigate, respond to, and recover from. Moreover, most actual modern disasters are multi-hazard. We choose 18 hazards that pushed us to develop the broadest set of capabilities that will be useful no matter what Seattle experiences.

Terrorism and climate change emerged as special cases of 'meta-hazards' that manifest through other hazards. Terrorism is a motivation rather than a specific hazard. We found that acts of terrorism in transportation incidents, hazardous materials incidents and small arms attacks. Instead of having a stand-alone terrorism chapter, we address it in chapters that concentrate on the weapon used. The Attacks chapter includes information about the unique aspects of terrorism that are not found in other chapters that include both accidents and attacks. Similarly, climate change is not a specific hazard. It intensifies other hazards like flooding. Because of its complexity, we have a chapter covering climate change, but the hazards it affects are covered in their own chapters.

2.2 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 Ranking. Finally, the Scenario Rankings for the two scenarios were summed and added to the "Future Emphasis" parameter to get a Combined Ranking. The equation is written below.

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

Combined Ranking = (Scenario Ranking – Most Likely) + (Scenario Ranking – Maximum Credible) + Future Emphasis

Draft scores were assigned by Office of Emergency Management staff with suggestions from the Office of Emergency Management Strategic Working Group.

2 2.1 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.

2 2.2 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 direct 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.

2 2.3 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 2-1. Hazard Ranking

	Most Likely Scenario															Maximum Credible Scenario																
	Geographic Scope	Duration	Health Effects	Displacement	Economy	Environment	Structures	Transportation	Critical Services	Confidence in Govt	Base Score	Frequency (F)	Cascading Effects (CE)	Multiplier (F + CE)	Subtotal	Geographic Scope	Duration	Health Effects	Displacement	Economy	Environment	Structures	Transportation	Critical Services	Confidence in Govt	Base Score	Frequency (F)	Cascading Effects (CE)	Multiplier (F + CE)	Subtotal	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	5.0	2	5	7	35	3	**56.4**
Snow & Ice Storm	5	3	2	2	2	1	2	2	2	1	2.2	5	2	7	15.4	5	4	2	3	3	2	2	4	3	3	3.1	3	3	6	18.6	5	**39.0**
Windstorms	5	1	2	2	2	2	2	2	2	1	2.1	5	2	7	14.7	5	2	2	3	3	2	3	4	4	3	3.1	3	3	6	18.6	3	**36.3**
Power Outages	3	2	2	2	2	1	1	2	2	1	1.8	5	2	7	12.6	5	4	2	4	3	1	2	3	3	5	3.2	3	3	6	19.2	3	**34.8**
Cyber-attack/Disruption	5	4	1	1	2	1	1	2	1	3	2.1	3	1	4	8.4	5	4	2	5	4	3	1	4	4	3	3.5	2	4	6	21	5	**34.4**
Landslides	4	3	2	2	1	2	2	3	1	1	2.1	5	1	6	12.6	3	3	3	3	3	3	3	4	2	3	3.0	2	4	6	18	3	**33.6**
Disease Outbreaks	5	5	4	1	2	1	1	1	1	1	2.2	4	1	5	11.0	5	5	5	5	4	1	1	3	3	3	3.5	3	2	5	17.5	5	**33.5**
Flooding	5	2	1	2	2	2	2	2	1	1	2.0	5	1	6	12.0	5	4	2	4	3	2	3	4	3	3	3.3	2	3	5	16.5	5	**33.5**
Excessive Heat Events	5	3	2	2	2	1	1	2	1	1	2.0	5	1	6	12.0	5	4	4	4	3	2	1	3	3	3	3.2	3	2	5	16	5	**33.0**
Tsunamis and Seiches	3	2	2	3	3	2	3	2	1	1	2.2	2	2	4	8.8	4	2	4	5	4	3	3	4	3	3	3.5	2	4	6	21	3	**32.8**
Infrastructure & Structural Failure	1	2	1	2	2	2	2	2	2	3	1.9	5	2	7	13.3	4	5	3	4	3	3	2	4	3	5	3.6	1	3	4	14.4	5	**32.7**
Fires	2	2	2	4	1	1	2	2	2	1	1.9	4	2	6	11.4	2	4	4	3	3	2	2	4	2	3	2.9	2	4	6	17.4	3	**31.8**
Transport Incidents	1	1	3	2	1	1	2	2	1	1	1.5	5	2	7	10.5	3	2	4	3	2	2	2	3	2	3	2.6	2	5	7	18.2	3	**31.7**
Water Shortages	5	5	1	2	2	2	2	1	3	1	2.4	5	2	7	16.8	5	5	1	3	3	3	2	1	3	3	2.9	2	2	4	11.6	3	**31.4**
Social Unrest	3	1	2	3	3	1	2	2	2	3	2.2	5	2	7	15.4	5	3	3	5	3	1	3	2	2	5	3.2	2	2	4	12.8	3	**31.2**
Attacks	1	1	2	2	2	2	2	2	1	3	1.8	5	2	7	12.6	4	2	3	3	2	1	2	4	4	3	2.8	2	1	3	8.4	5	**26.0**
HazMat Incidents	3	1	3	4	2	2	2	2	2	1	2.2	3	2	5	11.0	3	3	2	2	3	4	2	3	2	5	2.9	1	3	4	11.6	3	**25.6**
Volcano Hazards	2	5	1	4	3	2	3	2	3	1	2.6	2	1	3	7.8	5	5	2	2	3	2	4	5	2	1	3.1	1	3	4	12.4	3	**23.2**

Table 2-2. Hazard Metric Definitions

Consequence Category	Definition	One	Two	Three	Four	Five
Frequency	How often has the hazard occurred in the past?	Never occurred locally	One in past thousand years	One in past hundred years	One in past fifty years	Nearly every decade.
Geographic Extent	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	City-wide	Regional. Winter Storms
Duration	How long does the acute crisis part of the disaster last?	Less than 24 hours	1 -3 days	4 - 7 days	7 - 30 days	30 + days
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 ecosystem, but restoration possible.	Permanent loss of ecosystem
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 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. Vulnerable populations begin to have problems with food, water, and access to services	100 - 250 displaced. Vulnerable populations having serious difficulties. General population starting to have problems	251-1000 people displaced. 5 - 30% of population experiencing facing acute shortages.	1000+ displaced people. 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 measureable 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% to assess value. Loss of ability to generate revenue.

Consequence Category	Definition	One	Two	Three	Four	Five
Built Environment [EMAP - Property, Facilities, and Infrastructure]	How does the hazard affect buildings and physical infrastructure? This includes utilities.	No effects. Heat Wave	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 worker to access the resources they need? Watch the combination of high mobility and duration impacts.	No effects on mobility	All critical services accessible, but delays reaching work or non-essental services	One crtical 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 inpassible.
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, utilites, financial, food distribution, and medical. This includes the loss of responders due to death or injury.	Of impairment on 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 complexity 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 there 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 clorine 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 2-3. Relationships Between Primary and Secondary Hazards

		Secondary Hazards																	
		Earthquakes	Landslides	Volcano Hazards	Tsunami and Seiches	Disease Outbreaks	Civil Disorder	Attacks	Cyber-attack/Disruption	Transportation Incidents	Fires	HazMat Incidents	Infrastructure/Structural Failure	Power Outages	Excessive Heat Events	Flooding	Snow & Ice	Water Shortages	Windstorms
Primary Hazard	Earthquakes		X	X	X				X		X	X	X	X		X		X	
	Landslides				X					X	X	X	X	X		X			
	Volcano Hazards		X							X		X	X	X		X			
	Tsunamis and Seiches									X	X	X	X	X		X			
	Disease Outbreaks																		
	Civil Disorder							X			X								
	Attacks					X				X	X	X	X						
	Cyber-attack/Disruption									X		X		X				X	
	Transportation Incidents										X	X	X	X				X	
	Fires								X			X	X	X					
	HazMat Incidents					X					X								
	Infrastructure/Structural Failure									X		X		X		X			
	Power Outages						X												
	Excessive Heat Events										X		X	X					
	Flooding		X						X			X							
	Snow & Ice		X							X				X		X			
	Water Shortages													X					
	Windstorms												X	X					

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 snow storm 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.

3. COMMUNITY PROFILE

Seattle is the hub of the Pacific Northwest. With 730,400 residents[8] (2018) and 581,780 jobs (2017)[9], Seattle is the largest municipality in the region. It is the center of cultural, governmental and economic activity. Paradoxically, Seattle is both a city of neighborhoods that looks inward and one of the most trade dependent cities in the U.S. Forty percent of Washington State jobs are dependent on international trade, with the Port of Seattle serving as the main international trade hub.[10] 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. This chapter builds a picture of Seattle that embraces this complexity while at the same time making it easier to understand how its response to hazards is uniquely, Seattle.

Understanding a community is essential if you want to understand how hazards affect it. This community profile does three things: explains what is at stake, broadly demonstrates the community's "defenses" against hazards and centralizes the core facts about the community to avoid repetition in the hazard sections.

The topics covered are physical geography, a brief history, population and economy, land use, infrastructure, and services. Because raw statistics by themselves don't mean much, Seattle is compared with other cities about the same population. The table below lists these "reference cities".

Table 3-1. Reference Cities

Name	land area (sq miles)	Pop 2016 (estimate)	persons / sq mile
Seattle	84	704,532	8,496
Atlanta	133	472,522	3,553
Boston	48	673,184	14,025
Denver	153	693,060	4,530
Nashville	475	660,388	1,390
Portland	133	639,863	4,811
San Francisco	47	870,887	18,530
Vancouver	44	631,486	14,352

3.1 Physical Geography

From the Aurora Bridge, commuters can look east to watch the sun rise over the Cascade Mountains then turn their heads and see the morning light falling on Puget Sound and the Olympic Mountains. The view evokes a strong sense of place and appreciation for how water and mountains have guided Seattle's development. Those with a role in protecting the public from disasters will also realize that this same geography underlies our vulnerability to disasters.

3 1.1 Location

Seattle is the northernmost major city in the lower 48 states. Fargo, North Dakota and the northern border of Maine are south of Seattle. Even the major cities of eastern Canada are south of Seattle.

Seattle is midway between Vancouver, Canada and Portland, Oregon. If Seattle sometimes feels far from the rest of the U.S., it feels 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. The proximity has led to strong trade and immigration relationships with northeastern Asia, especially China, Japan, and Korea. 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 edge.

3 1.2 Land Forms

Seattle is an isthmus sitting on the 84 square miles between Puget Sound to the west and Lake Washington to the east. Right in the middle, Seattle is pinched by Elliott Bay, an extension of Puget Sound. This pinch gives Seattle an hourglass shape. Downtown is in this narrow section, causing many major transportation routes and services to compete for land where we have the least space.

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.

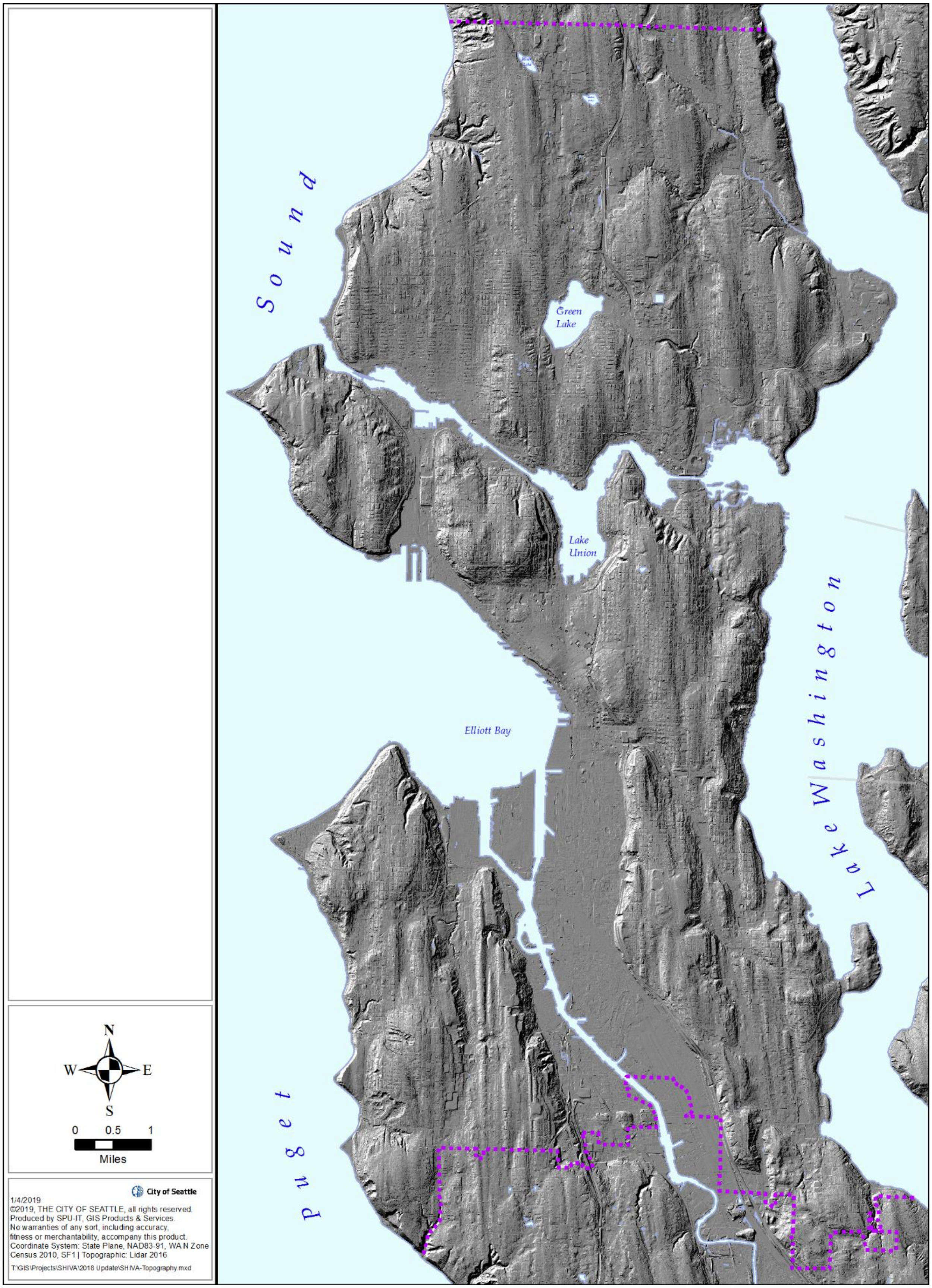
Hills are the other major defining feature in Seattle. During the ice ages, glaciers pushed down from the north over the area that is now Seattle. Ice 3,000 feet thick scoured the land and left north/south trending ridges and troughs. The troughs filled with water to become Puget Sound and Lake Washington. The ridges are our hills with their steep eastern and western sides. The highest hills reach over 500 feet. Like the water barriers, the hills have guided development in Seattle. Roads are forced to jog around obstructions or dead end suddenly. Early in Seattle's history, huge public works projects re-graded many areas in an effort to improve transportation.

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.

Many government services and employers are located in or near downtown. Most of the hospital beds in the City of Seattle are on First Hill, including Harborview, the only Level 1 Trauma Center for Washington, Idaho, Montana, and Alaska. In addition, 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 that 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 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.

Figure 3-1. Topography



3 1.3 Geology

The movement of earth and ice created Seattle. Tectonic activity (the movement of large plates of the Earth's crust) have sent whole island chains crashing into the West Coast and scraped up the sea floor creating the Cascade and Olympic Mountains and thrust up Washington's five active volcanoes. As for ice, at least seven times the Cordilleran Ice Sheet ground down from British Columbia covering the Puget Sound basin in ice up to 3000 feet thick. Each time, the surface geology was massively altered. The current shape of the city is almost exactly as the glacier left it.

Nature has not been the only shaper of the city. People have undertaken massive alterations of the landforms. Whole hills have been removed. The tide flats in the Duwamish Valley were filled. A cut was made in Beacon Hill. Massive amounts of garbage were dumped in Union Bay near University Village. In all, nearly 20% of the surface of Seattle is covered with made land.[11] During earthquakes, shaking on this type of land is amplified and is prone to failure. The earthquake chapter has more on the effects of these soils.

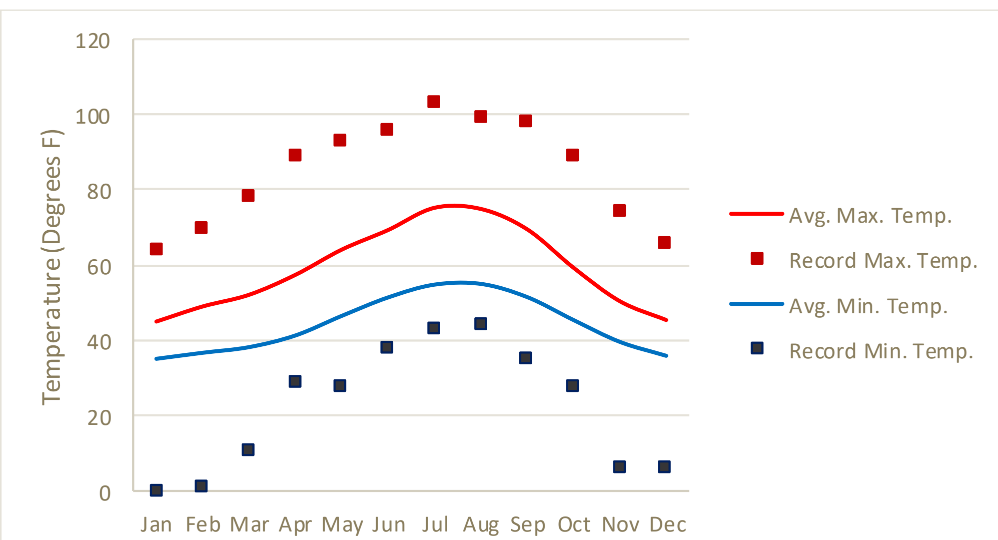
Seattle's steep hills are composed of mainly glacial till (mix of grain sizes) and sand with frequent layers of clay. When the weather is wet, water seeps down through till and sand only to stop at clay layers. The till and sand become saturated, heavier and less cohesive.[12] In many areas human activity 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.[13]

In 2006, deposits of volcanic ash were found along Hamm Creek, a tiny tributary of the Duwamish located just south of the city limits.[14] Usually the prevailing winds carry ash from nearby volcanoes east, but the layer suggests that Seattle is not immune to ashfall.

3 1.4 Climate

Seattle's climate can generally be described as "mild and moist," even though it gets less annual rain than Nashville, Atlanta, Boston, and Vancouver and has drier summers than only one reference city, San Francisco. Seattle can also receive hurricane force winds and even the rare tornado. To understand these complexities, one must first understand how the Pacific Ocean and Western Washington's mountain ranges influence Seattle's weather.

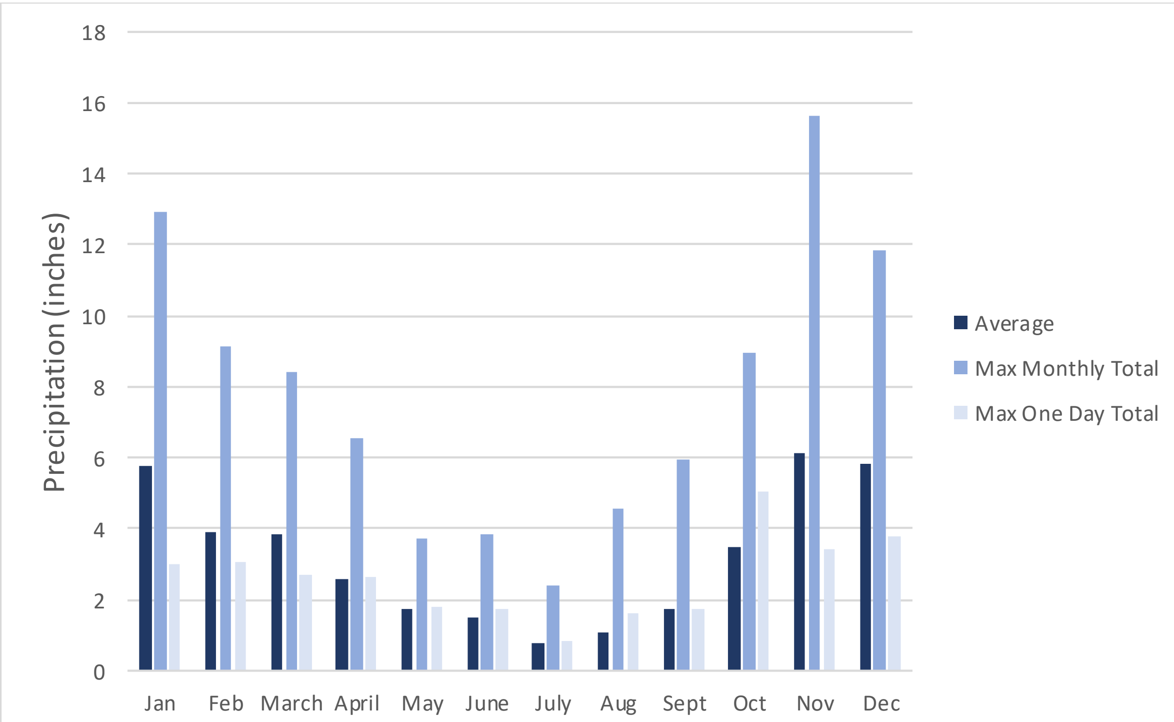
Figure 3-2. Temperature Summary (Sea-Tac Airport) 1945 - 2016[15]



Pacific Ocean

Prevailing winds bring the city's weather from the west over the 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 there are just 2.8 days over 90 degrees and just 2.7 days where the temperature never gets above freezing.

Figure 3-3. Seattle Precipitation Summary (Sea-Tac) 1948 - 2012[16]



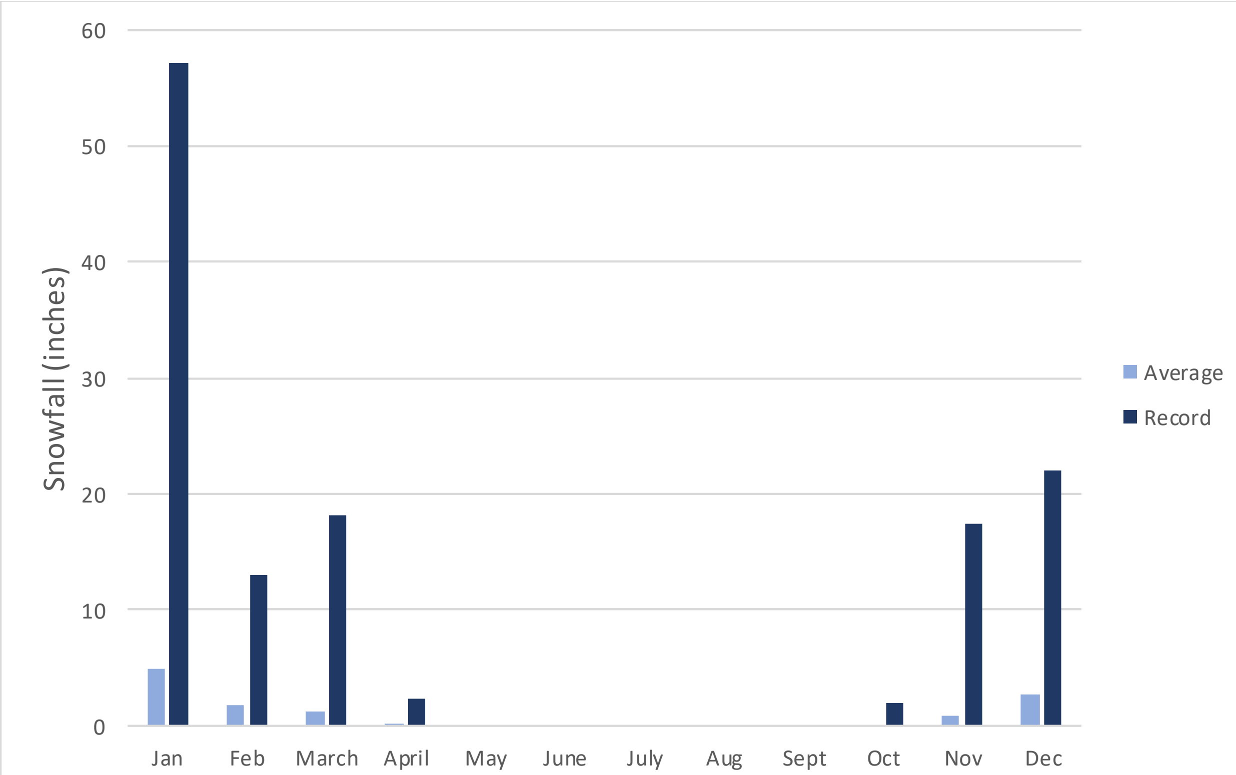
The ocean also accounts for the seasonality of our precipitation. Weather systems tend to follow the jet stream, a narrow band of high, strong winds. During the winter the jet stream frequently passes over Seattle, bringing wet, stormy weather. As temperatures rise over the Pacific in the summer, the 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 Cascade Range is 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, but the mountain barriers mean that 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. It must move up to get over the mountains. As it does so it cools and condenses creating clouds and moderate rain. As a result, Seattle has rainier 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. 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 breaks through the mountains and collides with an incoming Pacific storm. The reasons for the occasional heavy snow are covered in the chapter on snow storms.

Figure 3-4. Snowfall Summary (Sea-Tac) 1948 - 2012[17]



Seattle's generally mild climate ironically leads to some dilemmas. 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 make. Adding to the complexities is Seattle's hilly topography that multiplies the effects of heavy rain, mud, and snow.

Weather can complicate 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.

3 1.5 Natural Environment

This section discusses Seattle's natural environment and its two major habitat groups: the urban forest and aquatic environments. The Pacific Northwest is famous for its mountains, forests, and waterways. Despite being a major urban area, Seattle is a functional ecosystem integrated into the larger environment. Seattle still has vestiges of its original forest, wetlands, streams, and marine environments, but they are all fragile and endangered. In recent years, citizens, government, and businesses have become aware that environmental resources are not just found in wild lands, but also in our urban areas.

Urban Forest

The land on which Seattle sits was originally heavily forested. In 1972, 40% of the city was covered by trees. Seattle's areas with heavy tree canopy, defined as over 50% tree coverage, declined from 5,400 acres in 1972 to 2,800 acres in 1996.[18] The City adopted the Urban Forest Stewardship Plan in 2013, which included a goal of 30% canopy cover by 2037. A 2016 LiDAR analysis showed 28% tree cover in Seattle.[19] New York City in comparison is 24% tree covered.[20]

The species mix is important, too. Native species are declining. In 1999, less than 293 acres of Seattle was covered with the conifer forests that once dominated Seattle's 54,000 acres and this number is declining.[21] Remaining natives, mostly big leaf maple and red alder, replaced the original Douglas fir and western hemlock logged in the 19th and early 20th century. Now these trees are aging. A natural cycle would see them replaced by conifers, but this is not happening because the Douglas fir and western hemlock were not re-seeded. The 2016 canopy cover report found that 72% of Seattle's tree canopy is deciduous, while only 28% is coniferous.[22]

Trees reduce stormwater runoff and reduce flooding. The City estimates that tree canopy loss costs Seattle $1.3 million per year by causing an extra 7.5 million cubic feet in stormwater runoff – a factor in urban flooding.[23] Trees also improve urban air quality by removing thousands of pounds of pollutants from the atmosphere.[24] The estimated benefits from carbon storage amount to $10.9 million in savings.[25]

Trees are also a hazard. During storms they damage houses, power and telephone lines and their roots pull up underground pipes. The 2016 LiDAR 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.[26] 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. The potential damage caused by falling trees can be mitigated by trimming the weak limbs and removing weakened trees near buildings and infrastructure.

Aquatic Environments

Seattle contains lakes, rivers, streams, wetlands, and extensive shorelines. Seattle is bordered by Puget Sound on the west and Lake Washington on the east. In all Seattle has 146 miles of shoreline, 31 of which border Puget Sound. The City contains four small lakes: Haller Lake, Bitter Lake, Green Lake and Lake Union. The single river is the Duwamish. It enters Seattle in the middle of its southern border and flows north into Elliott Bay. The Ship Canal, dividing the city into north-south halves, connects Salmon Bay, Lake Union, and Lake Washington through a series of cuts. In addition to these large channels, Seattle supports five major creeks: Piper, Thornton, Longfellow, Fauntleroy, and Taylor. Many of these water bodies support wetlands. The largest are found at Union Bay, Warren Magnuson Park, North Seattle Community College, and the Fauntleroy area. Seattle also has many former wetlands and bogs that are now covered by development. They cause excessive subsidence when cut off from ground water.

Like Seattle's urban forest these water environments are simultaneously resources to protect and hazard sources. Their environmental quality varies but all have impacted by urbanization. The most severely compromised is the Duwamish River, six miles of which was designated as an Environmental Protection Agency (EPA) Superfund site in 2001. A large clean-up effort is now underway, but it will continue for up to 40 years.[27]

Seattle's shoreline is heavily modified. Only 10% is unaltered.[28] All of Seattle's 31 miles of Puget Sound shoreline is listed as a coastal flood hazard by the Federal Emergency Management Agency (FEMA). The most environmentally productive habitats in Seattle are some of these shoreline areas: Seward Park, Union Bay, West Point, and Magnolia Bluffs and Lincoln Park to Fauntleroy Cove.

Seattle has system of Combined Sewer Overflows (CSO) that sends untreated sewage into local waters during periods of heavy rain. The City of Seattle Shoreline Characterization Report found decreased water quality near these locations after storms.[29]

Many of Seattle's shorelines are ringed by bluffs. In a natural environment Puget Sound bluffs provide material for beaches and shoreline environment below them. Wave action rarely causes slides, but it can steepen slopes making them more susceptible to groundwater induced failure.[30] In Seattle, much of the shoreline has been armored in an effort to prevent beach erosion and landslides. Over 90% of the Puget Sound shoreline between Everett and Tacoma is armored.[31] Armoring is detrimental to shoreline habitat. It increases wave speeds. The faster speeds cause waves to scour beds and reduce food sources for microorganisms forming the bottom of the food chain. Armoring can cause some bluffs recede faster by depriving their bases of sediment. During the 1996-97 landslides many landslides occurred on slopes where a bulkhead had protected the toe for decades.

3 1.6 History

Seattle's real growth did not start until 1880. 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 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 the University District. 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. The moderate earthquakes of the mid-1990s jolted the city into an awareness of the risk that a major earthquake poses for it. 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. The new construction introduced a vulnerability to the then unnoticed risk of earthquakes.

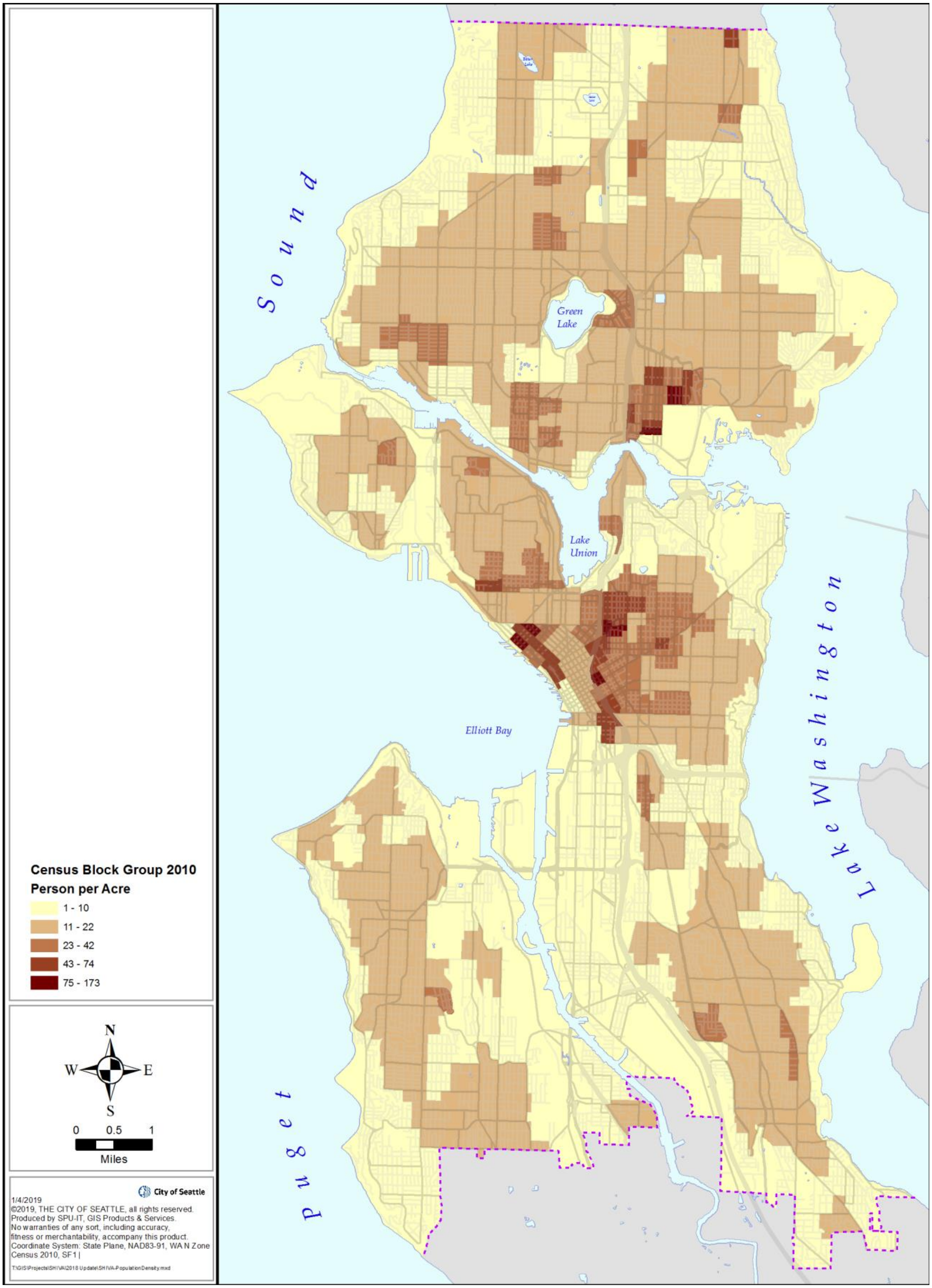
3.2 Population and Economy

Seattle typifies America's social and economic changes in the population and economy of the last half century. Like most cities at the center of urban areas, Seattle declined through the 1960's and 70's only to start growing again after 1980. While its growth has been strong, the suburbs have grown faster until 2012, when for the first time in 102 years, Seattle grew faster than its suburbs. So far, the trend has continued. Seattle's population increased by 15.4% from 2010 – 2016, while the rest of King county saw only 8.9% population growth during the same period. In 2017, Seattle grew by 16,700 people, more than any other city in Washington state.[32] It is not clear if this change is short term or a major demographic shift.

The local economy echoes the national economy with a shift from manufacturing to technology and services. While Seattle used to be centered on manufacturing (Boeing) it has diversified to include the technology (Amazon) and health sectors as key components.

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. The

Figure 3-5. Population Density 2010



income gap in Seattle is growing and as the cost of living rises, those with lower income are finding it harder to get by. In 2017, The Cost of Living Index ranked Seattle in 6th for most expensive place to live, with goods and services costing about 53% higher than the national average.[33]

Population and Demographics

In 2017, Seattle's population pushed over 700,000 for the first time and has kept growing[34]. As of April 1, 2018, Seattle had an estimated 730,400 residents.[35] About half of the population is between the ages of 25-55 and the majority live alone or with one other person. The growing population is a good first order indicator that Seattle remained fundamentally healthy despite the Great Recession. The overall picture painted by statistics is of a community in which most people have been doing well but also where a sizable chunk of its population has not been able to share in the general prosperity and is experiencing challenges, especially with housing.

Like other American cities, Seattle's population first peaked around 1960, experienced a slow decline through 1980 and then began to rise again. Today Seattle has passed its earlier peak and continues to grow. In the 1990's, Seattle's recent growth was fueled by in-migration from younger, single, well-educated, and relatively affluent people during the 1990s. During the late 2000's Seattle demographics shifted again. The number of children began increasing, especially in the north end and downtown area. The shift has resulted in school crowding in Seattle Public Schools. In 2012, it made plans to open its first new elementary school in decades.[36] Since then, Seattle Public Schools have gained about 1,000 students per year and have opened several schools and added portable classrooms to existing schools to accommodate the growth.[37]

2016 census data show that:

- Seattle has an average household size of 2.12. Almost 40% of Seattleites live alone.
- Over 60% of residents have at least a bachelor's degree.
- 17.9% of Seattle residents are under 19, a decrease from 19.6% in 2014, when Seattle ranked 3rd for lowest share of households with children.[38]
- Seattle has seen many new residents in recent years. From 2016-2017 alone, the Seattle metro area gained about 21,000 people from domestic migration and another 21,000 from international migration.[39] In 2017, Seattle ranked 1st in population growth out of the top 50 most populous cities in the US.[40]

Seattle is a comparatively affluent city. In 2018, Seattle's economy was ranked 4th strongest among the 40 largest cities in the U.S.[41] Median household income has been growing since the 1990s. In 2015, Seattle's median household income grew more than any other large city to $80,349, placing it third for median income, behind San Francisco and San Jose. Like many other cities, household income is less evenly divided than in the country, and less evenly divided than it is in King County as a whole. A comparison of income distribution among the nine reference cities found that three had a measurable difference. Atlanta, Pittsburg, and New Orleans had a more uneven distribution of income.

In 2000, poverty rates fell to some of the lowest of any large city, especially for children. In 2008, after the Dot-Com bust, but before the Great Recession, Seattle ranked 3rd lowest in overall poverty among cities over 500,000. More recently, the Seattle metro area ranked 6th lowest in overall poverty among the 25 most populous metro areas for 2016.[42] However, Seattle's poverty rate of 11.5% is higher than the broader metro area (9.6%).

Seattle saw a rise in poverty among its elderly population from 1990 through 2008. This can possibly be explained by an out-migration of younger seniors with more resources, leaving poorer and older seniors in the city. Poverty among the elderly in 2016 was almost identical to the overall rate, at 11.6%.[43]

Growing income inequality and the recent influx in migration of new residents to Seattle is reflected in its housing market. From 2016 to 2017, home prices for the Seattle metro area grew 12.7%, the highest growth in the nation. The median home price has reached a record $820,000.[44] Renters are struggling to keep up with the market as well. In 2015, almost half of Seattle residents reported putting 30% of their income towards rent, while 22% put over 50% of their income towards rent.[45] While new apartment buildings are rapidly being constructed in the city, many are not affordable and competition for lower-cost rentals is high. 2016 vacancy rates for low-cost rentals were below 3%.[46]

During the 1990s Seattle also grew more diverse, but the rate of diversification in Seattle was exceeded by that of the suburbs. As of 2016, Bellevue, Tacoma, and King County were more racially diverse than Seattle. Immigration followed the same pattern, with rapid increases in Seattle exceeded by even greater increases in the suburbs. In 2008, King County had a slightly higher share of foreign born (19%) than Seattle (18.4%) and Bellevue had a much greater share (29.8%)[47]. This gap has widened in the past 8 years, with Seattle's share slightly decreasing (18%), and King County and Bellevue increasing (21.6% and 37%, respectively) in 2016. Immigrants appear to be migrating directly to the suburbs.

These demographics refer to Seattle residents. Less is known about the demographics of the daytime population that swells as people commute into the city to work. The Seattle Police Department estimates the daytime population to be around 842,000 (2017).[48]

Seattle's demographics suggest a unique hazard vulnerability profile. Several local and national studies linked 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.

One of the most influential surveys is FEMA's Personal Preparedness in America. A new report was released in 2014. It connects demographic profiles to levels of preparedness, barriers to preparedness, and perception of risk. Those considered more prepared were more likely to own a home, have a college degree, earn at least $75,000, and live in a low to medium population density area. Those considered less prepared were more likely to live in high population density areas, be unemployed, earn $25,000 or less, and have a high school diploma or less. It is difficult to apply these findings to the general Seattle population because while median income is high overall, and over half the population has at least a bachelor's degree, Seattle is also very dense, and most people are not home-owners. Along with lack of preparedness, people who live in high-density areas are less confident in their ability to respond, and more reliant on fire, police, and emergency management personnel than those in low to medium-density areas.

3 2.1 Social Vulnerability

Hazards do not affect the population equally. Some people suffer more than others. These people are 'socially vulnerable.' If large numbers of socially vulnerable people are impacted by a hazard, this inequity will make the resulting disaster "bigger." Seattle's most vulnerable people tend to be clustered around Seattle's edges, in Rainier Valley, Beacon Hill, south downtown, and North Seattle (around Northgate and Lake City Way).

Social vulnerability affects all hazards. One of the most effective ways to reduce a community's overall vulnerability is to target social vulnerability.

The University of South Carolina has developed an index to measure social vulnerability. It synthesizes socioeconomic and built-environment variables then maps them to the census tract level. Figure 3.6 summarizes Seattle's Social Vulnerability Index.

Figure 3-6. Social Vulnerability

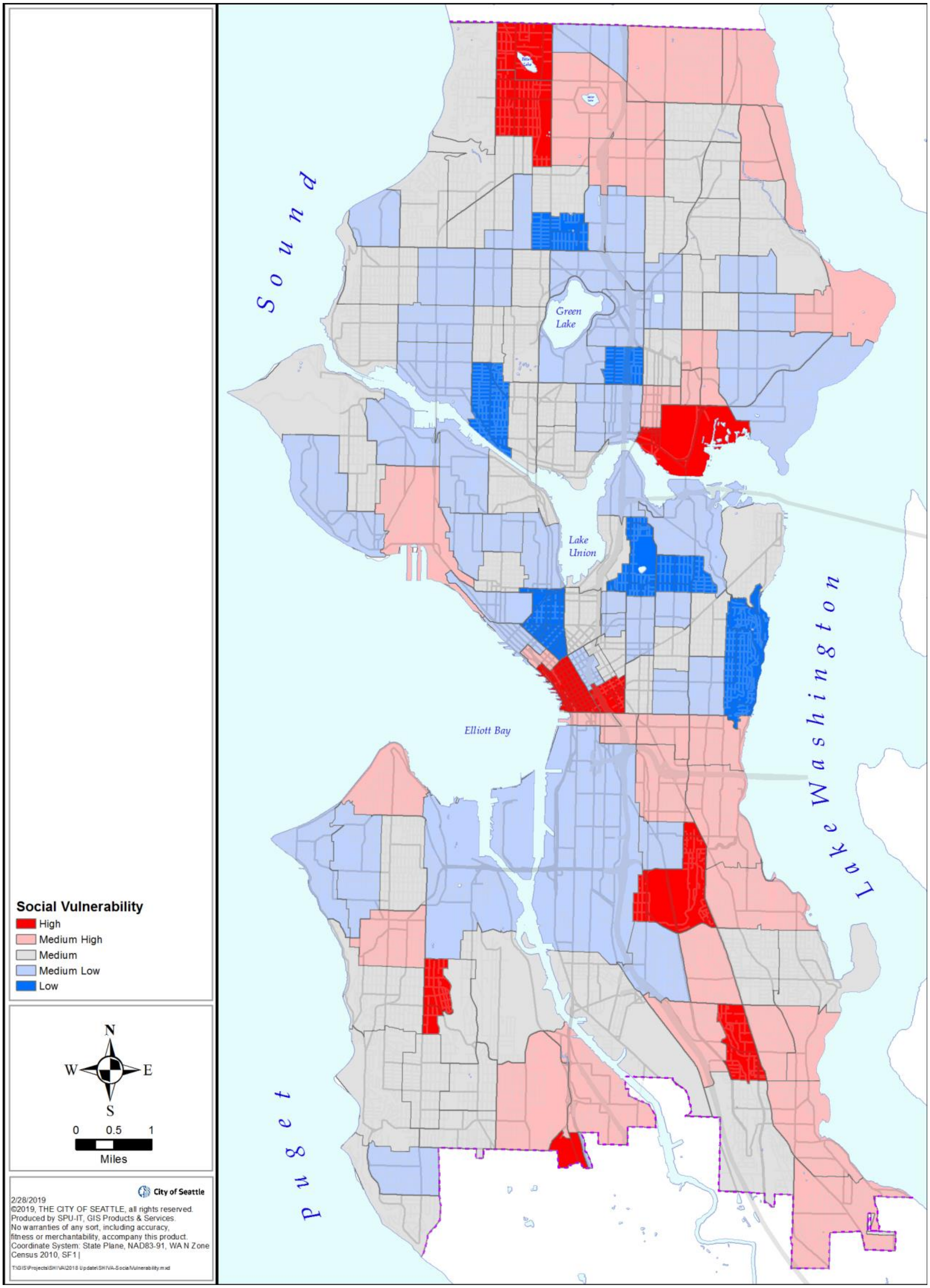


Table 3-2. Demographic Summary of Seattle and Similar Cities[49]

		Similar Cities Nationally							Regional Comparison			Nation
Item	**Seattle**	Portland	Denver	San Francisco	Minneapolis	Boston	Nashville	Atlanta	Tacoma	Bellevue	King County	U.S.
Total population	**668,849**	620,589	663,303	850,282	404,670	658,279	643,771	456,378	205,602	136,718	2,079,550	318,558,162
Median age	**36**	37	34	38	32	32	34	34	36	38	37	38
Pop 25+: Bachelor's or higher	**60.4%**	46.9%	45.7%	72.3%	47.7%	66.4%	37.6%	48.3%	26.7%	64.1%	49.1%	30.3%
Average household size	**2.12**	2.36	2.31	2.33	2.28	2.35	2.4	2.24	2.49	2.48	2.46	2.64
Average family size	**2.89**	3.04	3.21	3.14	3.16	3.15	3.15	3.41	3.23	3.01	3.09	3.24
Disability Status	**9.4%**	12.9%	9.4%	10.6%	10.9%	12.3%	11.9%	11.9%	15.0%	8.2%	9.6%	12.5%
Non-English language at home	**21.7%**	19.0%	27.1%	44.0%	20.9%	37.1%	16.9%	9.8%	19.2%	41.0%	26.5%	21.1%
Foreign Born	**18.0%**	13.7%	15.9%	34.9%	15.3%	27.6%	12.5%	7.0%	13.1%	37.0%	21.6%	13.2%
Foreign Born - Asia	**29.0%**	40.7%	18.1%	63.8%	26.1%	25.6%	30.1%	38.7%	48.3%	69.0%	53.5%	30.1%
Foreign Born - Latin America	**4.0%**	25.0%	62.8%	18.9%	32.6%	49.0%	44.1%	32.6%	26.0%	10.2%	17.8%	51.5%
Means of Transport to Work												
Mean Travel to Work (minutes)	**26.9**	25.6	25.1	32.4	22.7	30.3	24.3	25.8	27.1	23.1	28.7	26.1
Drove alone	**49.2%**	57.8%	70.2%	35.0%	61.3%	38.9%	79.4%	68.6%	75.5%	65.1%	63.6%	76.4%
Carpooled	**7.7%**	8.9%	8.2%	7.2%	8.1%	6.0%	10.1%	7.0%	10.7%	9.0%	9.6%	9.3%
Public transportation	**20.8%**	12.1%	6.8%	33.7%	13.1%	33.6%	2.2%	10.0%	4.9%	12.6%	12.6%	5.1%
Walked	**10.1%**	6.0%	4.5%	10.6%	7.2%	14.8%	2.0%	4.6%	3.3%	5.3%	5.0%	2.8%
Other means	**5.2%**	7.8%	3.4%	6.9%	5.2%	3.4%	1.3%	2.1%	1.8%	1.3%	2.8%	1.8%
Worked from home	**7.0%**	7.5%	6.9%	6.6%	5.2%	3.4%	5.0%	7.6%	3.9%	6.7%	6.3%	4.6%
Mobility: Lived last year in another state/country	**6.6%**	5.5%	5.1%	4.0%	5.0%	6.2%	5.2%	4.9%	3.1%	8.3%	5.1%	2.9%
Income												
Per capita income	**$48,686**	$34,778	$36,616	$55,567	$33,490	$37,288	$29,427	$38,686	$27,947	$54,883	$43,629	$29,829
Families below poverty	**6.9%**	10.5%	12.2%	7.0%	14.6%	16.7%	13.3%	18.8%	13.2%	5.4%	6.7%	11.0%
Individuals below poverty	**13.0%**	16.9%	16.4%	12.5%	21.3%	21.1%	18.0%	24.0%	17.9%	7.5%	10.7%	15.1%
Housing												
Owner-occupied	**46.2%**	53.1%	49.4%	36.8%	47.7%	34.7%	53.5%	43.0%	50.0%	56.5%	57.3%	63.6%
Renter-occupied	**53.8%**	46.9%	50.6%	63.2%	52.6%	65.3%	46.5%	57.0%	50.0%	43.5%	42.7%	36.4%
Median home value	**$484,600**	$319,400	$292,700	$858,800	$212,800	$423,200	$174,600	$222,300	$212,400	$608,500	$407,400	$184,700
Median rent	**$1,266**	$1,025	$1,035	$1,632	$898	$1,369	$902	$998	$980	$1,629	$1,273	$949
Age												
Under 5	**5.0%**	5.7%	6.7%	4.6%	6.8%	5.4%	7.1%	5.9%	6.6%	5.8%	6.1%	6.2%
Under 18	**15.3%**	18.4%	20.7%	13.5%	20.0%	16.5%	21.5%	18.7%	21.7%	20.8%	20.9%	23.1%
Over 65	**11.9%**	11.6%	10.9%	14.4%	8.8%	10.7%	10.8%	10.8%	12.8%	14.1%	12.2%	14.5%

Source: U.S. Census Bureau American Fact Finder 2012 - 2016 American Community Survey 5-year Estimates (Accessed on 7/9/2018)

While the Social Index of Vulnerability is a valuable tool, it is a national model. Each community is a bit different. Public Health—Seattle & King County has identified the following groups that are at-risk for disproportionate impacts in an emergency:[50]

- Aging adults and children
- Individuals with medical needs
- Individuals who are blind
- Individuals who are deaf, deaf-blind, hard of hearing
- Individuals with developmental disabilities
- Individuals with mental health conditions
- Individuals with limited mobility
- Individuals who have experienced domestic violence
- Individuals experiencing homelessness or transitional housing
- Immigrant and refugee communities
- Individuals who are undocumented
- Individuals who are limited or non-English speaking
- Clients of the criminal justice system
- Individuals who are drug or alcohol dependent
- People of color

The aging adult and elderly population in Seattle 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.[51] 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.[52] Efforts are being made to reduce social isolation among aging adults and to educate the elderly about emergency preparedness.[53]

The Seattle region has seen a rise in the number of people experiencing homelessness. The total number of homeless individuals in King County has grown from about 9,000 in 2009 to over 11,500 in 2017, a 30% increase.[54] The unsheltered population, or those staying in a place not meant for habitation (such as a vehicle or street), has increased by about 90% from 2009 to 2017.[55] The sheltered population, on the other hand, has only grown by about 1%. 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, excessive heat events, or flooding.[56] Almost a quarter of homeless youth in Seattle identify as LGBTQ,[57] a population that has historically faced discrimination that may compound the stress felt in a disaster situation.[58]

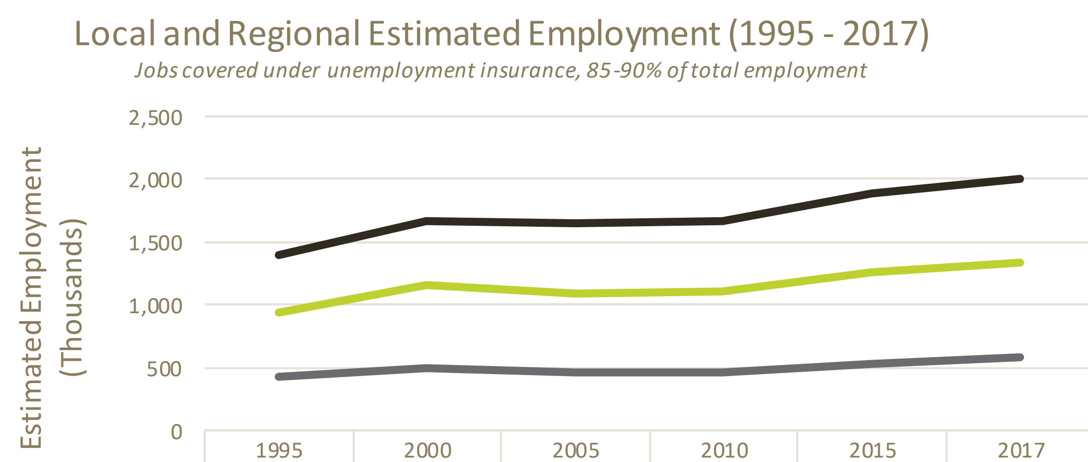
3 2.2 Economy

Seattle is the center of the Puget Sound economy and a leading hub of the Western United States. Historically, the regional economy was centered around the timber, shipping, and aerospace industries combined with the military. In the last several decades Seattle's economy has grown much more diverse. The healthcare, biotechnology, software, communications, tourism and transportation industries are now critical components of Seattle's economy. Over the long-term Seattle's growth has been above average, but it has also been strongly cyclical due to the historically large influence of the aerospace industry.

Seattle supported an estimated 581,780 jobs in 2017 (this number represents jobs covered by unemployment insurance, 85-90% of jobs).[59] Unemployment has dropped from 9.9% in 2010 to 3.7% in 2017, illustrating Seattle's recovery from the Great Recession.[60]

Services account for 53% of jobs, followed by government and education (16%), retail (11%), and manufacturing and construction (9%).[61] These percentages reflect national trends away from manufacturing and into the service sector.

Table 3-3. Local and Regional Estimated Employment[62]



	1995	2000	2005	2010	2015	2017
Seattle	426,411	502,832	464,429	462,985	535,430	581,780
King County	937,211	1,149,642	1,093,085	1,099,639	1,252,463	1,335,408
Central Puget Sound*	1,395,767	1,662,879	1,643,031	1,673,354	1,888,658	2,002,504

* Includes King, Pierce, Kitsap, and Snohomish Counties

The aerospace industry has long been central to Seattle's economy. While Boeing still has a huge presence in the Puget Sound region, its influence is decreasing. It still spends billions in the Seattle area, but it has dramatically cut employment in Seattle proper, with most jobs located in Renton and Everett. The aerospace industry is very cyclical, and the swings of Seattle's economy have been very dramatic, however 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 remain in higher 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. Most of its industry sits in a liquefaction zone on top of the Seattle Fault. 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 2016, there were 78,099 healthcare and social assistance jobs, accounting for about 13% of the job market.[63] This number does not reflect the growing number of biotech and medical research jobs, which have become a prominent industry 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 software and internet services industry has become essential to Seattle's economy. Since getting its start in 1994, Amazon has had an undeniable influence on the city, now serving as its largest employer with over 40,000 employees.[64] It occupies 19% of all the prime office space in Seattle (8.1 million square feet) and continues to construct new buildings.[65] While its original growth was centered in the South Lake Union area, Amazon has gradually moved south towards the downtown core. Microsoft continues to employ many people in the area but has primarily located jobs in Redmond, a suburb east of the city. There are many linkages between the healthcare and software industries.

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, and the number of visitors has steadily grown over the past decade. In 2017, the city had 39.9 million visitors, up 2.6% from the previous year.[66] The arts, music, and sports are major contributors to the local economy generating revenues in the billions and employing thousands. Seattle tourists spent $7.9 billion in 2017, generating over $760 million in tax revenue.[67] A 2017 survey also found that tourists spend an average of $195 per day when visiting the downtown area.[68] The city is planning to expand its convention center, which has turned down many requests for events in recent years due to space limitations.

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 its effect is hard to quantify, this attractiveness is cited as a major reason that businesses locate in Seattle. Maintaining Seattle's 'brand' is one of the reasons the perception of the community is included in this study.

Overall, the core of Seattle's economy has recovered from the Great Recession and continues to experience growth.

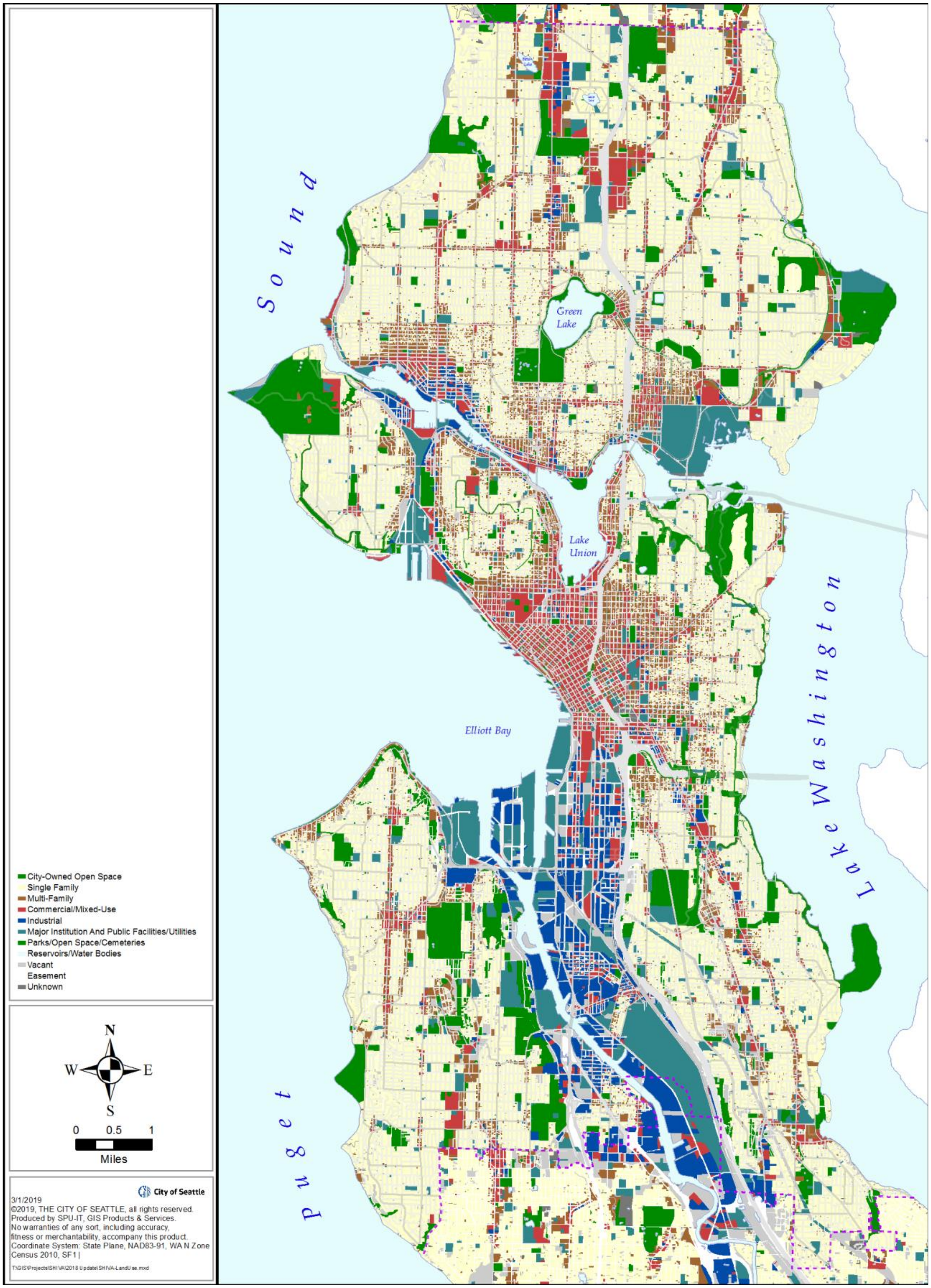
3.3 Land Use

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 and 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. Greater densities are being encouraged within urban villages clustered around transportation hubs.

Over one-third of Seattle is covered in single family lots (35%) and just over one-quarter in right of way (26%). Seattle has 10% of its area as city-owned open space but does not have a large regional park like Portland's Forest Park (5,170 acres).

The major employment uses (commercial, industrial, and major institutions) cover 16% of the city's area. Multi-family uses are just 6% of Seattle's area even though they account for over half (51%) of the dwelling units.[69] The reason is that most of Seattle's multi-family units are in larger apartment and condo complexes rather that smaller 2, 3, and 4-plexes. **Error! Reference source not found.** displays d ata from the City's Office of Planning and Community Development and shows the breakdown of the city's land uses in 2017.

Figure 3-7. Land Use



Land use drives population shifts on all time scales, from daily commutes to weekly recreation and 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.[70]

Table 3-4. 2018 Land Use Summary[71]

Seattle Land Use excluding Right of Way	Square Feet	Percentage
City of Seattle Facilities	4,124,793	0.15%
Commercial/Mixed-Use	218,741,242	7.69%
Duplex/Triplex	1,273,079	0.04%
Easement	338,209	0.01%
Entertainment	3,086,548	0.11%
Hotel/Motel	1,655,034	0.06%
Industrial	128,049,685	4.50%
Institutions	180,212	0.01%
Major Institution And Public Facilities/Utilities	325,832,738	11.46%
Mixed-Use	374,366	0.01%
Multi-Family	202,298,234	7.12%
Office	3,054,243	0.11%
Open Space	158,253,671	5.57%
Other Housing	387,357	0.01%
Parks/Open Space/Cemeteries	68,973,773	2.43%
Private	1,133,565	0.04%
Public Facilities	41,734	0.00%
Retail/Service	6,802,067	0.24%
Schools	1,179,600	0.04%
Seattle Housing Authority	88,154	0.00%
Single Family	1,351,340,918	47.54%
Transportation/Utility/Communications	26,401,479	0.93%
Unknown	7,978,485	0.28%
Vacant (includes undeveloped 'land' in water)	322,997,092	11.36%
Warehouse	496,133	0.02%
Water Bodies	7,624,079	0.27%

Seattle is home to the region's biggest sports and entertainment venues as well as cruise ship terminals. In 2017, the Port of Seattle reports 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 just under 8,500 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 later 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 100 people per acre in some blocks.[72]

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 strongly influenced 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 that stresses development in urban centers and villages. These are areas built around current commercial, multi-family residential, and transport hubs. The major goal is to locate housing, jobs and stores near each other to reduce the necessity of car use. Tables within hazard chapters show what percentage of these areas fall within mapped hazard areas (e.g., landslide prone).

3.4 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 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 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.

3 4.1 Passenger Transport

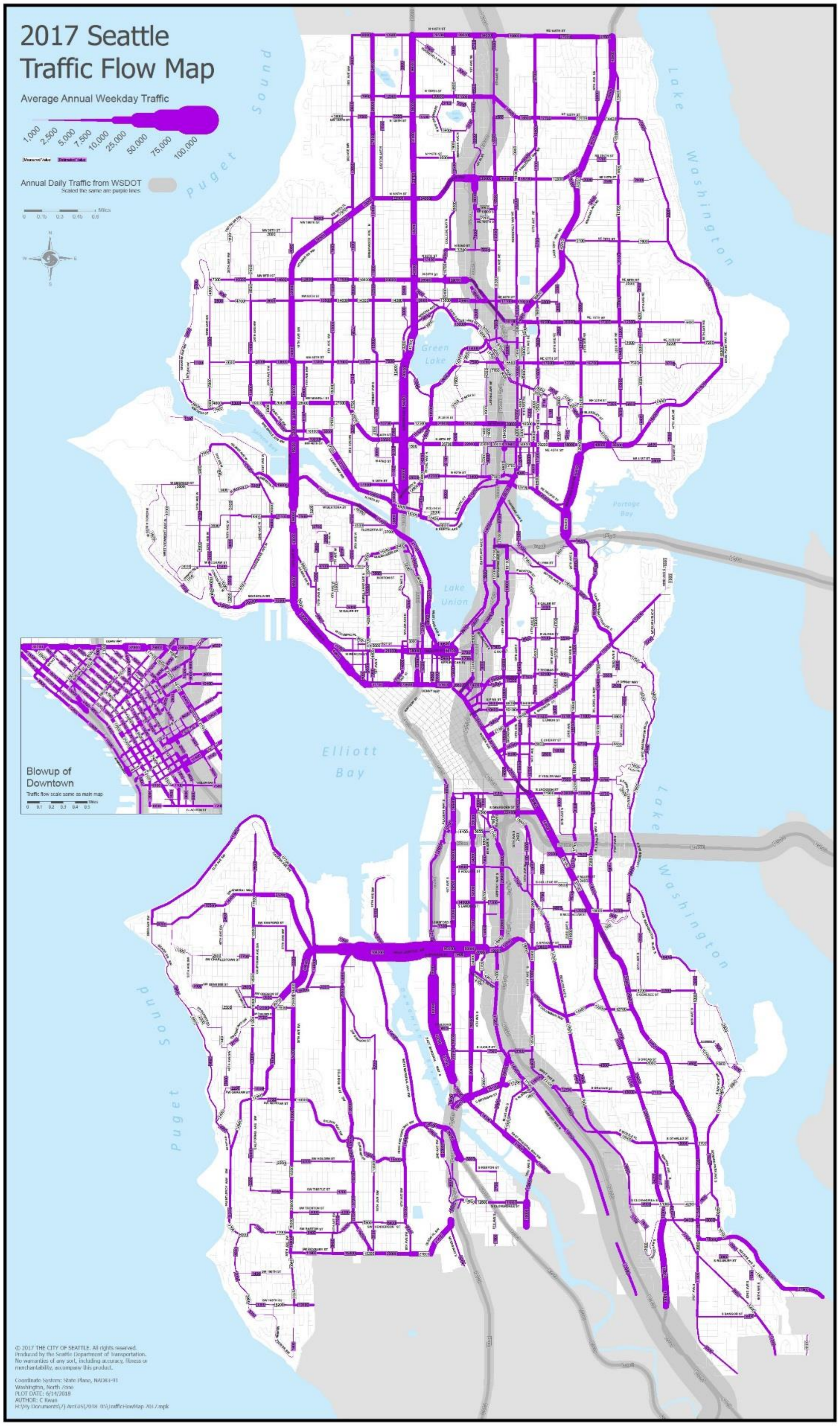
Like most American cities, Seattle's ground system has been dominated by cars. However, this dependence on cars may be decreasing slightly as measures designed to reign in urban sprawl begin to take effect. In 2016, 14% of Seattle workers walked or biked to work while 20% used public transit (compared to 5% nationally).[73]

Transit

Transit is a vital part of Seattle's transportation system for Seattle's residents, visitors and workers. Because Seattle is a major business and entertainment hub, much of Seattle's ground transportation system centers around moving large numbers of people into and out of the downtown core on a daily basis. A 2017 survey completed by Commute Seattle shows that workers who commute into downtown during peak hours rely heavily on public transportation. Almost half of the survey respondents used transit to get downtown, while only a quarter drove alone.[74] People are more likely to use transit for commuting than personal trips.

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). County wide, Metro had over 121 million passenger boardings in 2016.[75] Trips involving Seattle make up the biggest share of this number. Sound Transit had over 47 million boardings in 2017, of which about half were on its Link Light Rail service, which spans from the University of Washington in the north down to SeaTac, south of the city.

Figure 3-8. 2017 Traffic Flows



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 80-bus fleet shuttles an average of 2,160 round-trip passengers every weekday.[76]

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. In 2017, the two combined have a monthly ridership of about 4,500.[77]

Marine

Seattle has a strong maritime history. Unlike many other cities, marine transport plays an important role in Seattle's passenger transportation. Washington State has the largest ferry system in the United States. Five routes dock in Seattle. Four dock in downtown (Seattle-Bainbridge, Seattle-Bremerton, Seattle-Vashon passenger only, Seattle-Bremerton passenger only) and one docks in West Seattle (Fauntleroy-Vashon). The Edmonds – Kingston ferry, while outside the city, also serves Seattle residents and workers. These routes have a combined ridership of over 16 million. Many of the people using the system are commuters. In 2013, about 19,500 passengers per day were carried into and out of Seattle. The biggest ferries have a capacity equal to 60 40-foot buses. Additionally, cruise ship operations frequent Seattle, increasing demand for air and ground transport.

Air

Most passenger air transport is through Seattle Tacoma International Airport (SeaTac) located south of Seattle. In 2017, SeaTac handled 416,124 total air operations and over 45 million passengers, making it the 9th busiest airport in the nation.[78] 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, announced in 2017 that it will begin operating commercial passenger flights. So far only three airlines are set to operate out of Paine Field with an expected 24 daily departures between them. 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.

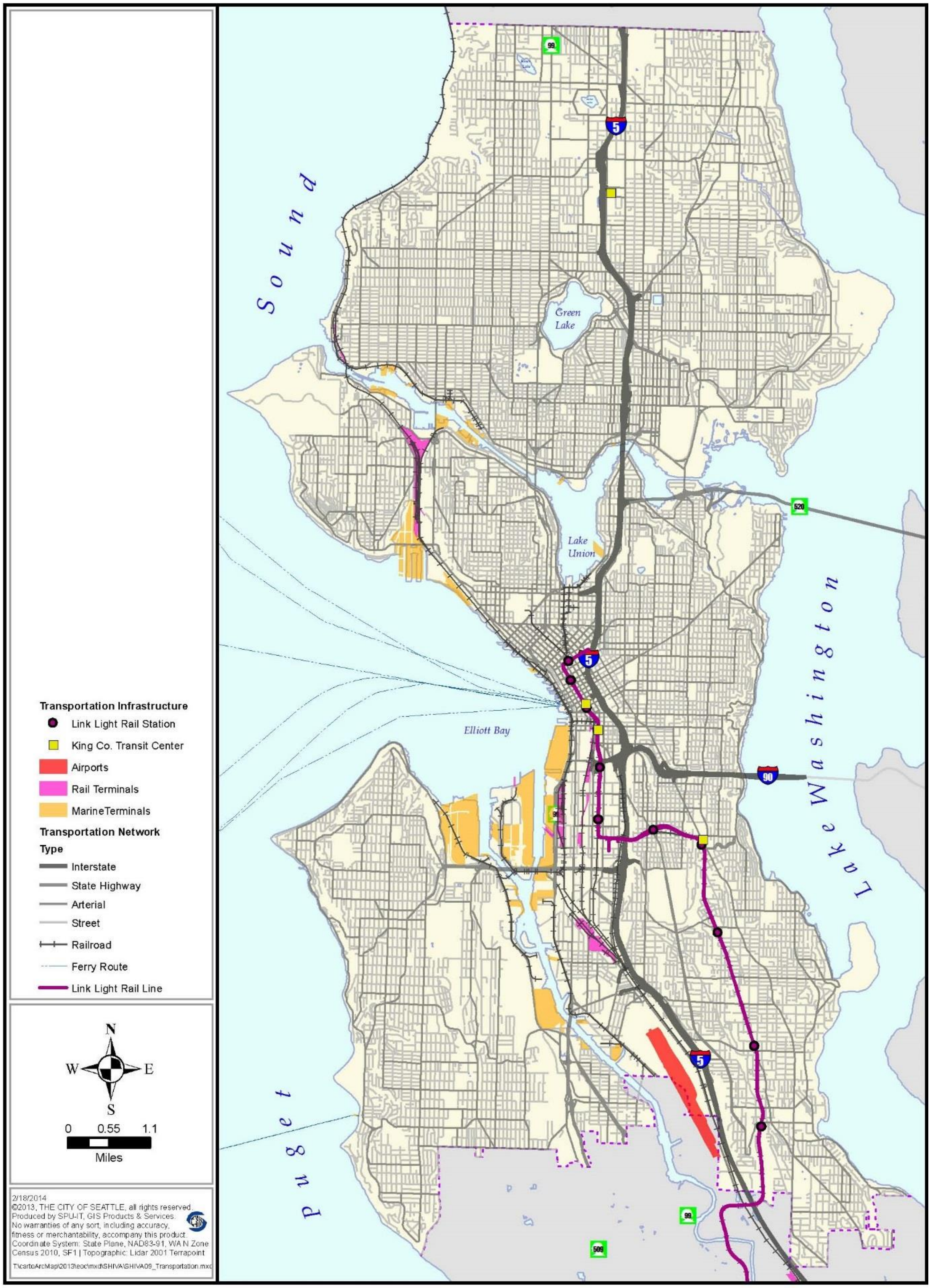
Rail

Seattle is a rail center. Passengers use Amtrak for long-distance travel and Sound Transit commuter rail for short trips. Passenger service in Seattle is centered at the King Street Station. Both Amtrak and Sounder commuter trains use this station. The Sounder is a commuter line running on BNSF track on the weekdays between Tacoma and Everett. Amtrak operates three routes in Seattle. Most significant is the route serving the corridor between Vancouver, B.C. and Eugene, OR. The other two are Seattle / Chicago and Seattle / Los Angeles. In 2017 the Amtrak Cascades route had 817,000 passengers. The number of passengers is declining due to competition with new bus service.[79]

3 4.2 Freight Transport

Trade is essential to Washington State's economy, and Seattle sits at the center of it. In 2017, Washington ranked 3rd nationally for foreign exports ($77 billion) and 12th for foreign imports ($50 billion).[80] Large quantities of goods move through Seattle on a daily basis 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.

Figure 3-9. Major Transportation Infrastructure



Seattle's marine cargo terminals and rail yards are located close to downtown. They must contend with completing land uses and passenger transportation. 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. A series of docks, terminals, inter-modal rail yards and many designated truck streets serve the marine business.

Marine

Seattle is home to a diverse port that supports container traffic, bulk cargo, a major grain terminal, and a large fishing fleet. About 12 million metric tons of cargo moved through Seattle's port in 2015.[81] In 2015 The Port of Seattle and the Port of Tacoma formed an operating partnership under the name The Northwest Seaport Alliance. Together, the two port systems form the fourth largest container gateway in the nation. In 2017, the Northwest Seaport Alliance saw over 27 million metric tons of cargo move through its ports and had almost 2,000 vessel calls.[82] Most incoming goods are loaded onto trains and shipped to Chicago. There is some indication that Seattle's cargo volume may grow as capacity at other large ports in Los Angeles and Long Beach shrink. 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 operates differently than marine shipments because of greater time constraints, so 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. SeaTac handles 63% of the regional air cargo traffic and Boeing Field handles 22%.[83] SeaTac's air cargo operations have increased significantly in the past decade. In 2017, SeaTac handled 425,856 metric tons of cargo, up from 290,653 metric tons in 2007 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 join the Puget Sound. All the yards are in liquefaction zones because they require large flat areas. 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. Washington State's most deadly transportation disaster was the 1910 Wellington avalanche that killed 96 people on a train halted along the Steven's pass route.

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. At the time Olympic Pipeline Company operated the pipeline. Today BP owns the pipeline.

3 4.3 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. While we most often associate streets with vehicles, they serve other important functions such 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. Finally, streets are where a lot of a community's public life occurs. Urban designer Allan B. Jacobs asserts that great streets make great communities.[84]

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.

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 average of 245,000 vehicles per day.[85]

Seattle ranked 9th in the nation for traffic congestion in 2017.[86] This finding suggests that Seattle possesses little reserve capacity. A prolonged closure of a major roadway would shift traffic onto already overloaded infrastructure.

Bridges

Seattle is an isthmus divided by waterways. Puget Sound lies to the west and transportation across it depends solely on ferries. To the east is Lake Washington, 22 miles long. Seattle is divided in the middle by the Lake Washington Ship Canal. West Seattle is separated from the rest of the city by the Duwamish Waterway.

Two floating bridges, the SR-520 Bridge (also called the Evergreen Point Floating Bridge) and I-90 Bridge (running over Mercer Island) cross Lake Washington. Together they bring over 200,000 vehicles into Seattle on an average weekday.[87] Washington State began replacing the SR-520 bridge in 2012, due to concerns around hollow support columns that are vulnerable to damage in earthquakes.[88] 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. Tolling on SR-520 has reduced usage and diverted some traffic onto the I-90 bridge.

The Ship Canal is spanned by seven bridges (six roadways and one rail). The most important is the I-5 Ship Canal Bridge, handling 172,000 vehicles per weekday. It would be catastrophic for transportation if this bridge went out of commission. The next busiest, the Aurora Bridge, handles just a fraction at approximately 68,000 vehicles per weekday.[89] 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 nearly 200,000 vehicles per day. I-5 and East Marginal Way both cross the Duwamish just south of the city.

3 4.4 Utilities

Utilities make urban life possible, but they impose 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.

Seattle has a mix of publicly and privately owned utilities. All utilities provide a public service. They differ from other public services such as police protection because they require extensive infrastructure. Utilities include electricity, gas, water, drainage, sewage, solid waste, and telecommunications. In the downtown area, steam is also an important utility.

Electricity

Electricity in Seattle is supplied by Seattle City Light (SCL), a publicly owned utility that is part of the City of Seattle. Unlikely 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 95% of SCL's generated power comes from the Skagit River (North Cascades) and the Pend Oreille River (northeast Washington). In 2016, they provided electricity to over 447,000 residential and commercial customers.

Seattle's heaviest electrical loads occur in the winter because many Seattle buildings have electric heat.[90] 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. This rise creates financial risks for SCL.

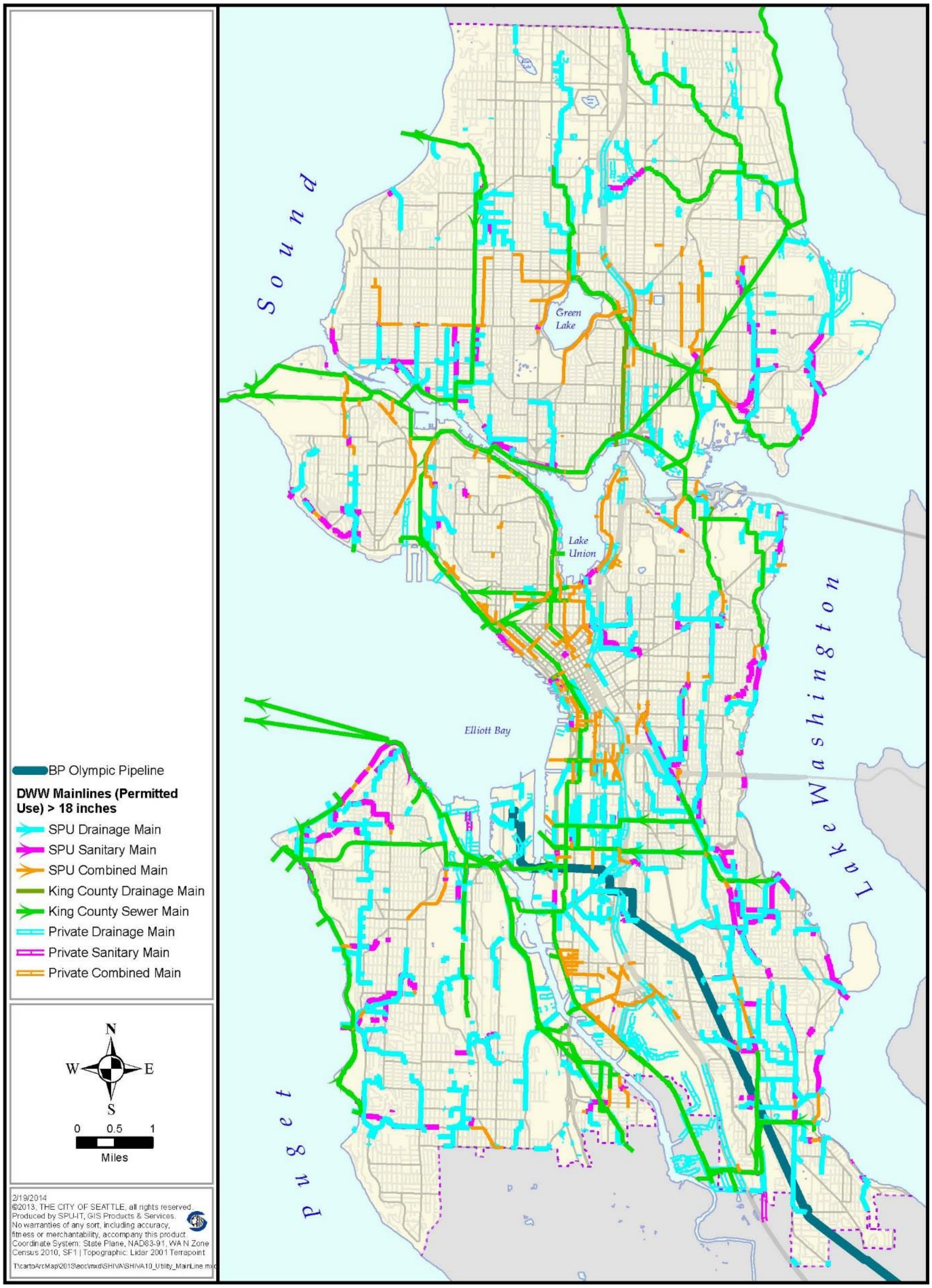
Seattle's use of hydroelectric power makes the city dependent on the snowpack in Washington's mountains. During years of low snowpack SCL must purchase more power from BPA and other providers. Climate change may be reducing the Cascade snowpack. This trend is a major concern for SCL.[91]

Natural Gas

Natural gas is provided to 131,182 residential and 13,953 commercial customers in Seattle by Puget Sound Energy (PSE), a private, regulated utility. 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. The use of natural gas lagged behind electricity in the Northwest, which still uses less natural gas than in many parts of the country. Cheap hydroelectric power, lack of access to cheap U.S. natural gas fields in the 1960s and early 1970s and the high cost of Canadian sources slowed the development of natural gas in the Pacific Northwest.

Figure 3-10. Major Utility Infrastructure



In Seattle, the use of natural gas has been stable over the past few years. According to U.S. census statistics, 37% of Seattle residences are heated by natural gas.[92] Peak demand is often in the winter. The Jackson Prairie underground storage facility stores reserves near Chehalis, Washington. Gas there is pumped into deep porous sandstone for later retrieval.

Water

Seattle's water is provided by Seattle Public Utilities (SPU), a department of the City of Seattle. 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 1.4 million people in the region. Nearly all of Seattle's water comes from two watersheds in the Cascade Mountains east of Seattle. 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. Like electric power, Seattle's water supply is dependent on snow pack in the surrounding mountains. Unlike power, 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 throughout King County. Total consumption peaked in the late 1980s near 160 million gallons per day. Now King County uses about 120 million gallons per day despite the population increasing by over 1 million people. The main drivers 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.[93]

Sewer and Drainage

The removal of wastewater from buildings and the drainage of runoff have been closely linked historically. Cities create large waste streams from indoor plumbing. Drainage systems are necessary in cities because they have large amounts of impermeable surfaces that cause water to run off them and they have nowhere to store this runoff. One of the great advances in public health was the creation of sanitary sewers to reduce disease. In Seattle, SPU handles the collection and King County Department of Natural Resources and Parks (DNRP) handles the treatment and discharge.

When constructed early in the 20th century, sanitary and storm sewers used the same collection system. This design is not good for the environment because untreated waste was frequently discharged into local streams and water bodies when heavy rain overwhelmed treatment capacity. These discharge sites are called Combined Sewer Overflows (CSO). Seattle has 124 of them.

To update the public when CSO discharges are occurring, King County's CSO website shows CSO status in real-time for its 39 sites, and monitors some of the 85 additional sites maintained by SPU. Although the City has more CSO sites, King County discharges more wastewater because they control mainlines.

The amount of CSO overflow has been reduced since the early 1960s, from the 20 – 30-billion-gallon range to around 1.5 billion gallons in 2016.[94] Both King County and SPU have programs to reduce the number of overflows. Efforts include operations improvements, capital intensive projects and separating sewage from surface runoff.

Despite the problems caused by CSOs, they serve a valuable purpose in the combined system that Seattle has now. Urban flooding is a significant problem in Seattle. When high intensity storms occur, the drainage system reaches capacity and backups can occur. The problem would be much worse without CSOs because the water discharged would have nowhere to go.

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. Enwave Seattle, formerly known as Seattle Steam, heats approximately 200 buildings in downtown Seattle and First Hill, including many hospitals. 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.

Enwave 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 will burn wood waste and reduce carbon emissions. While district energy systems have many benefits and high reliability, they have to 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 soils that can liquefy in an earthquake.

Communications

Seattle's overall telecommunications infrastructure is a mix of broadcast media (television and radio), landline phone service, cellular networks, internet, and cable television. Although telecommunications is becoming more reliant on digital networks and servers, radio and landline services remain important components of emergency response capabilities.

Telephone / Voice

Like everywhere else, phone service in Seattle has undergone rapid changes in the past two decades. The majority of customers now use voice-over-Internet Protocol (VOIP) phones and smartphones with Internet access. The PEW Research Center reports that in 2018, 95% of Americans own a cell phone of some kind, and that 77% own a smartphone. Traditional landline phones have been on the decline as cellphone popularity has increased. The Center for Disease Control estimates that over half of U.S. households no longer have a landline telephone.

The number of cell phone-only households becomes more of an issue as the use of automated emergency notification software grows. That's because cell phone numbers are not included in the directory listings that these notification systems use as their calling database. People who solely rely on cell phones must be aware of and opt into emergency notifications. Also, landlines are important as safety backups during power outages because they require no commercial power to work or charge.

All the major U.S. cellular providers (AT&T, Sprint-Nextel, Verizon, and T-Mobile) have a strong presence in Seattle. The hilly topography in the area creates problems for all carriers with dead spots reported in some locations. Seattle often is one of the first markets to receive new wireless technologies. Cellular providers, as well as the City of Seattle, have been replacing traditional copper cables with high-speed, longer-lasting fiber optic cables. 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.[95] If a fiber cable along this ring is cut in one spot, calls can be rerouted the opposite direction and still delivered.

Television / Video

In 2014, 59% of Seattle residents subscribed to cable television, down 13% from 2009. Comcast is the dominant cable provider, with about 200,000 subscribers (94% share of residential customers). The city also franchises with Wave Broadband, mainly servicing the Central District, and Century Link. Many subscribers also get high-speed internet connections from their cable provider.[96] 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.

Internet / Data

The use of high-speed internet has expanded rapidly in the last two decades. In 2000, only 18% of residents had high-speed connections; now, almost 99% do. Most of these high-speed connections are over cable modems using a cable television connection or DSL, a phone-based technology. The average download speed in Seattle is 40.05 megabits per second (mbps), which is about 8% faster than the state average and 19% faster than the national average.

The fastest way to connect to the Internet is with a fiber optic connection. It is also the most expensive. However, with the growing demand for high speed connections, internet providers are beginning to invest in more fiber optic infrastructure. In 2016, Wave Broadband was building 100 miles of fiber network per month in Seattle area.[97] While large institutions are the biggest users of fiber optics, network expansions have increased availability to business and residential customers. Forty percent of King County residents now have access to fiber optic internet.[98] Most fiber services have download speeds of up to 1,000 mbps. There have been campaigns in recent years to push the City towards investing in its own fiber infrastructure to provide public internet service. So far, none have been successful and internet service remains a private market. The City has over 550 miles of fiber cable for its own network.

Gaps remain in access to the internet and digital literacy skills even as overall usage grows. The biggest barriers to using technology are income, education, race/ethnicity, age, disability, and immigrant status.

Two-way Radio Systems

There are many two-way systems operating in the City of Seattle. The Seattle Disaster Readiness and Response Plan (SDRRP), Vol. 2 describes these systems in detail. The 800MHz Public Safety Radio has been the backbone of Seattle's emergency wireless communications, but the aging system is based on 1980s technology. The city is replacing the old radio system with the Puget Sound Emergency Radio Network (PSERN), which is scheduled to be completed in 2020.[99] Construction and updates of radio towers and new equipment at radio sites and for users of the system will improve 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.

Broadcast Systems

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. During the 2003 east coast blackout, broadcast radio became a major emergency communications tool. Broadcast television is used by only 20% of Seattle residents but importantly reaches communities that have lower rates of access to technology.

3 4.5 Media

Media provides information that residents, businesses and government need to make effective decisions. They range from national corporations to individuals writing a blog for their neighborhood. Before the telecommunications revolution, media were bound to a specific medium of distribution. Now, most are available through multiple pathways. For example, television stations that used to only broadcast their stories now offer internet content including transcript, written stories, photos and video clips. Most Americans use multiple devices to check news and they check throughout the day.[100]

Traditional broadcast and print media outlets are facing more and more competition with online news sources. While almost 60% of Americans still get news through television, 38% are regularly seeking news online.[101] Print newspapers have seen steady declines in readership, with only 20% of Americans getting their news in print in 2016. These patterns change when observing age groups. The elderly population still relies on print news (48%) and television news (85%), while younger people tend to use the internet as their main news source. For those who get news through television, 46% rely on local TV stations.

Print

Print news is still important, especially for reaching the elderly, and other communities that are underserved by the Internet.

Newspapers play a strong role before emergencies by publishing stories on new hazard research, preparedness and mitigation. When the Seattle Post-Intelligencer ceased publication in March 2009, Seattle lost some capacity to bring these valuable stories to the public.

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 are becoming 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

Broadcast radio remains a powerful medium. 93% of Americans listen to the radio in any given week. Seattle is the 12th largest broadcast radio market in the U.S.[102] In emergencies, live radio call-in shows can quickly become effective ways to create a community forum and disseminate information. 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 state plan can be found on the Washington State EAS Plan website. KIRO radio 710 AM is the primary station in the Seattle area and KPLU is the secondary station. Alerts would start with these stations and propagate to other radio and television stations.

Television

Seattle is the 13th largest television market in the United States.[103] Fourteen local television stations broadcast here, including affiliates of all major U.S. networks. These stations are all available via broadcast and over cable television. Nationally, local television news is the most prominent news source for citizens about what is happening in their communities.[104] In 2014 only 59% of Seattle residents said they subscribe to cable television and most of these subscriptions are with Comcast.[105] 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.

3 4.6 Emergency Services

Seattle gets its emergency protection from its police department and an all-professional fire department. The fire department also provides emergency medical services. American Medical Response, a private company, contracts with the City of Seattle for non-life-threatening emergency transport services.

Law Enforcement

The Seattle Police Department (SPD) is the primary law enforcement agency operating within the City of Seattle. With 1,376 sworn officers and 513 civilian employees, SPD is the largest law enforcement agency in the State.[106]

Other agencies with limited jurisdiction inside Seattle include: 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 city wide. They include Special Weapons and Tactics (SWAT), Harbor Patrol, Canine Unit, Mounted Patrol and a Traffic Unit.

Dialing 9-1-1 in Seattle first connects a caller with the Seattle Police 9-1-1 Communications Center. Trained employees transfer calls concerning a fire or medical issues to the Fire Alarm Center; they evaluate calls concerning law enforcement issues and send them to dispatch, as necessary. The 9-1-1 Center handles around 900,000 calls per year.[107]

Overall, major crime in Seattle has declined in the past three decades but there has been a slight uptick in crime in recent years. Seattle saw a 52% drop in crime from 1988 to 2012, but crime has since grown from 34,607 crimes in 2012 to 42,317 crimes in 2017.[108] Seattle ranks 8th for highest overall crime rate among the 30 largest cities in the U.S., but only ranks 21st for violent crime.[109]

SPD is the lead agency for responding to civil disorder and terrorism investigation. The Office of Emergency Management (OEM), the lead office for community-wide disaster coordination, is part of the Seattle Police Department.

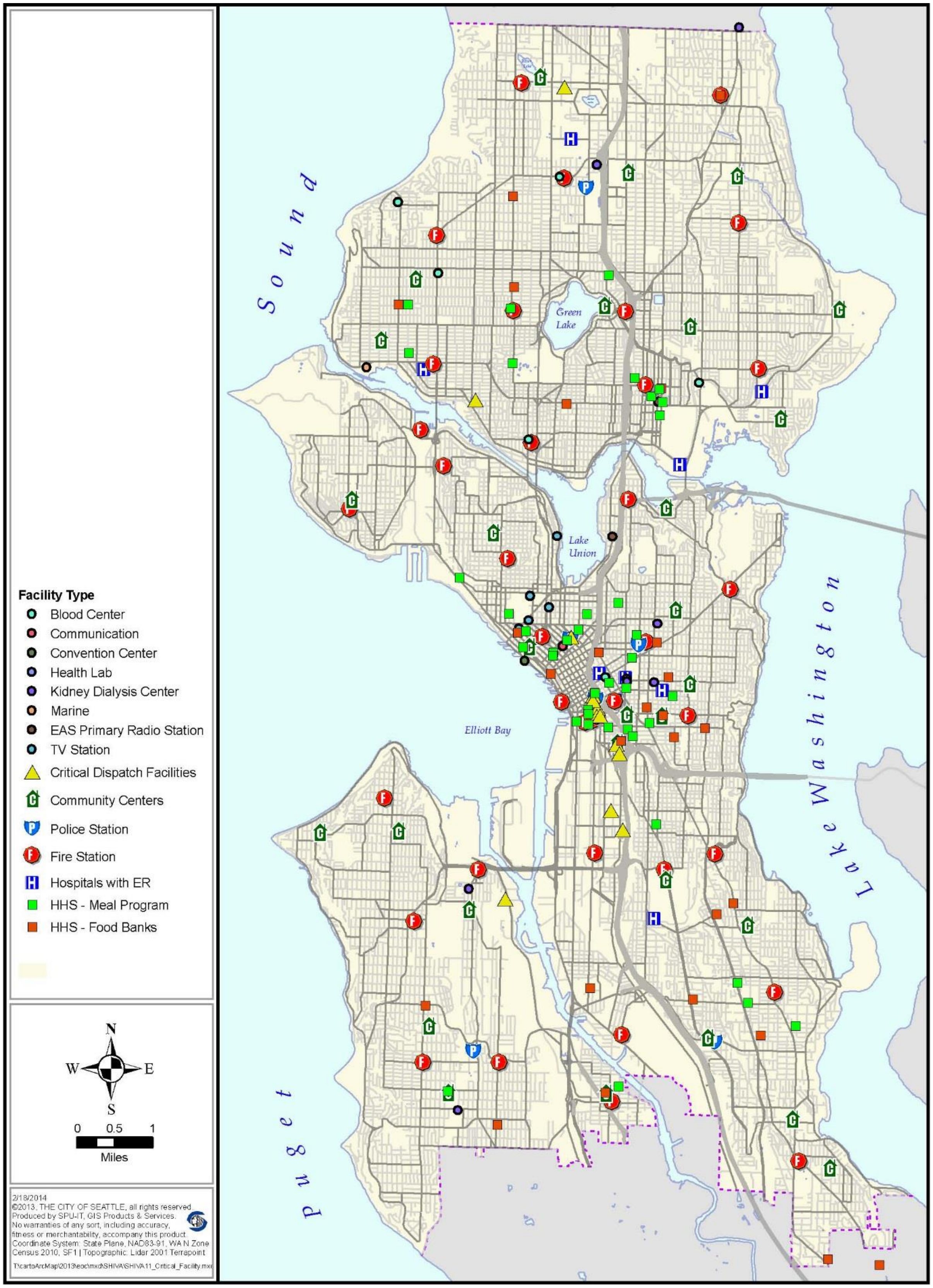
The King County Department of Adult and Juvenile Detention (DAJD) maintains two correctional facilities serving Seattle. The King County Correctional Facility is the primary detention facility in Seattle, and the Kent Regional Justice Center is located south of the city. The DAJD books over 50,000 people per year; 70% of the adult population is released within 72 hours.

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 of these 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, unless a unified command is formed in a large incident. SFD's force consists of 990 uniformed personnel, 37 department chiefs, 924 fire fighters/EMTs, 66 fire fighters/paramedics, and 72 civilian personnel, with an on-duty staffing of 209.[110] These personnel are divided among 33 fire stations, each of which house one engine company. SFD also operates specialized apparatus. Fire accounted for only 17% of all responses in 2017.[111] Recently, SFD

Figure 3-11. Critical Facilities



began tracking information about homeless related fire responses in derelict buildings and vehicles/RVs. There were 30 homeless related building fires and 21 homeless related vehicle/RV fires in 2017.[112]

In 2003, voters approved a levy to improve fire infrastructure throughout the city. The project was completed in 2017 and has resulted in the upgrading or replacement of 32 fire stations; the construction of a new training facility, a new Fire Alarm Center and a new Emergency Operation Center; purchase of a new fire boat and other improvements.

The number of total fire responses has steadily increased over the last five years, with 13,388 in 2013 and 16,548 in 2017.[113] Structural fires in Seattle declined nearly 50% between 1994 to 2008, from 784 to 387. It appears they have continued to decline despite the uptick in overall fire response. In 2017, SFD responded to 215 structural fires.

Data suggests that deaths and injuries have declined overall but Seattle still experiences multiple fatality fires; property losses have not declined. Large property losses do not correlate to high casualty rates.

Emergency Medical Services (EMS)

SFD is Seattle's primary provider of emergency medical services provided somewhere other than healthcare facilities. All Seattle fire fighters are certified EMTs or paramedics, as well as about 100 police officers. 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 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%.[114] Medic One has 78 paramedics and 7 medic units in Seattle.[115] The Medic One system consists of an additional 171 paramedics in neighboring cities and in King County.[116] In 2017, SFD responded to a total of 78,758 EMS calls, with 60,168 BLS responses and 18,590 ALS responses.[117]

Due to a growing number of people experiencing homelessness in Seattle, SFD has seen an increase in low-acuity (non-emergency) calls. This growing demand appears to be concentrated in the downtown area. To try and prevent these calls, an SFD case manager and a social worker provide coordinated care to individuals who chronically use 911 for non-emergency purposes. Other initiatives include providing more specialized medical services to this population to divert people from the Emergency Room and giving local shelters access to a 24-hour nurse hotline.

3 4.7 Healthcare and Human Services

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

Healthcare

Seattle has the largest concentration of medical facilities and personnel in the Pacific Northwest.[118] There are ten hospitals, a public health department shared by the City of Seattle and King County, as well as integral supporting businesses and services—medical laboratories, research institutions, training centers, and medical suppliers. 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. Specialty medical staff such as pediatricians or obstetricians may work in Seattle but tend to live outside the city.

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.

Human Services

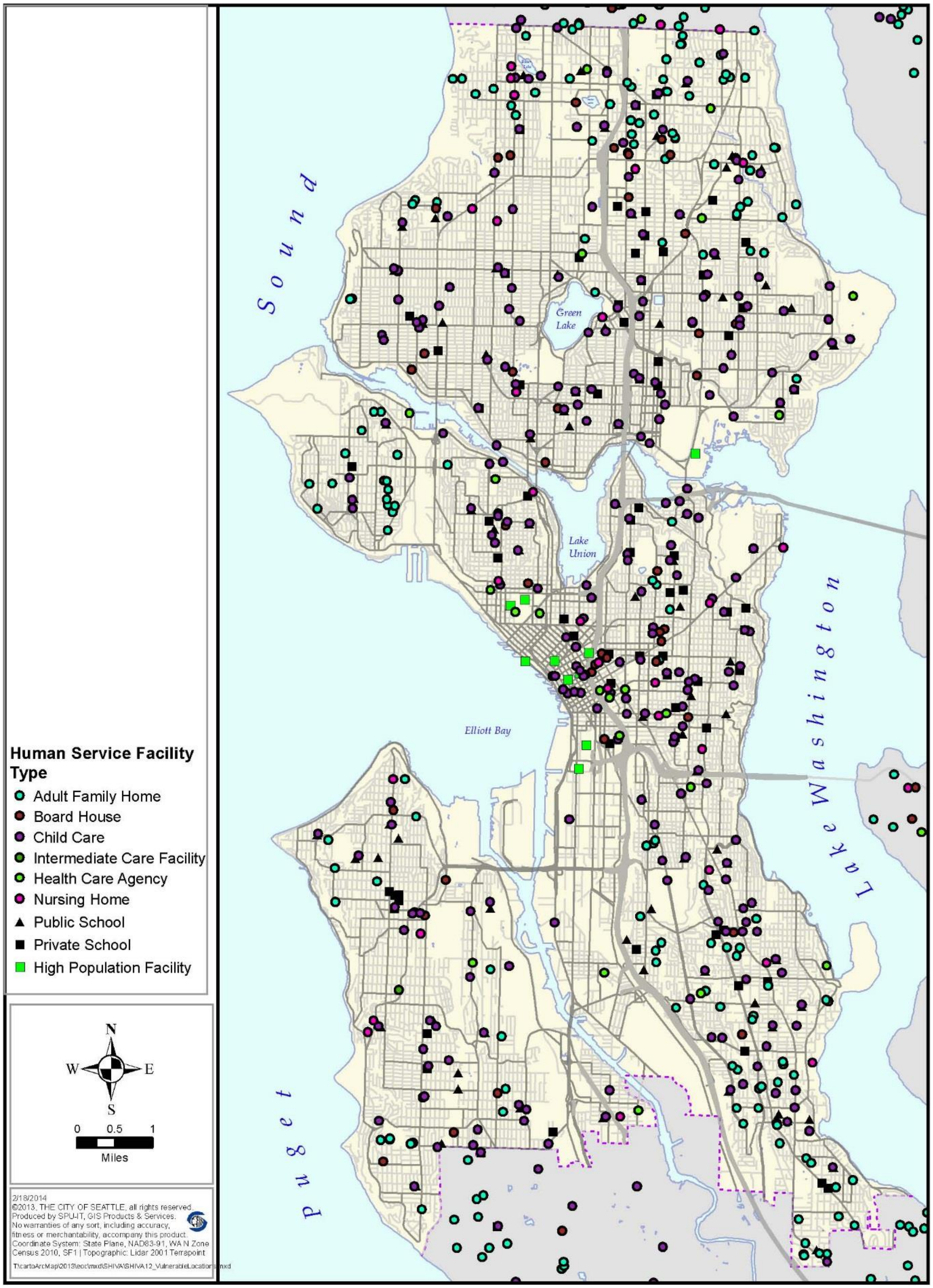
The human service sector addresses the basic needs of the most vulnerable members of the community After a disaster, basic human needs expand and the human service sector steps in to help the community recover. The sudden spike in demand can pose challenges. A community that is well prepared for emergencies can lessen the demand for post-disaster human services. Seattle has established a community disaster preparedness program, in part, to lessen the burden on the human services sector.

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.[119]

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 is 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 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.

Seattle's Human Services Department 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. Taken together, 350,000 individuals or households

Figure 3-12. Human Service Facilities



were served in 2017. However, this estimate is likely inflated as it reflects duplicate counts when people receive services within multiple areas. The total number of people served by the entire Seattle human services network is unknown.

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:

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

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. Following the 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."[120] Following the release of this report, the City of Seattle and United Way began a program to assist local nonprofits in planning for disasters.

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.

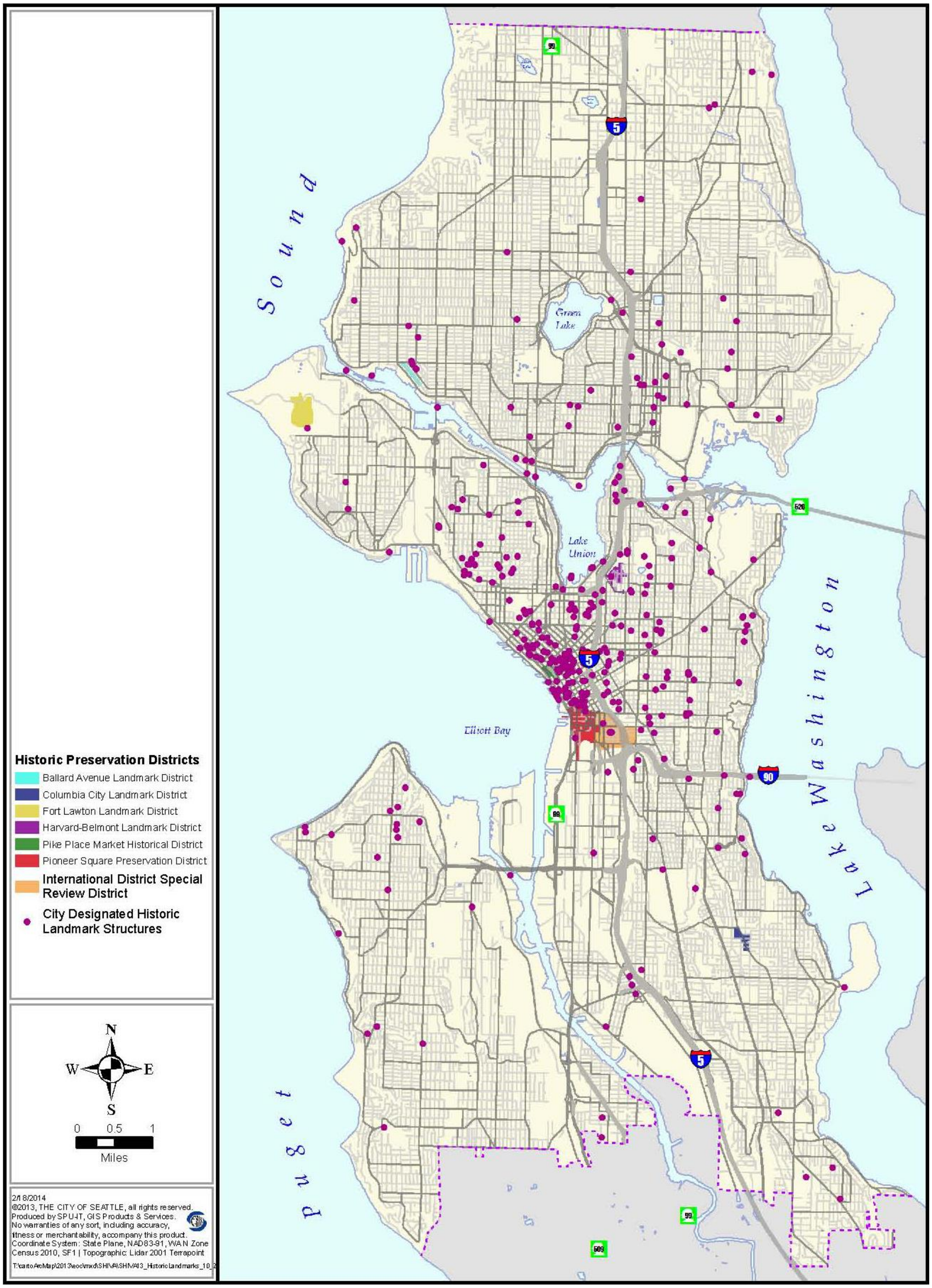
Several tools have been developed to assist with sharing human service information after disasters. For example, the Crisis Clinic uses a database of human service organizations to operate a 2-1-1 information referral service and direct people to organizations that can help them. This service is used for everyday operations as well as during disasters. The Coordinated Assistance Network (CAN) is an online tool that was piloted nationally as a disaster case management tool. Currently, it lacks the resource information to be a viable tool in Seattle although it is still operational in the Gulf area.

3 4.8 Structures

Seattle is a young city, but over half of its housing units were either built prior to the 1949 building codes that introduced seismic standards, or the city's 1992 upgrade of its seismic codes. The table below shows the age distribution of the housing stock.

Most of the 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 has identified 1,144 unreinforced masonry structures, that are prone to collapse in an earthquake. Other forces like wind and landslides are accounted for in the building code, but there are no studies that determine how the codes have affected the performance of the city's structures to better withstand these hazards.

Figure 3-13. Historic Districts and Landmarks



3 4.9 Summary

Cities have a different hazard exposure profile than rural areas, suburbs or 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 may have limited redundancy and reserve capability. 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 Superstorm Sandy, many urban residents had to temporarily move out of their dwellings for this reason.

Table 3-5. Age Distribution of Housing Stock (2016)

Total housing units	322,795	100%
Built 2014 or later	2,657	1%
Built 2010 to 2013	11,227	4%
Built 2000 to 2009	46,414	14%
Built 1990 to 1999	27,279	9%
Built 1980 to 1989	25,372	8%
Built 1970 to 1979	27,995	9%
Built 1960 to 1969	28,998	9%
Built 1950 to 1959	36,017	11%
Built 1940 to 1949	28,702	9%
Built 1939 or earlier	88,134	27%

Often cities have the capacity to quickly rebound after small and medium sized shocks but fail 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 could cities function without power and roads? If the services are out for weeks or months, the result can be an irreversible decline, especially if the city's fortunes were declining already.

4. CLIMATE CHANGE

This section recognizes climate change and its effects on the magnitude of hazards identified in the SHIVA. Climate change is not an additional hazard. Rather, it is an 'overlay' on hazards covered in the SHIVA.

Climate change is a long-term threat that is expected to persist for decades. This chapter identifies climate change's direct effects, the implications for the city's identified hazards, and policy challenges that interact with emergency management but lay mostly outside it. Climate change is a factor that may intensify and/or increase the likelihood of certain hazards. The hazard discussed in this chapter include landslides, disease outbreaks, fires, infrastructure failures, power outages, excessive heat events, flooding, water shortages, and windstorms.

- *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 excessive heat and air pollution.*
- *Increased risk of wildland fire for both sides of the mountains.*
- *Degraded salmon habitat.*

There is evidence that the climate has been changing over the past few decades and is projected to change into the future at an increasing rate. Climate change is caused by the build-up of greenhouse gases (GHG) in the atmosphere. Even if the world stopped burning fossil fuels tomorrow, existing levels of atmospheric GHGs would continue to contribute to warming global temperatures.

According to 2014 data from the Seattle Office of Sustainability and Environment, 66% of the city's GHG emissions comes from road transportation, 32% comes from commercial and residential buildings, and 3% from waste management.[121] The most prominent GHGs in the Seattle region are carbon dioxide (CO_2), fluorinated gases (e.g. hydrofluorocarbons), methane (CH_4), and nitrous oxide (N_2O).[122]

Seattle has set a goal to reduce carbon emission by 58% by 2030 and to become carbon neutral by 2050 (with 2008 emissions as the baseline year), in hopes to reduce the future effect of local climate change.[123] A 2014 progress report showed that emissions have decreased by 6% overall, and per resident emissions decreased by 17%. 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.

Despite these local efforts to reduce GHG emissions, climate change is caused by global GHG emissions that continue to rise. Climate change presents Seattle with many challenges: flooding, summer heat and drought, rising sea levels, heightened wildfire risk, and declining snow pack. Seattle will also experience indirect impacts. These could include higher commodity prices, increased migration and increased economic and political instability across the globe.

4.1 Direct Effects

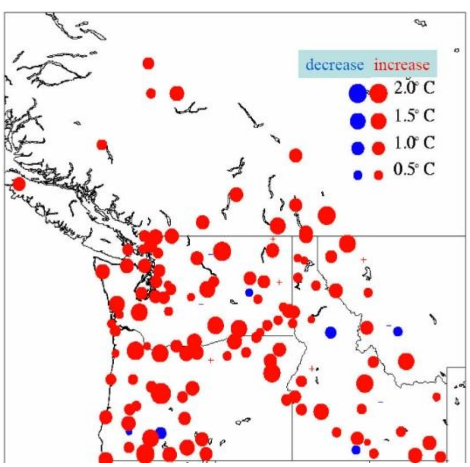
Climate change will not affect the Pacific Northwest uniformly. This section outlines what the primary effects are expected to be for the Puget Sound region. It relies heavily on projections from the Climate Impact Group (CIG). The CIG is an interdisciplinary research group at the University of Washington. They provide the most rigorous and comprehensive climate change information for the Pacific Northwest.

The average annual temperature for the Pacific Northwest has increased 1.3°F between 1895 and 2011.[124] 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.[125] In addition, almost all temperature monitoring stations show warming, but the rate of warming has not been consistent across the region, as shown in Figure [Temperature Changes in the 20th Century] . The map illustrates the temperature trends in the Pacific Northwest since 1920, with the red dots marking an average annual temperature increase.

4 1.1 Temperature

The Puget Sound region is projected to warm between 4.2°F and 5.5°F on average by the 2050s (relative to 1970 – 1999).[126] The range reflects the difference between low and high future GHG scenarios. The low GHG scenario (4.2°F) represents GHG emissions continuing at the current rate until mid-century and then decreasing dramatically thereafter. The high GHG scenario (5.5°F) represents "business as usual," or, 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.[127] Figure [Projected temperature and precipitation changes for the Puget Sound region] shows the projected temperature changes for the Puget Sound Region, with the lighter colored lines representing individual model projections and the bold colored lines representing the average of the modeled projections.

Figure 4-1. Temperature Changes in the 20th Century



Source: Mote, P.W. 2003. Trends in temperature and precipitation in the Pacific Northwest during the twentieth century. *Northwest Science* 77(4): 271-282

Historical data show that the *global* climate has also been warming and trends are measurably accelerating.[128] Average global surface temperatures rose 1.5°F from 1880 to 2012.[129] Regional warming is likely to occur faster than global warming.

4 1.2 Sea Level Rise

The global average sea level has risen about 8 inches since 1900. Since the mid-1800s, the rate of sea level rise has surpassed the previous two millennia, indicating an accelerating trend.[130] Land movement can compound or mitigate the effects of sea level rise and create inconsistencies across the Puget Sound region. In Seattle, where the land is experiencing subsidence (gradual sinking) at the rate of about 0.5

inches per decade, one gauge reveals 8.6 inches of sea level rise from 1900 to 2008, averaging 0.8 inches per decade.[131] Subsidence appears to be the trend in most locations, but some places, such as the Northwest Olympic Peninsula, are experiencing uplift of the land and therefore a decrease in relative sea level.

Assuming land subsidence continues at the same rate, Seattle is projected to experience a 24-inch rise in sea level by 2100 (relative to 2000).[132] Factoring in the uncertainties around variations 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.[133] As with temperatures, the rate of sea level rise is expected to vary over time due to seasonal and decadal climate variability.

Seattle has already begun adapting to the future effects of sea level rise. For example, in designing its new sea wall, the City 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.[134]

4 1.3 Snowpack

Seattle's water system and power system are dependent on Cascade Mountain snowpack and glacial melt. Peak snow accumulation and snowmelt-derived streamflow across the West have shifted 10 to 30 days earlier over the past half century.[135] Snowpack in the Washington Cascades has declined by 25% since the mid-1900s.[136] Additionally, there have been observed decreases in glacier area in the North Cascades of around 56% since 1900. 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).[137] Fewer projections have been produced for glaciers, but two studies show that glacial recession is likely to continue over the next century. Figure [Projected future watershed classifications] shows the projected decline in snow-dominant watersheds in the Puget Sound region. The impact of the decline in snowpack on the city's water supply system has been somewhat mitigated by a dramatic decline in per-capita water usage despite a rise in Seattle's population.

4 1.4 Streamflow

Due to the decreased snowpack and early 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 about 28% to 34% by 2080, while summer streamflow is projected to decrease by 24% to 31% by 2080.[138]

4 1.5 Precipitation

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).[139] The estimated changes in annual precipitation are smaller, between -4% to 14% by the 2050s (relative to 1950 – 1999).[140] While projections of seasonal precipitation are mixed, most models point towards drier summers. Figure [Projected temperature and precipitation changes for the Puget Sound region] shows the projected precipitation changes for the Puget Sound Region, with the lighter colored lines representing individual model projections and the bold colored lines representing the average of the modeled projections. 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.[141]

4 1.6 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 attributed to ozone are projected to increase to 132 per year by 2050, up from 69 per year from 1997 to 2006.[142]

4.2 Effects of Hazards

Climate change has the potential to affect some of Seattle's hazards: landslides, disease outbreaks, fires, infrastructure failures, power outages, excessive heat events, and some weather-related hazards. It affects both the likelihood and the consequences for most hazards.

4 2.1 Disease

Climate change poses more questions than answers for the region's disease vulnerability. How will warmer temperatures and modest changes in precipitation affect the spread and distribution of zoonotic diseases spread through animals? What if infectious disease carriers that are sensitive to temperature and moisture levels, such as mosquitoes and ticks, change their range? How will climate change affect organisms that cause water and food-borne diseases?

4 2.2 Excessive Heat Events

Historic trends for the 19th century do not indicate that daytime heat waves are increasing in frequency. However, daytime heat waves are projected to become more severe when they do occur. By the 2050s, CIG projects that temperatures on the hottest days in the Puget Sound area will increase by 6.5°F on average.[143] This could contribute to increased smog and health problems, particularly for vulnerable populations. There is evidence that the Puget Sound region has been experiencing more nighttime heat waves. Nighttime temperatures are increasing faster than daytime temperatures, reducing the relief of nighttime cooling that many Seattle residents are accustomed to.[144]

4 2.3 Fires

Climate change will mean potential increases in the total area burned in wildland fires. Wildland fires are less frequent in the western Cascades than in the eastern Cascades, but climate change increases fire risk in both regions. A wildland fire in a Seattle watershed could degrade Seattle's water quality and threaten utility equipment and infrastructure. Due to this risk, Seattle Public Utilities (SPU) has its own fire crew to support wildland fire suppression in the watersheds.

4 2.4 Flooding

Climate change will likely increase urban flooding in winter. If rainfall becomes more severe over shorter periods of time, as is projected, Seattle's drainage system (built for slower rainfall rates) will be strained. Without upgrades the result could be an increase in urban flooding. Coastal flooding is projected to increase with climate change. Higher sea levels can extend the reach and impact of storm surge.[145] Low-lying areas fronting Puget Sound could be subject to flooding, especially when winter storms coincide with high tides.

4 2.5 Infrastructure Failures

A 2008 analysis of the King County Wastewater Treatment Division revealed that 30 major wastewater treatment facilities are at risk of flooding from sea level rise by 2100, when considering both sea level rise projections and an extreme storm event. Using 2008 CIG projections, the analysis concluded that the risk of flooding at these facilities should remain low until after 2050.[146] The Seattle Office of

Sustainability and Environment estimates that sea level rise above 24 inches could impact 8.2% of bus routes and 0.18% of freight rail.[147] One study of sea level rise on internet infrastructure estimated that 23.6% of Seattle's fiber optic cable could be inundated by 2033.[148] Rising air temperatures also threatens infrastructure. High heat causes steel to expand which can damage older structures. During excessive heat the Seattle Department of Transportation (SDOT) must cool its drawbridges to ensure they can be opened and closed.

4 2.6 Landslides

Water is a trigger for landslides. Increased soil water content beyond a given threshold can heighten the risk of landslides. Climate change is expected to contribute to an increase in frequency and intensity of heavy rainfall events, resulting in a higher likelihood of landslides.[149]

4 2.7 Power Outages

While summer power demand for cooling may increase, it will be offset by the decrease in winter demand for heating and overall decreases in demand due to advancements in energy efficiency. Therefore, warmer temperatures are not expected to make power outages more likely. However, if a power outage occurs during an excessive heat event, warmer temperatures along with the inability to power cooling devices could make the consequences of the excessive heat event more severe.

4 2.8 Water Shortages

Seattle Public Utilities (SPU) states that existing water resources will be sufficient to meet forecasted demand until 2060.[150] 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. SPU supplies drinking water to roughly 1.4 million people in Seattle and surrounding communities. Most of that water originates in the South Fork Tolt River and Cedar River watersheds, both in the Cascade Mountains.

Seattle City Light's (SCL) hydroelectric projects on the Skagit and Pend Oreille Rivers provide about half of the power its customers need. The remainder comes from a mix of power sources, including long-term contracts with the Bonneville Power Administration (BPA), which produces power in the Columbia River Basin. 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). The same seasonal pattern of change is expected to occur in the Skagit watershed, though the exact amount of change is not well known. In the long term, 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. SCL is also planning for more variability in the precipitation levels in river basins, including the increased potential for drought and floods. The utility's Power Operations and Marketing Division is working closely with the Environmental Affairs Division to determine potential effects on the salmon and steelhead in the watersheds where it operates hydroelectric projects.

4 2.9 Windstorms

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.[151] Small increases in frequency were found in mountain locations but were minor compared to natural variability. Additional modeling is needed to more fully understand the projected effects of climate change on extreme wind events in the Puget Sound region.

4.3 Policy Considerations

In addition to intensifying hazards, the slow onset of climate change presents a unique set of challenges around decision making. The effects of climate change will happen over long periods of time, threatening the sense of urgency to mitigate them within the community. Although these risks are outside the traditional emergency management framework, it is important to recognize them. The possible consequences are listed below as policy considerations for our community.

4 3.1 Urban Forestry

Climate change projections for the region suggest that plant hardiness zones will change, threatening certain conifer species that exist in Seattle's urban forest.[152] One analysis reveals that future climate conditions in low elevation forests in Washington will not support the establishment of Douglas Fir, one of Seattle's native conifer species.[153] It is likely that insect and disease outbreaks will also change, but the effect on Seattle's urban forest is difficult to predict because it will depend on the particular species of tree, insect, or pathogen and its response to increasing temperatures and precipitation changes.[154] For example, one analysis found that Mountain Pine Beetle outbreaks may increase in frequency and severity in Washington but will likely be a threat to higher elevation forests, as the temperatures in lower elevation forests will be unfavorable to the insect.[155]

4 3.2 Sea Level and Sea Temperature Rise

The location and design of shoreline facilities, development regulations, and habitat restoration projects will all face the challenge of adapting to sea level rise. Existing infrastructure may require adaptations as well. Some projections of sea level rise are high enough that the water levels would threaten the separation of Lake Union and Lake Washington from Puget Sound. If this is the case, will the federal government improve the Ballard Locks to maintain the separation?

Sea surface temperatures in the Puget Sound have increased by 0.8°F to 1.6°F since 1950 and are projected to increase another 2.2°F by the 2040s.[156] Increasing water temperatures may promote the growth of harmful algal blooms that can contaminate shellfish, generating public health concerns. This may have harmful impacts on Seattle's commercial fisheries.

4 3.3 Food Systems

Climate change has the potential to impact agriculture that will affect our food and nutrition sources. While the local agricultural system is expected to adapt to climate change, there could be wider impacts to the global food system. The Puget Sound region is expected to see a longer growing season and shifts in crop production due to climate change.[157] In addition, climate change will present challenges with managing water supply, potential increases in pests, increasing winter flood risk, and increasing risk of saltwater intrusion.

4 3.4 Coastal Ecology

Unavoidable air temperature and sea surface warming in the next century will have a significant impact on local species and habitats. The larger the degree and rate of change, the harder it will be for most fish and wildlife species to adapt. For example, a significant reduction in the area of estuarine beaches would affect important spawning habitat for forage fish, which make up a critical part of the marine food web. Unless species are able to find alternative spawning areas, their populations could decline.

Sea level rise is projected to both expand and reduce the area of tidal wetlands in Puget Sound, depending on the wetland type, amount of sedimentation, and availability of landward buffers. CIG projects that salt marsh habitat will increase while tidal freshwater marsh habitat will decrease.[158] Inundation of tidal flats in some areas would reduce stopover and wintering habitat for migratory shorebirds. It could also have a major impact on the region's economically-important shellfish industry. Loss of coastal marshes would affect habitat for thousands of wintering waterfowl that visit the region each year. Changes in the composition of tidal wetlands could significantly diminish the capacity for those habitats to support salmonids, especially juvenile chinook and chum salmon. While rising water temperatures are projected to negatively affect salmon populations,[159] a lesser known factor is how sea-level rise might affect the region's salmonids. Nearshore ecosystems play a critical role in the life cycle of anadromous fish, many of which use coastal marshes and riparian areas for feeding and refuge as they transition between their freshwater and ocean life stages.

Coastal habitats and the fish and wildlife that depend on them are at great risk. Some species may be able to respond to changes by finding alternative habitats or food sources, but others will not. Compounding this dilemma, coastal modifications such as dikes and seawalls have significantly reduced the ability for habitats and wildlife to migrate inland to accommodate for sea level rise.

Changes in freshwater flows into coastal waters are likely to alter salinity, water clarity, stratification and oxygen levels. In addition, higher water temperatures in Puget Sound and the Pacific Ocean could exacerbate the impact of excess nutrient runoff into coastal waters, enhancing harmful algal blooms and hypoxia events.

Many coastal plant and animal species are adapted to a certain level of salinity. As a result, prolonged changes can make habitats more favorable for some species, and less so for others. Sea-level rise will also contribute to the expansion of open water in some areas – not just along the coasts but also inland, where dry land can become saturated by an increase in the height of the water table. Furthermore, sea-level rise will lead to significant beach erosion and make coastal areas more susceptible to storm surges.

4.4 Policy Responses

The city's approach is twofold: reduce local levels of climate pollution to slow the rate of climate change and plan for and adapt to the inevitable changes that are already here and will continue into the future. In 2013, Seattle published a Climate Action Plan to improve preparedness and develop a comprehensive strategy. In 2017, the City published a follow-up report on the actions it will take to improve climate preparedness of infrastructure and services. The report prioritizes collaborating with community-based organizations and working to advance environmental justice as climate change disproportionally affects communities of color and vulnerable populations. It outlines multiple preparedness and adaptation strategies for the following sectors: transportation, land use and the built environment, city buildings, parks, drainage and water supply systems, electrical systems, and community preparedness.

5. GEOLOGIC HAZARDS

This section covers hazards caused by geophysical processes like earthquakes, landslides and volcanic activities. Tsunamis are included because they are generated by earth movement.

5.1 Earthquakes

- Earthquakes are the most serious hazard facing Seattle. Unlike other potentially catastrophic hazards, Seattle has had and will experience powerful earthquakes.
- The Seattle area experiences three earthquake types with varying consequences:
    - **Crustal or Shallow Quakes** occur in the North American plate at 0-30 km near the crust's surface along faults. Intense shaking occurs near the epicenter but usually diminishes quickly with distance relative to the other earthquake types. Crustal earthquakes are expected on the Seattle Fault Zone, which is the primary but not only source for this type of quake in Seattle. An example of a crustal earthquake is the magnitude (M)6.2 Christchurch, New Zealand earthquake that occurred in 2011.
    - **Intraplate or Deep Quakes** occur at depths of 30-70 km in oceanic crust as it dives under lighter continental crust. Because of the depth, even buildings located right above them are far enough away that seismic waves are attenuated. An example of a deep earthquake is the M6.8 Nisqually Earthquake that occurred in the Pacific Northwest in 2001.
    - **Subduction Zone or Megathrust Quakes** occur on the interface between the North American plate and the Juan de Fuca plate, a small plate extending from northern California to British Columbia. An example of a megathrust earthquake is the M9.0 Tōhoku Earthquake that occurred off the coast of Japan in 2011.
- The amount of shaking at a location depends on an earthquake's magnitude, the distance between the location and the earthquakes's source, and local geology. Other factors like the frequency of seismic waves also affect how structures shake in earthquakes.
- Earthquake frequency intervals are estimates, not predictions. The estimated occurrence rate of a M6.0 or larger deep earthquake is about every 30-50 years. The estimated occurrence rate of a megathrust earthquake is every 200 to 1,100 years, or on *average,* every 500 years. The estimated frequency of a Seattle Fault earthquake is difficult to determine due to lack of data. Estimated recurrence intervals range from every 200-15,000 years.
- An earthquake on the Seattle Fault poses the greatest risk to Seattle because:
    - The Seattle Fault Zone extends east-west through the middle of the city.
    - A Seattle Fault quake could be as large as M7.5,[160] but less than M7.0 is more probable.
    - The most recent Seattle Fault earthquake was about 1,100 years ago;
    - The Seattle Fault has been active about three or four times in the past 3,000 years.
- Deep quakes are the most common large earthquakes that occur in the Puget Sound region. Quakes larger than M6.0 occurred in 1909, 1939, 1946, 1949, 1965 and 2001.
- Megathrust earthquakes are the greatest risk to the broader west coast region. A megathrust earthquake could reach M9.0+ and affect an area from Canada to northern California. A Cascadia megathrust earthquake could rank as one of the largest earthquakes ever recorded, but because Seattle is several hundred miles from the source seismic waves would weaken slightly before they reach Seattle. Shaking would be violent and prolonged, but not as intense as in a Seattle Fault quake.

- About 15% of Seattle's total area is soil that is prone to ground failure in earthquakes. The Duwamish Valley, Interbay, and Rainier Valley are vulnerable to ground failure and shaking because of the liquefiable soils in these areas.
- Seattle has over 1100 unreinforced masonry buildings (URMs) that are prone to collapse in earthquakes. These older brick buildings tend to be concentrated in areas expected to experience the strongest ground motion during earthquakes.
- Seattle has many bridges that, despite seismic retrofits, may not be useable after a strong earthquake. Damage to them would impair emergency services and the economy.
- An earthquake will produce costly damage. Combined property damage for quakes in 1949 and 1965 in the region amounted to roughly $400 million (2010 dollars). The 2001 Nisqually Earthquake resulted in damage to City of Seattle buildings, infrastructure, and response costs that exceeded $20 million. Adding in the costs of repairing arterial road structures, the figure topped $36 million.
- Secondary impacts such as landslides, tsunami, fires, infrastructure failures, and hazardous materials releases could become disasters themselves. In past earthquakes, more people have died from fire than building collapse.
    - 2013 research finds that Seattle could experience *thousands* of landslides following a strong (M7.0) Seattle Fault earthquake. Estimates range from 5,000 in dry conditions to 30,000 in the wettest conditions.
    - A large Seattle Fault earthquake could trigger a tsunami up to 16 ft high that would strike the Seattle shoreline within seconds of the earthquake and flood it within 5 minutes. A megathrust earthquake will not cause a tsunami with inundation for Seattle but is expected to cause strong currents in Seattle's waters that may be dangerous for vessels. A deep earthquake could cause landslides that trigger a tsunami.
    - A M7.0 Seattle Fault earthquake could cause dozens of fires. Suppressing the fires may be more difficult due to severed transportation routes and possible damage to the water system, which could reduce water pressure in many parts of the city.
    - Structural failure and fires would probably cause multiple hazardous materials releases. They could range from minor spills to major incidents with public health and environmental ramifications.

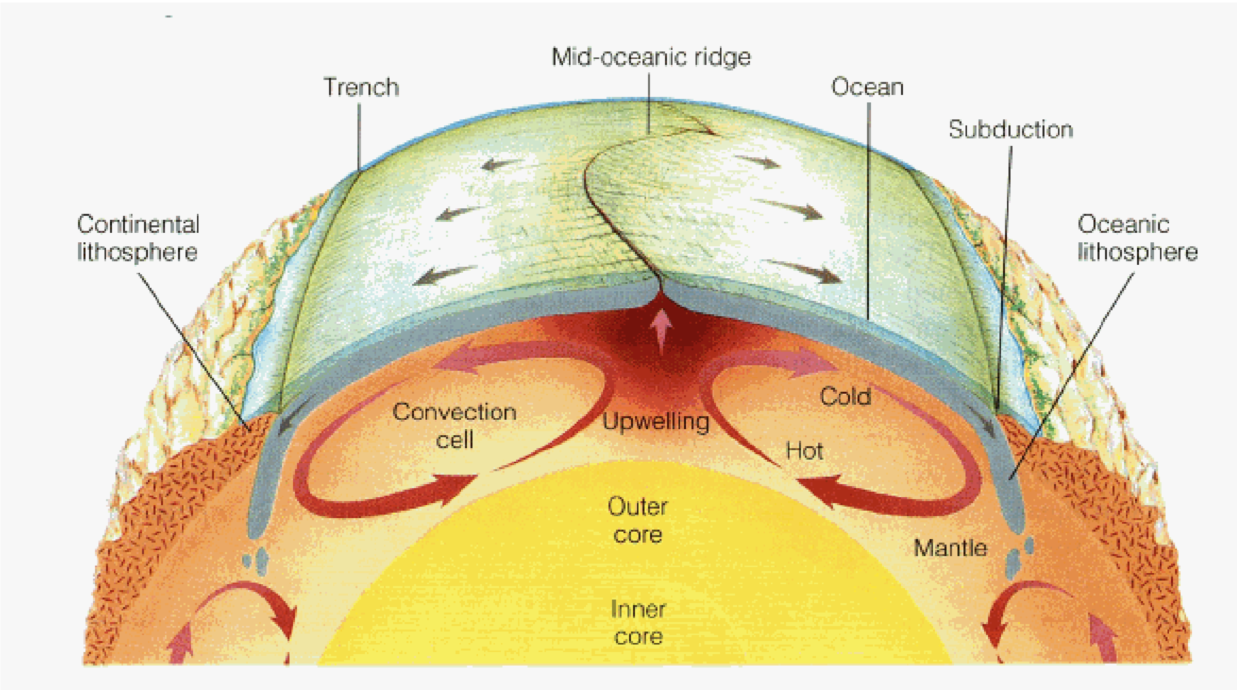
5 1.1 Context

Plate Tectonics

Earthquakes happen when the strain accumulating in rock becomes greater than the strength of the rock or the pressure keeping it from slipping. Plate movement is primarily driven by very slow convection currents in a hot, dense, plastic rock layer of the Earth called the mantle (see Figure [Convection 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 down, 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.

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.

Figure 5-1. Convection in the Earth's Crust

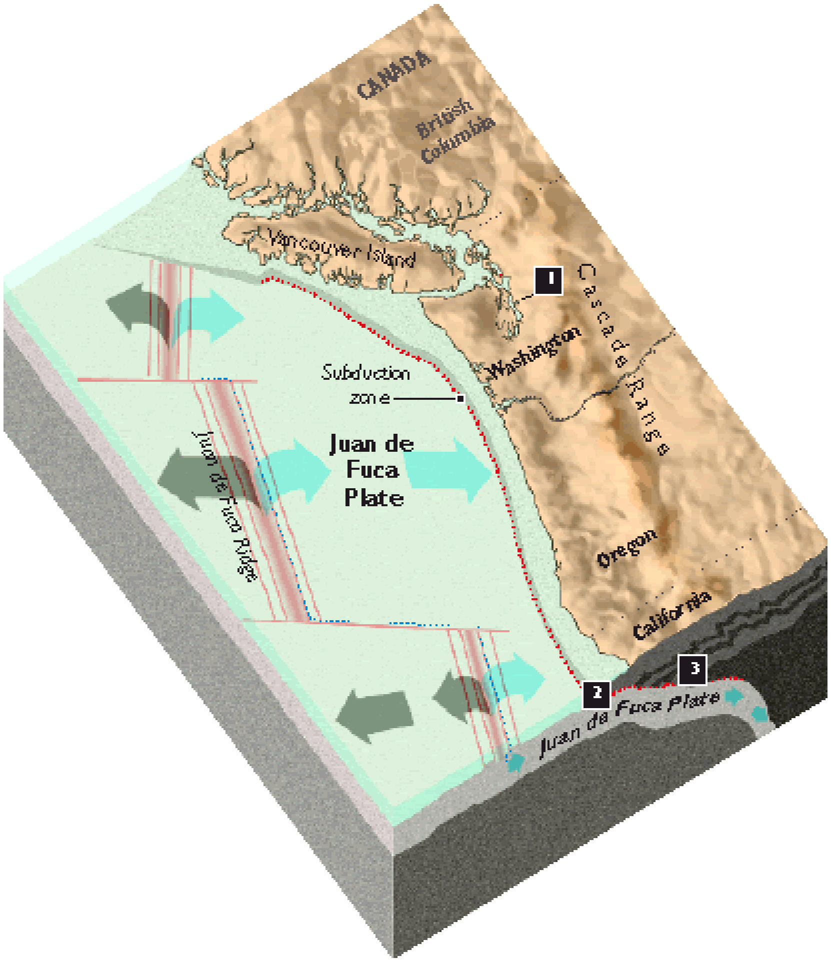


Source: http://clarkscience8.weebly.com/forces-inside-earth.html.

Types of Earthquakes

The Puget Sound region experiences three types of earthquakes:

1. **Crustal earthquakes** (also called "shallow") occur in the North American Plate as it adjusts to the build-up of strain along the interface of 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. There is an active shallow fault system running through the middle of Seattle, called the Seattle Fault Zone.
2. **Megathrust earthquakes** (also called "subduction") happen when pressure at the interface between the Juan de Fuca plate and North American plate unlocks along a sloped plane from 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 M8.0 to over M9.0. They have occurred at about 500-year intervals, on average, ranging along the Pacific Coast.[161]
3. **Intraplate earthquakes** (also called "deep") occur at depths between 35 and 70km (about 21 - 43 miles). Since they are farther from the surface, they are not felt as intensely, but are experienced over a wider area than crustal quakes. They are the most common type of large earthquake in our region. Western Washington has experienced three since 1949.



Source: http://www.burkemuseum.org/static/earthquakes/bigone/threekinds.html. Accessed: 3/5/2019

Measures

Moment Magnitude

Moment magnitude measured the amount of energy released by an earthquake. It has three components: the size of the area that has slipped, the amount of slippage, and the viscosity of the material. Low viscosity is like fingers scraping a stick of butter; high viscosity is like fingers scraping a blackboard. 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 5-1). The MMI scale uses twelve steps to describe how the earthquake felt to people and its damage to structures. 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 5-1. Modified Mercalli Intensity (MMI) Scale

I. Instrumental	Not felt by many people unless in favorable conditions.
II. Feeble	Felt only by a few people at best, especially on the upper floors of buildings. Delicately suspended objects may swing.
III. Slight	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. Moderate	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. Rather Strong	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. Destructive	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. Ruinous	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. Disastrous	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 of velocity in a unit of time. During an earthquake, ground shaking experiences acceleration. Peak ground acceleration is the largest increase in velocity experienced by particles on the ground. Spectral acceleration is what is experienced by a building, modeled after the velocity of the ground shaking. In other words, it is what the building would experience at its base during an earthquake. All structures have a "natural period," or, the rate at which they move back and forth from horizontal force.[162] For example, 10-20 story buildings typically have a natural period of 1 to 2 seconds. The natural period of the ground is between 0.4 and 2 seconds. In an earthquake, if the natural period of the ground movement is close to the natural period of the structure movement, the additional small pushes from the ground can increase acceleration by up to 5 to 6 times. This phenomenon is known as resonance.

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. They are explained below.

Sometimes duration is also used as a measure because the longer shaking occurs, 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 depends on soil type, soil stiffness, soil thickness and soil geometry (see Figure 5-2).[163] 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. Notice how in Figure 5-2, the Duwamish Valley area experiences more intense shaking than the surrounding hills even though they are the same distance from the epicenter. This is because the Duwamish Valley sits on artificial fill that is more susceptible to ground shaking.

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 enough tensile strength 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.

5 1.2 History

The Puget Sound region is been the most seismically active area in Washington.[164] Nineteen earthquakes that were large enough to be felt by humans (approximately greater than M3.0) have occurred in western Washington since 1880 (see Figure [Major earthquakes since 1880 in Washington State]). Twelve of these ten were centered in the Puget Sound region.

Around 900. M7.5 Seattle Fault earthquake. It caused massive landslides and a tsunami. Whole hillsides slid into Lake Washington and Puget Sound. A tsunami estimated to be 16ft flooded much of the low-lying area around the mouth of the Duwamish River. It is estimated that the Seattle Fault has been active 3 – 4 times in the last 3,000 years. Glaciers covering the Puget Sound region probably destroyed any evidence for earthquakes over 15,000 years old.[165]

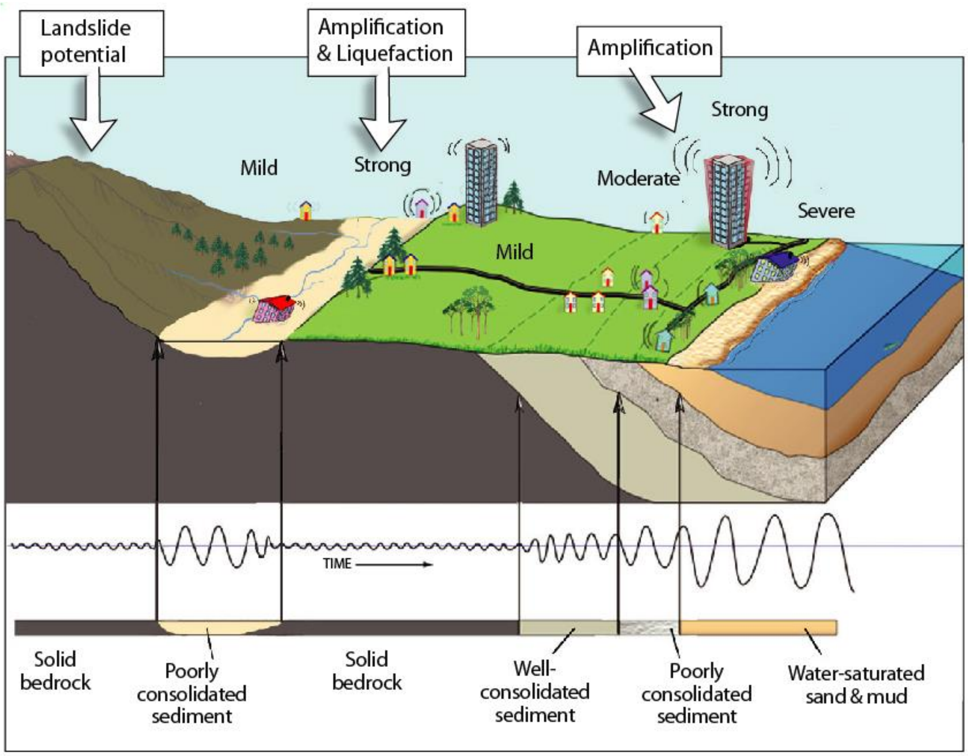
Jan. 1700. M9.0 megathrust earthquake along the Pacific Northwest Coast. Coastal areas dropped 1.5 meters as the Cascadia Subduction Zone ruptured along its 1000 km length. It generated a tsunami that struck Japan.

Dec. 1872. M6.8 shallow earthquake shook the North Cascades. It triggered a huge landslide that temporarily blocked the Columbia River.

Jan. 1909. M6.0 deep earthquake centered in the San Juan Islands.

Nov. 1939. M5.75 deep earthquake centered near Olympia. Chimney and building façade damage near the epicenter. No damage reported in Seattle.

Figure 5-2. Soil Amplification, Liquefaction, and Landslide Hazards from Earthquake Ground Shaking



Apr. 1945. M5.5 (no data on depth) earthquake centered under North Bend. Chimney and building façade damage near the epicenter. Boy hit by falling brick in Cle Elum. No damage reported in Seattle.

Feb. 1946. M6.3 deep earthquake centered under mid-Puget Sound. Damage in Seattle mainly limited to the Duwamish Valley and structures built on pilings.

Apr. 1949. M7.1 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 $314 million in damages (2010 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. M6.5 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 $104 million (2010 dollars). Based on these records, one report estimates that M6.5 events have a repeat rate of 35 years and M7.0 events have a repeat rate of 110 years.[166]

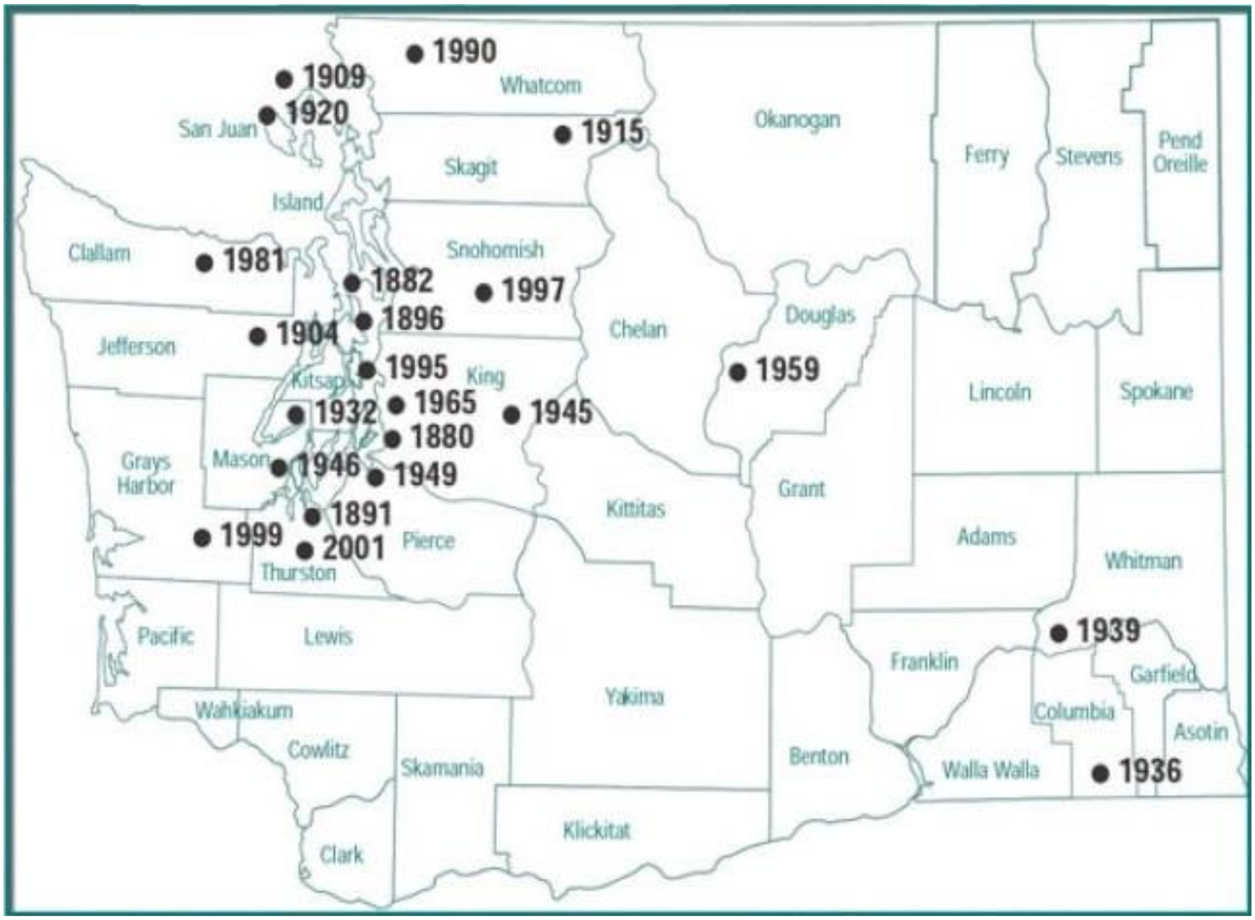
Jan. 1995. M5.0 shallow quake, with a depth of 11 miles. Centered under Robinson Point on Bainbridge Island. No damage reported.

May 1996. M5.3. A shallow quake centered under Duvall. Some light damage reported, mainly objects falling from shelves. No damage reported in Seattle.

Jun. 1997. M4.9. Another shallow quake centered under Bremerton. No damage reported in Seattle.

Feb. 2001. M6.8. 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.[167]

Figure 5-3. Major earthquakes in Washington since 1880

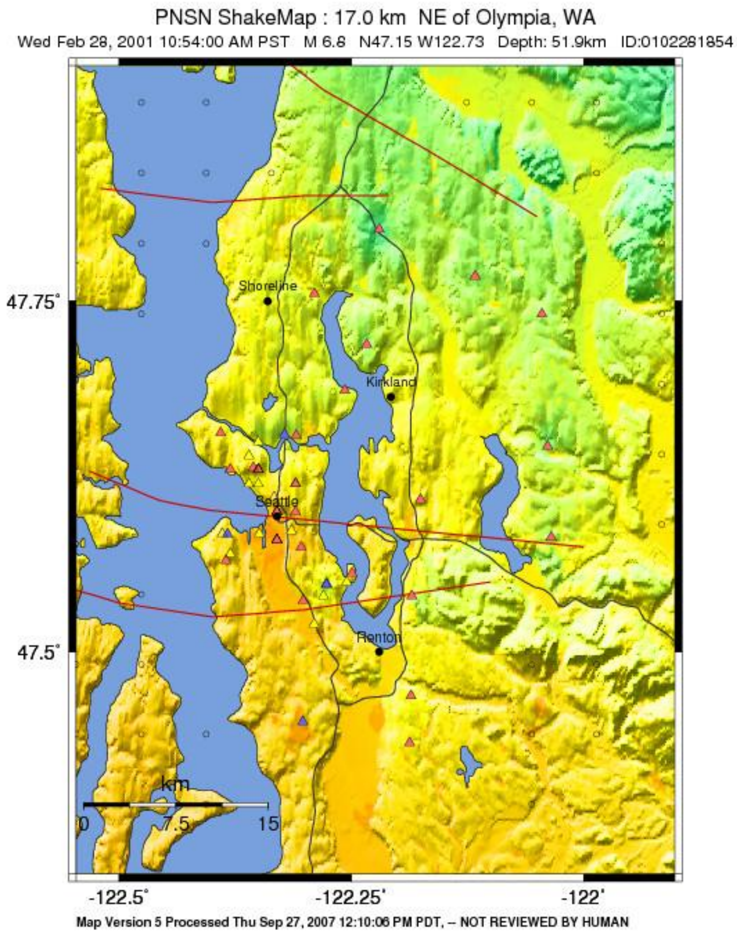


Significant public and private damage occurred as a result of this deep quake. Four residential homes were destroyed, 46 suffered major damage and 120 had minor damage.[168] 217,000 people lost power but only for a few hours. The City of Seattle incurred over $36 million in response costs and repairs to city-owned facilities and systems, and costs from damage to arterial roads and bridges. Eighteen bridges were damaged in the city.[169] Total damages in Seattle were estimated to be over $200 million.[170]

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.[171] 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. The Seattle Housing Authority (SHA) also faced damage to its buildings, which house 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).[172]

The earthquake had 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 (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

Figure 5-4. Nisqually Intensity Measured By Modified Mercalli Intensity Scale



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

identifiable, concentrated small business damage were Downtown Olympia, Seattle's Pioneer Square, and Seattle's Harbor Island.

The largely industrial Harbor Island experienced the highest level of shaking in Seattle, similar to that experienced in heavily damaged areas 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 disruption of operations.[173]

5 1.3 Likelihood of Future Occurrences

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 occur every 200 to 1,100 years, or on *roughly* every 500 years.

The last megathrust earthquake occurred in 1700 AD. The last Seattle Fault earthquake was around 900 AD, 1,100 years ago. The USGS sees evidence that the Seattle Fault has been active 3 to 4 times in the past 3,000 years, with an earthquake about M6.5 or greater occurring roughly every 1000 years. Due to

Figure 5-5. Seattle Fault Zone, Liquefaction Areas and Ground Failures

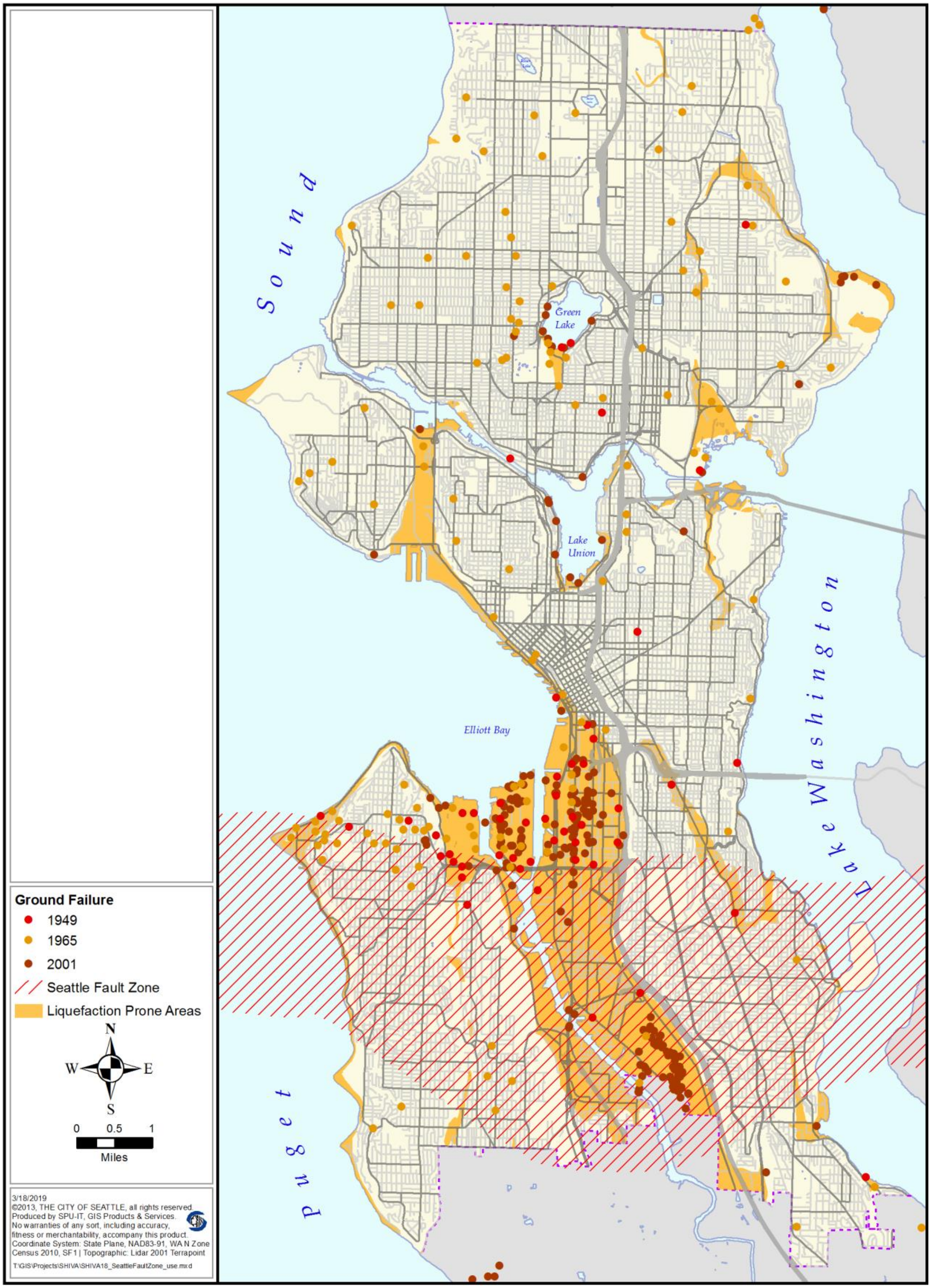


Table 5-2. Earthquake Type and Estimated Frequency

Type	Size	Estimated Frequency
Deep Earthquakes like Nisqually	Over 6.0	Every 30 to 50 years
Megathrust Earthquakes	8.0 to 9.0+	Every 500 years on average
Seattle Fault	Over 5.5	Every 200 – 12,000 years
Seattle Fault	Over 7.2	Every 5000 – 15,000 years

the lack of data for Seattle Fault events, the estimated recurrence intervals have wide ranges. Taking into account estimates from local earthquake scientists and the USGS, the recurrence interval for smaller Seattle Fault earthquakes is every 200 to 12,000 years, and larger events every 5,000 to 15,000 years.[174]

In 2007, the USGS produced a series of probabilistic earthquake hazard maps for Seattle (**Error! Reference source not found.** [Probabilistic Ground Motions]). These maps illustrate the chance that different 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 URMs. However, they display the underlying geology, such as areas with artificial fill and soft soils, which are expected to amplify ground shaking for many building types. Ground shaking is measured as a percentage of the force of gravity. It requires more than 100% of the force of gravity to throw objects up in the air. For comparison, reports of "dishes, windows, and doors disturbed" corresponds to about 1.4% to 4% of gravity. Reports of "some chimneys broken" correspond to a range of 18% to 34% of gravity.[175] 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.

5 1.4 Vulnerability

Seattle's most vulnerable parts are where fragile populations, soft soils, and weak buildings come to together in areas that could be easily isolated due to breaks in the transportation network. These locations produce vulnerabilities for the whole city because of their social, political, or economic importance.

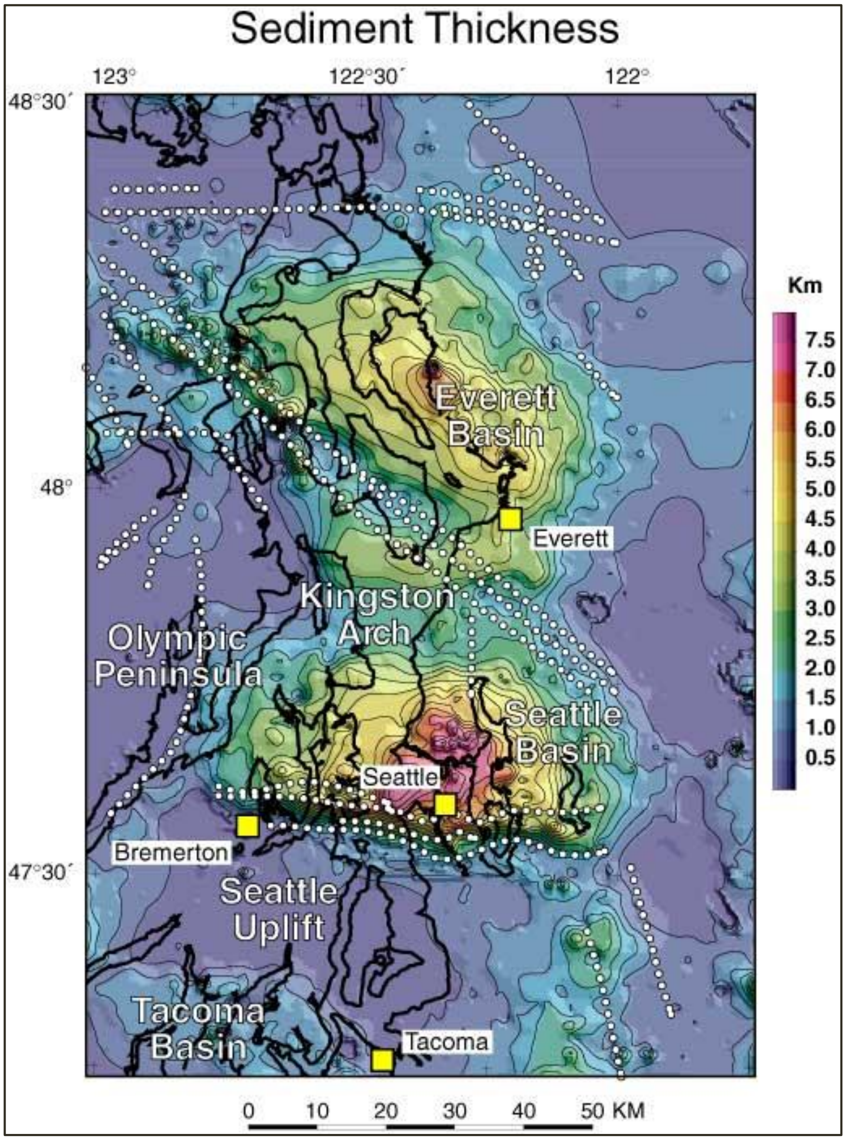
Seattle has a heightened vulnerability to earthquakes because the middle of the city sits on top of the "Seattle Basin," a deep geologic basin filled with glacial deposits, sediments, and sedimentary rock, roughly 7 km deep (see Figure [Sediment thickness in the Seattle Basin]). This looser ground material 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.[176] Additional modeling is being done by the University of Washington's M9 group, to understand the effects of the Seattle Basin on ground motion in a megathrust earthquake.

While the Seattle Basin will influence ground motions for all of Seattle, surface geology creates variability in shaking for different parts of the city. The 2007 USGS seismic hazard maps (see Figure 5-9 Probabilistic Ground Motions) reveal that Seattle's neighborhoods experience dramatically different levels of shaking. Seattle's liquefaction and landslide-prone areas appear to experience more severe ground motion than other areas and southeast Seattle is likely to experience serious but comparatively less shaking than the rest of the city.

Liquefaction

Looser, fill soils that are prone to liquefaction are present in Seattle's Duwamish area, including Harbor Island, the east side of West Seattle, the Interbay area, University Village area and along the Puget

Figure 5-6. Sediment Thickness in the Seattle Basin



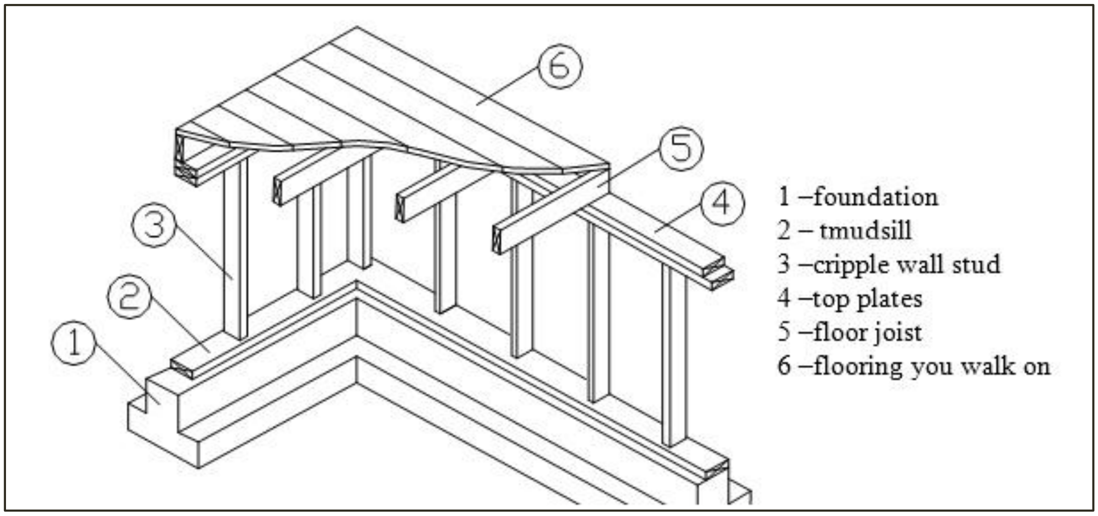
Sound. Ground failures caused by previous earthquakes in Seattle have primarily been located in these areas of artificial fill (see **Error! Reference source not found.** [Seattle Fault Zone, Liquefaction Areas and G round Failures]). The tables below summarize land use in liquefaction prone areas.

Structures

Vulnerable structures are not evenly distributed throughout the city. Those constructed with unreinforced masonry (URMs) are the most vulnerable, followed by non-ductile concrete frame structures with masonry infill and tilt-up concrete structures. Seattle has over 1100 identified URMs.[177]

The neighborhoods with the greatest number of URMs include Capitol Hill, Pioneer Square, Duwamish/SODO, Queen Anne, and the University District. The majority of URMs are commercial or office buildings, residential buildings, or public assembly buildings. URM damage in Seattle alone amounted to $8 million in the Nisqually earthquake.[178]

Figure 5-7. Cripple Wall Construction



Source: Homeowner's Guide to Seismic Retrofitting, Bay Area Retrofit. Retrieved July 24, 2018, from https://www.bayarearetrofit.com/seismic-retrofit/

The number of non-ductile concrete frame and tilt-up structures is not known; however, these construction types are fairly common in the Pacific Northwest. Many concrete frame structures built before 1980 do not have enough steel reinforcement to withstand the shaking from a strong crustal or megathrust earthquake.[179] Tilt-up structures, commonly used for warehouses or strip malls, often lack adequate connection between their walls and roof, making the roof prone to collapse in an earthquake. There is a concern for structures built before 1995 that have not been retrofitted. Most of these buildings are commercial and older multi-family dwellings. Additionally, many older buildings have parapets that are easily damaged and often fall into the right of way during earthquakes.

Most of Seattle's single family residential housing stock is wood frame, a construction type that performs better than most others in earthquakes. However, having a wood frame does not guarantee that a home will ride out an earthquake problem free. More than half of Seattle homes were built prior to the introduction of modern seismic codes in 1949. Many have short cripple walls (also called "pony walls") between the foundation and floor joists. They are prone to failure, pitching the building off its foundation and causing major utility damage. These homes can be inexpensively retrofitted to eliminate this danger, 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.

Seattle's multi-family structures are vulnerable, too. Many built in the late 1950s and early 1960s have "soft" stories where pillars hold up parking on the ground floors. The soft stories lack shear strength and are prone to failure. Neighborhoods that have concentrations of older and soft-storied multi-family buildings will suffer disproportional impacts. They include Downtown, Belltown, First Hill, Capitol Hill, Queen Anne, University District, and Ballard. Downtown has the highest concentration of high-rise office and apartment buildings. Even if a multi-story building does not sustain much structural damage, there can be damage to utilities or elevators that could contribute to displacement of workers and residents after an earthquake.[180] After Hurricane Sandy hit New York in 2012, there were 65 residential and office buildings in lower Manhattan alone that suffered long-term utility damage and displaced many residents.[181]

A large-scale study of how Seattle's building stock would fare in an earthquake has not yet been conducted. Research from other earthquake-prone areas can shed light on the vulnerabilities of the

Figure 5-8. Home Damage Due to Inadequate Cripple Walls

Photograph by John K. Nakata. Source: Nakata, J. K., Meyer, C. E., Wilshire, H. G., Tinsley, J. C., Updegrove, 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/

urban environment to intense ground shaking. After reviewing building damage in the 1989 Loma Prieta and 1994 Northridge earthquakes in California, the USGS found that for every collapsed structure, 13 red-tagged buildings can be expected, and for every red-tagged building, 3.8 yellow-tagged buildings can be expected.[182] For the 2001 Nisqually Earthquake, Seattle had 6 yellow-tagged buildings for every red-tagged building.[183]

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 possibly expect in an urban area from a megathrust earthquake. For Multnomah County (includes Portland), the researchers estimate that in dry conditions, 3,536 (1%) of buildings would have complete damage and 302 would collapse.[184] In wet conditions, that number jumps to 13,039 (5%) completely damaged and 677 collapsed, due to the increased likelihood of landslides and liquefaction.[185] Wood-frame single-family structures fare best while industrial and commercial buildings fare the worst (it should be noted that Portland has around 50% more URMs than Seattle[186]). Injuries and fatalities were studied at the city level. If an M9.0 megathrust earthquake occurs during the day, they estimate that Portland will experience 10,404 injuries, most of which are minor, and 604 fatalities.[187] The nighttime estimation drops to 2,491 injuries and 119 fatalities considering that most people will be in wood-frame structures.[188]

Portland does not sit on top of a deep geologic basin of glacial deposits like Seattle. The effect of basin amplification on structures has been studied. Marafi and colleagues analyzed data from earthquakes that occurred in deep basins in Japan that have a similar profile to the Seattle Basin. They found that in a megathrust earthquake, the basin effects lower the threshold at which reinforced concrete moment frame structures collapse for 30 different building archetypes.[189] In other words, if two identical buildings faced the same ground shaking scenario from a megathrust earthquake, the one located in the basin would collapse easier than the one outside of the basin. A second study by Marafi examined the sway of buildings in an earthquake from 4 to 40 stories high and found that buildings within the Seattle Basin sway three times more than those outside of it.[190]

Another study used past ground motion data to quantify the effects of megathrust earthquakes on 24 older and modern buildings in Seattle and Portland. They concluded that megathrust earthquakes are more likely to cause building collapse than crustal earthquakes and contribute this consequence to the longer duration shaking that is expected in a megathrust earthquake.[191]

Isolation Vulnerability

Seattle is highly dependent on bridges. The City of Seattle owns 159 bridges. Fifty-one have received seismic retrofits or were built to current seismic standards, and an additional 17 are scheduled to receive retrofits pending approval of a levy.[192] A remaining 91 bridges have not been retrofitted as of 2018. The improvements should save these bridges from catastrophic collapse, but many will not be functional after a strong Seattle Fault or megathrust earthquake.

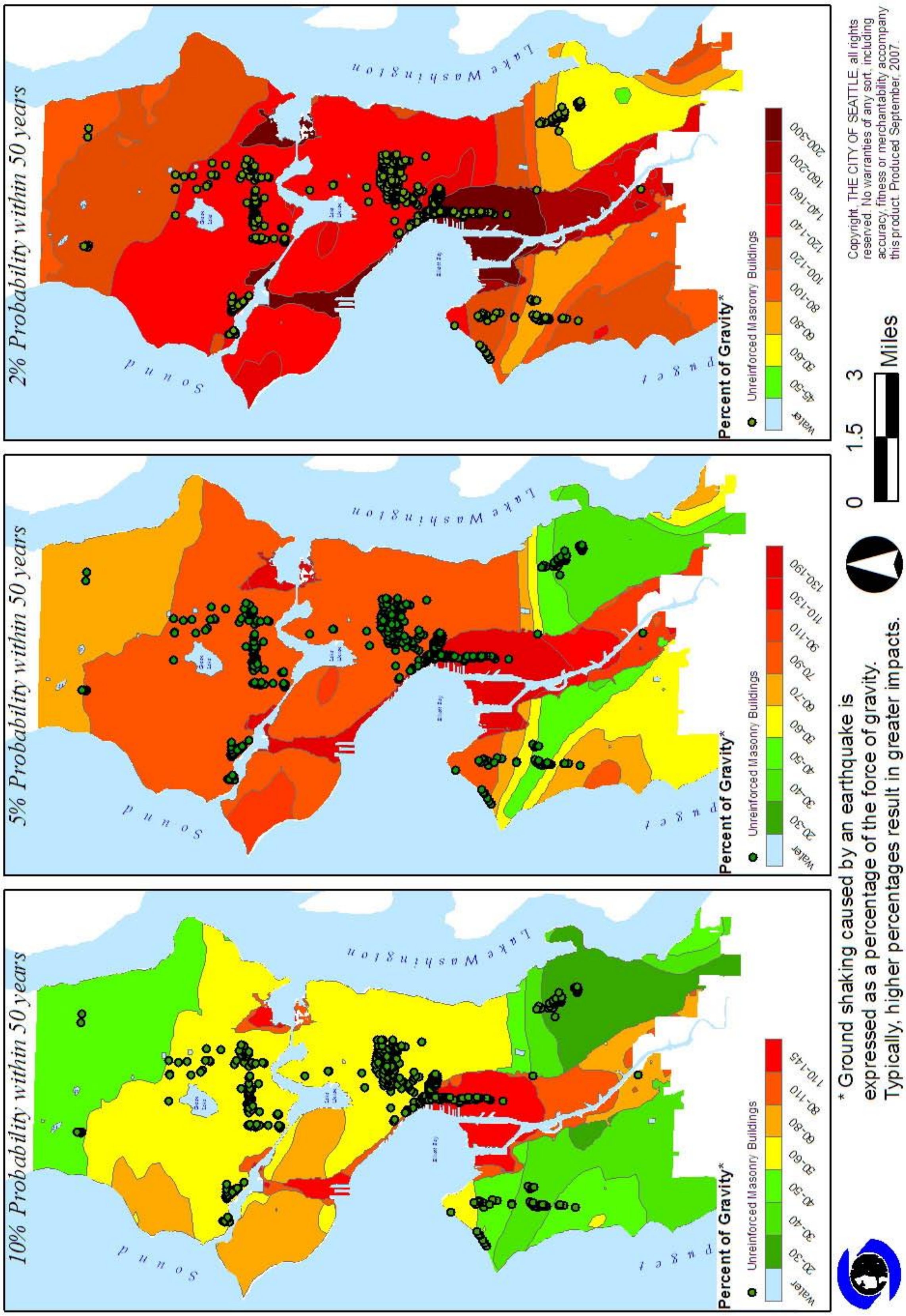
The Loma Prieta, Northridge, and Kobe earthquakes showed that even modern freeways and overpasses can collapse. Large portions of I-5 and I-90 rest on columns and run near slopes prone to failure. The Washington State Department of Transportation (WSDOT) owns the rest of Seattle's bridges including critical ones such as the Aurora Bridge and the I-5 Ship Canal Bridge. Through their own seismic retrofit program, they have completed retrofits for 53 out of 102 state-owned bridges in Seattle as of 2018.[193] The bridge being 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.[194] It is the world's first "flexible" bridge.

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 or 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.

Transportation Vulnerability

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 Alaskan Way Viaduct, the West Seattle Bridge, the First Avenue South Bridge, and approaches to the end of I-90. The King County International Airport is completely in the liquefaction zone as are most of the city's rail and marine terminals.

Figure 5-9. Probabilistic Ground Motions



Utility Vulnerability

Water systems have suffered significant damage in major earthquakes that have occurred around the world. 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 has further complicated water service restoration. In the most catastrophic earthquakes, it has taken over two months to restore water to some customers.

Seattle Public Utilities (SPU) completed a seismic water system evaluation in 1990. Based on this 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 daylight at Ginger Creek.

A new seismic study was conducted by SPU from 2016 to 2018. Since the original 1990 study was completed, the understanding of the seismicity in western Washington has evolved and building codes have been updated. The determination that large shallow earthquakes are possible in western Washington from such sources as the Seattle Fault Zone has significantly increased the earthquake hazard level that SPU facilities may experience.

The new study estimates 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 estimates 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. In smaller, more frequently occurring 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)
- Use earthquake-resistant distribution pipe in those areas susceptible to permanent ground displacement

Seattle's power, sewer, and telephone systems have not been recently studied. Their vulnerability can be somewhat deduced from past performance and studies of other earthquakes. A Washington State report mentions that both the 1949 and 1965 quakes interrupted service in water, sewer, gas, and electric systems. The report does not describe any damage to the telephone network. A summary of the infrastructure damages from the 1989 Loma Prieta quake outlines the same problems. It adds that widespread utility outages were common, but most were less than a day long.[195] This performance is quite good, but the epicenters in these quakes were far from the areas studied. Puget Sound Energy has replaced over 8,000 miles of its 12,000-mile network of gas mains with flexible plastic pipe that can withstand earthquakes.[196] 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.[197]

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. Other vulnerable equipment includes substations and rigid bus connections. BPA has prioritized anchoring high-voltage transformers to their foundations to ensure that power flow is not compromised in an earthquake. They use base isolation technology for protecting transformers.[198]

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. SCL's South Service Center and two of its substations are in a liquefaction zone, but all sit on pilings. SCL uses an uncommon voltage in their system, so if transformers are destroyed due to liquefaction or other earthquake hazards, they must be rebuilt from scratch. The biggest danger for these facilities is the potential loss of access due to transportation system damage.

Secondary Hazards

Secondary hazards can have more impact than the initial ground shaking. The most significant secondary hazards are fires, hazardous materials releases, tsunamis, and landslides. Each of these hazards is described fully in its own chapter.

Fires

Fires were the most frequent cause of death in the 1995 Kobe earthquake. Additionally, most of the 28,000 buildings destroyed in the 1906 San Francisco earthquake were lost in the conflagration that followed it. Multiple ignitions developing into a conflagration is the most dangerous post-earthquake fire hazard. 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.[199] 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.[200] In an MMI X ("disastrous") scenario, one ignition per 1.5 million square feet of building floor area is expected.[201] To put these rates in perspective, Amazon, which is believed to occupy about 13.6 million square feet of building space, would experience about 9 ignitions. However, one should note that commercial construction is less vulnerable to fire than wood-frame construction.

Normally, Seattle would call on neighboring city fire departments for help, but in a Seattle Fault earthquake they will probably not be able to provide it. With Seattle's fire-fighting resources spread thin, a conflagration becomes very likely, especially if the water system has been damaged and water pressure drops. There is additional concern for conflagration with the expected increase in development of multi-story wood structures in Seattle (see fires chapter).

Hazardous Materials Incidents

During earthquakes, stored chemical containers can rupture and release their contents. Most of these spills will be small and contained within structures, 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 damages with possible hazardous materials releases.[202] Additionally, building debris often contain toxic substances like asbestos. The Seattle School District implemented a non-structural mitigation program to limit post-earthquake release of hazardous chemicals. A small number of releases could escape into the atmosphere creating a widespread hazard.

Tsunami

Tsunamis in Seattle are not likely, but should they occur they have the potential to be extremely dangerous. New tsunami modeling for a Cascadia Subduction Zone scenario is underway. Preliminary findings show that there would be less inundation in this megathrust earthquake compared to a Seattle Fault earthquake.[203] The most dangerous source of tsunami is the Seattle Fault, which is believed to have produced a 16ft tsunami in the past. Although there is no precise correlation between earthquake size and tsunami size, a rough estimate is that earthquakes usually have a magnitude of 7.0 or greater before they generate a tsunami.[204] In 2001, the National Atmospheric and Oceanic Administration (NOAA) modeled a Seattle Fault-generated tsunami. It is covered in full in the Tsunami chapter. The low-lying areas around the downtown sports stadiums, Harbor Island, and Interbay are the most at risk for inundation in a tsunami. Because a tsunami generated inside Elliott Bay would strike within minutes after the most powerful earthquake Seattle has ever experienced, the only realistic escape option would be into the upper floors of buildings, many of which will be severely damaged. The waterfront is a popular and densely packed area, compounding this exposure.

Landslides

Allstadt and colleagues examined the potential for shallow (less the 2.8 meters deep) landslides following a M7.0 Seattle Fault earthquake. They found that the quake could cause 5,000 landslides in dry conditions and 30,000 in extremely wet conditions. While the study only models a single scenario, and completely wet conditions are unlikely, it is still a sobering look at the potential for 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. The major northern landslide area is Golden Gardens in Ballard. In the middle of the city, Magnolia, Queen Anne, Madrona, West Seattle, and the northern end of Beacon Hill are all potential landslide areas.

5 1.5 Consequences

Earthquakes cause widespread physical damage across the whole city through intense ground shaking, with higher damage rates in areas that were once valley bottoms or estuaries. The physical damage can cause high casualties, transportation blockages, utility outages, hazardous materials releases, and fires. If the earthquake is powerful enough it can trigger landslides, tsunamis, and seiches.

When estimating annualized earthquake losses in 2017, FEMA ranked Washington second to California.[205] Among metropolitan areas, FEMA ranked Seattle fifth, behind four metropolitan areas in California: Los Angeles, San Francisco, Riverside, and San Jose.[206]

A megathrust earthquake would cause several times more damage than the 2001 Nisqually Earthquake. Damage locally would be just a small fraction of that extending up and down the whole Pacific Northwest coast. A strong Seattle Fault earthquake would be a catastrophe for Seattle, but outside response and recovery resources would be easier to obtain because the damage would be more localized than in a megathrust earthquake.

In 2005, 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. 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.[207] Estimates are 1,600 fatalities regionally. Despite the enormity of the 2005 scenario, the Seattle Fault is capable of causing earthquakes up to magnitude 7.3, but earthquakes of that size are probably much rarer. Modern building code in Seattle requires that structures can withstand the types of ground motions that a 6.7 Seattle Fault earthquake would produce.

Effective earthquake response begins with a working transportation system, yet it would be severely impacted by either a megathrust or Seattle Fault earthquake. Due to its dependence on bridges, Seattle could face major difficulties responding if key structures go out of service. It would be difficult to move emergency personnel and resources to where they are needed or to get the injured to hospitals.

If the region experiences a larger shallow/crustal or megathrust quake, most utility services would be severely impacted in large parts of the city. If trunk lines break or critical substations and transformers are broken, outages would occur over a wide area. If many lines are damaged, outages would 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/crustal or megathrust quake, limiting the ability to fight post-earthquake fires. This danger has been mitigated by plans to reroute water, the ability to draw water from open water sources such as reservoirs, lakes, and the Sound, and the use of flexible overland piping.

The economic impacts 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 $43 billion in 2018 dollars). It's likely that number would be much higher now, considering Seattle's population has grown by about 27% since 2005. A successful recovery would depend on local, regional, and national political and economic conditions. Additionally, in a megathrust earthquake, where consequences will be felt across the whole region, Seattle will have to rely mainly on itself, with reduced outside assistance. Locally, the city would have to be able to work well as a community to develop a set of shared goals. Recovery can be delayed for years if a community cannot achieve consensus about how it should rebuild post-disaster. A recovery would also depend heavily on favorable economic conditions. Overall community and economic health status trending at the time of a disaster can impact recovery.

Seattle's URMs are likely to suffer heavy structural damage or collapse in a large earthquake. About half of the city's URMs 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 enterprise could face a permanent loss of business, as Kobe did following the 1995 earthquake.

The 2005 Seattle Fault earthquake scenario estimated that 46,000 households 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 of these 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.

One factor that could mitigate the loss of life from an earthquake is the development of the Earthquake Early Warning (EEW) system. Strong ground shaking comes after the first wave of energy that radiates from an earthquake's epicenter. An EEW system detects this first wave of energy and instantly sends out a warning that strong shaking is to be expected in a matter of seconds to tens of seconds, depending on the location of the earthquake. These few seconds of warning time could allow people to shelter in a safe place, could warn drivers or train conductors to stop, or could allow workers to isolate or shut down industrial systems. Pilot testing for EEW in Washington, called "ShakeAlert," is underway, with limited public notification set to begin in 2018.[208]

5 1.6 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 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.

5.2 Landslides

- Seattle has steep hills, wet winters, and geology that is prone to landslides. Landslides occur frequently, especially in the winter and early spring.
- 8.4% of the city's surface is covered by areas identified as slide prone in the city's Environmentally Critical Areas Ordinance. 81% of the slide-prone area is zoned for open space, the right of way, or single-family residential areas. The City of Seattle is the largest owner of landslide-prone slopes.
- The most common landslides in Seattle are shallow (less than 6 – 10 feet deep), fast moving (up to 60 km per hour) slides that occur on undeveloped slopes. Shallow slides can have run-outs that exceed 50 feet.[209] Less common are deep-seated landslides that cover a wider area and have a depth of movement greater than 6 – 10 feet.[210] Small movements of deep-seated slides occur gradually over weeks or months. They can be very destructive to property and infrastructure if this gradual movement is not identified before a large failure of the slope occurs.
- Landslides are more likely to occur when soils are saturated. Many landslides can occur within a few days when Seattle experiences heavy rainfall or rapid snowmelt.
- Response to landslides can be more difficult when they are triggered by an event like a winter storm, which is often associated with other hazards such as widespread flooding.
- Traditional home-owners insurance policies do not cover landslide damage, making property owners extremely vulnerable to economic loss.[211]
- Freight and passenger rail lines run along landslide-prone slopes. Landslides have disrupted or canceled passenger trains along the Puget Sound over 500 times from 2015 – 2018.[212]
- 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 inventorying and mapping landslide prone areas, requirements to stabilize building sites during construction, public education, and slope stabilization projects. Mitigation often requires cooperation between private land owners and the city.

5 2.1 Context

Washington state experienced its most deadly landslide in March 2014, when the SR 530 "Oso" Landslide destroyed an entire neighborhood and took 43 lives. Nationally, landslides cause over 25 deaths and cost about $3.5 billion per year in the U.S. Landslides are a common natural hazard in Seattle, but most result in minor consequences to private property.[213]

A landslide is the movement of a mass of soil, rock, or debris down a slope. Landslides occur when the force of gravity on a slope exceeds the strength of the earth materials that compose the slope. The amount of downslope force and/or slope material strength changes with a variety of factors including precipitation, changes in water level, erosion, ground water, earthquakes, prior landslides, or human activity.[214] There is typically more than one cause. 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. Landslides that occur under water are called submarine landslides.

While landslides do not always fit neatly into a specific category, Seattle experiences four general types:[215]

- Shallow landslides: shallow (less than 6 – 10 ft) and rapid slides on a slope, which may result in a debris flow. These slides can attain speeds of up to 60 km per hour and can have debris runouts that exceed 50 feet.[216] Although they are typically minor, their potential speed and long runout can make them dangerous to humans. Over two-thirds (69%) of all landslides in Seattle are shallow.
- Deep-seated landslides: deep (more than 6 - 10 ft), typically ancient, landslides that have been on the landscape for centuries or longer. People build on them, not recognizing the hazard. Deep-seated landslides may reactivate, often due to months or years of above average precipitation or modification of the slope or other processes. Most deep-seated landslides are slow, allowing people to escape them without issue. However, some can be dangerous if they go undetected, and they can cause considerable damage to buildings and infrastructure. Between 18-19% of all landslides in Seattle.
- High Bluff Peel-off: blocks of soil fall from the high bluffs primarily along the cliffs of Puget Sound. Between 3-4% of all slides.
- Groundwater Blowout: groundwater pressure built up at the contact between overlaying pervious (sand) and underlaying impervious (clay) soil units causes increasing groundwater pressure that may initiate a landslide. Between 5-6% of all slides.

Deep-seated landslides 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.[217] When slopes are struck by a sudden event such as an earthquake, heavy rain, or human alteration, landslides can occur.

It is difficult to correlate the size of landslides with fatalities. Fatalities have occurred in relatively small slides, many of which happened at construction sites. While deep landslides have caused fatalities when they go undetected, such as with Oso, they are often slower moving, giving people enough time to detect the threat and remove themselves from harm.

Most landslides happen between late October and late March, due to greater levels of precipitation during these months. However, even if the landslide "season" is over, slides can be delayed and occur beyond early spring.[218] According to Tubbs, the probability of sliding rises after a wet, cold winter, especially if a freeze occurs in late winter and early spring.[219] The ground becomes saturated over the winter, and then porous following a freeze, so a subsequent rain will penetrate the surface while the high water table will prevent 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 there is a heightened risk for landslides. This tool can be found online at https://landslides.usgs.gov/monitoring/seattle/. It consists of various graphs modeled on historic events and current national weather service data. The graphs show the 15-day cumulative precipitation forecast, the intensity of rainfall in the past 70 hours, a rainfall intensity and duration index for the past 14 days, and a water balance model that shows how wet the soils are. The tool also includes graphs that show real-time data from monitoring instruments located north of Seattle on slopes similar to those in the city. Those graphs 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. This work also produced a map of shallow landslide hazards that shows relative likelihood of shallow landslides (i.e., from low to high).

Figure 5-10. Landslide and Landslide Prone Areas

5 2.2 History

From the time records began being kept in the 1890s to 2000, Seattle has recorded 1,326 landslides. The events listed below were found in newspaper articles and city records. Only the events that required significant city response are included. Most of them happened during winter storms and involved multiple slides incidents throughout the city. Shannon & Wilson indicated that Seattle's three worst years for landslides were 1933/34, 1985/86 and 1996/97.[220]

1921 Six major slides occur during one weekend.[221]

1933/34 More than 400 Seattleites battle slides in ten areas of the city. These slides prompted numerous repair projects.[222]

1941 Several slides occur during December around Sand Point.[223]

1947 Several children die when a slide destroys their home.[224]

1948 Multiple slide events in Magnolia and Yesler Terrace.[225]

1950 Many slides occurred in the spring. They may have been connected with heavy snowfall as the 1997 events were.[226]

1961 Slides occur in many areas of the city during the spring.[227]

1965 SR 520 threatened, one lane closed, Roanoke interchange closed.[228]

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.[229]

1971/72 Slides destroy homes in Madrona causing about $1.8 million in damage. These slides were also probably connected with snowfall.[230] Largest number of landslides since 1933/34.

1974 West Seattle experiences multiple slides in the winter. Golden Gardens was also damaged. The mayor authorizes assistance.[231]

1983 Queen Anne slide closes Aurora for a day. Mud travels as far as Lake Union.[232]

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 damages. More slides occurred in March in a continuation of the wet winter.

2014 A deep landslide occurred the morning of March 22 near the city 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,[233] and State Route 530 was closed for more than two months. The state estimated capital losses of at least $50 million.[234]

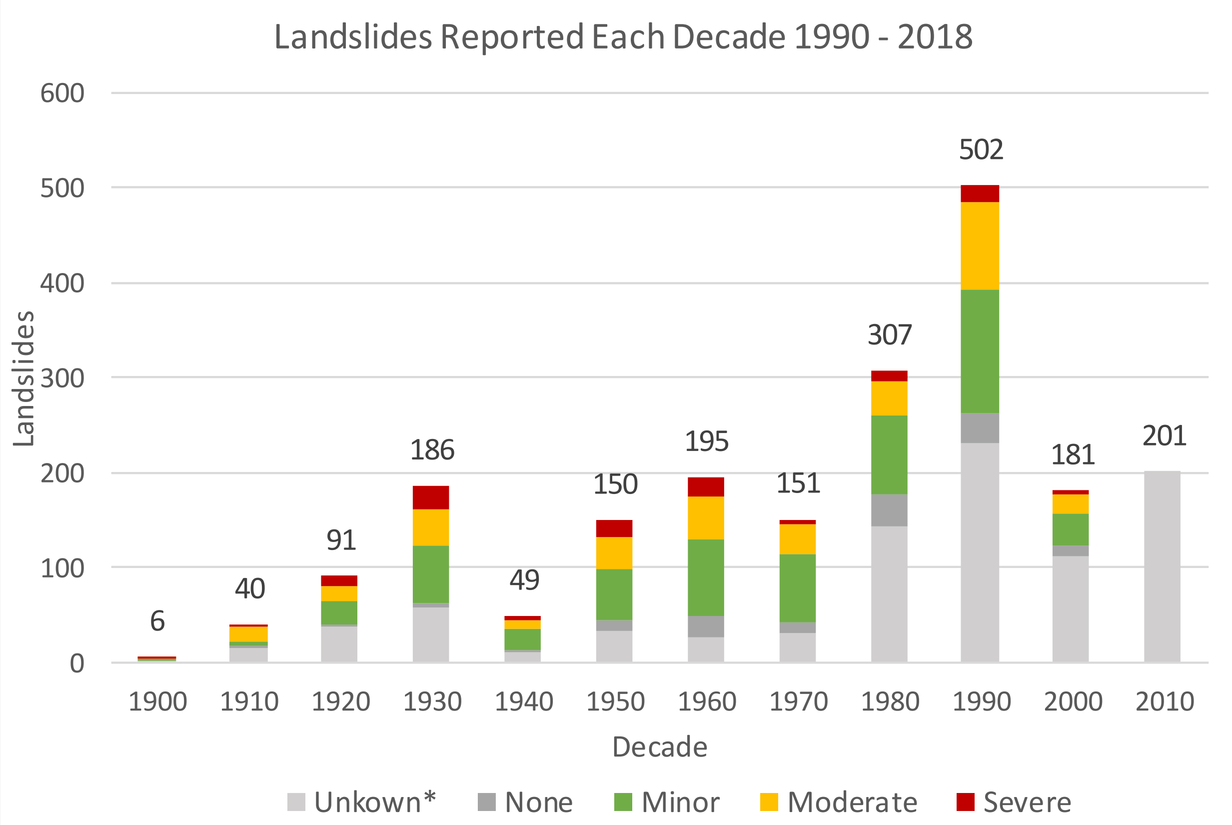
A study of 50 landslides in Seattle found that hillside excavation for roadcuts and other construction activities contributed to 40% of the slides.[235] During the construction of Interstate 5, and newspaper accounts document several landslides along Beacon Hill and Capitol Hill during this time.

Urban development has the potential to reduce risk but can also expose more people to the consequences of a landslide. When impervious materials like concrete are added to a slope, water is diverted, and soils are 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.[236] 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.[237]

5 2.3 Likelihood of Future Occurrences

The number of landslides recorded by the city increased dramatically from the mid-1900s to the end of the century (Figure 5-11). 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 1996/97 winter. Since the 90s, the number of landslides recorded has decreased to about 190 slides per decade.

Figure 5-11. Landslides By Decade

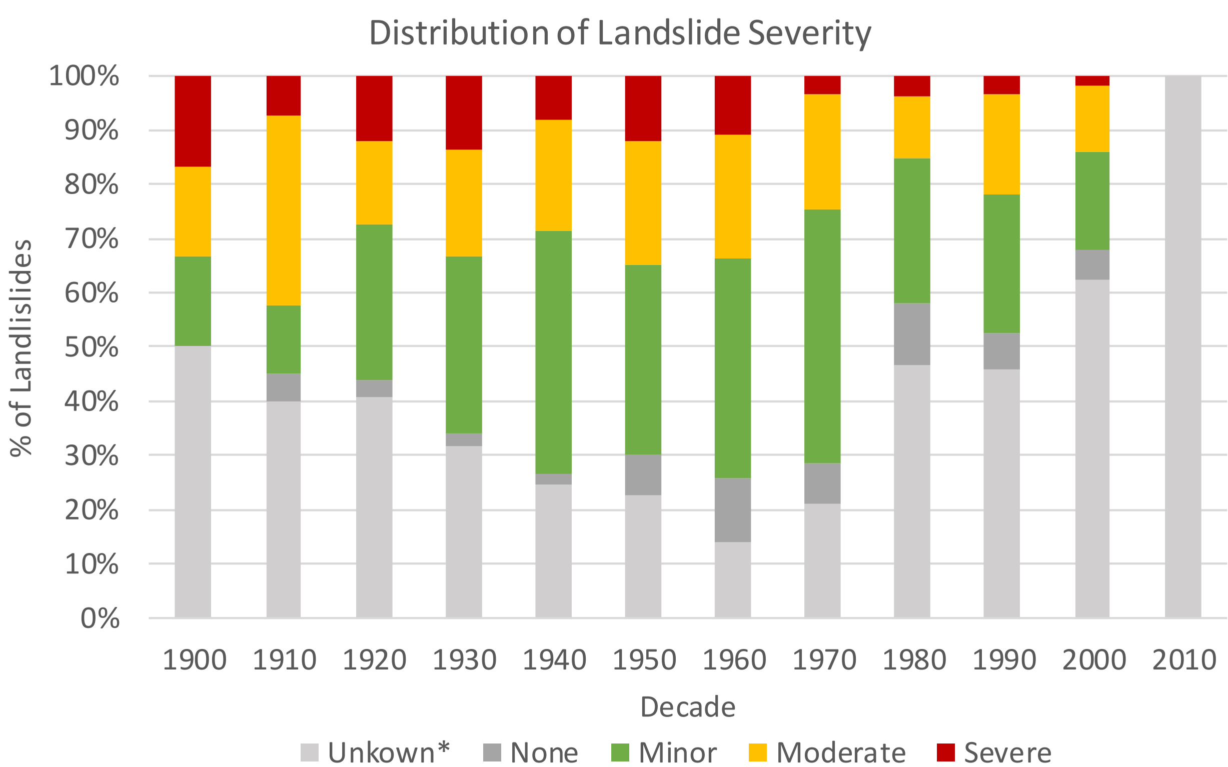


*Data on slide severity comes from the Seattle Landslide Study completed by Shannon & Wilson in 2000. The unkown category represents slides recorded by other sources that did not track severity (45% of the data).

The number of landslides that have severely damaged property decreased between 1980 to 2000 (Figure [Distribution of Landslide Severity by Decade]). 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 (except for the 1990s).

The tragic Oso landslide caused concerns around the risk of a massive landslide occurring in a more densely populated area, like Seattle. A recent study analyzed and dated 25 deep-seated landslides, including the Oso landslide, in the North Fork Stillaguamish River (NFSR) Valley, about 60 miles north of Seattle. 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.[238] The NFSR Valley has different topography and is much less developed than Seattle. However, the soil structure that makes the slopes in the Valley landslide prone, are similar to soil structures in Seattle.

Figure 5-12. Distribution of Landslide Severity by Decade



*Data on slide severity comes from the Seattle Landslide Study completed by Shannon & Wilson in 2000. The unkown category represents slides recorded by other sources that did not track severity (45% of the data).

5 2.4 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 21 [Landslides and Landslide Prone Areas]).[239] The map reflects slopes where landslides are prone to start. However, it does not account for the potential runout of a slide, which can extend further than 50 feet.[240] The homes that were destroyed in the Oso landslide were not in landslide-prone areas but were reached by the massive debris flow that occurred as a result of the slide. Additional research is needed to understand the potential length of runout for different types of slides. 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 Northwest Seattle.[241] Human alteration of the slope was at least a partial cause in 84% of landslides in Seattle in the 20th century.[242]

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 been located in Southwest Magnolia, Northwest and Southwest Queen Anne, East Queen Anne, Alki, Admiral Way, West Beacon Hill, Interlaken, Madrona and Pigeon Point.[243]

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 their home in a landslide-prone area, but it does require a more intensive geologic assessment and mitigation work to eliminate risk to the home and neighboring properties. Common mitigation measures can include special foundation designs or pipes that divert water from the slope. Nevertheless, there is always a risk of danger when building on a slope. A home built underneath a bluff on Bainbridge Island was buried in a landslide in 1997, tragically 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.

Transportation / Right of Way

Public right of way, such as roads, railways, and trails, accounts for one-quarter 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 that which is parallel to a slope. Seattle has many such locations, importantly, 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.[244] 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. In late 2013, BNSF and the State of Washington began a $16 million, multi-year project to mitigate landslides in this corridor. They are building retaining walls, improving drainage systems, and conducting erosion control in six different areas.[245] 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.

Usually, a landslide going over a right of way does not 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.

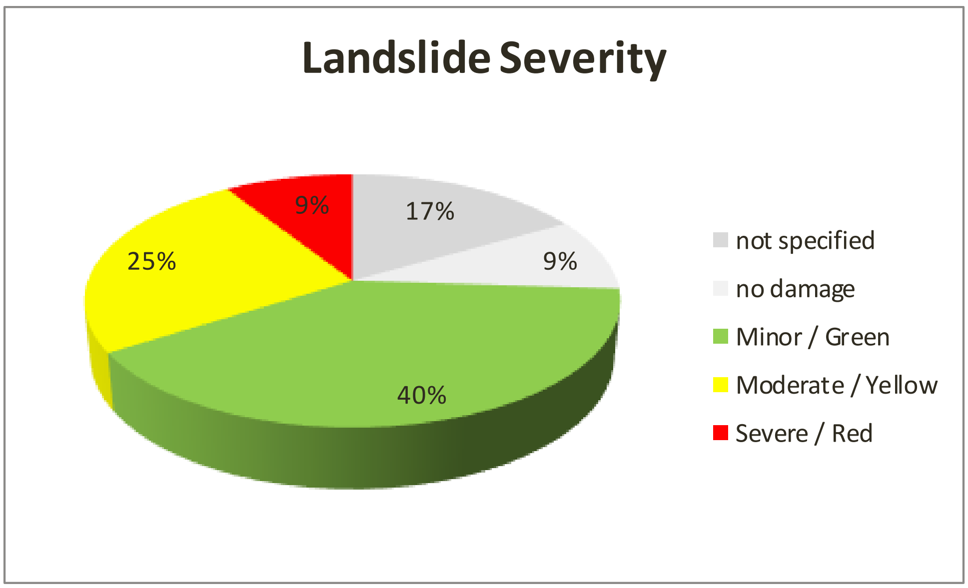
5 2.5 Consequences

Landslides will continue to be 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 of a Bainbridge Island family underscored the human costs.

Property damage from the flurries of landslides in 1974 and 1997 was shared roughly 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 pattern 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.

Figure 5-13. Landslide Severity Summary



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 of the Cedar River water pipelines enter the city in this area.

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.

Landslides can induce other 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 derailing 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 look into the potential 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 the majority of 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.

5 2.6 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. Complicating response is the fact that landslides are often secondary to other hazards, such as earthquakes and storms. Following the major slides of 1996/97, the City convened an Interdepartmental Landslide Team to address the problem. Since then, several structural and non-structural mitigation measures have been taken. In addition, USGS monitoring of rainfall and soil conditions and availability of new landslide susceptibility maps add greater accuracy to the city's predictive ability.

5.3 Volcanic Hazards

- Washington State is home to five active volcanoes located in the Cascade Range, east of Seattle: Mt. Baker, Glacier Peak, Mt. Rainier, Mt. Adams and Mt. St. Helens (see figure [Cascades volcanoes]). Washington and California are the only states in the lower 48 to experience a major volcanic eruption in the past 150 years.
- Major hazards caused by eruptions are blast, pyroclastic flows, lahars, post-lahar sedimentation, and ashfall. Seattle is too far from any volcanoes to receive damage from blast and pyroclastic flows.
  - Ash falls could reach Seattle from any of the Cascades volcanoes, but prevailing weather patterns would typically blow ash away from Seattle, to the east side of the state. However, to underscore this uncertainty, ash deposits from multiple pre-historic eruptions have been found in Seattle, including Glacier Peak (less than 1 inch) and Mt. Mazama/Crater Lake (amount unknown) ash.
  - The City of Seattle depends on power, water, and transportation resources located in the Cascades and Eastern Washington where ash is more likely to fall. Seattle City Light operates dams directly east of Mt. Baker and in Pend Oreille County in eastern Washington. Seattle's water comes from two reservoirs located on the western slopes of the Central Cascades, so they are outside the probable path of ashfall.
  - If heavy ash were to fall over Seattle it would create health problems, paralyze the transportation system, destroy many mechanical objects, endanger the utility networks and cost millions of dollars to clean up. Ash can be very dangerous to aviation.
- Lahars are mudflows and debris flows that originate from the slopes of a volcano and travel down river systems. Mt. Rainier is the only volcano connected to Seattle via a river system.
- Lahars from Mt. Rainier have buried the Kent Valley in the past, but there is no evidence a lahar has reached Seattle in the past 10,000 years. A Washington Department of Natural Resources analysis states that it is possible for a lahar to reach Seattle but would be extremely unlikely.[246]
- Seattle faces vulnerabilities from a lahar reaching the Kent Valley. Interstate 405, as well as oil and natural gas pipelines, water lines, power lines, and sewer mains that serve Seattle all cross the potential lahar area in the Kent Valley. This area also hosts many of Seattle's major food distributors.
- Lahars can cause floods that transport massive amounts of sedimentation farther downstream. In a Mt. Rainier eruption, if lahars reach as far as the Kent Valley, Seattle's Duwamish Valley could experience post-lahar sedimentation.

5 3.1 Context

Washington's volcanoes are part of the same tectonic motion that gives the Pacific Northwest its seismic activity. As the earth's continents and oceanic plates move, the heavier oceanic plates slip under the lighter continental plates. This process is called "subduction" and it causes friction along the plate faces (see figure [Subduction in the Pacific Northwest]). Typically, the hottest part of the subduction area is under the continental plate about 100-200 miles inland from the coast, where the heat and pressure melt rock into magma. The magma forms reservoirs near the surface. As the rock melts into magma it expands.

Under normal conditions, the constraining pressure of the surrounding rock keeps the expansive force of the magma in check. An eruption is triggered when the balance of forces is upset. Sometimes an increase in pressure from tectonic activity causes the magma to blow out the surface. On other occasions water mixes with the magma, gets superheated, and produces enormous steam explosions.

Washington's volcanoes have explosive eruptions. They produce viscous magma that plugs the vent of the volcano. As the magma rises to the earth's surface, pressure decreases, and gases separate from liquid. When the pressure from the trapped gases exceeds the pressure of the hardened magma, the volcano erupts.[247] These violent eruptions produce several hazards, including pyroclastic flows, landslides, gases, lava flows, tephra (ejected ash and rock) and lahars (see figure [Volcano Hazards]). While the Hollywood image of a volcanic eruption may be fast flowing lava, the viscous lava of Washington volcanoes typically cools and hardens before traveling very far. The major hazards to Seattle are tephra (ash falls) and post-lahar sedimentation.

Figure 5-14. Cascade Volcanoes

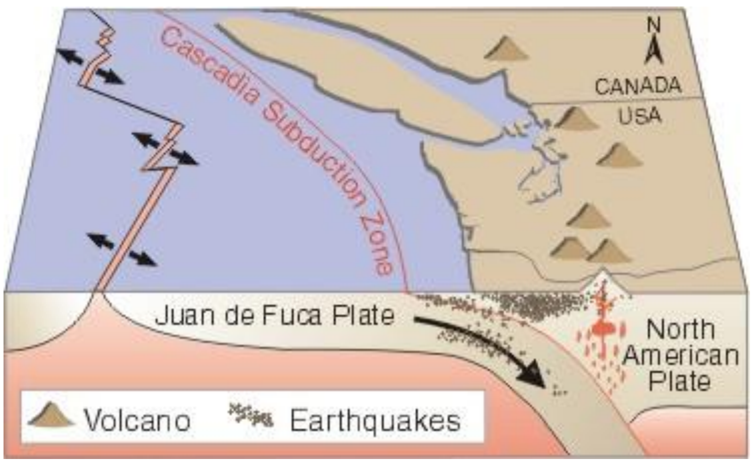
Ashfall

The most widespread eruption impact is ash, which can cover hundreds of square miles. Ash is a health risk to people with respiratory problems. Ash also has many indirect effects by causing hazardous driving conditions, damage to mechanical equipment, and interference with wireless communications. Ash flows can also interfere with aviation. If ash is ingested into a jet engine it can melt and coat turbine blades and eventually cause them to stop running. Roughly 300,000 people fly over or near volcanoes every day, mostly those located in Alaska.[248] In 2010, an ash cloud from a volcanic eruption in Iceland forced the week-long closure of airspace for most of northern Europe.[249] The cost of this disruption was estimated at $10 billion.

Lahars

The USGS defines lahars as mudflows and debris flows that originate from the slopes of a volcano. Lahars contain at least a 60% concentration of rock debris. Most, but not all, are preceded by volcanic and seismic activity. Most commonly, they are triggered by pyroclastic flows. Other possible triggers are intense rainfall on loose volcanic rock deposits, breakout of a lake dammed by volcanic deposits, and debris avalanches.[250] 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 distal valleys. Higher speeds of more than 60 miles per hour are possible on steep slopes near Mt. Rainier. Though spontaneous lahars are possible, most would be preceded by volcanic and seismic activity. Lahars from Cascades volcanoes can travel tens of miles from their source, making them extremely dangerous to communities close to volcanoes. A lahar that occurred 5,600 years ago covered roughly 212 square miles of the Puget Sound lowlands.[251]

Figure 5-15. Subduction in the Pacific Northwest



Source: Myers, B., Faust, L., & Janda, C. (0Mount Hood-History and Hazards of Oregon's Most Recently Active Volcano. *United States Geological Survey*. Retrieved August 2, 2018, from http://pubs.usgs.gov/fs/2000/fs060-00/

Post-Lahar Sedimentation

After a lahar initially stops, the erosion and transport of loose volcanic deposits can lead to large sediment loads that flow downstream. "Post-lahar sedimentation" is the incremental transport of excess sediment from the headwaters of a river to lower river reaches that occurs days, weeks, or even years after a lahar occurrence. The resulting rise in sediment can decrease carrying capacity for river channels and increase flood risk. It is a risk to navigation and the environment that can persist for decades.

Volcano Hazards That Are Not a Threat to Seattle

Volcanoes produce a variety of hazards that are localized to the volcanoes immediate area and are therefore not a threat to Seattle. These are:

Pyroclastic Flows

The USGS defines a pyroclastic flow as a chaotic mixture of rock fragments, gas, and ash that travels rapidly (tens of meters per second) away from a volcanic vent or collapsing flow front. Pyroclastic flows hug the ground, flattening most everything in their path. The ejected material melts the glaciers and other snow covering the volcano. The melt water combined with the volcanic material can create muddy slurries called lahars and is even more dangerous since it increases the size of the pyroclastic flow and enables it to move farther. This process caused the mudflows that raced down the Toutle River following the Mt. St. Helens eruption.

Volcanic Landslides

Volcanoes are naturally weak structures and experience slope collapses, typically during an eruption. Volcanic landslides are 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.

Volcanic Gases

Magma contains dissolved gases. These gases are ejected along with tephra high into the atmosphere during eruptions. They can become attached to tephra particles or water droplets and fall with them back to earth. The major gases are water vapor, carbon dioxide (a greenhouse gas), hydrogen sulfide (acid rain), hydrogen, carbon monoxide, hydrogen chloride, hydrogen fluoride and helium. A few historic eruptions have caused gas concentrations that were acutely lethal to people, animals, and vegetation, but the highest probability effect of volcanic gases is exacerbating existing pollution problems.

Lava Flows

Lava is the classic Hollywood volcano hazard, but the volcanoes of the Pacific Northwest produce a very viscous type of lava that moves very slowly and extends only a few miles from its source if it even moves at all. Much of the lava in nearby volcanoes is so thick and viscous that it builds domes.

5 3.2 History

Only two volcanoes have fully erupted in the Cascades in the 20th century, Mt. Lassen in northern California in 1917 and Mt. St. Helens in 1980. The events listed in this section focus on the most recent activity observed for the volcanoes with the greatest hazard risks for Seattle.

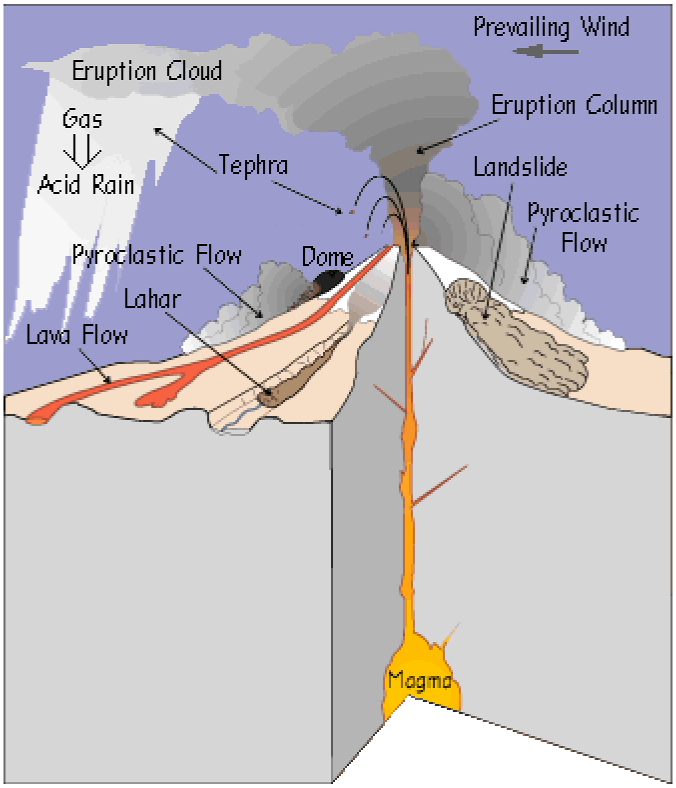
Mt. Rainier

The last magmatic eruption is believed to be about 1,000 years ago.[252] 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. Geologic records show Rainier was active 5,600 to 4,500 years ago and again 2,700 to 2,000 years ago. Both eruptive periods are believed to have produced excess sedimentation in the Duwamish river, near Seattle.

During the past 10,000 years, at least 60 lahars of various sizes have moved down valleys that head at Mount Rainier; but there is no evidence that any have reached Seattle.[253] The two largest lahars that have originated from Mt. Rainier were not triggered by an eruption. One is the Osceola Mudflow that occurred about 4,500 to 5,600 years ago. At least ten times larger than any other known lahar from Mount Rainier, it was the product of a large debris avalanche composed mostly of hydrothermally-altered material. 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 Kent and to Tacoma's Commencement Bay.

At least six smaller debris avalanches have spawned lahars in the past 5,600 years. As recently as 500 years ago, the Electron Mudflow nearly reached Puyallup.[254] The Electron Mudflow has not been correlated with an eruption. It is thought to have derived from a slope failure on the west flank of Mount Rainier. The Electron Mudflow was more than 90 feet deep at its head. Its deposits at Orting are

Figure 5-16. Types of Volcano Hazards



Source: United States Geological Survey website: http://pubs.usgs.gov/fs/fs002-97/

as much as 18 feet thick and contain remnants of an old-growth forest. About 1,200 years ago, a lahar of this type filled valleys of both forks of the White River to depths of 60 to 90 feet and flowed 60 miles. Less than 2,200 years ago, the National Lahar inundated the Nisqually River valley to depths of 30-120 feet and flowed all the way to Puget Sound. More than a dozen lahars of this type have occurred at Mount Rainier during periods of volcanism in the past 6,000 years. In 1963 and 1967, large landslides occurred the slopes of the mountain. Increased heat was responsible, suggesting renewed volcanic activity.[255]

Mt. St. Helens

The 1980 eruption was the largest in the Cascades in recent history but only produced trace ash dustings in Seattle. A magnitude 5.1 earthquake preceded the eruption, which produced the largest debris avalanche in recorded history.[256] Mt. St. Helens has been consistently the most explosive of the Cascade volcanoes, with earlier, smaller eruptions in 1800, 1831, 1842 and 1857.[257] Mt. St. Helens is the most prolific tephra (ash) producer of the past few thousand years because of the frequency of its eruptions. It produced a small ash plume in 2004.[258]

Out of Washington's volcanoes, Mt. St. Helens is believed to be the most likely to erupt in the 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 1980 eruption.[259]

Mt. Baker

The last major eruption was approximately 6,700 years ago. Since then, Mt. Baker has experienced a steam eruption in the mid-1800s and an increase in steam and heat in 1975 but did not erupt.[260] Small lahars occur from Mt. Baker every decade or so. It is not showing any current signs of eruption, but the biggest threat of a future eruption would be lahars, which could reach the Puget Lowlands.[261]

Glacier Peak

Glacier Peak generated a sequence of six tephra eruptions over a period of several hundred years about 13,000 years ago. The largest 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. More recently, Glacier Peak experienced small steam eruptions in the 1700s.[262] The Cascades Volcano Observatory estimates that each year there is a 1 in 1,000 chance that Glacier Peak will erupt.[263]

Mt. Adams

Mt. Adams has erupted in recent geologic time although not during the past 1,000 years. It has had several debris avalanches over the past 10,000 years. Physical evidence suggests that past eruptions were fairly quiet with little ash or pyroclastic material. Some observers speculate that it is dormant or extinct, but the Cascades Volcano Observatory states that it will erupt again but probable future eruptions would be small tephra and lava flows from vents on the summit.[264]

Mt. Hood

Mt. Hood has been very active recently, with an eruptive period in the late 1700s. Early settlers reported eruptive activity in 1859 and 1865, but no deposits have been found that confirm these accounts.[265] Ashfall and pyroclastic flows from Mt. Hood eruptions have been limited to Oregon and southern Washington.[266] Mt. Hood is more of a threat to Portland than Seattle.

Mt. Shasta

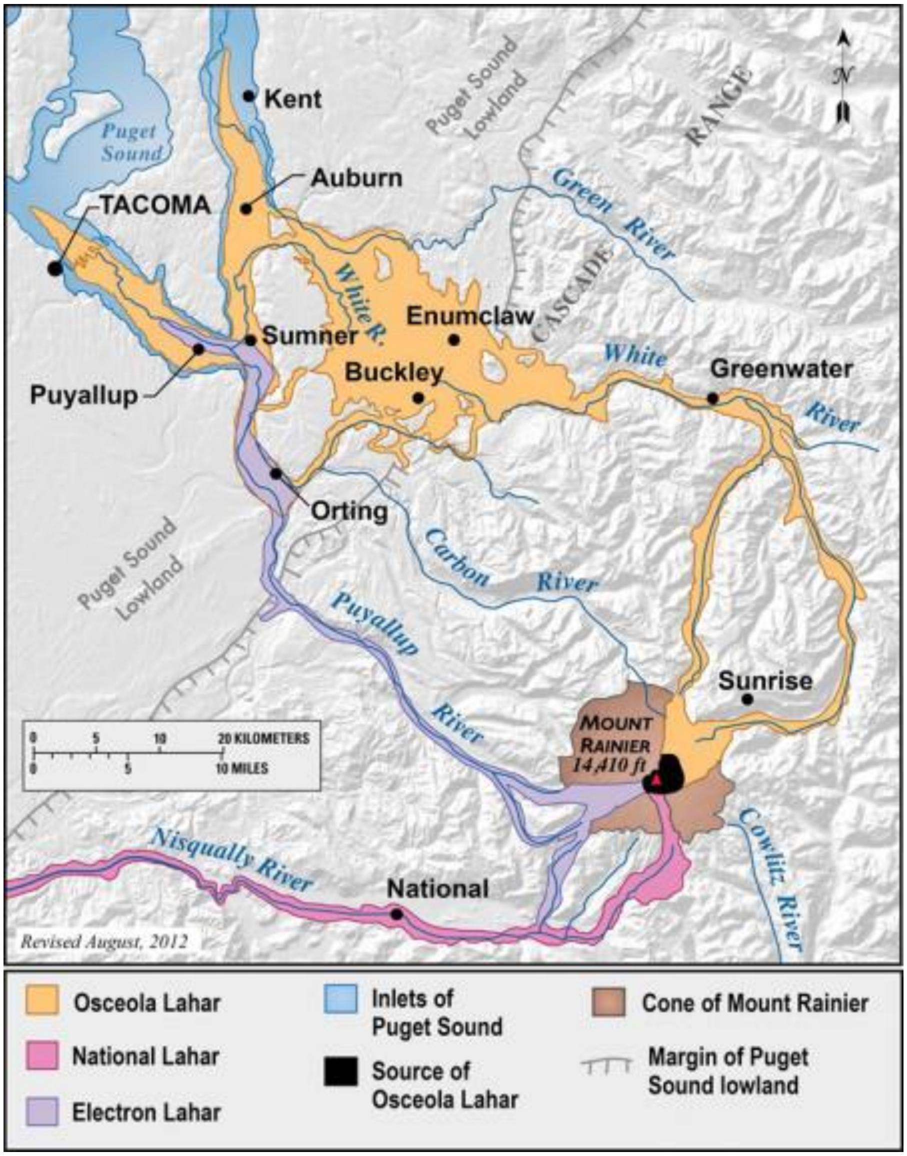
Mt. Shasta has erupted roughly once per 250 years in the past 750 years, with the last eruption in 1786. Eruptions in the past 10,000 years have produced lava flows and pyroclastic flows that have reached as far as 12.4 miles from the summit. It is possible that ash from Mt. Shasta could reach as far as Seattle.

5 3.3 Likelihood of Future Occurrences

The most likely volcanic hazard facing Seattle is ashfall. The USGS estimates that there is a 1 in 5,000, or 0.02% chance per year that Seattle will accumulate 1 centimeter or more of tephra.[267] The USGS has produced a map showing annual probabilities of 1 cm ash accumulation throughout the West Coast (see Figure [Annual Probability of 1cm Ash Accumulation]). Geologists have found volcanic ash deposits from eruptions that happened thousands of years ago in various areas of Seattle. Ash from the 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.[268] 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.[269] The Glacier Peak ash layer was less than 1-inch thick, and the amount of ash received from the other eruptions is unknown.

Lahars happen more commonly than eruptions. Mt. Rainier is a major producer of lahars because of its size, relatively westward location, and the volume of water trapped in the glaciers along its slopes. Lahars 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.[270] Most Cascade glaciers, including those on Mt. Rainier, are shrinking. As they retreat very unstable terrain is exposed. As a result, small debris flows are becoming more common and the released sediment is being

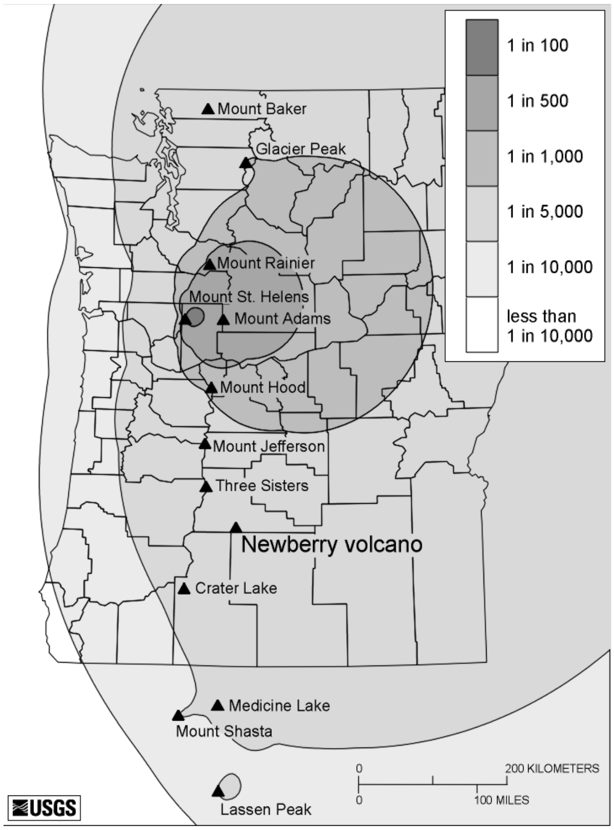
Figure 5-17. Past Mt. Rainier Lahars



Source: United States Geological Survey, Cascades Volcano Observatory (website: https://volcanoes.usgs.gov/volcanoes/mount_rainier/hazard_lahars.html)

washed downstream. This, in turn, decreases the capacity of rivers originating at Mt. Rainier and makes them more likely to overflow their banks with water or lahar debris. These types of lahars would be too small to reach Seattle, and typically do not even go outside the Mt. Rainier National Park boundaries. Larger lahars with the potential for post-lahar sedimentation in the Duwamish Valley are estimated to occur every 500 to 1000 years, according to the Cascades Volcano Observatory.[271] Although the risk of lahars seems quite small, some uncertainty exists because the last major lahars occurred hundreds of years ago before modern development. It is not fully understood whether or how the development will affect a lahar.

Figure 5-18. Annual Probability of 1cm Ash Accumulation



Source: Sherrod, D. R., Mastin, L. G., Scott, W. E., & Schilling, S. P. (1997) Volcano Hazards at Newberry Volcano, Oregon. *United States Geological Survey.* Retrieved August 3, 2018, from http://vulcan.wr.usgs.gov/Volcanoes/Newberry/Hazards/OFR97-513/OFR97-513_inlined.html

5 3.4 Vulnerability

Seattle's main vulnerability is to ashfall and post-lahar sedimentation. It is possible that a lahar could reach Seattle because of the connection between the Duwamish river and Mt. Rainier. However, there is no evidence of a past lahar reaching this far.

Lahar Vulnerability

Seattle's Duwamish river valley is exposed to lahars and a process known as post-lahar sedimentation. The 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 lifelines and facilities located in the area.

Seattle is downstream from Mount Rainier, the Pacific Northwest's major lahar producer. 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 they have. It is most likely that a lahar would stop south of Seattle in the Kent Valley. Then in the coming days, weeks or months, lahar sediments would push downstream to Seattle in a process known as post-lahar sedimentation.

Hydrologists state that levees will probably contain the sediment inside the river channel but cannot provide guarantees. Therefore, most of the Sodo area should be considered at risk of sediment inundation (see Figure [Potential Post-Lahar Sedimentation Area with Key Transportation

Infrastructure]). Containing the sediment depends on its volume, its speed, the time of year, and the levees' condition. Only about 3% of the area exposed to post-lahar sedimentation is residential. If sediment overtops levees or they fail, low-lying areas along to the river could be inundated.

Table 5-3. Washington 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

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 highly 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. All the Cascade volcanoes can generate lahars that can reach Puget Sound, crossing many transportation and utility trunks along the way.

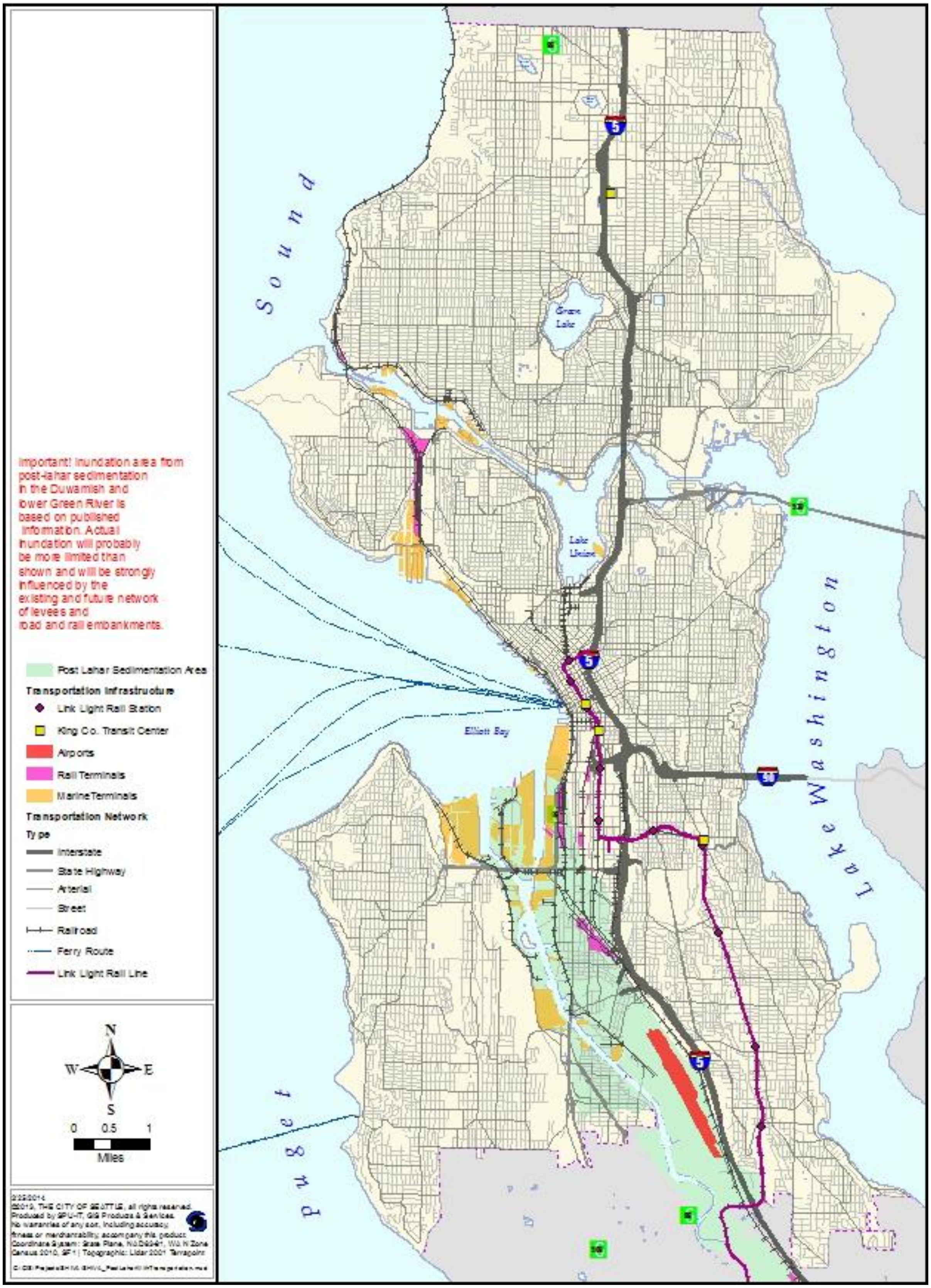
Ashfall Vulnerability

Seattle is exposed to ashfall, but the likelihood of a large event is remote. Volcanic ash deposits from eruptions that occurred 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. If Seattle does receive ash, the most likely source would be Mount St. Helens, which has had the most frequent eruptions and largest ash eruptions of all the Cascade volcanoes in recent history. In the Pacific Northwest, prevailing winds blow from the west to the east. Seattle is west of the Cascade volcanoes. Weather patterns would have to reverse to 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 chemistry and turbidity (clearness).

The power system can be vulnerable in the right conditions. Ash that falls on electrical insulators can cause flashover, a disruptive electrical discharge that can cause outages.[272] 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

Figure 5-19. Potential Post-Lahar Sedimentation Area with Major Transportation Infrastructure



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 so 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.[273] 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.[274] 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.[275]

5 3.5 Consequences

Seattle's consequences to 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

The consequences of a lahar 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 Cascade 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. In the case of a Mt. Rainier lahar, the greatest consequence is post-lahar sedimentation in the Duwamish waterway.

In a post-lahar sedimentation event, sediment could wash down the river for years. Lahar material from the Kent Valley would introduce more polluted debris into the waterway which is already undergoing a 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 $13 million (2009 dollars) when its port closed after the 1980 Mt. St. Helens eruption.[276]

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

If sediments breach the levees, the consequences grow more severe. Property, lifelines, and critical facilities would be affected. The property exposed to the lahar hazard (surrounding the Duwamish) is predominantly commercial and industrial but includes roughly 117 acres of residential area and all of the King County International Airport. 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 high loss of life if people did not evacuate. 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 would be buried under mud ranging from a few feet thick near the end of the lahar to hundreds of feet thick closer to Mt. Rainier.

Roughly 3,300 people live in the Post-Lahar Sedimentation Area, mostly in the Georgetown and South Park areas. The precise day time population is unknown, but it is a major employment area. People are exposed to danger only from a lahar reaching Seattle, not from post-lahar sedimentation.

Ashfall

The experiences of Yakima and Spokane in 1980 reveal a "typical" case 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" effect 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.[277] 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.[278] 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. Many people would be stuck, and 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 worse that 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. Waste water 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. It could also damage power distribution and generation facilities, prompting expensive emergency power purchases.[279] 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.[280] Considering that cost would be $3.5 million in 2018 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 would 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 "typical" scenario. If the ash is acidic or acidic rain falls, injuries and damage would increase. One 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. Since an ashfall would affect the whole Puget Sound region, Seattle could not rely on aid from neighboring governments. A mudflow would increase the damage and probably stop port activity for several weeks. Aviation would be disrupted. Seattle could be economically impacted even if not physically damaged.

5 3.6 Conclusions

Casualties are likely to be small compared to the economic effects. A lahar, the deadliest volcanic hazard, is extremely unlikely to reach Seattle. Unusual weather patterns could produce ash falls heavier than those in Eastern Washington during the 1980 Mt. St. Helens eruption.

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 might make evacuation unnecessary.

Planners should be prepared for ashfall. During the Mt. St. Helens eruption many cities were caught unprepared because they assumed they would not be hit.

5.4 Tsunamis and Seiches

Tsunami

- *Definition*: Tsunamis are water waves caused by earthquakes, volcanic eruptions, or landslides. In deep water tsunamis have long wavelengths, short wave heights, and travel up to 30 mph. As tsunamis enter shallow water they slow down, and the waves increase significantly in height.
- Tsunamis do not have to have large wave heights to be damaging. Tsunami damage is caused by both the forces exerted by flowing water onto structures, and by run-up of the wave onto land that causes flooding and carries debris. Tsunamis can also generate dangerous current speeds that can be hard for vessels to navigate.
- Tsunamis generated in the Pacific Ocean off Washington's coast will not have as great of an effect in Seattle as they will on the Pacific Coast, but low-lying areas may experience flooding, and strong currents will likely be present in Puget Sound for hours after the earthquake.
- Tsunamis can be generated in Puget Sound by both landslides and earthquakes.
- The most frequent cause of Puget Sound tsunamis is landslides. The 1949 Olympia earthquake triggered a landslide in the Tacoma Narrows that caused a 6 to 8-foot tsunami that affected nearby shorelines three days after the earthquake.
- The most damaging tsunami would likely come from a Seattle Fault earthquake, or earthquakes on other local faults. There is evidence that an earthquake on the Seattle Fault that occurred around 900 AD produced a 16-foot tsunami. The National Oceanic and Atmospheric Administration (NOAA) recreated this tsunami using a model.
- The modelled tsunami would flood areas up to one mile inland with depths up to 5 meters. The tsunami would hit immediately after the ground stopped moving. People along the shore would have little time to escape. It would destroy buildings along the shore and flood low-lying areas up to one mile inland. Structures built to modern code would fare better than older ones.
- The 900 AD tsunami was probably a worst-case event. It is more likely (but not certain) that the next Seattle Fault earthquake and tsunami will be smaller.
- The preliminary results from modeling a tsunami generated by an M9.0 megathrust earthquake predict the main impacts to be current speeds of 3 to 5 knots in Elliott Bay and 15 inches of inundation near the Duwamish river.

Seiche

- *Definition*: Seiches are standing waves in waterbodies caused by most often by seismic waves or atmospheric pressure. They can occur at great distances (100s or 1000s of miles away) from an earthquake epicenter. Because they are *standing* waves they move vertically rather than horizontally.
- Lake Union is especially prone to seiches due to its shape. The east and west sides are roughly parallel, and the V-shaped northern end focuses waves. There is a historical report of a seiche or tsunami on Lake Washington, but it is not clear how large seiches on Lake Washington could be.
- Seiches have occurred multiple times in Seattle, but they have not caused extensive damage so far. Large seiches are a danger to the I-90 and SR 520 floating bridges. A large seiche could strain cables anchoring the bridges. The new SR 520 bridge is designed to take about 12-feet of upward motion

and 8-feet of downward motion from a seiche. Based on models the most damaging seiche would probably be caused by a Cascadia subduction zone earthquake.

5 4.1 Context

Tsunami

Tsunamis are water waves produced by an offshore earthquake, volcanic eruption, landslide, or an impact of an object from space. Any event that suddenly displaces a huge volume of water can generate a tsunami.

Tsunamis generated by four sources have the potential to reach Seattle: 1) distant sources, including subduction zones from around the Pacific, 2) Cascadia Subduction Zone megathrust earthquakes, 3) earthquakes on local faults, such as the Seattle Fault, and 4) landslides.

Tsunamis are hard to detect in the deep, open ocean. The wavelengths of tsunamis are between 93 and 155 miles, with amplitudes of three feet or less, and travel at speeds of about 450 (and up to 600) miles per hour.[281] As a wave approaches the shoreline, its front slows, allowing the rest of the wave to ride up and increasing the wave's height dramatically. Tsunamis nearing the coast can rise to 100 feet in height and move at a speed of 30 miles per hour.

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. 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.

While tsunamis are often depicted as one large wave, they are actually a series of waves, with a distance between crests of 60 or more miles. The time between successive waves reaching the shore can vary from 5 to 90 minutes.[282] These waves interact with each other, and with shorelines, which is why a single tsunami event can last for several hours.

Whether a tsunami is generated by a potential trigger depends on the volume of water displacement and the speed of the displacement. Most tsunamis are triggered by earthquakes of magnitude 7 or larger.[283] However, magnitude alone is not sufficient in predicting a tsunami. Along with the vertical movement of the earth during an earthquake, horizontal movement and the bathymetry (underwater topography) of the sea floor influence tsunami generation and size.

Some tsunamis break when they reach land. Some 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 "run-up" and its size is what often determines a tsunami's destructiveness.[284] The tide at the time of the tsunami can also influence potential run-up. A tsunami or seiche riding on a high tide presents greater danger than one occurring at low tide.

Tsunamis rarely crash ashore without warning. Though localized coastal flooding may precede the first wave, often the shoreline water recedes before the first tsunami wave arrives. This is dangerous since many people, unaware of the looming danger, venture too close to shore and are caught by subsequent waves. During the Indian Ocean Tsunami, a ten-year-old girl who had studied tsunami recognized this phenomenon and saved more than 100 people.

Three main factors could influence the size, shape, volume, and potential destructiveness of a tsunami generated by the Seattle Fault. These are 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 open 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.[285]
- Puget Sound's steeply sloping bathymetry may increase the chance that a tsunami will break on the shore, thus enhancing the tsunami's destructiveness.[286]
- The shape of Elliott Bay could increase damage by funneling waves together, thereby increasing wave height.[287]

Seiches

Seiches are vertical 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.[288] In other words, it is the waves created by the sloshing of water in an enclosed or partially enclosed waterbody, like water sloshing in a bathtub. Pushes from a seismic wave or air pressure cause the water to rock back and forth. Under the right conditions, resonance builds up wave height just like pumping one's legs to make a swing go higher. Since larger bodies of water usually have longer frequencies, it takes longer frequency waves traveling through the ground to create seiches in them. Due to the mechanics of an earthquake, areas close to the epicenter shake at high frequencies. Therefore, seiches tend to occur far from earthquake epicenters.[289] The biggest danger is from subduction zone or megathrust earthquakes that cause powerful, low frequency ground waves.

5 4.2 History

Both tsunamis and seiches have occurred in the past 1200 years in Central Puget Sound area.

Tsunami deposits attributed to the Seattle Fault have been found in five locations in Puget Sound, including Seattle.[290] It is not known if they are the result of one event or several closely spaced in time, but the most likely source in an estimated magnitude 7.3 earthquake on the Seattle Fault around 900 AD.

The 1964 Alaskan Earthquake caused a tsunami that was detected in Seattle, with a sea level rise of 0.8 feet detected on the Elliott Bay tide gauge. 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. The tsunami's effect was negligible in Seattle because the wave had lost energy as it traveled up the Strait of Juan de Fuca, and Whidbey Island may have acted as a baffle for the incoming waves. New, nuanced models of a Cascadia event show that the main impact would be increased currents in Puget Sound, and very few areas would experience run-up.

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.[291] This tsunami probably left deposits of the same age that have been found under the tidal marshes of Discovery Bay and the head of Hood Canal in Washington, but there is no geologic evidence for this tsunami elsewhere in Puget Sound.[292]

Landslides have caused localized tsunamis in at least two locations in Puget Sound since the late 1800s. Other records include oral history from the Snohomish Indian people who describe a deadly tsunami in the early 1800s, a small tsunami or seiche in 1891, and a damaging tsunami in 1894 caused by a submarine landslide in Commencement Bay. The most recent was in 1949 when the Tacoma Narrows experienced a landslide that triggered 6 to 8-foot tsunami following that year's magnitude 7.1

earthquake. The 900 AD Seattle Fault earthquake triggered massive landslides into Lake Washington, but there is no geologic evidence that these slides caused tsunamis in the lake.

The 1964 Alaska megathrust earthquake and 2002 Denali earthquake caused seiches in Lake Union.[293] These seiches damaged boats by battering them against docks and moorings in Lake Washington and Lake Union. Interestingly, the seismic waves that caused them could not be directly felt by humans.

Seiches have been more common than tsunamis and have not caused extensive damage so far. In 1891, an earthquake near Port Angeles caused an 8-foot seiche in Lake Washington, big enough to endanger people along the shore.[294] Both Lake Union and Lake Washington experienced seiches during the 1949 Puget Sound deep earthquake, but they did no damage.[295]

5 4.3 Likelihood of Future Occurrences

Tsunami

Seattle will almost certainly experience tsunami and seiches again, but the question is how often the biggest ones will occur. Seiches and tsunamis from distant earthquakes are the most common instances recorded for Seattle, but they have produced only minor to moderate damage and, to the best of our knowledge, no casualties.

Based on history and the number of landslides in Puget Sound, the most likely source of a tsunami is a large landslide. It is not known how big these waves can get but limited historical evidence suggests at most 6 to 8 feet high, and typically affecting a limited area.

Distant tsunamis originating from around the Pacific Ocean basin (the “Ring of Fire”) are likely, but they will probably have only minor effects on Seattle because they must travel through the Strait of Juan de Fuca then make a 90 degree turn south into Puget Sound and once in the Sound they are disrupted by the many islands and complex shoreline.

Local tsunamis from the Cascadia Subduction zone recur about every 500-600 years on the northern end of the subduction zone. Simulations of a magnitude 9.0 Cascadia earthquake generate a tsunami with wave heights reaching about 4 feet high offshore of Discovery Park and in the channel on the east side of Harbor Island.[296] Despite these wave heights, the simulation predicts almost no inundation of Seattle coastal areas, due in part to steep shorelines.[297] The area most impacted by inundation is Kellogg Island, near the mouth of the Duwamish River, but the model predicts only about 15 inches of inundation there.[298] The greatest predicted hazards are potentially dangerous ocean current velocities off of Discovery Park and Alki Point. Tsunami modeling estimates current speeds of up to 3 knots off of Discovery Park, 3.6 knots off of Alki, and up to 5 knots on the southwest side of Harbor Island.[299] Currents would increase suddenly and potentially last for multiple hours.[300] Such current speeds could make it difficult for maritime traffic, mainly small watercraft, navigate the waters.

The worst tsunami for Seattle would be triggered by a Seattle Fault earthquake.[301] The Seattle Fault runs through Bainbridge Island, across Puget Sound, through West Seattle, Sodo, Beacon Hill and then east to Bellevue (see Figure [Nisqually Shaking Intensity] for a map). The biggest earthquake possible on the Seattle Fault is magnitude 7.3. The frequency estimates for Seattle Fault Earthquakes are difficult to estimate due to lack of data about past events. USGS recurrence interval estimates range between 200 and 12,000 years for any Seattle Fault earthquake.[302] 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.[303]

It is likely that the next Seattle Fault earthquake will be smaller than the one in 900 AD. A team of seismologists and earthquake engineers chose to model a magnitude 6.7 Seattle Fault earthquake that they consider more likely than a magnitude 7.3. A magnitude 6.7 earthquake would probably trigger a smaller tsunami than the one that happened in 900 AD. The Seattle Fault shows evidence of episodic fault rupture of about 6 feet, enough to produce a tsunami.[304]

The size of a tsunami depends on the amount of uplift caused by an earthquake. The 900 AD earthquake caused over 15 feet of uplift. 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. A tsunami generated by a magnitude 6.7 Seattle Fault earthquake has not been modeled. It would probably cause a fraction of the damage of the NOAA-modeled tsunami following a magnitude7.3 earthquake or the earthquake-generated tsunami in 900 AD.[305]

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.[306]

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.[307] Cascadia megathrust earthquakes happen, on average, every 500 years. See the chapter on earthquakes for more details.

5 4.4 Vulnerability

Further tsunami modeling is in progress for the tsunami impact to Seattle from magnitude 9.0 Cascadia Subduction Zone earthquake, but preliminary results suggest that the Seattle Fault earthquake presents the greatest tsunami danger to Seattle.[308] Figure [Worst Case Tsunami Inundation Area from M7.3 Seattle Fault Earthquake] shows the worst-case Seattle Fault inundation area.

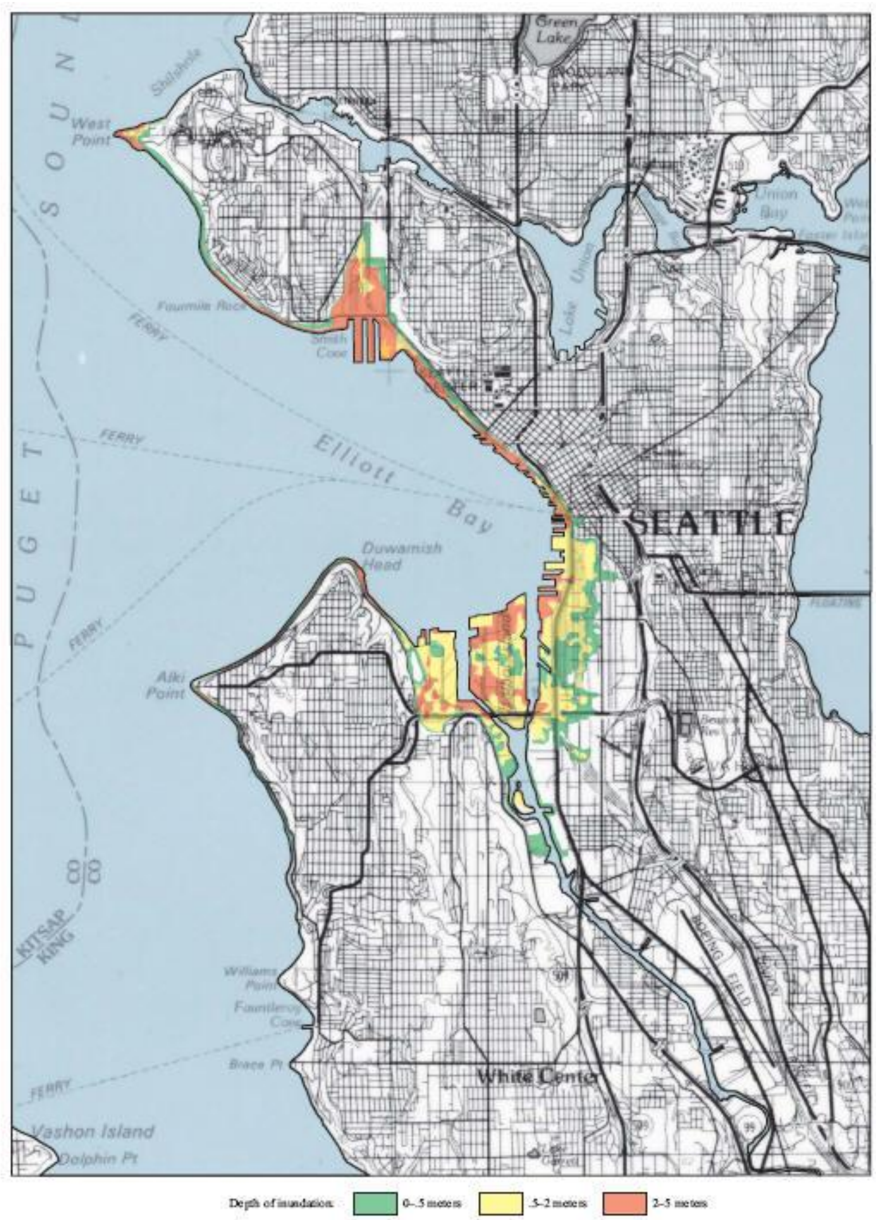
Seattle has a highly developed shoreline that makes it vulnerable to tsunami and seiche damage. Large numbers of people work, play, and live near the water. Major port facilities, tourist attractions, and housing ring Elliott Bay. Lake Union's shoreline is home to houseboats, businesses (including Amazon),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

The short time between a triggering event (e.g. earthquake, landslide) and arrival of the wave train (30 seconds to 5 minutes) would not permit many people to escape.[309] The only possible escape would be trying to get to higher floors in multi-story buildings. Some of these buildings are likely to be severely damaged if the trigger is a Seattle Fault earthquake. Most engineered structures performed fairly well in recent tsunamis.[310] Steel frame and modern concrete frame buildings built to seismic codes fared best in the tsunami following the 2011 Tohoku earthquake in Japan.[311] Likewise, the low death toll in the 2010 Chilean earthquake and tsunami was attributed to the country's strict adherence to building codes.[312] Structures already damaged by a landslide or earthquake would be especially susceptible to more damage from a tsunami.

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. Buildings 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 the storm water. The worst-case tsunami scenario modeled for Seattle does not include the effects of the built environment. In 2017, Seattle replaced its weak, aging seawall to meet current seismic standards. The new seawall is built to withstand a M6.7 Seattle Fault earthquake and subsequent tsunami. However, waves are expected to top the seawall in the M7.3 worst-case Seattle Fault scenario.

The primary impacts are likely to be from the earthquake itself. The new 520 floating bridge is built to withstand waves in a 100-year wind event. The Washington State Department of Transportation anticipates that these storm-generated wave forces would exceed the forces from a small to moderate-sized tsunami.

Figure 5-20. Worst Case Tsunami Inundation Area from M7.3 Seattle Fault Earthquake



Tsunami Lifeline Exposures:

- None of Seattle's 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.
- 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. 30 transmission towers are in the area.
- 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.
- Enwave's steam plant is located in the area, at Western Avenue and Union Street.

Tsunami Transportation Exposures:

- 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 inundation area.

5 4.5 Consequences

Tsunamis

Tsunamis have the potential to cause extreme damage and high casualties. The worst tsunami for Seattle would be a repeat of the one that occurred in 900 AD and modelled by the National Oceanic and Atmospheric Administration (NOAA). It is likely that the next Seattle Fault earthquake and tsunami will be smaller, because earthquake occurrence has a power law distribution. In other words, as earthquake frequency increases, magnitude decreases exponentially, meaning there are many very small earthquakes and a few very large earthquakes. Since the 900 AD event was a very high magnitude, we would expect the next one to be smaller based on the high probability of small magnitude earthquakes (see page 22 for additional discussion on power law distribution).

The NOAA model (see Figure [Worst Case Tsunami Inundation Area from M7.3 Seattle Fault Earthquake]) assumes a maximum of 7 meters of uplift on the Seattle Fault's south side (on Bainbridge Island), 4 meters uplift at Alki Point and 1-meter subsidence on the north side at West Point (Magnolia). The model assumes the earthquake happens at high tide. 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 areas.

The largest part of a Seattle Fault tsunami would be in Puget Sound between Seattle and Bainbridge Island. Most of this part would miss Seattle. Inside Elliott Bay the first wave crest would form a bore with an amplitude of 6 meters (i.e., 6 meters above the normal 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 5 minutes after the earthquake.

The wave would flood an area up to 1 mile inland around the Duwamish River's mouth. Figure [Worst Case Tsunami Inundation Area from M7.3 Seattle Fault Earthquake] shows the extent and depth of the inundation. The highest vertical run-ups are about 10 meters along Magnolia, Alki Beach, and east of Alki Point.[313]

The consequences of a worst-case tsunami would be catastrophic. 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. Roads would be blocked by debris. The best evacuation strategy 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 it safer than facing a tsunami in the open.

The tsunami would impact most of Seattle's port facilities including critical fuel terminals. Prolonged disruption to the Port would have economic impacts 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.

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 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.[314]

The tsunami would probably 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 Enwave Seattle (previously Seattle Steam) loses generating capacity, Seattle's major hospitals could lose their ability to sterilize medical instruments.

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 2009 modelling, Lake Union would experience wave heights of up to 6 feet (measured trough to crest) for minutes following the earthquake. 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. 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 [Area Exposed to Lake Union Seiche]).

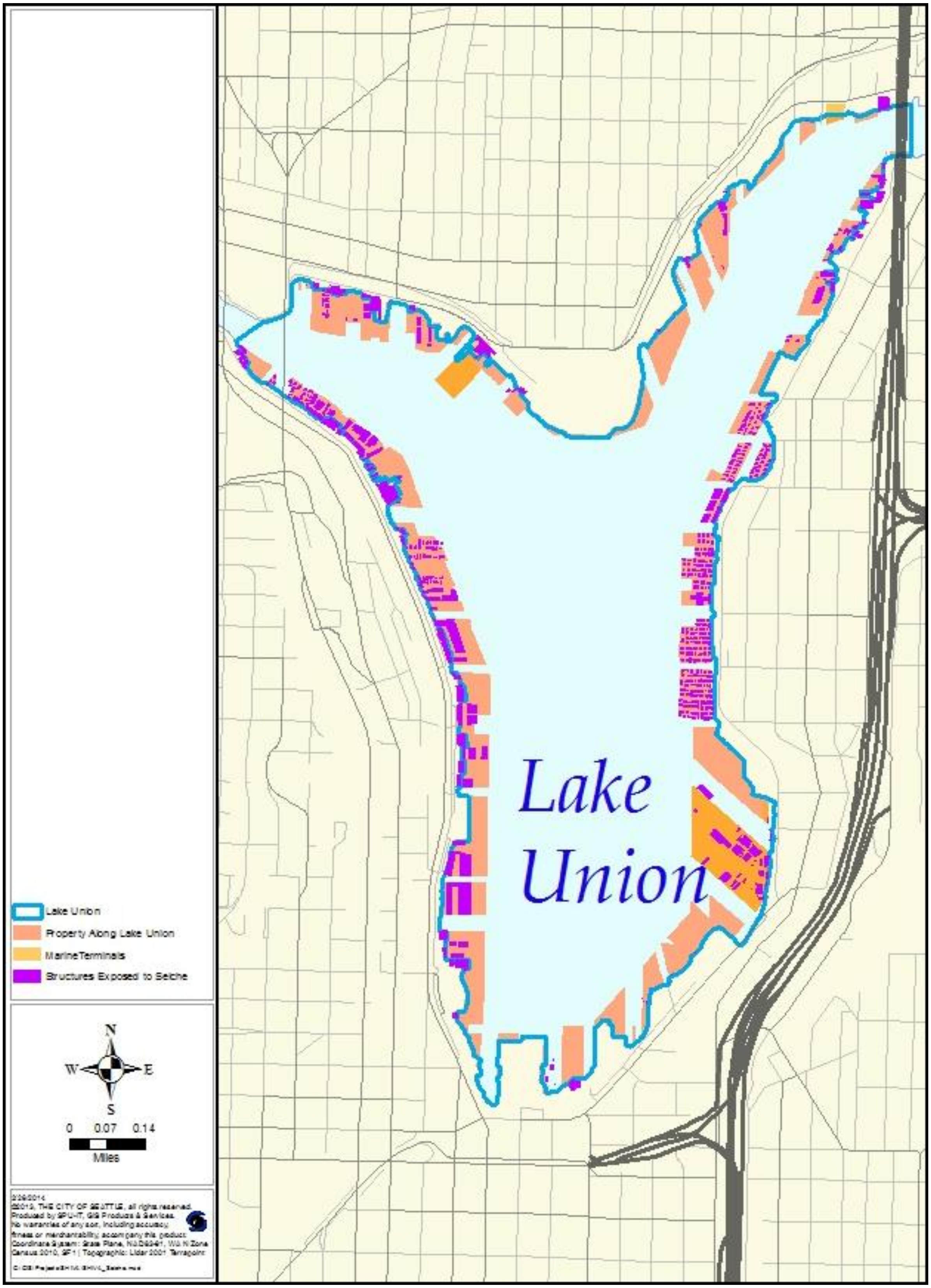
The likelihood of a seiche on other local waterbodies is not as well understood, but seiches in these bodies will probably be smaller than those on Lake Union. The consequences of a Lake Washington seiche could include people near the shore being knocked into the water, residential and commercial property damage, and damage to the two floating bridges. 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.

5 4.6 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 mitigated due to the infrequency of incidents that generate truly powerful tsunami and seiches.

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

Figure 5-21. Area Exposed to Lake Union Seiche



The worst case, modeled by the National Oceanic and Aeronautic Administration (NOAA), would be a devastating blow on top of the worst earthquake Seattle has ever faced. It is estimated that this type of event happens only about once every 5,000 to 15,000 years; the last such event occurred 1,100 years ago.

6. BIOLOGICAL HAZARDS

6.1 Disease - Pandemic Influenza / Bioterrorism

- Disease is considered a hazard because:
  - The chance of widespread disease is relatively high
  - Diseases can affect many people
- Social distancing and other counter measures could mitigate the effects.
- Diseases can have high rates of morbidity (illness) and mortality (death), affect large areas, and impede normal social functions. The impact of these diseases varies based on the virulence of the disease, duration of the illness, susceptibility of the population to the disease, and the spread of the disease within the community.
- Common disease outbreaks include influenza, 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. It is estimated that a severe pandemic influenza could cause illness in 540,000 people and over 11,000 deaths in King County.
  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 Disease Epidemiology & Immunization Section within Public Health – Seattle & King County investigates and coordinates the surveillance of communicable disease cases and outbreaks.

6 1.1 Context

Disease has been one of the most influential factors in human history. Throughout the 20th century great strides in medicine have produced many treatments and cures for the deadliest diseases. These medical advances can give us a false sense of security that all diseases can be treated or cured in a timely manner, even though the potential for a devastating disease outbreak continues to threaten our community.

The impact of a disease can be tracked and characterized using several different indicators. These indicators can help Public Health assess and respond to potential disease outbreaks.

- *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 with 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.

Endemic refers to the usual or predicted rate of a disease for a given area. Epidemic refers to an increase, usually sudden, in the number of cases of a disease beyond what is typically expected for a certain area. Pandemic refers to an epidemic that has spread globally.[315]

Epidemics are not uncommon in the Puget Sound area. Public Health – Seattle and King County monitors dozens of communicable diseases. Some of these, like seasonal influenza, infect many people every year but most cases are mild. Other epidemics, like whooping cough, are very severe but infect only a small segment of the population. These epidemics can be handled within the normal health care system, and typically do not lead to levels of high morbidity and mortality.

The Center for Disease Control and Prevention (CDC) identifies certain situations that may cause an epidemic to occur.[316] They are:

- A recent increase in the amount or virulence of the disease
- The recent introduction of the disease into a setting where it has not been before
- An enhanced mode of transmission so that more people are exposed
- A change in susceptibility of a person's response to the disease
- Factors that increase a person's exposure or involve introduction through new portals of entry

Although chronic disease has placed a lasting strain on the healthcare system, acute disease is a greater immediate threat to the health system's capacity. Acute disease outbreak has the potential to degrade or paralyze critical medical services.

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.

Influenza has been the deadliest type of pandemic in Seattle's history. A pandemic influenza is a new influenza virus that is much more severe than the typical seasonal "flu." People have little to no natural resistance to the strain of influenza, so it spreads more easily and can cause more deaths. Adding to the impact is the expected 6-month gap between the virus emerging and the development of a vaccine.[317]

In additional to natural disease outbreaks, there is the possibility of the intentional spread of disease to cause harm, known as bioterrorism. The CDC defines bioterrorism as the biological agents (microbes or toxins) used as weapons to further personal or political agendas (See attacks chapter for other types of terrorism).[318] A biological attack would most likely be covert, meaning people would not express symptoms immediately. Public Health – Seattle and King County 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.[319] Seattle has never experienced an act of bioterrorism.

6 1.2 History

Throughout the 20th century several epidemics and pandemics have affected our community.

Influenza. 1918-1919: The highly virulent influenza pandemic of 1918 killed a large number of young, otherwise healthy adults. The pandemic 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 1,600 lives.

Influenza. 1957-1958: The influenza pandemic of 1957 was less severe than the 1918 pandemic and caused a total of 70,000 fatalities nation-wide.[320]

Influenza. 1968-1969: The influenza pandemic caused more than 34,000 deaths in the U.S. and caused severe morbidity and mortality around the world.[321]

E.coli. 1993: E.coli-contaminated hamburger meat from a local Jack in the Box caused illness in 400 people and led to the death of two people within one month in the Washington area. Cases were seen in California, Idaho, and Nevada as well.

Pertussis. 2002-2005: Between 2002 and 2003 Public Health reported an 82% increase in the number of Pertussis infections in infants, and a three-fold increase in the number of cases in children <6 months. The occurrence of Pertussis in adolescents and adults has been on the rise since 1990, culminating in a national epidemic in 2005 when 25,616 reported cases nation-wide. Outbreaks within healthcare facilities can occur quickly because the bacterial infection is highly contagious.

Influenza. 2009: Like the 1918 pandemic, the H1N1 outbreak of 2009 affected the 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 3 schools in response to the disease.[322] 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 seasonal influenza virus does.

While there are no local instances of bioterrorism, there have been a few instances in the Pacific Northwest, and nationally. In 2013, threatening letters containing ricin were intercepted in Spokane, Washington.[323] They were addressed to military bases and U.S. government officials. Nobody was injured from the letters. In 2001, several locations on the East Coast were struck with anthrax. In 1984, the 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.[324]

6 1.3 Likelihood of Future Occurrence

Disease outbreaks are not uncommon and can produce devastating effects on a community. While medical advances have increased our ability to counteract disease, increases in the number of people without adequate healthcare, as well as the evolution of antibiotic resistant bacteria and globalization help make outbreaks spread more quickly and increase their magnitude.

Climate change could influence the likelihood or severity of future disease outbreaks, but much remains unknown. Warming temperatures or precipitation changes could alter the range of insects that carry diseases such as mosquitos and ticks. Likewise, warming water temperatures could affect organisms that contribute to water and food-borne diseases in ways we cannot predict now.

There is disagreement among experts about the likelihood of a non-state actor successfully carrying out a bioterrorism attack. Unlike other methods of terrorism, the materials needed to make a biological weapon are readily available, are inexpensive, and only require graduate-level science.[325] However, some believe that there are too many barriers to make it an attractive tactic for terrorists, including creating a successful strain of a disease, producing a large enough amount, and successfully distributing it where it will infect people.[326] While terrorists groups continue to have an interest in obtaining and using biological weapons, 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.[327]

6 1.4 Vulnerability

There are many factors that can increase Seattle's vulnerability to disease exposure and spread.

- Rapid population growth, such as is occurring in King County, increases the potential for acquisition and spread of infectious diseases.
- King County's large international air and seaports (including an active cruise ship industry) increase the number of visitors to our area and the risk for importation of infectious diseases. Diseases that

are not endemic to Washington have the potential for introduction and spread among our residents. Vaccine preventable diseases (e.g., acute viral hepatitis, measles, and influenza) are significant contributors to morbidity and potential mortality in international travelers and can cause local outbreaks among susceptible persons.

- Persons experiencing homelessness often also have limited access to medical care, so many people living homeless and with health problems have difficulty getting prompt treatment. Living conditions – like crowding 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 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 persons experiencing homelessness in King County.

Disease often affects those who are generally considered most vulnerable in our communities. Young children, the elderly, the poor, and those with underlying health conditions typically face the greatest consequences of disease. Those with existing health disadvantages (diabetes, asthma, disabilities, low life expectancy, etc.) appear to be concentrated in south Seattle (Pioneer Square, Sodo, Rainier Valley, Delridge) and north Seattle (Lake City, Bitter Lake, Northgate) (see figure [Map of health disadvantages in Seattle]). The neighborhoods that appear to have both high concentrations of people under 5 years of age and over 65 years of age are Delridge, Fauntleroy, and Beacon Hill.[328]

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.

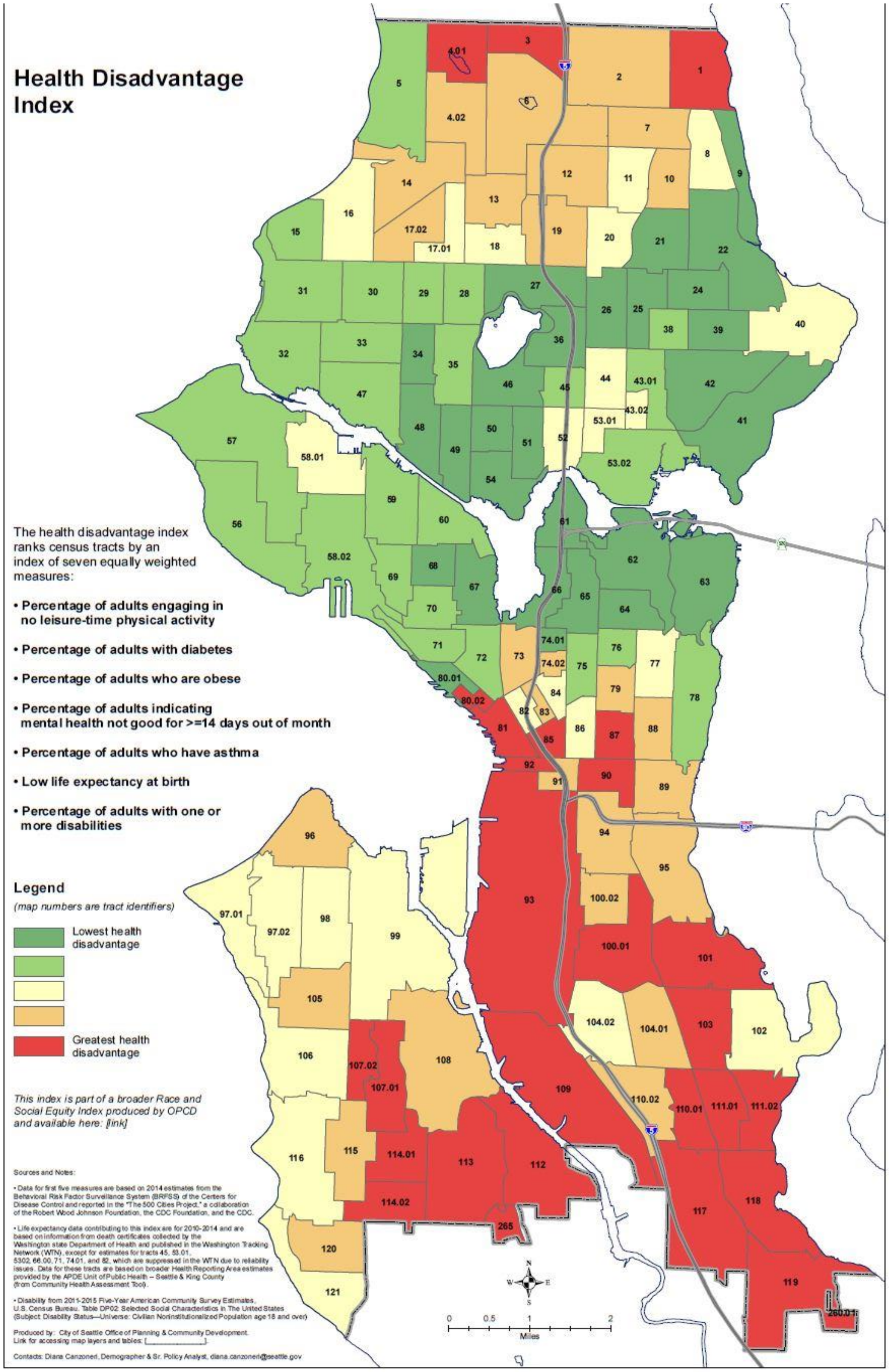
Other resources, such as food and water, are also a concern when planning for disease outbreaks. It is unlikely that Seattle's water reservoirs, which are underground or on secured watershed lands, would be exposed to potential contamination. On the other hand, food sources can become contaminated by improper food handling practices or ill food workers. Public Health conducts ongoing surveillance for food- and waterborne illnesses to identify and quickly control outbreaks. However, Seattle is still home to a dense network of restaurants that rely on regional farmers and distributors that are all vulnerable to spreading food-borne illness.

6 1.5 Consequences

Epidemics directly affect the health of people who live, work and visit a community. They have the potential to be one of the deadliest hazards a community can face. Illness is the most notable consequence of an epidemic, but outbreaks can also severely impact the community as schools, businesses, government agencies and non-profit organizations curtail operations due to employee illness or as countermeasures. The effects of these curtailments grow the longer the disease persists.

The most likely scenario that activates the City's emergency management system would be a disease outbreak that just exceeds our public health system's capacity and has many indirect socio-economic effects like the need to close schools or businesses. We have chosen a hepatitis A outbreak for the most likely scenario. It occurs in small numbers each year in King County, but more widespread outbreaks occur regularly. It is one of the deadliest food borne pathogens and one of the hardest to investigate because it can be dormant for a while before it makes a person sick.[329] A large outbreak centered in

Figure 6-1. Health Disadvantage Index



Source: Seattle Office of Planning and Community Development

Seattle would cause a strain on the public health system and potentially have strong impacts on local businesses, especially any that the public perceives as responsible for the outbreak.

The most severe disease outbreaks would involve pathogens that would infect a large percentage of an exposed population and hospitalize or kill many people. Pandemic has the potential to cause this disaster. It poses a great threat to the health of our local community as well as the national/international community. In addition to human morbidity and mortality impacts, pandemic influenza has many socio-economic consequences. Cancelations of schools, work, and public gatherings may be enacted to attempt to halt the spread of disease. Staff absenteeism can create a strain on government and healthcare systems causing limitations of services and care. The 2009 H1N1 flu epidemic showed how potentially easy it is to overwhelm the healthcare system, even though H1N1 was an influenza that caused less severe disease than a typical seasonal flu. Seattle-King County Public Health was a leader when the H1N1 flu surprised health officials by not being as severe as feared. The Public Health Director was one of the first in the country to reverse guidance to close schools. A pandemic influenza that caused moderate or severe disease would have a much larger impact on the community. The following table outlines expected disease rates based on Center for Disease Control modeling.

Table 6-1. Estimated Number of Episodes of Illness, Healthcare Utilization, and Deaths Associated with Moderate and Severe Pandemic Influenza Scenarios for the US Population and King County.

Characteristic	Moderate (1958/68 - like)		Severe (1918 - like)	
	US	King County	US	King county
Illness	90 million	540,000	90 million	540,000
Outpatient Care	45 million	270,000	45 million	270,000
Hospitalization	865,000	5,190	9,900,000	59,400
ICU Care	128,750	733	1,485,000	8,910
Mechanical Ventilation	64,875	389	742,500	4,455
Deaths	209,000	1,254	1,903,000	11,418

Data Source: Pandemic Influenza Response Plan (2013). Public Health - Seattle & King County. Retrieved August 9, 2018, from https://www.kingcounty.gov/depts/health/emergency-preparedness/preparing-yourself/~/media/depts/health/emergency-preparedness/documents/pandemic/pandemic-flu-response-plan.ashx

6 1.6 Conclusions

Disease outbreaks can be severe and unpredictable. Many diseases can cause epidemics and pandemics such as influenza, pertussis, hepatitis A virus, *Salmonella*, *E. coli*, West Nile virus, and tuberculosis. 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.

7. INTENTIONAL HAZARDS

7.1 Social Unrest

- Social unrest includes civil disorders, acts of 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.
- Civil disorder is a public disturbance by a group or groups of people involving acts of violence that cause immediate danger, damage or injury to others or their property. They are often but not always politically motivated. They are both illegal and violent.
- Civil disorders can be divided into two rough categories: those in which the perpetrators deliberately set out to harm others and those in which the perpetrators are focused more on crimes against property. Most of Seattle's disorders have been the latter.
- 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 they can be both illegal and violent.
- There are not clear lines differentiating civil disorder, civil disobedience, and strikes. The World Trade Organization (WTO) protests began with acts of civil disobedience then spiraled into civil disorder.
- The World Trade Organization (WTO) unrest was Seattle's most damaging experience with social unrest. For five days in late 1999 police battled protesters in downtown and Capitol Hill. There were no fatalities, but the economic disruption was significant, and the unrest was a serious blow to the city's reputation.
- For the past five years, May Day protests in Seattle have routinely exhibited violence or vandalism that requires police intervention.
- Disorders often occur in dense areas where people naturally gather and in crossroads areas. In Seattle, downtown, Capitol Hill, and the University District have seen the most frequent civil disorder events.
- Looting and arson are the most common crimes in Seattle's civil disorder events.
- Reputation damage has been a major impact to some areas hit by civil disorders, but Seattle has not seen major, lasting reputation damage.

7 1.1 Context

Social unrest includes a wide range of activities from violent to peaceful, legal to illegal, criminal to principled and highly planned to completely spontaneous. With such diversity, it seems impossible to generalize about them as a class of activities. What they share is an effort by a group of people to disrupt the community. Sometimes violence against people and property is added. This section will concentrate on the aspects of community disruption. There is no intention of equating moral parity between mob violence and peaceful protest of the sort championed by Dr. Martin Luther King, Jr. It must be recognized, however, that even peaceful civil disobedience is the application of pressure.

Civil Disorder

Civil disorder has been an episodic presence in the United States since its founding. The most widely held theory of modern American civil disorder distinguishes between "communal" and "commodity" riots.[330] Communal riots involve direct battles between two or more ethnic groups. They can cause high casualties and usually 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. The violence is generally aimed at symbols of the prevailing social structure, not at people. Because property is the most common target, casualties tend to be lower in commodity riots than communal riots. The majority riots during the 1960s were commodity riots.[331]

Disorders in Miami and Crown Heights, Brooklyn during the 1980s and 1990s were marked by inter-ethnic violence, suggesting a return to communal type disorders.[332] But the 1992 Los Angeles riots demonstrated that something more complex might be developing. The main targets were stores and structures symbolic of authority, but the ethnic diversity of the arrested persons was something new. There seemed to be a new element of interethnic and interclass conflict involved that had the potential to make disorders more dangerous. These developments showed the importance of taking intergroup tensions seriously.

The 1992 LA riot did not begin with an arrest, as many of the 1960s riots did, but with the announcement of a trial verdict. The difference is important because it began with an anticipated, yet unscheduled event that allowed crowds to gather quickly. Unlike the 1960s, rioters used more firearms and assaulted fire department personnel more frequently. Fifty-five people died as a result of the riots. Unlike riots in the 1960s where most of the fatalities resulted from National Guard and law enforcement fire, most fatalities in LA were caused by rioters or people defending themselves from them.[333] The official studies of the mid-1960s riots, the LA riots, and the Crown Heights riots all noted that municipalities were reluctant to activate their disaster plans and sought to downplay events until they were out of hand. [334]

The turn of the millennium saw a shift back towards commodity riots, aimed at various social issues such as workers' rights, globalization, and the environment. The 1999 World Trade Organization protests in Seattle began peacefully but quickly turned into disorder, with both violence and vandalism. Multiple riots in the 2000s and 2010s have been about police force against African Americans, including riots in Cincinnati, Ohio in 2001, Oakland, California in 2009, and Ferguson, Missouri in 2014. 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.[335] In 2017, a white-supremacist protest in Charlottesville, South Carolina resulted in the murder of a counter-protestor.

Riots do not always stem from protests. Some are situational, such as riots following sporting events or riots 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.[336] A riot arising from the 1977 New York City blackout led to over 1,000 fires and 1,600 stores being looted.[337]

Prolonged power outages and natural disasters like flooding or earthquakes often heighten a community's fear of subsequent civil disorder, mainly looting. However, disaster and recover experts say that the risk of looting is widely overstated and sensationalized by the media, and disaster situations actually promote cooperative behavior in communities.[338] 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.[339]

Protest and Civil Disobedience

Organized protest has long been a cherished right of Americans and a hallmark of the right to freedom of speech. Nearly all protest is peaceful. For local governments, the right of citizens to protest must be balanced against the rights of non-protesting citizens to conduct their own business. Typically, this is accomplished by rules designed to permit non-protesting citizens to move freely and to respect private property. Use of the street requires a street use permit because it closes the street to other users for the duration of the demonstration. When conflict arises between demonstrators and law enforcement, it is frequently centered on the use of streets and private property.

Civil disobedience also has a long history in the U.S. It is the peaceful refusal by a group of people to obey laws or pay taxes that they regard as unjust and 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 the peaceful nature of most protest and civil disobedience, they are disruptive and have the potential to degenerate into violence, as illustrated in the examples above. The 1968 Democratic Convention is the archetype of this type of disorder. Most planned events involve a protest rally or march. Protest leaders and law enforcement can meet before the event to develop mutual understanding and often do. Sometimes, this pre-planning does not work because one or both sides will not or cannot control its people on the street. The use of the internet and social media to organize events has allowed law enforcement to obtain intel prior to events. However, both new technology and policy are preventing some surveillance activities. Online communications are increasingly being masked by groups who do not want the police to know about their plans.[340] Additionally, a surveillance ordinance enacted in Seattle in 2017 requires city council approval (after at least one community meeting) of all surveillance equipment used or sought by city departments.[341]

Strikes

Strikes are the organized stoppage or slowdown of work in order to force an employer to grant concessions. Today many strikes are legally protected. Some critically important workers do not have the right to strike. The vast majority of strikes are legal and peaceful. They are disruptive to the businesses or organizations involved, but they have limited impact on the whole community. Examples of strikes that affect the whole community have become rare and are often illegal. The air traffic controllers' strike of 1981 was one example.

There is no clear definition of a general strike, but it involves a work stoppage by a substantial number of workers across industries in a city, region, or country. They are used to achieve broad economic or political objectives, rather than negotiate with a specific company or organization. There has not been a general strike in the United States since the Great Depression. They are very hard to organize and maintain.

7 1.2 History

Seattle has experienced periodic civil disorder, large-scale disruptive protest, and strikes throughout its history. The issues have been different in each case. The tactics used in the disruptions have also evolved.

1886 Anti-Chinese Mob

Seattle's first large civil disturbance occurred in 1886 when a mob attempted to evict Chinese residents from the city. The mayor called out the militia to prevent the expulsion. The mob resisted. Fighting erupted and the troops fired on the crowd, killing two people.[342]

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 violent incident. After 1919, the labor unrest declined.

The 1960s

After 1919, there were no large incidents of civil disorder until the 1960s. During those upheavals, Seattle remained a secondary site for national trends. As with the rest of the nation, Seattle experienced strife connected with racial tensions, the Vietnam War, and the youth movement.

1967 Post MLK Assassination Disorders.

The late 60s were a period 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.[343] 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 University District Parties.

The 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.

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.[344]

1992 Rodney King Verdict

The night of the Rodney King verdict, 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 did occupy I-5 for a while, shutting down traffic.[345]

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 (bean-bag, 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 saw a smaller downtown protest and the night 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, 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 in committing 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.[346]

2001. Mardi Gras Riot

In February 2001, chaos erupted for two consecutive nights during Mardi Gras. A crowd 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 between $100,000 and $200,000. This was a pure riot, with no element of protest involved. An after-action review recommended intervening to disperse the crowd sooner.

2017. Inauguration Day Shooting

Mostly peaceful protests happened throughout the city on January 20, 2017, the day Donald Trump was inaugurated as president. No violence occurred during the day, although police confiscated wooden poles, pipes, flares, and hammers from protestors in Westlake Park.[347] 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.[348] A married couple, who are believed to have come to the protest to invoke violence, were charged with the assault.

7 1.3 Likelihood of Future Occurrences

The social conditions cannot be predicted, but as long as people have strong passions about social issues, there will be instances of unrest. While earlier events 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

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 similar to the 1969 University District events but had more conflict between people in the crowd 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.

While it's unclear whether political violence is increasing, there is a perceived political polarization occurring in the United States that 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. Social media may be changing the risk of social unrest as well. "Cyber troops" are government or political party actors who strategically manipulate public opinion over social media. 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.[349] It is unclear whether these emerging political challenges will increase the amount of social unrest. Seattle's emergence as a leading cultural and economic center increases the chance that controversial events like WTO will occur here in the future.

7 1.4 Vulnerability

Seattle is the social and economic hub of the Puget Sound region, making it highly exposed to social unrest. Social disruptions are often planned and target community vulnerabilities, places, or systems where pressure will be most strongly felt.

Most disorders in Seattle occur in locations that already have a lot of public assemblies (Downtown, Capitol Hill, and the University District), around large public institutions (the Federal Building, the University of Washington, Seattle Central Community College, or the King County Jail), and occasionally on major transportation routes like I-5.

Large-scale incidents require large numbers of police officers. Mutual aid is a critical component of a successful response. Bringing in officers from neighboring jurisdictions is a common occurrence, but it is also a vulnerability because it requires extra time and planning.

The greatest vulnerability is the transportation network, as it creates the greatest disruption to 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. The only mitigating factor is that traffic is already frequently bad so many drivers are used to slowdowns.

Many businesses are vulnerable to civil disorder. Downtown is a frequent site of demonstrations. The WTO protests closed large parts of downtown at the start of the holiday season. Some businesses are direct targets of property crime. Others suffer indirectly due a lack of business. The holiday season is an especially vulnerable time for retail businesses.

On several occasions ethnic, racial, religious and political groups have been targets of mob violence. Most of the examples from Seattle's history are long in the past. The Jewish Federation shooting, although it was not mob violence, provides evidence that the sentiments that lead to mob violence are still with us. The current events around 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 shift towards communal conflict. Groups or communities that are perceived to be connected with hot button topics are especially vulnerable.

Confidence in government and community reputation are two factors that are especially vulnerable to these types of events. They are 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. Besides the loss of faith in authority, a community's reputation and confidence in itself are sensitive to conflict and disorder.

7 1.5 Consequences

Because the pace of social change is so much faster than the changes in physical forces that cause floods or earthquakes, it is impossible to talk about "100-year civil disorders" the way we talk about "100-year floods." The risk of social unrest is not constant, like many natural hazards, but fluctuates with changing political, economic, and social climates.

Most incidents of unrest are confined to one neighborhood. They feature widespread minor property damage and injuries due 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.

Public Safety

Public safety is always the number one concern during socially disruptive events. Any event that involves heated confrontation between groups can degenerate into violence, even if the original event was supposed to be non-violent. Nationally, many civil disorders have resulted in fatalities. Until 2001, Seattle was very lucky and had not suffered loss of life through many demonstrations, protests and large confrontations. That changed in 2001 when Kris Kime was struck in the head and killed during the 2001 Mardi Gras riots.

We do not know how many injuries have occurred. Many injuries resulted from the WTO protests, but the total is not known. The examples given in the press include bruises, sprains, some broken bones, and the shooting that occurred at the University of Washington. Several police officers have been injured as well.

The growing conflict between political opponents raises concerns about future violence. The University of Washington Inauguration Day shooting, a shooting that occurred at a Republican congressional baseball team practice in 2017 that injured Representative Steve Scalise, and the killing of a counter protestor at the 2017 Charleston protest are some examples of recent political violence. According to the Anti-Defamation League, right-wing and left-wing extremists accounted for 74% of domestic extremist killings in 2017,[350] compared to 29% in 2016.[351] It is possible that extreme political groups will continue to use violence if there continues to be feelings of deep political divides in the U.S.

It is probable that there will continue to be future disorders directed mostly against property. The destruction of property has been selective and will likely be selective in the future. Most of it is aimed at government facilities and establishments that are perceived to be at the root of whatever controversy that sparked the disorder. So far, the damage has been limited to vandalism and, less commonly, arson.

One of the most insidious impacts of civil disorder is psychological. Following a civil disturbance, most people in a community feel violated regardless of their opinion on the issues at hand. The amount of live media coverage today magnifies these feelings. People watching events on their television sets or connected through real-time electronic communications feel personally connected to what they are witnessing. This mood of mass victimization is the most widespread effect of a civil disturbance. These effects can last for years.

There can also be indirect impacts of social unrest. Cities often worry about being stigmatized and losing investment and tourism as a result, especially when violence has been highly visible.[352] The Los Angeles Times reported that commercial real estate investment and tourism slowed down after the L.A. riots, in some areas for years. Seattle's disorders have never been scrutinized as much as those in other locations. If Seattle's disorders continue to be secondary events to larger disturbances elsewhere, it is unlikely the city will suffer any economic backlash.

While it is impossible to know what groups or issues could be involved in a future conflict, the worst type of incident Seattle could face would feature a large, violent crowd, an overwhelmed police force, and conflict between groups. It could be a large, more violent WTO-type protest or large-scale violence directed at a minority group.

These incidents would be spread over several neighborhoods and a longer duration of time. They might involve large groups of people organizing to harm other groups of people. Property damage would be more severe. Given that Seattle's biggest incidents have occurred when Seattle is the focal point for a large international or national issue, there would probably be people from outside the area coming to participate. The reputation of the community and government would probably be severely tarnished.

7.2 Attacks

- Attacks can be perpetrated by many different actors with different motivations, such as terrorists, violent extremists, and targeted violent offenders. All use violent tactics to harm people and/or property.
- 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 cyber-attacks, biological hazards, infrastructure failure, and hazardous materials incidents (including bombs).
- The 9/11 World Trade Center attacks in New York City critically 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. Threat actors are more likely to use small-scale tactics in today's security-conscious environment to avoid disruption of their plan.
- The threat of terrorism and violent extremism has grown with the interconnectedness afforded by the internet. Terrorist organizations can reach anyone around the world to support or participate in attacks. The openness of the internet allows for the disconnected/autonomous sharing of ideas, tactics, and successes that motivate others to act.
- The number of active shooter incidents has increased over the last decade. Intense media coverage of active shooter events has created a heightened sense of risk despite these events being relatively rare.
- 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.
- Seattle has experienced attacks perpetrated by domestic terrorists and other targeted violent offenders. However, Seattle has most commonly endured attacks targeted at property, active shooter events, and activity related to terrorism.
- Seattle has many public spaces and locations vulnerable to attacks, with the densely-populated downtown area being most vulnerable.

7 2.1 Context

Violent attacks can be perpetrated using a wide variety of means, such as bombs, chemicals, firearms, biological agents, and vehicles; all intend to do harm to people and/or property. Some of these means are covered in accompanying chapters. Cyber-attack is covered under cyber-attack and disruption, bombs are covered under hazardous materials, bioterrorism is covered under disease/pandemic influenza, and aircraft under transportation incidents. This chapter focuses on other intentional, violent attacks including terrorism, violent extremism, and targeted violence.

Terrorism

Despite nearly two decades of robust counterterrorism and homeland security efforts, forecasting potential terrorist targets and events continues to be a difficult, if not impossible, task at the national and local level. In comparison to other countries, the United States historically has had few terrorist acts committed within its borders. This was completely changed by the attacks by Al-Qaeda terrorists on New York City's World Trade Center and the Pentagon on September 11, 2001. In October-November of 2001, several incidents involving anthrax spores placed in the U.S. mail generated new and real fears about the use of chemical and biological agents. The creation of the federal Department of Homeland

Security and the city's participation in the Top Officials (TopOff) anti-terrorism exercises in May 2003 underlined Seattle's need to confront the threat of terrorism.

The 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."[353]

Terrorism can be differentiated as international or domestic. International terrorism is "committed by a group or individual, who has some connection to a foreign power or whose activities transcend national boundaries."[354] An example is the September 11, 2001 attacks on the World Trade Center and the Pentagon. Domestic terrorism is "acts of terrorism perpetrated by individuals and/or groups inspired by or associated with primarily designated U.S.-based movements or organizations that espouse extremist ideologies of a political, religious, social, racial, or environmental nature."[355] An example is the 2001 UW Center for Urban Horticulture firebombing.

The other definition associated with terrorism is Homegrown Violent Extremism (HVE). HVE is "a person of any citizenship who has lived and/or operated primarily in the U.S. who advocates, is engaged in, or is preparing to engage in ideologically-motivated terrorist activities (including support to terrorism) in the furtherance of political or social objectives promoted by a foreign terrorist organization but is acting independently of direction by the foreign terrorist organization."[356] An example is the 2013 Boston Marathon bombing.

Some of the groups that have employed terror tactics in the United States include racist groups like the Ku Klux Klan (KKK) and the Aryan Nations, radical environmental groups, and groups with ties to foreign terrorist organizations like Al-Qaeda or Hamas. The Congressional Research Service identifies domestic terrorism ideologies as supporting animal rights, environmental rights, anarchism, white supremacy, anti-government ideals, black separatism, and beliefs about abortion.[357]

The FBI lists three priority factors contributing to the current threat of terrorism.[358] First, the internet allows domestic and international actors to have an accessible platform to radicalize and recruit individuals who are receptive to their extreme messaging. Second, social media sites have allowed terrorists to more easily access and communicate with people living in the U.S. Lastly, identifying HVEs, or sympathizers, who have radicalized and aspire to carry out an attack.

Terrorist organizations are now espousing the "leaderless resistance" model for fighting people that they view as their enemies. By advocating independent actions by individuals or small leaderless cells, this strategy seeks to prevent authorities from connecting illegal activities to the organization's command and control structure. Individuals acting on their own perpetrate acts of "resistance" that support the espoused philosophy of the larger group.

Domestic Violent Extremism (DVE)

There are other acts of violence that are like terrorism events, but that do not have a connection to a foreign or domestic terrorist organization. Domestic Violent Extremism (DVE) is "encouraging, supporting, or committing a violent act to achieve political, ideological, religious, social, or economic goals."[359] An example is the 2015 Planned Parenthood arson in Eastern Washington.

Targeted violence differs from DVE in that it is not motivated by social or political ideologies, but rather uses a terror tactic as a means to satisfy personal grievances. The definition of targeted violence is "an intentional act committed by an individual or group for the purpose of (or resulting in) psychologically and/or physically affecting an organization or person associated with an organization, whereby the attacker selects a particular target prior to their violent attack."[360] This includes hate crimes, workplace violence, rampage shootings, non-terrorism suicide attacks, or cases of violence caused by mental instability. An example is the 2017 Las Vegas mass shooting.

Active Shooter Incidents

Active shooter incidents are a violent tactic that can be used by terrorism actors, as well as violent extremists or those inciting targeted violence. 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 definition of an active shooter incident is "an individual (or individuals) actively engaged in killing or attempting to kill people in a confined and populated area."[361] The active aspect implies that both law enforcement and citizens have the potential to affect the outcome of the event based on their response. 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.

There can be varying motives for an active shooter attack. Media accounts may claim psychopathology as the motive defining an active shooter, as in the student, fired employee or jilted lover who "snaps." However, active shooters have demonstrated extensive planning, deliberation and cognitive functioning in the commission of the attacks. Not all active shooters impulsively and randomly open fire in a public place. Like context and environment, an active shooter incident is defined by the action, not by the attacker's motive.

The FBI published a report on active shooter incidents in the U.S. between 2000 – 2013 indicating:[362]

- There were 160 incidents.
- The incidents resulted in 486 fatalities and 557 injuries.
- The trend appears to be that active shooter incidents are becoming more frequent, with an average of 6.4 incidents per year in the first 7 years and 16.4 incidents per year in the last 7 years.
- 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 arrived.

The FBI has published two subsequent reports since 2013, detailing active shooter incidents from 2014-2015[363] and from 2016-2017.[364] Since 2014:

- There were 90 incidents.
- The incidents resulted in 313 fatalities and 861 injuries.
- About 14% took place at educational institutions (13 out of 90).

Concern around school shootings in particular has grown in the U.S. due to heightened media coverage and the fact that these incidents violate the widely-held ideal that schools should be a safe place for children. However, while active shooter incidents may be trending upward generally, there is mixed evidence that school shootings are 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.[365] Another report found that the number of students killed in school shootings has actually decreased since the 1990s.[366] 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, fight, hide" 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 have the ability to lock all doors and they plan to install cameras at front doors to view visitors before granting access.[367] Any school security measure must be balanced with the fact that schools are public institutions and it is impossible to completely secure such facilities.

7 2.2 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. News stories that feature Americans going to Somalia and Pakistan make it seem as if this is a new phenomenon, but it dates back at least to the early 20^{th} century with heavy IRA fundraising in the U.S.

Seattle has also experienced DVE and active shooter incidents. Seattle events are listed as well as events with ties to Seattle.

1984. Seattle / Whidbey Island. 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. Tacoma / Seattle. Two bombs exploded in Tacoma in July, causing some property damage. A group calling itself the American Front Skinheads was responsible. They are also suspected of bombing a gay bar on Capitol Hill.

1996. Seattle. Jason Sprinkle started a bomb scare when he 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 to the reopening of Pine Street to traffic, but instead he caused a massive bomb scare. Nine blocks were evacuated during a busy weekday afternoon while the police investigated.

1999. Port Angeles / Seattle. Ahmed Ressam (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. Seattle. 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. Seattle. James Ujama pleads guilty to aiding the Taliban government in Afghanistan.

2006. Seattle. Naveed Afzal Haq 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.

2006. Seattle. Kyle Huff killed seven in a mass shooting at a house party in Capitol Hill.

2009. Seattle. Christopher Monfort set fire to police vehicles and shot into a police car, killing an officer. His motivations were deemed political.

2011. Seattle. Khalid Abdul-Latif and Walli Mujahidh 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. Seattle. Ian Stawicki shot and killed four people at Café Racer and killed a fifth person near downtown Seattle while attempting to escape.

2014. Seattle. Musab Masmari attempted to set fire to a gay nightclub in Capitol Hill while 750 people were attending a New Year’s Eve event.

2014. Seattle. Aaron Ybarra open fired at Seattle Pacific University, killing one student and injuring two students.

2014. Seattle. Ali Muhammad Brown 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. Seattle. Melvin Neifert 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.

Until early 2001, the Aryan Nations maintained a compound in Northern Idaho not far from Washington and stated that it would like to create a white homeland in the Pacific Northwest. The Southern Poverty Law Center recorded 26 active hate groups in Washington State in 2018, up from 15 in 2010.[368]

A review of the Seattle Police Department bomb disposal unit's incident log since 1995 shows two to six bomb hoaxes per year and a similar number of serious threats. Seven of them appear to be politically motivated. Victims included federal, county and city government facilities, women's clinics, and Jewish organizations.

7 2.3 Likelihood of Future Occurrences

It is impossible to predict the probability of future attacks. Given the number of potential weapons that can be used in violent attacks, it is also difficult to predict what tactic is most likely. Terrorist groups are always seeking new means of attack. In the past, tactics have included bombs, aircraft as missiles, vehicles, stabbing, chemicals, and firearms. Most troubling is the potential for using weapons of mass destruction: nuclear, radiological, chemical, and biological weapons.

The Washington State Fusion Center has statistically analyzed over 1,000 events that have occurred in Washington and in the U.S. over the last decade to identify any trends. Their analysis reveals:[369]

- The *Most Likely Tactics* include: active shooter(s), vehicle attacks, stabbing/cutting, bombings, and cyberattacks.
- The *Least Likely Tactics* include: chemical, biological, radiological, and nuclear bombing, hijacking/skyjacking, and maritime attacks.
- The *Most Likely Targets* include: human targets (particularly military, government, and law enforcement personnel), government facilities, commercial facilities (including public assembly, retail, and entertainment and sports venues), and transportation.
- The *Least Likely Targets* include: amusement parks, bridges, museums, national monuments or icons, and vessels.

The pattern of terrorism, DVE's, and targeted violence in the Seattle area has been a series of smaller scale attacks punctuated by the large arson attack against the University of Washington. Washington state has encountered more than 40 attempted and successful attacks in the past decade, an average of four per year. Recent national trends (2010 – 2016) reveal that right-wing extremist along with religious-extremist attacks are on the rise.[370] The typical trend has become attacks that are carried out by individual perpetrators who are loosely linked to a larger organization or ideological movement.

The growth of internet forums and social media activity increases the likelihood of people becoming radicalized. Threat actors are now using encrypted communication applications to attempt to circumvent authorities from detecting and preventing a threat.[371] Between 2015 and 2017, Twitter removed almost one million accounts for promoting terrorism.[372]

It is probable that future attacks will be small-scale actions carried out by individuals or small independent groups. Most previous attacks, especially those carried out by radical environmentalists and animal rights groups, have targeted property, but the Jewish Federation and Café Racer Shootings show that people can also be targeted. Based on the past events in Washington, DVE and targeted violence are the most common types of attacks in our region.[373] A large-scale terrorist attack, based on historic events, is assessed to be a low probability event, but cannot be ruled out. Both domestic and international attackers have proven they can deliver devastating attacks. Tall buildings in Seattle were among those on a potential target list leading up to the 9/11 attack. As long as the capability and motives exist, the risk of an attack is real. However, the threat of terrorism appears to be trending towards terrorist organizations promoting individuals to use simple tactics such as stabbing or vehicles to incite violence.[374] It is very difficult to detect individual actors; the expectation that all attacks can be prevented is unrealistic.

Active shooter incidents and other targeted violence are also impossible to predict but have occurred at common locations throughout the U.S. that also exist in Seattle, such as education institutions, places of worship, offices, shopping centers, event venues, parties, bars and restaurants, and family gatherings. Perpetrators of mass shootings are sometimes known to be a threat prior to the event but not all can be detected in order to take preventative actions.

7 2.4 Vulnerability

Being a large, diverse, densely populated, and open city, Seattle has many potential targets for attack. Terrorists and HVEs have demonstrated their desire to attack highly populated or popular areas to gain the greatest media attention and incite the greatest amount of public fear.[375] Downtown and adjacent neighborhoods have the greatest population density, which becomes even denser with the influx of daily commuters. Seattle also has a dense network of critical infrastructure. Many of our transport linkages connect through downtown and would be impacted by a large attack. With limited reserve capacity in surface transportation, this presents a vulnerability. The I-5 corridor is vulnerable to a major attack as it is critical to the local and state economy and transporting both people and goods.

Preparation can reduce vulnerability. After 9/11, all levels of government began efforts to better mitigate the effects of and prepare for terrorist attacks. Citizens have become more aware as well. An attempted 2009 Christmas Day bombing of a Northwest Airlines flight was stopped by alert citizens.

It is very difficult to construct a vulnerability profile for terrorism, DVE, or active-shooter incidents because they can happen in any community and in many different locations. Specific targets of active shooter events 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.

7 2.5 Consequences

While Seattle has never experienced a major terrorist attack with massive loss of life, the fact remains that there are groups in existence seeking to do harm to people and property. These groups exist in the Seattle community and can have the means to cause enormous harm. On the other hand, such groups face a number of obstacles that limit their capabilities. Post-9/11 reforms have been put in place to make it harder to act. Citizens are more alert and more likely to report something suspicious. Institutions have tightened security.

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.[376] A successful attack could result in bodily harm and/or loss of human life.

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 at terrorist, DVE, and active shooter incidents. 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. 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. An attack could deter people from going to public places, even if it occurred in a different city or country, which can hurt 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 and cannot be ruled out, 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, resulted 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. The U.S. has had number attacks by individuals or pairs. It is possible that Seattle could experience a CCA with similar or more severe casualties than past incidents.

7 2.6 Conclusions

It is nearly impossible to predict terrorism, DVE, and active shooter events. The pace and severity of attacks appears 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.

7.3 Cyber Attack and disruption

- Modern society is dependent on computer systems and the internet to maintain basic functions. They are increasingly used to run the infrastructure that supports dense, urban environments.
- Computer systems can face disruptions due to human error, intentional cyber-attacks, physical damage from secondary hazards, and electro-magnetic pulse (EMP).
- Cyber-attacks can take varying forms including amateur hacking, "hacktivism," ransomware attacks, cyber espionage, or sophisticated state-sponsored attacks. These attacks have the potential to cause internet or utility outages, leak or delete sensitive data and information, compromise critical infrastructure or services, or cause physical destruction.
- The City of Seattle faces daily threats of cyber-attack and disruption but has yet to experience a large-scale attack. The biggest concern is an attack on critical infrastructure such as the transportation, water, or power system. Manual backups still exist for these systems but would degrade overall service capabilities if it were required that these systems revert back to non-computerized technology.
- Cyber-attacks are becoming more frequent and sophisticated around the world. Despite improvements in security, the U.S. remains behind in mitigating the threat of cyber-attacks. Many experts believe that a major cyber-attack that will cause widespread harm to a nation's security and capacity to defend itself and its people by 2025.[377]
- Seattle faces a growing threat of cyber-attack 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 avenues for hackers.
- While a catastrophic cyber-attack or disruption has not yet occurred in our world, the consequences of such attack in Seattle could severely harm the public and degrade or halt basic city functions and services.

7 3.1 Context

Today, the internet touches almost every aspect of our lives. The internet is a "network of networks that consists of millions of private, public, academic, business, and government networks, of local to global scope, that are linked by a broad array of electronic, wireless, and optical networking technologies." Seattle, like the rest of the world, has become incredibly dependent on the internet and digital systems to maintain basic city functions such as communications, public safety, critical utilities and services, transportation, business and commerce, and more. Cyber-attack and disruption is a hazardous threat arising from intentional or unintentional incidents that cause a breach in security, damage to digital devices and networks, or a network outage. Digital systems can be damaged by human errors, cyber-attacks, electro-magnetic pulse (natural or man-made), or physical damage as a secondary impact from another hazard. A prolonged outage to digital infrastructure could have catastrophic impacts for the community.

Many modern telecommunications systems rely on digital connections, including large components of Seattle's private and public communications networks. The City of Seattle's communications infrastructure is discussed in the Community Profile. While parts of the City's telecommunications still use analogue connections, many systems are moving towards Voice Over Internet Protocol (VOIP), or communications delivered over Internet Protocol networks. Disruptions to telecommunications are discussed here because of their strong tie to digital systems.

Causes

Electromagnetic Pulse (EMP)

Electromagnetic pulse is an intense burst of electromagnetic energy resulting from natural (e.g., solar storms) or man-made (e.g., nuclear and pulse-power device) sources. Both types can destroy or damage unshielded electrical and electronic equipment. Solar storms can induce extreme currents in wires, disrupting power lines, and causing wide-spread blackouts to the communication cables that support the internet.[378] There is still much we do not understand about how effective nuclear weapons are as EMP weapons, especially lower yield bombs that terrorists or small states would probably use. The scale and scope of damage caused by an EMP could vary considerably based on the type of device, and the altitude and latitude of the detonation. A nuclear device detonated at high altitudes (30-400 km) could generate an EMP with a radius of effects from hundreds to thousands of kilometers.[379] While it could disable electrical and electronic systems in general, it would pose the highest risk to electric power systems and long-haul communications.[380]

Physical Damage

Cyber disruptions can also happen as secondary effects from other kinds of hazards. Earthquakes, floods, and fires can destroy computer and network equipment. Most of the time the 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 wide-spread and possibly prolonged. Communications can be disrupted by physical damage to copper or fiber cables or radio equipment located on buildings. Damage to cables has accidentally occurred during construction or repaving projects, causing temporary internet and phone outages for thousands of customers.[381]

Indirect Effect

Other hazards or human error can have effects on digital networks and information. Power outages can create cyber disruptions. In 2006 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, much of the City's communications equipment sits under high-powered 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.[382] Human error can also play a role in cyber-related incidents. An unintentional release of sensitive digital information presents a potential threat to personal and financial security.[383]

Cyber Attack

The City of Seattle experiences attempted cyber-attacks on a daily basis but has avoided a major compromise so far. A cyber-attack is "an attempt to gain unauthorized access to system services, resources, or information, or an attempt to compromise system integrity."[384] Cyber-attacks are intentional and can be carried out by individuals, organizations, or government entities. They range from unsophisticated attempts made by amateur hackers using existing computer scripts, to sophisticated attempts sponsored or carried out by international governments. There are many types of attacks in between these extremes (see Table). "Hacktivists" are individuals or groups who use hacking to promote their social or political ideology. Additionally, threat agents may use ransomware, malicious software designed to restrict access to a system or data until a sum of money is paid.[385] Espionage and data theft could degrade public safety, expose the City to financial risk and the public to identity theft. In 2016, Washington state victims of internet crimes lost over $24 million, mostly through fraud schemes.[386] Tactics used in cyber-attacks are always changing and becoming more sophisticated.

The U.S. Department of National Intelligence's 2018 Worldwide Threat Assessment states that multiple nation-state actors pose an increasing threat of cyber-attack to the United States in the next year.[387] The report goes on to say that while cyber-attack as a foreign policy tool has been mostly confined to low-level attacks, these state-sponsored actors have been testing more aggressive tactics in recent years. In 2016, the Department of Homeland Security stated that they were confident that Russia was responsible for hacking the Democratic National Committee (DNC) and leaking thousands of DNC emails during the presidential election.[388]

Table 7-1. Common Cyber Attacks and their Impacts

Type	Impact
Malware (ransomware, spyware, viruses, worms) Malicious software used by attackers to breach a network through a vulnerability, such as clicking a link, that automatically downloads the software to the computer.[389]	• Blocks legitimate access to components of the network • Installs additional harmful software • Obtains information by transmitting data from the hard drive • Disrupts components and makes the system inoperable
Phishing Fake communications (typically through email) appearing to be from a trustworthy source that allow hackers to obtain login information or install malware on a computer when someone interacts with their message.[390]	• Obtains a person's confidential information for financial gain • Obtains employee log-in credentials to attack a specific company • Installs malware onto a computer
Man-in-the-middle attack (MitM) Attackers insert themselves into a two-party transaction. Common points of entry include unsecure public Wi-Fi networks and computers affected with malware.[391]	• Interrupts a transaction to steal personal data
Denial-of-service attack (DoS) Attackers flood a site host or network with digital traffic until the target site/service cannot respond or crashes completely. A distributed denial of service attack (DDoS) is when multiple machines are used to attack a single target. Botnets, which are networks of devices that are infected with malware, are often used in DDoS attacks.[392]	• Legitimate users cannot access websites, online services, or devices • Slows down network performance
Structured Query Language (SQL) injection Attackers use malicious code on vulnerable servers to force the server to reveal	• Obtains contents of an entire database, including sensitive information • Allows attackers to modify and delete records in a database

information.[393] Can be done by submitting malicious code into vulnerable search boxes on websites.	
Zero-day exploit Attackers hack a network vulnerability before it is noticed and fixed by a patch or permanent solution.[394] Used by nation-state actors and sophisticated hackers.	• Allows attacker to plant malware into a system without the victim knowing

Computer Types and Threat Exposure

Computers permeate our society. Most of our financial and personal data is stored in networked computers systems along with our intellectual capital. They also control the machines that compose and maintain our infrastructure. Computers are increasingly being embedded into every day devices and products, such as phones, coffee makers, vehicles, home heating systems, and watches. Some of the networks connected to these computers are private, but most are connected to the Internet, the primary route for hackers.

General Purpose Computers

These are computers that built to handle many tasks. They include personal computers, most servers, tablets, and smartphones. They house most of our financial, organizational, and personal data as well as our intellectual capital. They are built from standard commercial off-the-shelf components like the Windows, iOS, or Linux operating systems. 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.

Specific Purpose Computers and the 'Internet-of-Things'

Specific purpose computers are systems with 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 that are integrated into a mechanical or electronic device. It is estimated there are over 10 billion embedded systems world-wide.[395] They have a wide range of applications from consumer electronics, industry, transportation, medicine, 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, a term has been coined "the internet of things" (IoT). While this merging of the physical and digital world promotes greater efficiency and convenience, it also poses greater security risks. The scale of the interconnectedness of these devices and their information sharing is being taken advantage of by hackers. They attempt to infect large segments of devices at a time to access data, cause an internet outage, or attack other computers.[396] In 2016, two apartment buildings in Finland had their heating system attacked, leaving them without heat or hot water for over a week.[397] These devices also pose a greater management challenge for IT security departments. IT departments do not always know when a personal device, which can be more vulnerable to hacking, is connected to sensitive servers or databases.[398] Some identified vulnerabilities of these devices include opportunities to hijack communication channels, to access sensitive information, to disrupt vital services, and to alter signals and data for malicious purposes.[399]

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. There are many specific types of SCADA systems. They provide real time data flow between sensors, workstations, and other networked devices in a system, as well as allow for monitoring and control.[400] They support both human-to-machine and machine-to-machine interfaces. They are used in power generation, transmission, and distribution; traffic control; water treatment, 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 on private networks to allow whole systems to be controlled. For example, all the devices in a water distribution system are linked to allow individual sites to behave appropriately given the status of the whole system.

SCADA systems are mainly vulnerable to attack because of issues in design, human interactions, and configuration.[401] Most 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" principal - that 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. According to Shodan, a search engine that catalogues online devices, the U.S. has over 57,000 SCADA systems connected to the internet, more than any other country.[402]

Many SCADA operators are not patching systems (a patch is temporary software to address bugs and security vulnerabilities) for concern that it will cause system outages, that a bug in the patch itself will crash the system, that it is not needed because systems are not directly connected to the internet, and 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.[403] Even if SCADA systems remain disconnected from the internet, past attacks have demonstrated that it is possible to deploy malicious code to computers that are not connected to the internet, as with the Stuxnet virus that was spread through infected flash drives. The U.S. Department of Homeland Security received 295 reports of SCADA-hacking incidents in fiscal year 2015, a 20% increase from the previous year.[404] Additionally, the U.S. Department of Defense has stated that while progress is being made towards more resilient infrastructure, these improvements are not on pace to achieve an acceptable level of risk within the next decade.[405]

7 3.2 History

2008 marked a cyber-attack turning point when the U.S. and Israel deployed a computer worm, Stuxnet, that destroyed Iranian centrifuges that are a key component of Iran's nuclear program. The event was the first documented of offensive cyber warfare that destroyed physical objects. It demonstrated that cyber-attacks can cripple critical, well defended infrastructure.

The following timeline comprises state, national, and international events that show the consequences of cyber-attack and disruptions.

2003. A power company representative unintentionally executed malware resulting in power outages for the Northeastern U.S. and part of Canada. The malware disrupted power grids across multiple states.

2008. Hackers disabled alarms, communications, and caused a crude oil refinery on the Turkish pipeline to explode, destroying operations and facilities.

2009 (Local). An electrical fire took Fisher Plaza data centers offline, bringing down several eCommerce sites including a credit card validation service. It was the third time Fisher had experienced downtime.

2014 (Local). Most of Washington State experienced a 6-hour 9-1-1 phone system outage due to human error. Around 4,500 calls went unanswered.

2015. The Deputy National Security Advisor confirmed that Russian hackers compromised a non-classified system over a several month-period to obtain information about the President's activities.

2015. As many as 22.1 million government employees, contractors, and other personnel records stored within the U.S. Office of Personal Management were compromised by a cyber-attack traced back to the Chinese government.

2017. A ransomware virus called WannaCry effected over 230,000 computers throughout the globe.[406] It did not require any user interaction to spread, but rather took advantage of vulnerable public-facing Server Message Block (SMB) ports. Boeing was attacked with the virus, but the vulnerability was small and there was no interruption to business.[407] 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 cyber-attack.[408]

2018. The City of Atlanta, Georgia and the Colorado Department of Transportation were hit with ransomware called SamSam. In Atlanta, attackers requested $51,000 in cryptocurrency to restore the city's data. It also caused a multi-week outage to Atlanta's website, hindering utility payments, business licensing, ticket processing, and court functions.[409] The attack also erased Atlanta Police Department's dashcam archives.[410] Colorado faced multiple attacks in the span of weeks, with the ransomware mainly affecting employee computers and not critical transportation systems.

2018. A borough in Anchorage, Alaska and the City of Valdez, Alaska suffered a ransomware attack that remained dormant in their computer systems for weeks before doing any damage.[411] Over 650 computers were compromised, and phone and email systems were inoperable. The borough manager in Anchorage declared the attack as an emergency.

7 3.3 Likelihood of Future Occurrences

The World Economic Forum predicts that the number of devices connected to the internet will grow from 8.4 billion in 2017 to 20.4 billion in 2020, greatly increasing the risk of cyber-attack.[412] Many experts believe that a cyber-attack on critical infrastructure will happen in the future. In 2014, the Pew Research Center asked 1,642 experts in internet evolution and technology if they think by 2025, a major cyber-attack 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).[413] Sixty-one percent of experts said 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 the internet. The major uncertainty that remains is how widespread an attack would be. Smaller attacks have already occurred that display the potential for major harm. San Francisco and Sacramento have both faced ransomware viruses on their metro systems. Additionally, an undisclosed municipal water system was hacked and had its levels of treatment chemicals changed, affecting 2.5 million customers.[414]

The City of Seattle is constantly facing attempted cyber-attacks on its digital systems. Most are minor and unsophisticated, but it is only a matter of time before a more sophisticated attempt is successful. The type of attack and extent of the damage is very difficult to predict. The recent ransomware attacks on Atlanta, Colorado, and Anchorage could signal that state and municipal governments are increasingly becoming a target for ransomware. Many government agencies face limited cyber-security budgets and capacity, which could make them an attractive target to the attacker. However, limited fiscal resources also make them less attractive in terms of potential monetary gain.

Seattle is a world leader in the technology and software industries. The city will continue to be on the cutting edge of implementing new technologies and devices that are connected to the internet. If cyber-security does not improve at the same pace, Seattle will face an increasing likelihood of cyber-attack.

7 3.4 Vulnerability

The density and interconnectedness of Seattle and its service network make it especially vulnerable to cyber-attack and disruption. Seattle routinely ranks high on Government Technology's Digital Cities Survey, which recognizes cities using technology to improve citizen services. In 2017, Seattle ranked 6th for cities with populations over 500,000, slightly down from 4th in 2016.[415] Critical facilities such as hospitals, fire stations, emergency medical services (EMS), and 9-1-1 centers are all increasingly relying on new technologies, which also makes them vulnerable to attack. If their functions were to be disrupted or compromised by hackers, it could threaten the safety and survival of people. Most of these emergency service facilities have back-up generators or battery backups that would allow them to operate during an outage but remain vulnerable to other types of attacks that would limit or interfere with their service capabilities.

Seattle relies on SCADA systems for many of its basic functions including maintaining and monitoring the water and power systems. In 2015, Seattle City Light (SCL) began implementing a new Energy Management System, that modernizes their SCADA system from the 1980s. The new system allows SCL to utilize more "smart grid technologies," such as wireless meters that automatically track wattage and transmit data.[416] Seattle Public Utilities (SPU) also underwent a major upgrade to their SCADA system in 2015.[417] Seattle's water transmission and distribution systems are mostly gravity feed which means that pumps are less important that in many other regions. Less reliance on pumps reduces the water system's vulnerability to cyber disruption. However, if control of the water or sewer system is compromised there could still be public health and environmental consequences. Despite these upgrades, the SCADA systems that the city relies on are still vulnerable to an attack that could disrupt essential water, sewer, power, and heating services.

The City of Seattle began working on "smart city" initiatives in 2015. The initiatives focus on implementing new digital technology to improve city functions, such as traffic lights that can adapt to traffic levels and sensors around the city to provide real time environment and activity data.[418] While these initiatives will bring important information and convenience to the city, they also make Seattle more vulnerable. Increasing the amount of infrastructure that relies on computing technology and the ability to connect to the internet also increases the number of avenues hackers have for an attack.

The "smart" city vulnerability is particularly salient for transportation. As more and more of our transportation systems become "smart" we incur a greater the risk that cyber-attacks and malfunctions will cause disruptions to our transportation system or worse: 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 breaking capabilities when the vehicle is at speeds under 30 mph.[419] 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 VOIP services, they are becoming vulnerable to attack and other digital disruptions. 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, among others. 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 large amount of products and money that move through the port makes the city's trade and business operations a target for cyber-attack.[420]

7 3.5 Consequences

Washington State estimates that a successful breach of critical networks could "severely diminish or destroy basic public utilities, fuel, health care systems, EMS, communications, and governance to at least 50% of the state's population."[421] An extended, local network outage would similarly halt most city functions. It would also harm the local economy, as many businesses would not be able to function. A City data breach that compromises consumer information could cause damage to the City's reputation and trust of its citizens.

The consequences of an attack on city infrastructure would depend on the systems affected and the problem's severity. The worst failures would affect SCADA systems that control critical transportation, power, water, health care, public safety, sewer, finance, and communications systems. While manual workarounds can be implemented, they greatly degrade overall system performance. In most cases the damage from computer failure will be temporary, but in some cases, it could cause physical damage. For a cyber-attack on infrastructure to be most effective, most experts conclude that physical attacks and sabotage would also be involved.

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 a temporary water shortage. Experiments have demonstrated that it is possible to destroy electrical generators by sending them instructions that cause them to overheat.[422] 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).

Physical attacks on infrastructure could also lead to cyber disruptions. The City of Seattle has built two data centers outside of the city, one in Spokane and one in Tukwila, to provide for continuity of operations in the event that local infrastructure is damaged. Terrorist groups and individuals who seek to harm the U.S. and Seattle may turn to cyber-attacks. There are cases of state-sponsored cyber-attacks that have damaged and destroyed critical infrastructure.[423] It is also possible that a conventional attack could be aided by cyber-attacks that disrupt a target's ability to respond. It is even more likely that terrorists would use cyber-espionage to collect intelligence on a target before a physical attack in order to make the attack more successful.

Some of Seattle's natural hazards such as flooding, or earthquakes can cause physical damage that triggers cyber disruption. The cyber disruption could feed back into the consequences of the primary hazard. Having good business continuity plans (BCP) or continuity of operations plans (COOPS) in place will greatly reduce the risk of cyber disruption following natural disasters.

7 3.6 Conclusions

Institutions in the Seattle area face hacking attempts every day. The vast majority of these are not successful, but it only takes one success to cause a major compromise. Moreover, due to the interconnected nature of modern society, Seattle's public and its institutions are dependent on organizations scattered world-wide. A compromise anywhere in the world could have major consequences for Seattle. Even though computer compromises and data theft pose a significant threat, the world has not yet seen a major disaster precipitated by cyber disruption whether accidental or intentional. Our perception of the severity of cyber-attacks seems to be changing. What once would have been considered a major attack, such as the 2016 WannaCry ransomware virus, is now becoming more commonplace in our computer-dependent world.[424] It is likely we will see an increasing number of cyber disruption incidents and attacks, but the severity of the direct or indirect effects on Seattle are still unclear.

8. INFRASTRUCTURE

8.1 Transportation Incidents

- This section covers all major transportation modes: aviation, surface (road, rail, and pipeline) and marine. It covers incidents where a vehicle accident is the primary impact.
- Some of Seattle's deadliest disasters were transportation accidents, but most occurred over 50 years ago when transportation systems were much less reliable. They are:
  - The sinking of the Dix off of Alki in 1906 that killed 42 people.
  - The 1943 crash of a B-29 bomber that killed 32 people.
  - Another bomber crash in 1951 that killed 11 people.
- While there have been huge gains in the safety and reliability of transportation systems, large, deadly accidents still happen today. In 2014, a "Ride the Ducks" vehicle collided with a charter bus full of international students on the Aurora Bridge. Five people died and many more were injured.
- Seattle's transportation systems have become busier, more congested, more tightly interdependent, and lacking in substantial reserve capacity. Disruptions in one part of the system can produce large consequences far from the site of the disruption and can spread from one transport mode to another.
- **Aviation**: The direct hazard for Seattle is a large aircraft crashing into a crowded part of the city. The odds of such a crash are low. Between 2012 and 2016, there were only 59 fatal aircraft incidents worldwide involving a loss of control inflight or a crash into terrain. In the context of millions of annual flights, aircraft incidents are rare.[425] Crashes are most likely to occur near flight corridors within two miles of an airport. Approaches and departures for SeaTac and Boeing Field, the country's busiest general aviation airport, take aircraft over the city.
- **Marine**: Seattle has a large port and ferry system. While incidents in the waters surrounding Seattle could be severe, incidents that impact Seattle directly are the greatest hazard. There have been no deadly marine incidents in the past fifty years, but there have been a number of large ship fires and collisions.
- **Rail**: Seattle has an active rail system that has traditionally transported freight but passenger service has been growing in recent years. 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.
- **Pipeline:** A spur of the Olympic/BP pipeline runs from Harbor Island to Renton, mostly along the City Light power transmission right-of-way. This pipeline carries mostly gasoline. Part of the same pipeline exploded in Bellingham killing three children.
- Transportation incidents can cause structural failure. Bridges are especially vulnerable. Barges and ships have collided with several Seattle bridges. The First Avenue South Bridge had to be rebuilt after a strike. Fires can also damage bridges. In 1975, the Alaskan Way Viaduct was damaged in a fuel tanker explosion.

8 1.1 Context

Transportation systems have been the source of some of the modern era's biggest disasters. The September 11th attacks exploited the air transportation system to inflict catastrophic damage on New York and the Washington D.C. area. Air, marine, and surface systems have all produced high casualty count disasters.

Much of the vulnerability to transportation accidents is built into a community's transportation infrastructure. For complete details on Seattle's infrastructure network, see the Community Profile. Some transportation accidents could fall under multiple categories. For example, the explosion of a fuel tanker on a bridge could fall under this section, hazardous materials, fires, or infrastructure failure.

An accident doesn't have to happen in Seattle for it to have a major impact on the community. Anytime a vessel originating here is involved in an accident, many Seattle residents are impacted. 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.[426] Figure [Transportation Fatalities by Mode] shows national transportation fatalities by mode for 2016.

Air Transport

About 95% of all accidents involve general aviation (private aircraft) and only 5% involve commuter, charter, and scheduled airlines. Almost half (48%) of fatal commercial aircraft accidents occur during the final approach and landing phase of flight. The second most common phase is take off and initial climb (13% of fatal accidents).[427] The FAA acknowledges this danger and requires airports to create special emergency plans that detail how they would respond to a crash within five miles from their boundaries. Nationally, despite the hundreds of thousands of planes that fly over urban areas, the number of crashes that have killed or injured non-passengers is very small.

Marine Transport

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 linkage. Great environmental damage has occurred as a result of oil spills.

Seattle is surrounded and bisected by water. Much of it is a working waterfront. Seattle is a major maritime center. The Port of Seattle is one of the largest in the U.S. It handles container, 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.

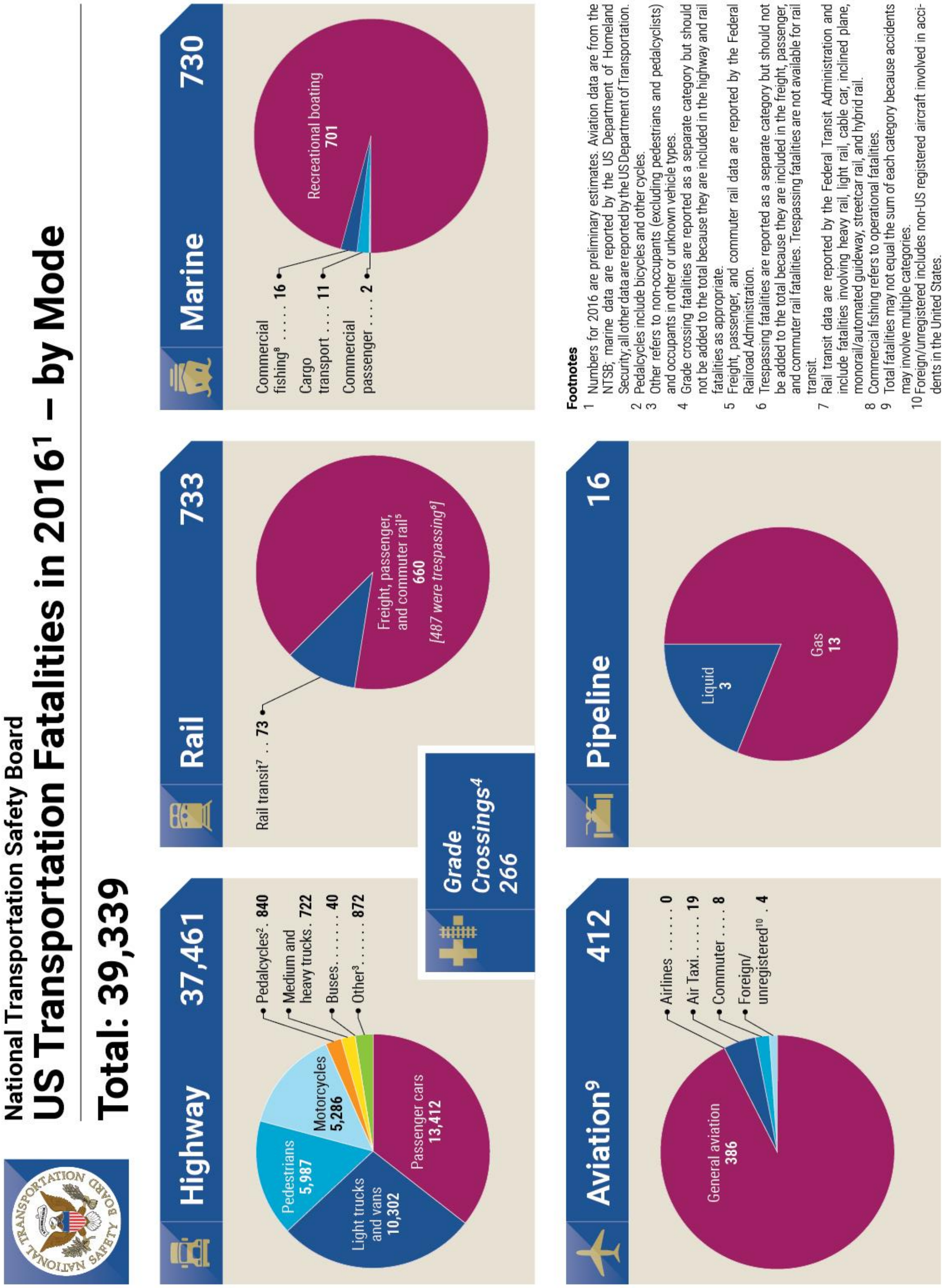
Surface Transport

Accidents on surface streets, highways, and railways can cause multiple fatalities, large hazardous materials releases, and damage to infrastructure. Nationally, large accidents have involved passenger buses, fuel tankers, and trail derailments. According to the Federal Highway Administration, the majority of weather-related car accidents happen on wet pavement or in rain.[428]

8 1.2 History

The time line of historic events focuses on accidents involving passenger vehicles. Seattle's most deadly disasters, aside from the 1919 influenza pandemic, were transportation accidents. The first was the 1906 sinking of a passenger ship off Alki that killed 42 people and the second was the crash of a B-29 bomber during World War II that killed 32 people. While safety standards have vastly improved since both of these events, they illustrate the potential for high loss of life for transportation hazards.

Figure 8-1. Transportation Fatalities by Mode



Source: Data & Stats. National Transportation Safety Board. Retrieved August 16, 2018, from https://www.ntsb.gov/investigations/data/Pages/Data_Stats.aspx

Aviation Overview

Going back to 1984, the National Transportation Safety Board has recorded 26 incidents regarding commercial aircraft in Seattle, none of them fatal. There was a total of 20 minor injuries that resulted from the incidents.[429] None of the accident reports indicated that aircraft were in danger of striking populated areas. While the Seattle area has not experienced a major crash in decades, there was a span of eight years mid-century when several deadly crashes occurred inside the city limits.

Maritime Overview

As indicated in the Community Profile, Seattle has an especially large maritime passenger sector. The Washington State Ferry system has never had a major accident. Despite this record, there have been 11 serious incidents since 1980. Five were minor collisions or near misses with other vessels. Four were dock ramming and two were groundings.

Seattle has become a major cruise ship terminal. There has never been a major accident involving them in Puget Sound. There have been some cases of Norwalk virus on Seattle based cruise ships.

Seattle is home to a major fishing fleet working on the Bering Sea. Fishing is a dangerous business and there have been a number of ships that have sunk, most recently the sinking of the F/V Destination in February 2017, taking with it all six of its crewmembers.[430]

Rail Overview

Seattle is a rail terminus for the BNSF and Union Pacific Railways. Historically, use of the rail network for passenger service has been limited, but has increased with the introduction of the Amtrak Cascades route between Eugene, Oregon and Vancouver, British Columbia, and the local Sounder commuter train. Amtrak Cascades has had roughly 800,000 annual passengers for the past 5 years and has a station in Seattle. While no major incident has happened within Seattle city limits, a new, faster Amtrak train traveling from Seattle to Portland derailed south of Tacoma on December 18, 2017 - its inaugural trip. Three passengers were killed and over 80 were injured.[431] Sounder Commuter rail, which runs between Everett and Tacoma, began in 2003. The Sounder has never had a major accident. As noted in the chapter on landslides, the tracks north of Seattle have been closed due to landslides. In 1997, a freight train was knocked into Puget Sound by a landslide.

Motor Vehicle Overview

Roadway accidents are a serious cumulative hazard in the Seattle area, but few individual incidents rise to the level of city-wide emergency, however tragic they are for the people involved. Nationally, several recent bus accidents have raised awareness that motor vehicle accidents can cause mass casualties. Several bus related incidents have occurred in Seattle. Accidents involving 10s or even 100s of vehicles have occurred in multiple locations, including Western Washington.

Major Accidents

Nov. 18, 1906. Maritime. The passenger ferry Dix sinks two miles off Alki. 42 fatalities.[432]

Feb. 18, 1943. Aviation. A B-29 Superfortress came down short of Boeing Field and struck the Frye slaughterhouse at 2101 Airport Way South. Eleven crew members, two firefighters and nineteen people on the ground were killed.[433] The crash caused a large fire, cut major cross-town power lines and released enough ammonia from the slaughterhouse to kill one fireman.

Jul. 19, 1949. Aviation. A C-46 cargo plane crashed shortly after take-off, cutting power lines over wide areas and striking two buildings in Georgetown. After coming to rest, it caught fire and exploded, setting six houses on fire. Flying debris damaged three other houses. A total of eleven homes were damaged or destroyed. Five people on the ground and two passengers were killed. Thirty-three people were injured.

Aug. 13, 1951. Aviation. A B-50 bomber crashed into Sick's Brewing and Malting at 3100 Airport Way and then bounced into the Lester Apartments, destroying one third of the building. The crash killed six people in the plane and five on the ground.[434] The location was about one mile north of King County International Airport, just north of where the West Seattle Freeway and I-5 join. The site is now occupied by I-5.

August, 1996. Motor Vehicle. A 42-vehicle accident that caused one fatality and 23 injuries closed I-5 southbound for four hours[435].

Nov. 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 32 passengers were injured.

Jan. 31, 2000. Aviation. Alaska Airlines Flight 261 crashes 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.

September 24, 2015. Motor Vehicle. A "Ride the Ducks" vehicle, from the popular Seattle tour company, veered into oncoming traffic on the Aurora Bridge, crashing into a charter bus full of international students. Five people died, and dozens were injured. The bridge was closed to traffic for roughly 12 hours.

Other notable incidents:

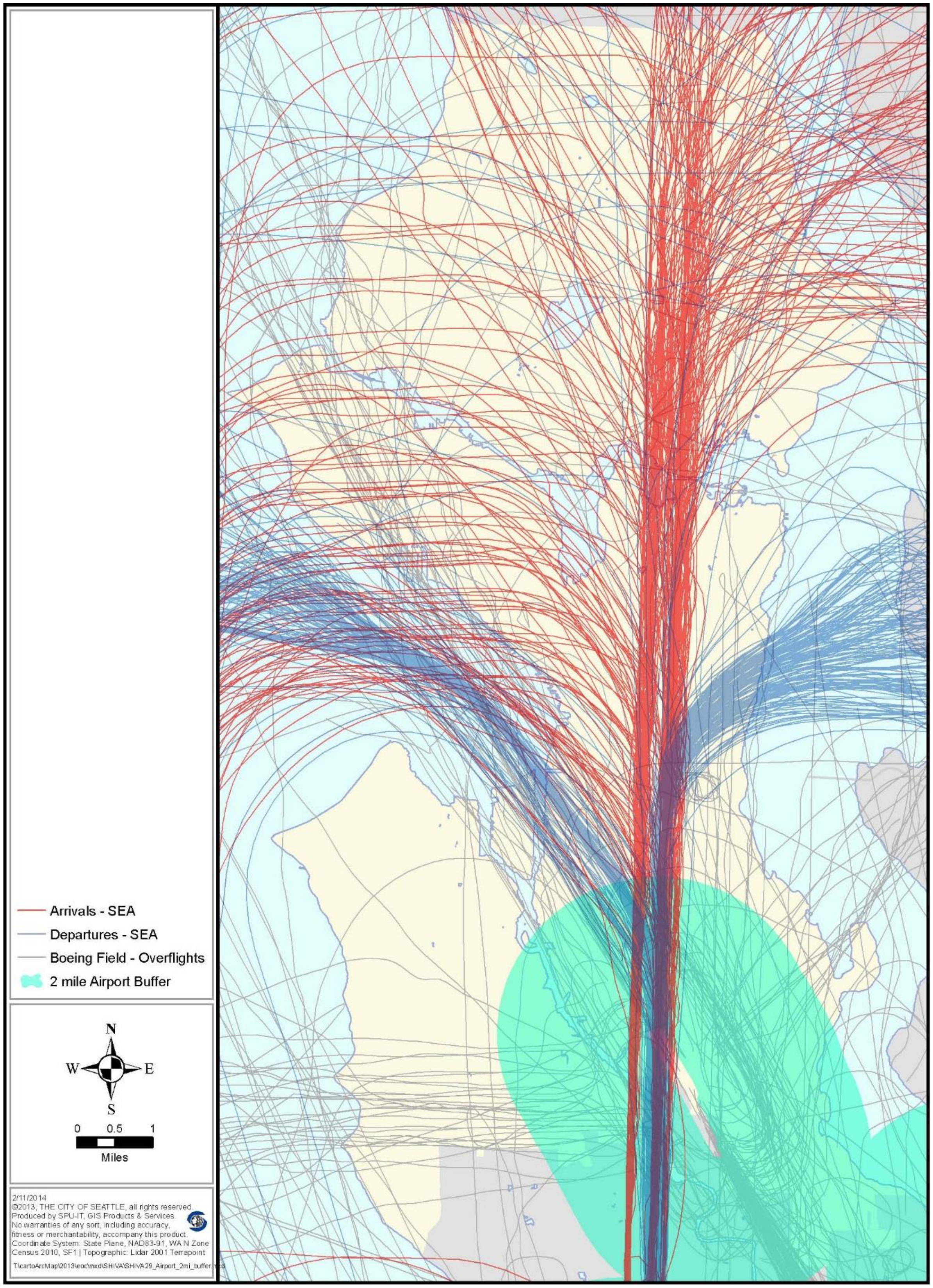
- October 18, 1984, Air Force Two and a private aircraft nearly collided eight miles from Boeing Field. The pilot of Air Force Two had to take evasive action to avoid a collision.
- December 19, 1984, only two months after the Air Force Two incident, a DeHavilland DHC-3 helicopter crash-landed on an athletic field and slid into a nearby street.
- October 10, 2001. A mechanical problem forced an emergency landing of Alaska Airlines flight 497. The accident occurred in California, but the plane was bound for Seattle.
- March 14, 2003. A commercial airliner landed on a SeaTac taxiway.
- May 8, 2003. A Seattle-based tour boat sinks in British Columbia. There were no casualties.
- Dec. 19, 2008. After a snowfall, a chartered bus slipped down an icy Capitol Hill street, plowed through a barrier, and teetered over I-5 near downtown Seattle. This was a near tragedy. No casualties resulted.

There have been several accidents in other parts of the county involving large commercial aircraft coming in populated areas, but such accidents are rare. Aviation safety systems have vastly improved since mid-century. In Seattle's case, the changes probably have a lot to do with shifting major commercial operations from King County International Airport to SeaTac and aircraft production to other locations outside the city.

8 1.3 Likelihood of Future Occurrence

Trends in transportation safety have long been pulling in two directions. On one hand, the rate and severity of accidents has been decreasing dramatically. On the other hand, the use of all transportation modes has been increasing. So far, the pull of the safety improvements that decrease the accident rate

Figure 8-2. Flight Corridor and Areas Within Two Miles of Airports



has been dominant. At some point, the saturation of transportation networks or other factors may reverse this trend, but there is no clear indication that that Seattle is reaching this point. Seattle will probably experience another major accident, but this probability seems to be holding steady or decreasing.

8 1.4 Vulnerability

Transportation accidents present two sets of vulnerability. The first is to the vessels and vehicles themselves and the people in them. The second is to everything and everyone around them. People in transit are in an inherently vulnerable position. They are densely packed into vehicles or vessels and then moved at high speed across environments in which they could not often survive without help (e.g. the ocean). When things go wrong, many passengers can get hurt.

As large vehicles and vessels move about, often containing hazardous materials, they are liable to affect people and the built environment around them. Areas near aircraft flight paths, highways, and the shoreline are more likely to be affected by an accident than other areas. Urban areas like Seattle are inherently vulnerable due to high population density and the cost and complexity of the built environment through which transportation systems run. Seattle is continuing to invest in its transportation network to accommodate new residents. The Link Light Rail service will span from Tacoma to Everett by 2040.[436] While safety will be a top priority in its construction, a denser transit network presents more opportunities for incidents.

Areas More Prone to Aviation Accidents

The areas that are most likely to be hit are the ones under or close to the flight paths, especially if they are within five-miles of an airport. Figure 8-2 -Flight Corridors and Areas Within Two Miles of Airports shows the area within five miles of both airports. Only Seattle's most southern sections—White Center, South Park, Dunlop, and Rainier Beach—are within five miles of SeaTac, but many planes take flight paths over the southern half of the city. King County International Airport (Boeing Field) is in the city itself. Planes often approach for landing from the north, over the Duwamish Valley and Georgetown, flying quite low as they near the landing area. FAA regulations state that except when necessary for takeoff and landing, aircraft must fly at least 1,000 feet above the highest obstacle over urban areas.[437]

Seattle is also indirectly vulnerable to accidents that disrupt transportation networks. Most of these slowdowns or stoppages are temporary, but they can be an inconvenience to travelers and an economic burden.

8 1.5 Consequences

Transportation accidents are a classic case of a hazard with a vast number of low-impact events and a minute number of high-impact events. Every year roughly 35,000 – 45,000 people die in transportation accidents in the United States.[438] The clear majority of these are the result of motor vehicle accidents. Most motor vehicle fatalities occur in passenger vehicles and small trucks, and on freeways and principal arterials.[439] While individual accidents are not large incidents, they have a large cumulative impact. The long-term trend has been down. Many programs and regulations have been established to improve safety and the means to handle the most frequent incidents fall well within the scope of daily operations of local government.

Occasionally, larger incidents occur that have a bigger, more lasting impact on the community and challenge the response capabilities of local government. Outlined below are characteristics of what we can expect from the "most likely" large incident and what we can expect from the "maximum credible" scenario.

With so many smaller transportation incidents, the most likely scenario is one that just exceeds the normal response capabilities of local government. This is in contrast to incidents like earthquakes in which individual occurrences are more likely to be high impact. The 1998 Metro bus incident was a good example of an incident that nearly exceeded normal response capability. It drew large amounts of resources from the police and fire departments. Special lighting was needed to search for survivors after nightfall and social services, such as lodging, were needed for the families of the victims.

The most likely scenario would present a slightly higher level of impact. Despite the different transportation modes that might be involved, there are some similarities in impacts.

1. There is high likelihood of fatalities. This is in contrast to other hazards in which the "most likely" scenario involves a lot more property damage.
2. The geographic scope would be limited to the immediate scene of the incident with a strong possibility that transportation routes through the impacted area would be blocked. Infrastructure outages are also possible.
3. The duration of the incident would be limited. It would be likely that rescue and recovery operations could be completed in less than a few days. Transportation and infrastructure outages would also be restored in a similar amount of time.
4. Neighboring buildings and the people in them will probably be affected to some degree, but the majority of the casualties will be among those on the vehicle or vessel.
5. Maritime accidents tend to involve more property damage, especially when ships collide with bridges and other infrastructure.
6. There is a high likelihood of secondary hazards, especially fires and hazardous material spills. Transportation incidents can also be secondary hazards themselves.

Overall, the most likely major transportation incident will be short, but intense. Unless there is major infrastructure damage (i.e., to a bridge) the recovery will probably quick and complete.

8 1.6 Conclusions

Transportation safety has improved dramatically since the early days of motorized and air travel. Most of the major historical incidents date back to this earlier time. Still, transportation accidents hold the potential to produce very high casualty counts. As the amount of transportation 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 the maximum credible events. The most likely events remain accidents that cause mass casualties among passengers and limited damage to surrounding infrastructure with the major caveat of damage to bridge or overpass structures.

8.2 Fires

- Fires include a broad range of incidents from wildland fires especially where urban areas abut natural areas, large single structure fires, multi-structure fires, ship fires, industrial fires, brush fires, and vehicle-related fires.
- Seattle has lost fourteen firefighters since 2000 and 104 civilians since 1994.[440] The trend in the number of casualties seems be dropping, but it is still statistically impossible to verify the drop because of the small amount of data. The number of structural fires has also been dropping, but the dollar losses have not been.
- 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. In an unintended consequence, many owners chose to leave floors unoccupied because the costs of retrofitting outweighed the revenues they produced.
- 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.
- While wildfires have not been a threat to the Puget Sound area traditionally, climate change is increasing the likelihood of wildfire west of the Cascade Mountains. A wildfire is still unlikely in Seattle because the city is far from any wildland areas but could threaten some city infrastructure located in wildland areas. Seattle regularly gets brush fires along roadways, such as I-5, that can threaten adjacent homes.
- Large structural fires remain a substantial risk and are most likely to occur in areas with older buildings, such as Downtown, the International District, First Hill, Ballard, and the University District.
- 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.

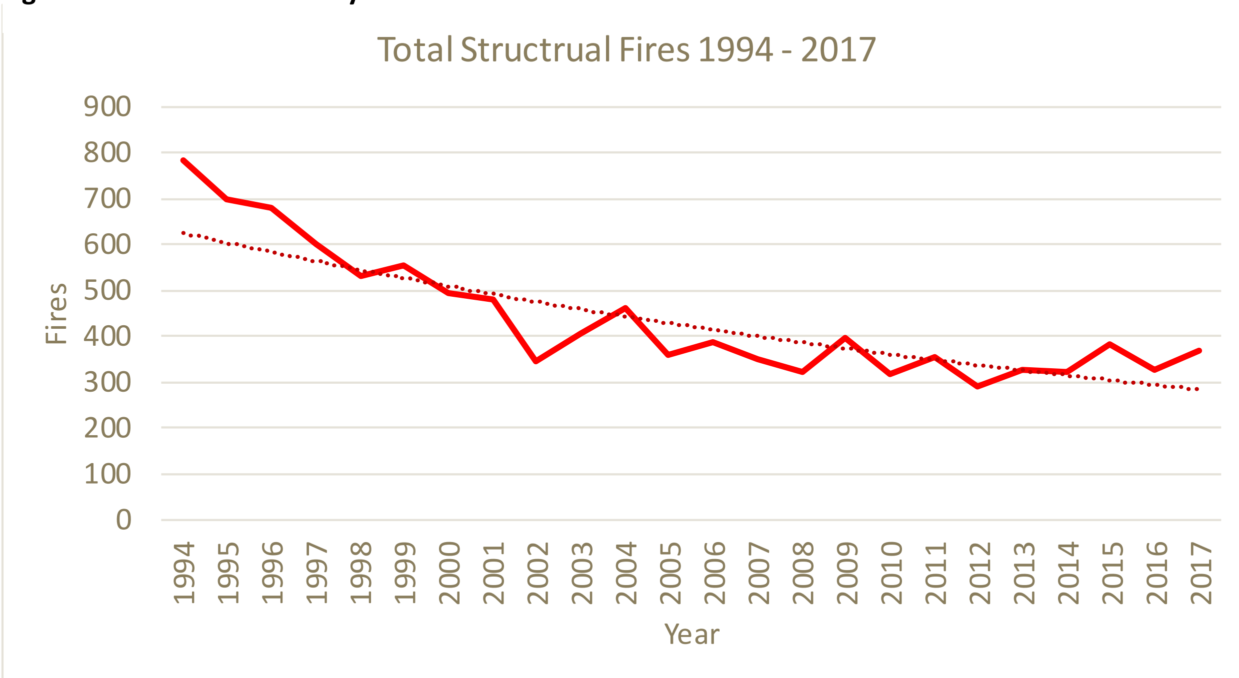
8 2.1 Context

Fires have long been a major hazard in urban areas. A series of catastrophic 19th century fires, including one in Seattle, led to the creation of modern fire departments. Even now, fires are among the deadliest of hazards nationally, with around 3,200 deaths per year (since 2006). The functions and capacity of the Seattle Fire Department (SFD) is discussed in detail in the Community Profile.

This section covers all major types of fires: multi-structure fires, large single structure fires, ship fires and fuel tanker fires. Seattle can also be affected by wildland fires in its Cascade watersheds. Electrical fires within the power system are a special category that is covered under the power outage chapter. Nationally, some of the worst urban fires have been in cities with a large urban-wildland interface. Seattle does not have such areas.

Nationally, structural fires are on the decrease, both in total number and in the number of deaths and injuries. Better education, a decline in smoking, and an increase in the number of smoke detectors seems to be behind this decrease.

Figure 8-3. Structural Fires by Year



Effective firefighting depends on speed. Firefighters have the best chance to respond effectively when they can detect a fire and reach it quickly in overwhelming numbers. The first step is to isolate the fire to prevent it from spreading; only then do firefighters try to extinguish it. Fires get out of hand when they spread too quickly to be contained (like the 2017 Santa Rosa fire), when automated suppression systems do not work properly, or when they occur in places that are difficult to reach.

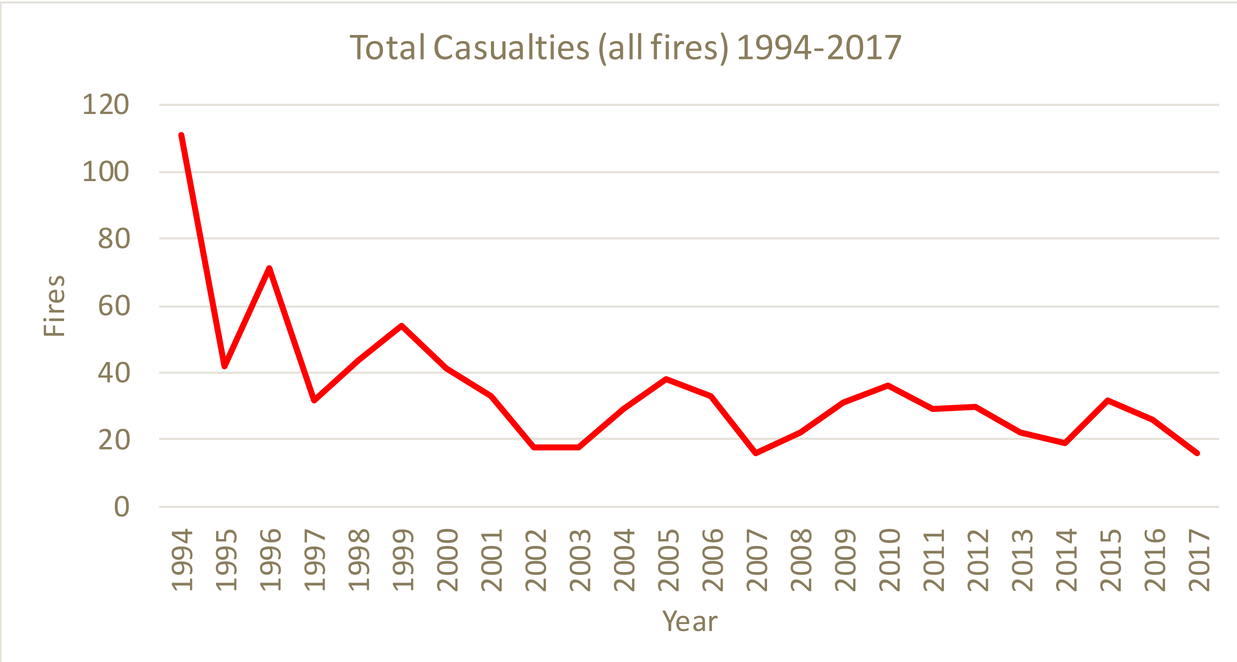
Fires can be a secondary impact of other hazards, as well as a trigger for hazards. Fire following earthquakes and during unrest are especially threatening. Damage to transportation infrastructure or security problems can result in fire fighters being unable to reach fires quickly or in adequate strength. An earthquake may damage the water distribution system, lowering water pressure at hydrants. 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. They can be extremely devastating. The 1906 San Francisco fire destroyed 28,000 buildings. Civil disorder presents the other major fire risk. Arson fires are commonly set during disorders. The 1992 LA riots produced large fires that engulfed whole city blocks. Some of these fires were left to burn after fire fighters were assaulted. The use of accelerants often makes these fires worse.

Since 2000, the number of structural fires in Seattle has decreased, following national trends, with a very slight increase after 2012 (see figure [STRUCTURAL FIRE TREND]). Since 2012, Structural fires in multi-family dwellings have increased more than fires in single-family dwellings. The overall decline in structural fires has occurred despite a building boom over the last decade that have added a considerable number of new structures Since 2013, there has been an average of about 345 structural fires per year. As with the rest of the country, a combination of better education, decreases in smoking and increases in the use of smoke detectors has contributed to fewer fires in the 21st century.

Besides the decrease in incidents there has been a decrease in casualties (see figure [Casualty Trend]). The trend in the number of deaths is less clear. Since 1994, the average number of fatalities has been 4, but 2000, 2005, and 2010 saw spikes with 11, 8, and 9 fatalities, respectively.

What has not decreased is the amount of property loss. While the number of casualties correlates with the number of incidents, property loss does not. This is because a few large fires dominate losses every year. This suggest that despite an overall downturn in the number of fires, the magnitude of events are staying large or getting larger. Structural fires result in average yearly property losses of about $15.5 million.

Figure 8-4. Fire Casualties by Year



Non-structural fires (i.e., brush, dumpster, vehicle fires, etc.) are another class tracked by the SFD. Like structural fires, vehicle fires have declined between 1994 and 2012, and stayed relatively flat, with an average of 232 per year since 2012. The other categories have not, they have held steady or slightly increased in recent years. It is not clear why.

8 2.2 History

Seattle is a city shaped by fire. The catastrophic Great Seattle Fire of 1889 consumed 60 acres of downtown Seattle just as the city was poised to become Washington State's leading urban center.[441] Amazingly, it caused no fatalities or major injuries. Equally impressive was the speedy and complete recovery. The fire occurred right before the biggest period of growth in Seattle's history. Seattle was able to totally rebuild the downtown within eighteen months, doing so with masonry instead of wood. This experience demonstrates how complete a recovery can be given the right circumstances and how hazard vulnerability can be mitigated during the recovery process.

Significant Fires After the Great Seattle Fire

SFD has kept records of all multiple alarm fires since 1912. While Seattle has not experienced an event as large as the Great Seattle Fire since 1912, there have been a number of large fires.

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 much ordinance, 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.

November 11, 1961. Pike Place Market. Fire destroyed 20 stalls and stores, a pedestrian overpass over Western Avenue, and a meat market connected to Pike Place Market. A new pedestrian overpass was constructed in 2017.[442]

March 20, 1970. Ozark Hotel. This arson fire killed 20 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 in often, but it was still vulnerable. It was in disrepair, had no sprinklers, and a poor escape route.

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). 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 though 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.

September 16, 1991. M.V. Omnisea. Another fish processor fire involved Seattle Fire units on site for five days.

September 21, 1991. Villa Plaza Apartment Fire. The day after the last units left the scene of the M.V. Omnisea fire, a huge fire broke out in the Villa Plaza Apartments. The complex was grandfathered in under the Ozark Ordinance and did not have sprinklers. There were no deaths, but 232 people were displaced. Because of the media stories alleging that it was a haven for criminals, many residents found it hard to find new housing.

January 5, 1995. Mary Pang Fire. An arson fire in a warehouse resulted in the deaths of four firefighters. SFD came under heavy criticism and undertook major reforms after this fire.

May 21, 2001. UW Center for Urban Horticulture. An arson fire set by environmental extremists caused $7 million in damage and destroyed years of research.

8 2.3 Likelihood of Future Occurrences

As noted above, the total number of incidents and casualties is decreasing for all structural fires and highway vehicle fires. This is a major success. It reduces the cumulative impact of all fires.

The amount of property loss is increasing rather than decreasing. It seems that the number of large fires is holding steady. Seattle is experiencing fewer fires, but a higher percentage of those that occur are major fires.

One very important fact the data show is that fires do not have to be large to cause injury and death. The number of casualties correlates well with the total number of incidents but very poorly with property loss.

The number of non-structural fires (any fire outside a building: trash fires, grass fires, vehicle, and ship fires) is holding steady with the exception of vehicle fires which are showing a major decrease.

Based on the trends and an analysis of the historical data, there is a strong likelihood that Seattle will continue to have fires that result in high property losses but that are less likely to result in high numbers of casualties.

The 1889 Fire remains the largest in Seattle's history. Seattle was a very different place when it occurred. The chance of another fire like it is remote. The most likely scenario for a multi-block fire is a post-earthquake fire. Large sections of Kobe, Japan were destroyed is a huge blaze following the M 6.9 earthquake. Damage to the water system crippled the response.

8 2.4 Vulnerability

A review of all multiple alarm fires reveals a clear profile of Seattle's vulnerability to major fires. Several factors emerge repeatedly:

- Businesses that contain a lot of fuel. Lumberyards, furniture stores, carpet warehouses, and other businesses using flammable materials are overrepresented in the record because fires started in these businesses are more likely to develop into major blazes.
- Apartments and hotels. These structures are vulnerable because of their high occupancy.
- Nightclubs, stadiums, and theaters are also vulnerable due to high occupancy.
- Substandard buildings.
- Arson Targets.
- Ships.
- Bridges.

In general, there are two types of fire vulnerability: 1) the conditions that allow the fire to spread, and 2) the concentration of people and property. Where the two factors overlap is the area of greatest vulnerability.

In the first category, factors that are more likely to turn an ignition into a major fire, are fuel-rich environments, substandard buildings, arson targets, and ships (because of the challenges in fighting them). To these must be added the capabilities of the fire suppression resources. Response time is a key variable. The National Fire Protection Association has determined that a "room and contents" fire will flashover to a structural fire within 5 to 10 minutes. The longer a fire burns without response the more likely it will spread to additional structures.[443] Therefore, a response time under five minutes is considered good. SFDs has set their own standard for the first fire engine to arrive on scene within 4 minutes 90% of the time. Between 2013-2017, they met this standard 83% of the time, on average.[444] In comparison, the Portland Fire Department responds under 5 minutes and 20 seconds 60% of the time. The Atlanta fire department has a response time of 7 minutes 90% of the time.

Building architecture governed by building and fire codes the other critical factor in reducing fire risk. Many high-population areas are now made from fireproof materials like brick, steel, and concrete that reduces the risk of fire spread. However, most of the city's residential structures are wood, which is vulnerable. In these places, the key variables are early detection, spacing between structures to isolate a large fire and easy access for fire trucks. Seattle building officials say that the majority of multi-family structures being built are wood-frame, because it is a cheap and abundant local material. This is the general trend along the West Coast.[445] 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.[446] 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 more vulnerable to a multi-structure fire than new areas.

The second category is concentration of lives and property. Seattle has the densest residential areas between San Francisco and Vancouver, B.C. and this density is increasing. More people are working and living in large structures. Density has many positives aspects like reducing sprawl but can put more people at danger if a fire does occur. The densest residential areas include Belltown, Capitol Hill, First Hill, and University District neighborhoods, with over 100 people per acre in some blocks.[447] Seattle's deadliest fire, the Ozark Hotel fire, occurred on the edge of downtown in the Denny Triangle area at 7th Avenue and Westlake. Because of the heightened vulnerability of dense areas of the city, more effort has been made to reduce frequency, mitigate the effects of, and heighten the response to fires in these areas.

In large buildings, the most critical factor is the functioning of passive and automatic systems. In high rises, the upper floors are impossible to reach from the outside and 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 of 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 improved. Seattle still has some older high-rise buildings, but these buildings are being replaced or retrofitted due to developmental pressures.

Structural fires can occur as a secondary impact from a civil disorder or earthquake. 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 resources are unable to command 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

Wildfire exposure is greatest near large open areas, especially those with large fuel loads. Few of these areas are close to high population areas. Areas near transportation corridors seem to have an increased frequency of fires, especially in the summer as brush dries out. A few times, brush along I-5 has burned, threatening homes adjacent to it and slowing traffic. SFD has been able to put these fires out using its own crews. Seattle has never experienced devastating urban wildfires as has happened in California, New Mexico, and Florida because it lacks large wildlands close to the city. Additionally, SFD has good access to most areas where they could occur. Wildland fires are a threat to Seattle's watersheds and power generation and transmission systems, which are in heavily forested, remote locations. Seattle Public Utilities and Seattle City Light maintain their own wildland firefighting capability to combat fires in the City's watersheds and project power generating equipment.

8 2.5 Consequences

Because of a long-term effort to reduce the effects of fires through fire codes, vehicle safety standard, public education, and professional firefighting services, the number of fires and the number of casualties is dropping, mainly through a reduction in structural and vehicle fires. Reducing yearly property loss has remained elusive mainly because yearly losses are dominated by a few big incidents.

Large fires are likely to happen again because there are so many potential sources. One of the main goals in any response is to contain the fire in the structure, vessel, or location where it started. Despite some tragic fires, the strategy of containing these fires has largely been successful. This reduces the likelihood of another conflagration like the Great Seattle Fire. While unlikely, it is also possible Seattle could experience a large outdoor fire like those that have occurred in southern California. Sometimes, even a single structure fire can be disastrous as in the case of the MGM Grand fire that caused 85 deaths or the Station Nightclub fire that caused 100 deaths.

Seattle could be affected by a wildland fire that threatens water and power infrastructure. If power transmission towers and lines are exposed to fire, it could cause outages, but they would likely be localized. Fire has also threatened dams that generate some of the city's electricity. Damaged equipment in at these sites would not cause outages but would require the City to purchase additional electricity from external providers. A fire in one of the city's watersheds could decrease water quality by increasing turbidity, harming aquatic life, and drawing down the City's reservoirs. The consequences of wildland fire outside the city are discussed further in the power outage and water shortage chapters.

Due to the factors outlined above, the scenario that Seattle is most likely to face directly is a large, deadly structural fire or a fire associated with a transportation incident. Large structural fires still occur every year. Despite all the mitigation efforts, it is not implausible for a major fire to occur in a vulnerable structure. The result could easily be a large number of fatalities and property loss. Damage would probably be contained as long as adequate resources could be brought to bear. Economic effects would probably be limited unless there was destruction of critical infrastructure, such as a bridge that had to be closed, forcing transportation detours.

8 2.6 Conclusions

With many high-occupancy buildings and densely populated areas, Seattle has a high exposure to fire loss. 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.

8.3 Hazardous Materials Incidents

- The 1984 disaster in Bhopal, India that killed over 2,200 people focused world-wide attention on the dangers of toxic chemical releases. In the U.S., 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.
- The U.S. Department of Transportation (DOT) collects data on hazardous materials incidents occurring in the U.S. during transportation.[448] Most are received from shippers, e.g., UPS or Federal Express. Since 1998, 838 hazardous materials incidents in Seattle resulting in total of $3,056,573 in damage, but no fatalities or injuries requiring hospitalization. There have been 13 injuries not requiring hospitalization and 15 incidents were classified as serious.
- The Seattle Fire Department (SFD) records hazardous materials-related dispatches. It lists 1,243 incidents from 1995 to 2017, with a spike in 2001 following 9/11 and the 2001 anthrax attack. Forty-four incidents were fires with hazardous materials components.
- Fixed sites are the most frequent locations for accidents, but transportation accidents are often riskier because they happen in uncontained spaces, they can be in close proximity to people, and responders usually have less information about the materials involved.
- Areas up to one-half mile downwind from an accident site are considered vulnerable, according the US DOT. An incident could affect thousands of people in densely populated sections of Seattle.
- Other hazards, such as earthquakes and landslides, could produce hazardous materials incidents.

8 3.1 Context

Harmful material in the environment has been a problem for a long time, but it has only been since the publication of books like Silent Spring (1962), and tragedies like the Bhopal chemical disaster (1984), that hazardous materials have become recognized as a significant hazard. Hazardous materials pose problems that vary widely in intensity and duration. While many materials pose long-term problems (e.g. asbestos, PCBs, etc.), this chapter focuses on incidents that pose an immediate threat to large numbers of people. Chronic problems have their own regulatory infrastructure outside of emergency management.

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) 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, EPA 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. The reporting requirements mandated by these acts have produced a rich data set of chemicals in the community.

Around 80% - 90% of accidents involving hazardous materials occur at fixed sites such as factories and storage facilities; the remaining 10% - 20% occur during transportation. Most of these incidents are small, however, and not reported to the SFD because facility staff are able to contain and clean them. 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.[449] Illegal drug labs or dumping can also pose a risk.

Transport incidents are usually 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 and chemical inventories. Hazardous waste dumps also present problems because they often house unidentified and unstable chemicals. An emerging concern is the increasing transportation of Bakken crude oil. This light, crude oil is more flammable than traditional crude. Bakken crude shipments began in 2012 and have increased to 1,100 tank cars per week being transported through the city in 2018.[450] 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 SFD, commonly referred to as the Fire Marshal's Office, 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 of the Fire Marshal's Office 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 can call on help from 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.

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 and 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. Responders can make matters worse by applying a material that will react adversely with the spilled chemical.

The possible use of chemical, radioactive, and especially explosives in a terrorist act significantly alters the risk profile for hazardous material incidents. Bombs are one of the most common methods of attack in many parts of the world. The use of chemicals is rare due to the difficulty of manufacturing the chemicals; however, the Tokyo Gas Attack that killed 12 and injured thousands in 1995 is an example of chemical weaponry. 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 uses 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. The amount of radioactive material released would likely not cause severe illness or death.[451]

8 3.2 History

The hazardous materials historical record does not extend past the early 1980s. Older records mix hazardous materials emergencies with fire emergencies. Constructing a long history is difficult, but since federal reporting requirements have taken effect, there is a wealth of data from local, state, and federal sources.

Prior to 1995, it is difficult to get consistent data. Two incidents stand out, however, in a review of multiple alarm incidents dating back to 1912.

December 4, 1975. Fuel Tanker Explosion/Fire on Alaskan Way Viaduct. (Also listed under Transportation Incidents and Fire). A gasoline tanker truck crashed and leaking gasoline caught fire, causing extensive damage to surrounding buildings. The fire caused a major downtown power outage when it burned though a power trunk line.

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.

Hazardous materials responses have been recorded by SFD since 1995. Between 1995 and 2009, SFD responded to 1,082 incidents, of which only three (or 0.2%) required more than one alarm. Of these three, only one was a pure hazardous materials incident; the other two were associated with fires. All three had biological functions. They were:

March 24, 1997. Fire with Hazardous Materials. Kincaid Hall, University of Washington. The zoology lab burned.

June 10, 1999. Bellingham Pipeline Explosion. Although this incident did not occur in Seattle, it focused attention regionally on pipeline safety. Seattle has a spur of the same pipeline that runs from Harbor Island to Renton. It transports mostly gasoline.

May 21, 2001. Center for Urban Horticulture, University of Washington. Arson fire.

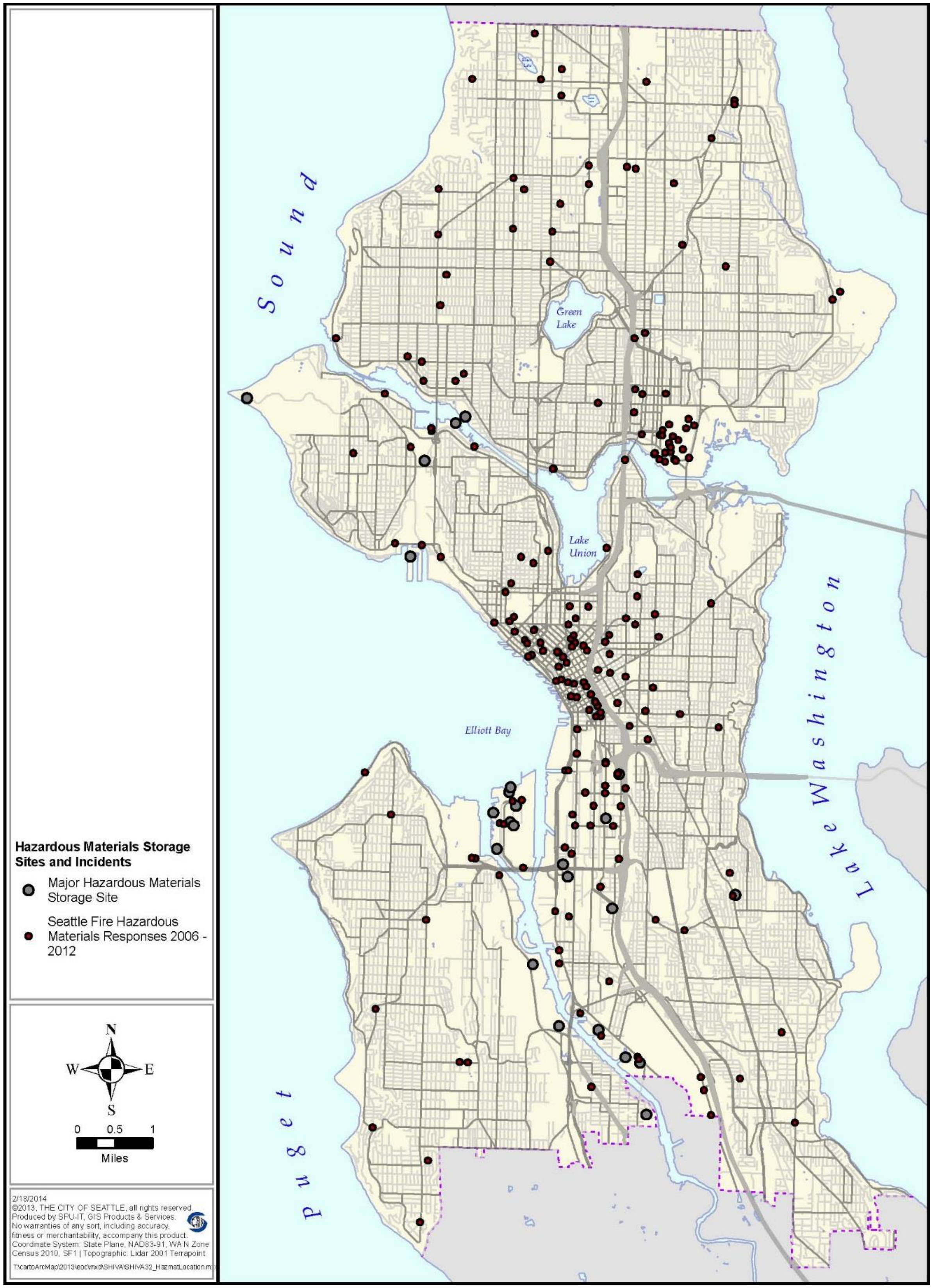
May 26, 2001. 509 Olive Way. Fire in a building housing many medical offices.

After the spike in 2001, hazardous materials incident dispatches fell steadily until 2008, where they have remained relatively flat since (See figure [Seattle Fire Department Hazardous Materials Dispatches]. Note: After the 2001 Anthrax attack there was huge spike in 911 calls related to white powder. These calls have been removed). There has been an average of about 38 incident dispatches per year from 2008 to 2017.

Some older data exists on transportation of hazardous materials. The Washington State Department of Health studied incidents that occurred in 1992. Most of the analysis covers the whole state and disaggregates the information by county. These data are too general for specific planning but do give some indication of the dangers faced in Seattle, especially when it is correlated with the logs of the SFD.

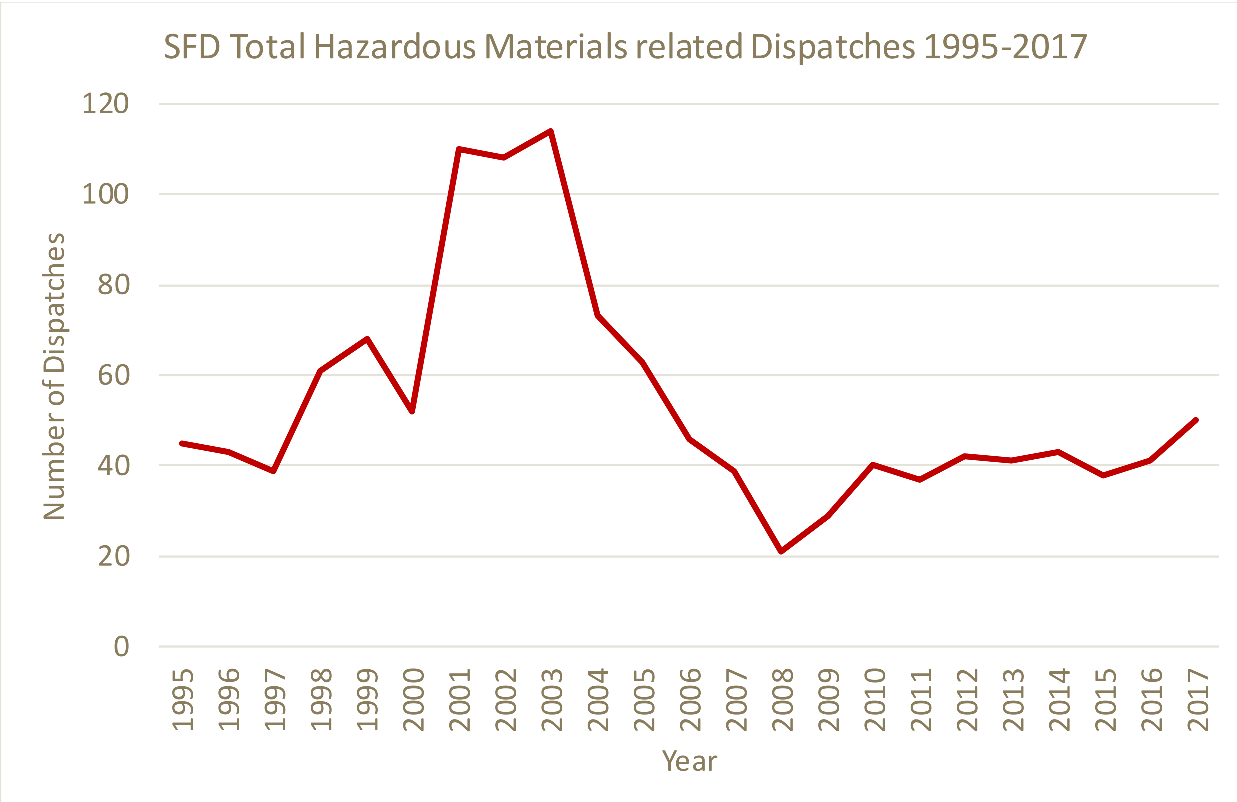
According to the report, there were 118 events in King County in 1992. Twelve (10.2%) of these involved transportation and 106 (89.8%) were at fixed facilities. Twenty-six incidents caused a total of 66 injuries. The most common injury incidents involved acids and volatile organic compounds. The report states there was one fatality in the state, but it does not indicate if it occurred in King County. Additionally, 29 incidents resulted in the evacuation of nearly 1,400 people. The report indicates that 44 incidents in King County occurred within one-quarter mile of residential areas, indicating some risk to people who are not directly involved with the released chemicals.

Figure 8-5. Hazardous Materials Incidents 2006 - 2012



A 1994 King County study shows that the most common material transported along I-5 is gasoline.[452] The most commonly released chemicals in transportation accidents were volatile organic compounds, acids, herbicides and insecticides.

Figure 8-6. Seattle Fire Department Hazardous Materials Dispatches 1995 to 2017



The federal Environmental Protection Agency has a Toxic Release Inventory (TRI) program. TRI 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.[453] They monitor chemicals that are either harmful to public health or the environment. In 2017, 105 Seattle facilities released around 50,000 pounds of toxic chemicals on-site.[454] Additionally, about 580,000 pounds of toxic chemicals were released by Seattle facilities off-site. A release does not mean that there was 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.[455] However, 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.

The U.S. Department of Transportation collects incident data at the state level and on the transportation mode. Washington ranks in the middle third in terms of the number of annual incidents. In 2009 in was 22nd with 230 and remained ranked at 22nd in 2018 with 272 incidents.[456] None were listed as major incidents. The most common transport mode is highway by far.

8 3.3 Likelihood of Future Occurrences

The available data on hazardous materials incidents is limited, but what does exist suggests the chance of an acutely disastrous incident has a low probability of occurring. Many programs exist to reduce the likelihood of an accident and to mitigate the effects of releases. These programs seem to be effective in limiting damage. The increase in transportation incidents from 1999 to 2009 runs counter to the general decline and bears watching. Additionally, the recent increase in the amount of Bakken oil being transported by rail through the city may increase Seattle's likelihood of a disastrous incident. The railcars that carry the majority of Bakken oil in the state were not made to carry oil and have been known to puncture upon impact.[457]

Seattle has never experienced a chemical or radiological attack, or a successful bombing. The difficulty of obtaining or manufacturing chemicals makes an attack unlikely, though not impossible. While explosives have been used around the world in past terror attacks, recent terrorism trends point towards the use of simpler tactics (e.g. vehicles, knives, etc.) to cause harm.

While there may be very significant long-term problems involving the build-up of toxic chemicals in the environment, there have been very few large releases of chemicals that pose immediate risks to large numbers of people. Most of the largest past events have been secondary impacts to fires and transportation accidents. It seems most likely that a future event would be related to another type of hazard, such as an earthquake or fire.

8 3.4 Vulnerability

The most likely location of a hazardous material emergency is at a user site, an abandoned dump or landfill, or on a major transportation route. If the chemical finds its way into the sewer system, treatment facilities or sewer overflow locations could become additional damage locations. Additionally, Seattle is a city surrounded by water and a chemical spill into these water bodies could severely harm aquatic life.

The Washington State and SFD information refine this set of assumptions with some empirical data. The vast majority of accidents in the county (90%) occur at fixed facilities, which theoretically means 90% of the spill locations are identifiable prior to an incident. The State's data shows more transportation accidents happen in rural areas, while most of the fixed facility accidents occur in industrial areas. On the basis of this information, the picture of a typical hazardous material accident site is in an industrial area or along a major transportation corridor such as I-5, I-90, SR 99, SR 520, or the railways within the city. The most vulnerable locations are where high density, vulnerable populations, and critical infrastructure occur close to the areas that are more likely to have incidents. Besides these areas, the University of Washington also has a large share of serious hazardous materials incidents, due to its many research labs.

The most common sources of large accidents are petroleum, metal, and chemical plants. There are relatively fewer of these facilities in Seattle compared to other U.S. cities, decreasing the probably of a large event.

8 3.5 Consequences

The effects of a large hazardous materials incident are unpredictable because there is not a long history of such large incidents in Seattle. Hazardous materials emergencies can be complex because chemicals have so many ways they affect people. They can disperse through the air or water and can enter the body through the lungs, digestive system, or skin. Many can explode. Some will react with water and other common agents that fire-fighters 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.

If future large incidents follow the historical pattern, only magnified, then they would most likely occur as a secondary effect or another type of hazard, especially a fire. It would most likely be at a fixed facility. If a transportation incident occurred in the city, consequences could be significant as was the case with the 1975 tanker fire. A crowded tavern was nearby the incident and could have caused multiple fatalities had it been affected.

These types of incidents are likely to be limited in geographic scope. The city is likely to have a quick and complete recovery. Unless there is a large explosion or fire in a crowded and enclosed location, fatalities are likely to be few, although the number of injuries due to chemical exposure could be quite large. In the 1995 Tokyo sarin gas attack there was about one fatality for each 200 injuries.

The most serious hazardous materials incidents would probably either involve an attack or multiple incidents occurring at the same time as a result of a trigger hazard, like an earthquake or flood. Attacks would be serious because of the deliberate intent to harm. Extremely dangerous substances would most likely be involved and would be released in locations that would impact many people, such as transit systems or entertainment venues. In a scenario where numerous hazardous materials releases occur as a secondary impact to another hazard, response capacity would be diminished. In past events, bystanders have been injured because people were not removed quickly enough or were allowed to return in a prolonged evacuation.[458]

The economic effects extend beyond immediate damage because chemicals produce a high amount of anxiety. A serious event would probably lower property values in the surrounding area, compounding economic damage into the future. They 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.

8 3.6 Conclusions

Minor hazardous materials incidents are fairly common, making them high probability events that typically do not involve emergency management. Fortunately, more serious threats, including fatal accidents, are extremely rare. Many of the decisions that govern the use of hazardous materials rest with the state and federal governments.

8.4 Infrastructure and Structural Failures

- Infrastructure is the network of structures, utilities, and facilities that supply and support our basic needs for mobility, power, water, sewer, and communications.
- 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-attack and disruption chapter.
- The American Society of Civil Engineers (ASCE) gives the infrastructure of the United States an overall D+ grade and estimates it will cost $2 trillion to fix. The ASCE gives Washington a C grade, with the main concerns being roads and mass transit.
- 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.

8 4.1 Context

On May 23, 2013, the I-5 Skagit River Bridge collapsed in Mount Vernon, Washington. Fortunately, there were no fatalities, but traffic on the busiest freeway in the state had to be rerouted for weeks.[459] This bridge collapse, along with other recent infrastructure incidents, such as the I-85 bridge collapse in Atlanta in 2017 and the sinking Millennium Tower in San Francisco, highlight aging and vulnerable infrastructure across the United States. This chapter encompasses infrastructure failures that can rise to the level of a disaster: bridge collapse, building collapse, crane collapse, dam failure, main breaks, pipeline failure, steam pipe explosions, industrial system failure, accidents at nuclear plants, and similar events. Because power failures are especially complex, they are covered in the power outage chapter.

Most complex infrastructure is now controlled with computer systems (called supervisory control and data acquisition or SCADA systems). While SCADA system failure is a type of infrastructure failure, it is covered in detail in the cyber-attack and disruption chapter.

Problems of failing infrastructure are typically small scale and cumulative. For example, a vast number of small leaks can cause some municipal water systems to lose up to 20% of their water during transmission. While reducing the effectiveness of a system, small, cumulative failures do not typically rise to the level of a disaster. This chapter concentrates on the upper end of the problem, large scale failures with immediate consequences. Nevertheless, it is important to note that these large-scale failures represent only part of a wider issue, and cumulative failures can have disastrous impacts, as was the case in Flint, Michigan, where lead contamination in the city's water supply eventually resulted in a public health emergency.

Locally, responsibility for Seattle's infrastructure rests with a collection of public and private agencies. Details of these systems and agencies are described in the Community Profile.

Many, though not all, of the problems are related to the age of American infrastructure. In many places pipelines, bridges, and other structures are over 100 years old. 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 100 years-old as of 2017. The shear amount of investment it would take to upgrade all of America's aging infrastructure would be $2 trillion according to the American Society of Civil Engineers (ASCE), which also assigned an overall D+ grade to the nation's infrastructure.[460] Washington's infrastructure received a C grade from ASCE, with roads and mass transit systems rating lowest and dams rating highest.[461]

Other causes of infrastructure failures can be structural fatigue, such as increased carrying loads on bridges, corrosion of materials due to environmental exposure, erosion, and stress beyond what the system was designed to do.[462] Infrastructure failures can also be a result of human error or accidents that occur during a construction phase. Workers can accidentally damage utility mains, errors can be made in the building's construction that cause failures later on, and construction equipment, such as cranes or scaffolding, can fail and collapse. Additionally, infrastructure failure is often felt as a secondary hazard to another incident such as an earthquake. While many of these primary hazards would damage even healthy infrastructure, the problem is compounded by weakened infrastructure.

Replacing aging and inadequate infrastructure is costly and politically difficult. Without a clear crisis, it is a challenge to convince taxpayers to replace expensive structures. Nonetheless, some programs have been implemented and are addressing infrastructure improvement needs, such as the $365 million "Bridging the Gap" levy, which addresses paving, bridge repairs, seismic upgrades, and transit enhancement.[463]

8 4.2 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.

November 7, 1940. Tacoma Narrows Bridge Collapse. 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. A sewer line tunnel built in 1909-10 collapsed, causing a massive sinkhole under Ravenna Boulevard. Ten families had to be evacuated. The system took two years to repair and cost $16 million (in 2013 dollars).

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 escape, so there were no casualties.

November 25, 1990. I-90 Bridge Sinking. The bridge was under construction and not being used. It sank following a major windstorm. The pontoons that support the bridge had been opened to temporarily store water. The openings allowing additional storm water to enter.

July 19, 1994. Kingdome Ceiling Tiles and Crane Failure. Hours before a baseball game, four large waterlogged tiles peeled from the ceiling and plunged into the seats. Two construction workers died during repairs when the basket on top of a crane broke loose and fell 250 feet. The cause of the ceiling tile failure was a badly leaking roof.

December 14, 2006. Drainage System. (Also in Flooding). Heavy rains overwhelmed the drainage system along Madison Street. Water built up in a valley in the street. It overtopped the curbs and rushed downhill, slamming into a home and killing one person.

May 2, 2007. Water Main Break Under University Bridge. A 24-inch main broke, causing a large sinkhole and worries about the integrity of the bridge abutment. The incident also damaged an 8-inch gas main and a conduit housing Qwest trunk lines. The bridge was not damaged, but water and gas service in the area had to be cut for most of a day.

January 19, 2009. Howard Hanson Dam. Engineers learned that parts of the abutment had a void. To reduce the chance of a catastrophic failure, dam operators would not be able to hold as much water in the reservoir, increasing the chance of flooding in the Kent valley. Temporary repairs were completed before a flood.

February 9, 2017. West Point Treatment Plant. Heavy rains and high tides caused flooding at the waste-water treatment plant, which fired an electrical circuit that shut down operating systems.[464] 235 million gallons of untreated waste was dumped into Puget Sound.[465]

8 4.3 Likelihood of Future Occurrences

Infrastructure failures are unavoidable, and often unpredictable. Even if our entire infrastructure system was in top shape, there would still be construction accidents, operations errors, design flaws, and unanticipated environmental issues. These types of failures occur every year but can normally be handled through daily business procedures. The question is how likely are major failures that precipitate large-scale emergencies? Unless a single failure, such as a dam failure or nuclear accident, affects a large area, most infrastructure failures do not scale up to the catastrophic level. There are no dams in the city limits and Seattle is far from the state's only nuclear power plant in Eastern Washington. The likelihood of an infrastructure failure as a secondary hazard seems to be decreasing as we become more aware of the potential effects of hazards, such as earthquakes. Scientific developments have allowed the city to identify its most vulnerable infrastructure and make the necessary upgrades. Developments in building code standards also make newly constructed infrastructure more resilient to hazards.

There is no data source containing all infrastructure failures, making it difficult to examine trends. However, some national trends in infrastructure age and spending point towards an increased likelihood of failures. The 1950s and 60s saw many of the nation's large infrastructure projects, including many of our national interstate highways.[466] Experts believe that many of these systems are now reaching the end of their lifespan and are in need of upgrades.[467] However, funding for these upgrades has slowed since their construction. For example, spending on transportation and water infrastructure at the state and federal levels has flatlined since 2000,[468] despite the average age of government-owned infrastructure systems increasing from 18 years old to 25 years old between 1970 and 2009.[469] This indicates that systems are being replaced at a slower rate than in previous years, and potentially increases the chance of failure due to age.

The effects of climate change could also impact infrastructure. Rising sea levels can extend the reach of coastal flooding and damage facilities located along the water, such as the West Point wastewater treatment facility. King County estimates that 30 major wastewater treatment facilities are at risk of flooding during storms due to sea level rise (assuming a 15-foot rise) by 2100.[470] Additionally, Seattle is projected to experience more extreme high temperatures. Hight heat can cause steel to expand which may impact older structures like drawbridges.

8 4.4 Vulnerability

Seattle represents the greatest concentration of infrastructure in the Pacific Northwest and one of the oldest settlements in Washington State. Seattle has a bigger collection of infrastructure maintenance needs than anywhere else in Washington State, giving it an intrinsic vulnerability to infrastructure failure. The City also owns or relies on infrastructure in more remote parts of the state, including a number of dams that are used for water supply, power generation, and flood control. The most significant vulnerability is failure of the Howard Hanson Dam, which could cause flooding around the Duwamish River.[471] If other dams were to fail it would mostly affect power generation and water supply capabilities.

The vulnerability of individual systems varies greatly according to the condition of the components, system complexity, the ease and speed with which damage propagates through an infrastructure system and the amount of redundancy in the system.

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 where an area can only be serviced by one utility line, facility or transport route.

The most vulnerable periods in the life of a structure are during construction, right after it is built, and as it nears or exceeds it 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 collapse of the Tacoma Narrows Bridge, Husky Stadium, and the I-90 floating bridge.

Seattle's growing population increases its vulnerability to infrastructure failure. Roads and bridges may be degraded faster with the increased volume of traffic. There is also a major construction boom happening across the city, increasing the likelihood of an infrastructure failure occurring during the building phase. In 2018, Seattle had 45 construction cranes, the most of anywhere in the U.S.[472] Seattle has never experienced a disastrous crane collapse, but other urban cities have. In 2006, a 210-foot crane collapsed in the neighboring city of Bellevue, severely damaging an apartment and office building and killing one apartment resident.[473] The collapse caused millions of dollars in building damage, ruptured water and gas mains, and blocked traffic while crews investigated and cleaned up debris. It was agreed that if the crane had collapsed during business hours, many more casualties would have occurred. The cause of failure was associated with a non-standard base construction, leading to more stringent crane-safety laws in the state. Despite new testing and inspection requirements, large cranes that have passed inspections have proceeded to collapse in cities across the U.S. If Seattle's population continues to grow at a similar pace, construction sites and cranes will continue to be erected throughout the city. Downtown is most vulnerable to the potential damages of a crane or building collapse due to its dense network of office, retail, and residential buildings.

8 4.5 Consequences

Infrastructure and structural failures have caused fatalities, injuries, utility outages, and economic losses in Seattle and are expected to do so again.

Many past failures have involved bridges and the water system. Failures are more frequent in systems under construction or in older components. Consequences would be worse if the failure occurs in a heavily used or populated area, and the failed component is co-located with other key infrastructure. Seattle has a lot of infrastructure and will continue to invest in more, creating many potential failure scenarios.

If Seattle were to experience a major structural failure, such as a bridge or crane collapse, or a large sinkhole, there would likely be fatalities and injuries to those in the immediate vicinity. In the past 50 years, the deadliest bridge collapses in the U.S. have caused between 3 and 114 fatalities.[474] 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).[475] Collapsing infrastructure has also disrupted power systems. The Skagit River bridge collapse caused a minor power outage for about 250 customers.[476]

Utility infrastructure failures would likely have fewer casualties, unless it involved a pipeline or steam explosion. Nevertheless, there can be delayed 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.[477] 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.

A break in one of the 42” water mains was chosen as the most likely scenario because Seattle has had large water main breaks in the past, it is critical service and could cause significant ‘collateral damage.’ A collapse of the I-5 Ship Canal Bridge was chosen as the maximum-credible scenario because it is the most heavily trafficked stretch of road in the city and would have many immediate and prolonged impacts.

8 4.6 Conclusions

Seattle’s growing population will put greater demands on infrastructure systems that were built decades ago with lower-capacity designs. Updating or replacing these systems requires huge investments and will happen slowly. In the meantime, old infrastructure has the potential to fail catastrophically. There were over 450 bridge collapses in the U.S. between 1989 and 2000. The average age of these bridges was 53 years.[478] Even if Seattle were able to update all of its infrastructure, the boom in new structures and infrastructure make the city vulnerable to design flaws, construction errors, and accidents.

Single site or structure failures have been shown to cause high numbers of casualties but have a limited geographic scope, such as the collapse of a pedestrian bridge in a Hyatt Regency hotel in Kansas City, Missouri, that killed 114 people.[479] Single failures can usually be contained relatively easily, and recovery tends to be quick and comprehensive, unless the failed infrastructure plays an essential part to the cities functioning, like a major interstate. On the other hand, infrastructure failures can have less severe impacts that are felt on a broader geographic scope. For example, a dam failure could flood communities many miles downstream from the dam.

8.5 Power Outages

- The 2003 Northeast Blackout highlighted the fragility and interdependence of the country's electrical system.
- The United States power grid is made up of three interconnecting networks. 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.[480]
- About half of Seattle City Light's unplanned power outages are caused by falling trees or branches.
- Almost 90% of Seattle's power comes from hydroelectric power; 47% of the power Seattle consumes is purchased.[481]
- Seattle could face power outages due to electrical vault fires, windstorms, or an issue in the regional grid. Seattle has the ability to 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.
- By 2028, peak demand may not be met in winter without purchasing additional power.[482]

8 5.1 Context

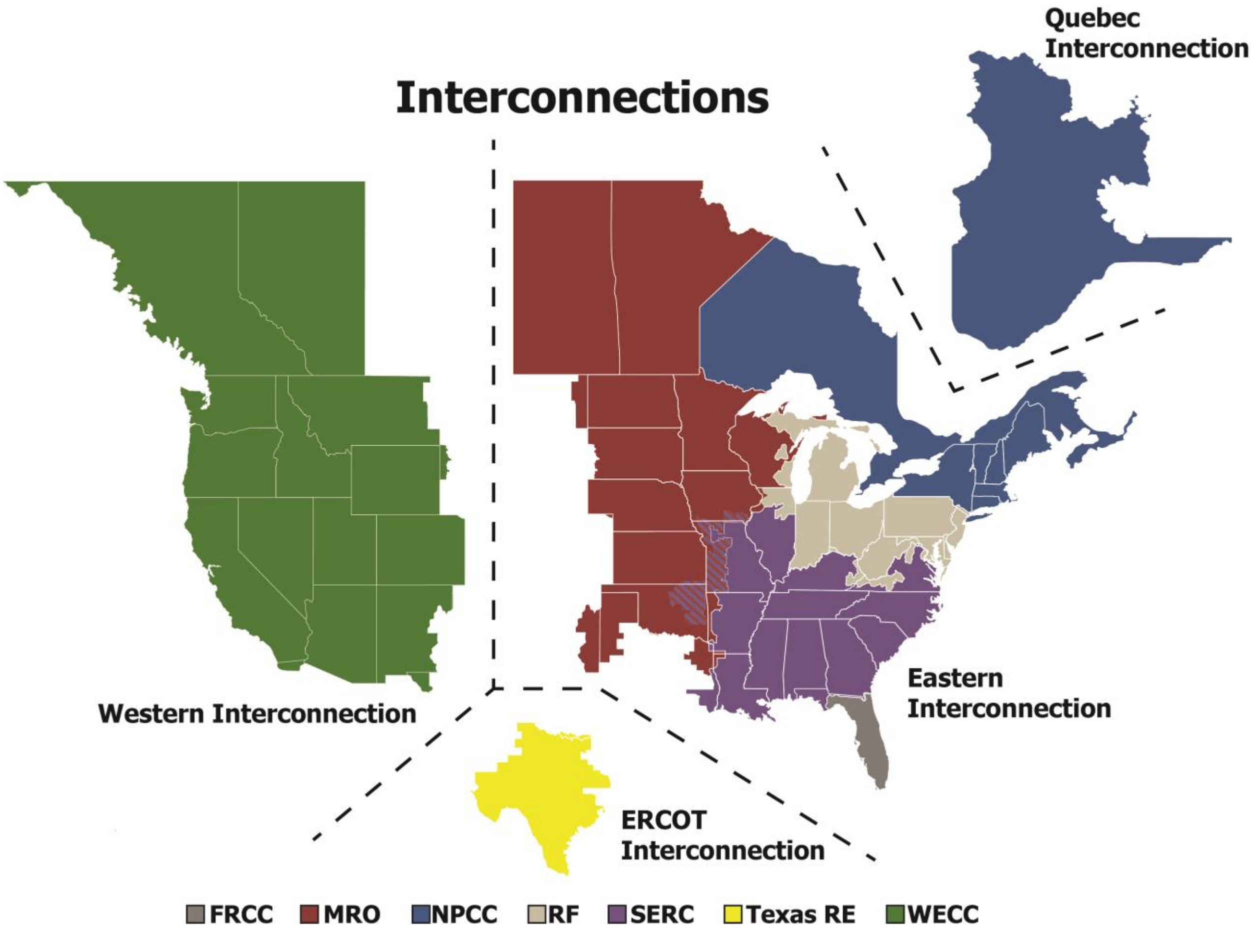
On August 14, 2003, a large part of the upper Midwest, East Coast, and Ontario, Canada went dark. The power outage affected 50 million people. Some parts of the United States waited four days for the power to be restored. Estimated losses ranged from $4 billion to $10 billion. The outage highlighted widespread infrastructure problems in the power grid, and the complexity and consequences of widespread power outages.

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, wide-spread 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, Mexico (see Figure [United States electricity networks]). The Western Interconnection has more Balancing Authorities, which 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 that provides situational awareness and real-time monitoring for the grid.[483]

Figure 8-7. 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 firm 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 more than 750,000 customers and is the tenth largest public electric utility in the country. 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.[484] 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.[485] 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.

8 5.2 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. 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 in 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.[486]

2006. Seattle. Hanukkah Eve Wind Storm. 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.[487] 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.

8 5.3 Likelihood of Future Occurrences

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 that the rest of the county, Seattle has successfully been re-growing its tree canopy. About half of SCL's unplanned power outages are caused by falling trees or branches. SCL has implemented a vegetation management program to trim trees that may grow into or fall on power lines.[488] 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.[489] 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.[490]

8 5.4 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.[491] 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.[492]

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.[493] 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 resident's 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 has 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 accelerate and make up for the downtime.

8 5.5 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 maximum credible scenario would probably be some sort of "perfect storm" of disparate elements coming together to create a huge problem. This would probably 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 very stable, but if it is not, that could be one more potential element in the mix.

8 5.6 Future Challenges

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). 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.

8 5.7 Conclusions

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 by 0.4% by 2035.[494] Additionally, some of the power purchase contracts will expire.

Forecasts estimate that the Pacific Northwest will have more than adequate reserves to meet a 12% recommended reserve margin for the next decade under normal conditions, accounting for climate impacts.

9. WEATHER HAZARDS

Seattle has long been known for its mild, damp weather, but as with most things, the reality is more complicated than the image. Not only does Seattle have less rain in a year than many people think, it has a less even distribution of rain throughout the year than most people realize. Seattle's summers are very dry. Water shortages can occur.

Dividing Seattle's weather hazards into distinct categories can be a bit misleading. Most weather events are complex, involving multiple hazards

9.1 Excessive Heat Events

- Excessive heat can be a hidden killer. In August 2003, excessive heat killed more than 15,000 people in France. In Cook County, Illinois in 1995, more than 700 deaths were attributed to heat. Because heat does no physical damage and deaths tend to occur in private dwellings, the extent of a heat disaster is often not visible to the public.
- Since the mid-1970s, an average of three or four heat-related fatalities has occurred each summer in Seattle. During excessively warm summers, such as the summer of 1992, up to 50 to 60 deaths have occurred.
- The season, humidity, duration and availability of cooling systems all strongly influence the impact of excessive 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. Health effects associated with heat begin in Seattle at lower temperatures than many other places. The relative temperature, compared to normal seasonal temperatures, is often more important than the actual temperature. 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.[495] Nighttime low temperatures are also increasing, limiting nighttime heat relief.
- Heat can be costly. The costs of one extreme heat wave in California in 2006 were estimated at over $200 million.

9 1.1 Context

On July 29, 2009, the temperature reached 103˚at SeaTac airport, an all-time record. Two people in Western Washington died. The most brutal temperatures lasted three days. If the extreme weather had lasted a few days more, the number of fatalities would probably have climbed dramatically. Seattle has a famously mild climate that makes it difficult for the community to acclimate to extreme heat when it occurs.

An excessive 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 dry air from the Northwest interior sinks along the western slopes of the Cascade Mountains it gets compressed and heats up. In the summer, when the sun is the strongest, Seattle experiences EHEs when the onshore flows of the Pacific decrease and there is an occurrence of downslope flow on the western slopes of the Cascade mountains. EHEs in Seattle usually do not last very long because the pressure difference that builds with the warming air eventually grows to the point where marine air will surge in and cool the area once again.[496]

In an average year, about 134 Americans succumb to the effects of summer heat.[497] During the summer of 2006, 253 people in the United States died as a direct result of heat.[498] Heat waves in August 2003 that affected all of Western Europe resulted in more than 15,000 deaths in France alone. In July 1995, "excessive heat" conditions were blamed for more than 700 deaths in Cook County, Illinois. In July 1993, similar temperature extremes led to roughly 120 deaths in Philadelphia, Pennsylvania.

Human bodies dissipate heat by varying the rate and depth of blood circulation, by losing water through the skin and sweat glands, and by panting when the body's core is heated above 98.6°F. The skin handles about 90% of the body's heat dissipating function. Sweating, by itself, does nothing to cool the body unless the water is removed by evaporation. High relative humidity delays evaporation. Heat disorders generally have to do with a reduction or collapse of the body's ability to shed heat by circulatory changes and sweating, or a chemical imbalance of salt caused by too much sweating. When heat gain exceeds the level the body can remove, 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 can cause damage to the brain and other vital organs. Heat-related illness may develop.

Once the air temperature exceeds skin temperature, convective cooling from the skin is no longer possible. The effects of ventilation/wind reverse, adding heat to the body. This is a dangerous scenario that causes individuals sitting in hot rooms with fans on to accelerate deterioration under hot conditions. Some decedents in the 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 that other cities in the United States. The research studied day to day baseline conditions and not extreme events.[499] Understanding our increased vulnerability to high temperatures, researchers have recently examined whether excessive heat days increase the risk of Emergency Medical Service (EMS) demand, hospitalizations, and mortality in King County. Calkins and colleagues found that on excessive 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.[500] 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.[501] 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.[502]

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.[503] Based on current models, EHEs are expected to increase in frequency due to climate change.

9 1.2 History

While good meteorological records exist for Seattle, heat waves are more complex that 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 heat[504].

1994. A city-wide 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.[505] 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.[506]

9 1.3 Likelihood of Future Occurrences

The Washington Climate Change Impacts Assessment looked at 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 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 (Table 47).

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.[507] In other words, night time temperatures are rising, meaning there could be less of a cooling effect at night during future EHE's.

Table 9-1. Projected Heat Events

	1980 - 2006	2025	2045	2085
1980 - 2006				
Mean annual heat events	1.7			
Mean (max) event duration in days	2.2(6)			
Low				
Mean annual heat events		2.6	3.1	3.8
Mean (max) event duration in days		2.2(6)	2.3(7)	2.3(8)
Medium				
Mean annual heat events		3.6	4.7	7.2
Mean (max) event duration in days		2.3(7)	2.6(14)	2.9(18)
High				
Mean annual heat events		5.8	8.8	10.1
Mean (max) event duration in days		2.7(18)	3.2(18)	6.1(57)

Source: Washington State Climate Change Impact Assessment, 2009.

9 1.4 Vulnerability

Demographic vulnerability to EHEs is similar to other hazards. Factors that increase vulnerability include: age (65+), ethnicity, preexisting health conditions, education, income. Many residents lack efficient cooling systems in their homes or businesses and remain unaware how to protect themselves. 2015 American Housing Survey data shows that only 33.7% of Seattle area homes have air conditioning. For those aged 65 and older, the percentage only jumps slightly, to 37%.[508] However, building trends suggest there could be a future increase. About a quarter of new apartment buildings constructed in Seattle in the past decade have air conditioning.[509]

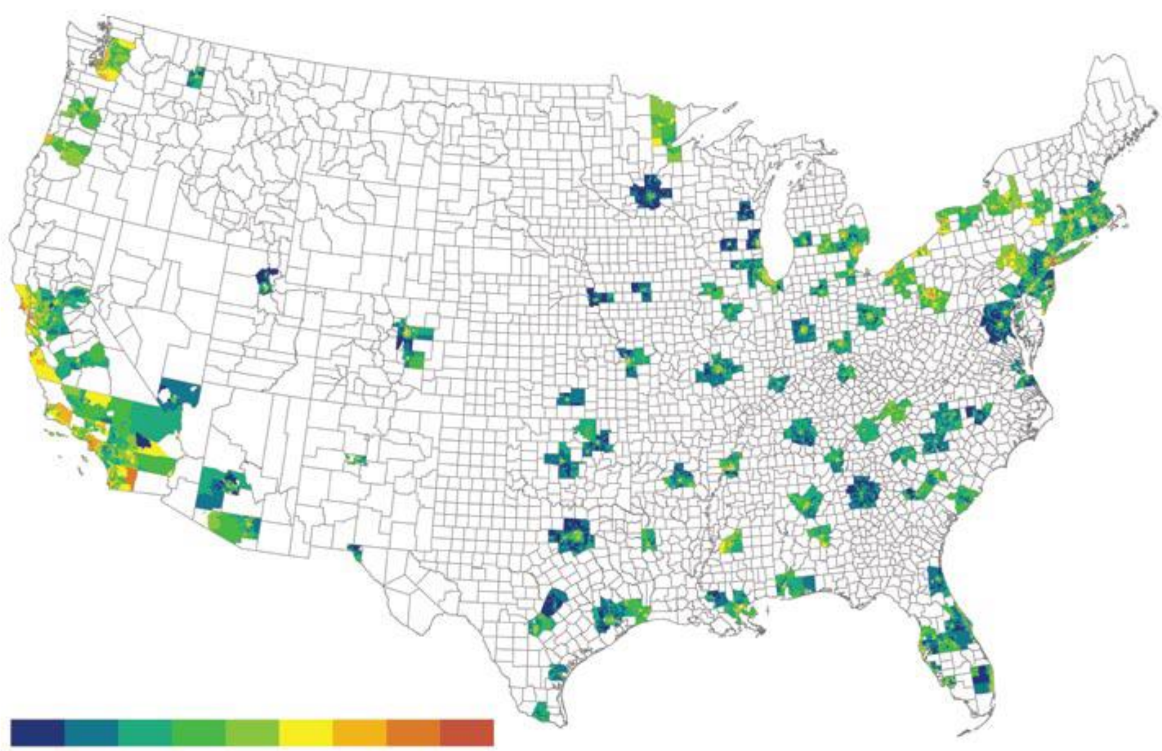
The difference between the normal temperature and the current temperature dictates the real impact that heat has on the individual. Since we normally have fairly mild temperatures, our population can feel more stressed at lower temperatures than many other places, especially if the rise happens suddenly.

Warmer average summer temperatures experienced in cities across the United States and elsewhere have led to premature death among certain populations, including those who are elderly, very young, poor, cognitively or physically impaired and already burdened with chronic disease, such as hypertension and diabetes. The most vulnerable people in Seattle tend to be the elderly.

Urban areas can also have reduced air flow because of tall buildings and increased amounts of waste 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.

A 2009 study of heat vulnerability on a national scale found that Seattle is on par with Chicago, 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 the population with chronic medical conditions, and social vulnerability (race, poverty, age, and housing conditions). The authors suggested that local and regional factors also play a role and suggested research of these as a next step in defining local hazard exposure.[510]

Figure 9-1. Comparative Heat Vulnerability Nationally

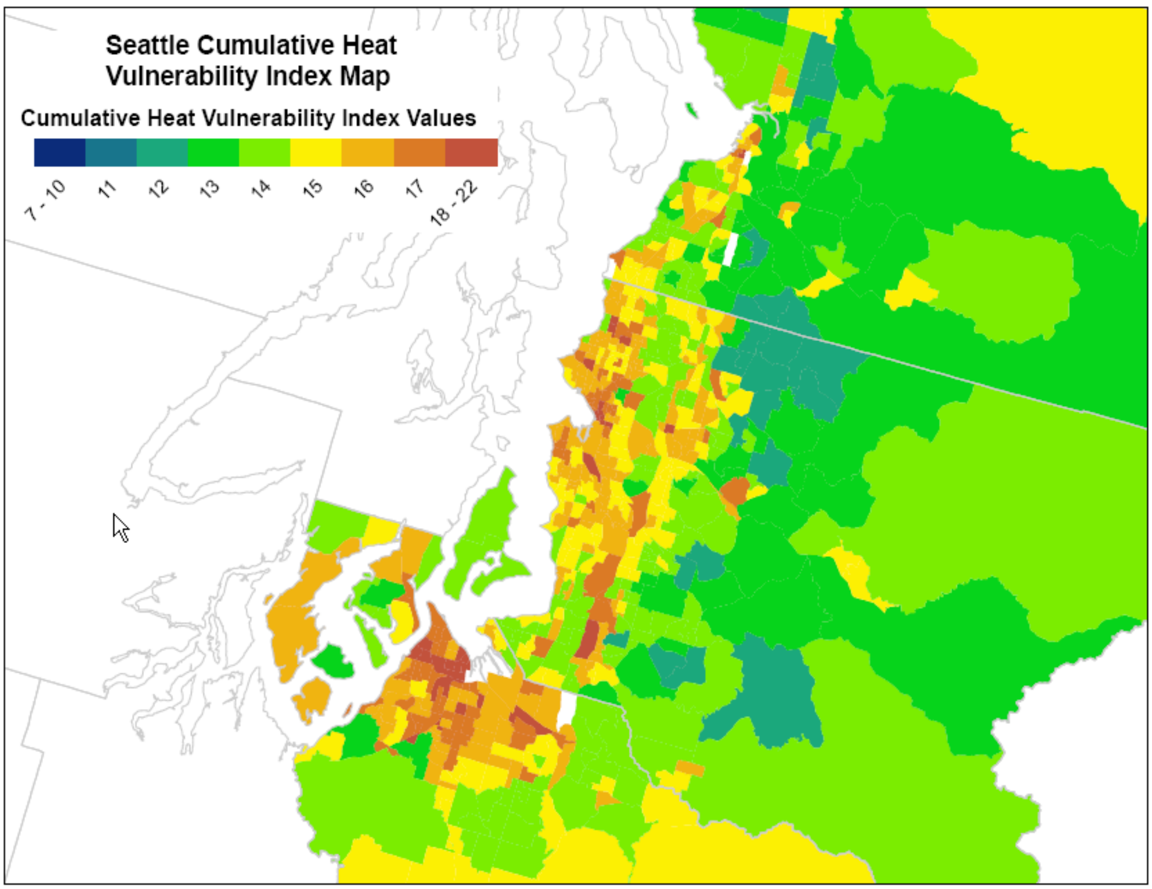


A separate study in 2015 showed that the risk of mortality from EHEs can vary even within cities. For Seattle specifically, postal code areas that have higher percentages of elderly (65+) residents and Pacific Islander residents are associated with a higher risk of heat-related death during EHEs.[511]

9 1.5 Consequences

Looking at Seattle area weather and mortality statistics back to the mid-1970s, an average of three or four fatalities have occurred each summer.[512] During excessively warm summers, such as the summer of 1992, up to 50 to 60 deaths have occurred. According to the state health department, hospitalizations for heat-related illness in Washington state range from 25-113 people each year.[513] In Seattle, most fatalities are indirectly caused by heat, such as heart attacks, strokes and respiratory illness.

Figure 9-2. Seattle Metro Area Heat Vulnerability Index



Source: Colleen Reid, personal communication. 2009.

Hotter temperatures may also make people with certain heath conditions such as diabetes and obesity less likely to pursue physical activity critical to management and improvement of their health conditions. These factors, along with research suggesting increases in the demand of healthcare services during EHEs, means that Seattle's EMS and healthcare institutions could be overwhelmed during a severe EHE.

Warmer temperatures are typically associated with precursors of air pollutants that are in turn linked to respiratory disease and reduced lung function. In addition to causing climate change, high carbon dioxide concentrations in the atmosphere are 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.

There are also non-health consequences of heat. EHEs can increase the risk of brush fires as vegetation dries. In July 2018, fire fighters in King County responded to 20 brush fires in one weekend alone.[514] 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.[515] Seattle has 7 bridges that must open to marine traffic.[516]

EHEs have the ability to lead to power outages if energy demand spikes as more people use cooling units. The majority of Seattle residents still do not have air conditioning units. Despite the growth of air conditioning in new apartment complexes, the technology being used is very energy efficient, so demand is not increasing locally.[517] 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.[518] 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.[519] About 73% of households have air conditioning in Los Angeles.[520] 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 to impose water usage curtailments.

Climate research suggests an increase in EHE severity, which is discussed further in the chapter on climate change.

9 1.6 Conclusions

Meteorologists can accurately forecast EHE development and the severity of the associated conditions with several days of lead time. The National Weather Service (NWS) has developed a Heat Health Watch/Warning System that tailors excessive heat guidance to specific regions in the country. The Seattle area implemented this new system in 2005, becoming the 15th urban region of at least 500,000 in population to do so. Excessive heat events may be becoming more severe in the Northwest. This may increase the exposure of vulnerable populations.

9.2 Flooding

- 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 three distinct flooding hazards: riverine flooding, coastal flooding, and urban flooding. 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.
- The area in the 100-year floodplains covers South Park and the drainage basins for Thornton and Longfellow Creeks. Flood control structures have been built in all of these 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.

9 2.1 Context

In December 2006, heavy rains 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 three types:

- **Riverine flooding** – Heavy precipitation causes a river or stream to overflow its banks into the adjoining floodplain. This is the classic flood. Seattle's creeks, especially Thorton 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 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. Low lying, bowl-shaped areas like Madison Valley and Midvale are the most likely to flood.

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 happening 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. Even small floods can cause heavy structural damage by rotting wooden frames and undermining foundations. More frequently they destroy moveable property and commercial stock.

Riverine floods can also affect city infrastructure when high water cuts transportation routes and pipelines. 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.[521]

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.[522] These events typically happen in winter, but have occurred in late fall and early spring as well.

Currently, all levels of government employ structural and non-structural means to reduce flood risk. 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.

9 2.2 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. Since that time, there has been no significant flooding downtown or near the mouth 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. However, the depth and current velocity of the floodwaters have been low, and they generally cause only localized structural damage and bank erosion.[523] 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 South Park neighborhood lies at a low elevation along the Duwamish and is prone to flooding due to backups in the drainage system when there is a combination of heavy rain and high tide. 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 through pipes that normally drain the neighborhood.

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 low, 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.

Both Seattle City Light (SCL) and Seattle Public Utilities (SPU) own and operate facilities located outside of the city limits on the Cedar and Tolt Rivers, the Skagit River, and the Pend Oreille River. Flooding can be a concern in these areas during times of heavy rains and extraordinary snowpack.

December 14-15, 2006. Six landslides of various sizes and approximately 300 flooded homes were reported throughout the city due to intense rainfall (about 2.17 inches in 24 hours) and overwhelmed storm water facilities. 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.

December 1-3, 2007. Three storms came through the Pacific Northwest, with the last being unusually intense.[524] Four-and-a-half to 5.5 inches of rain fell in north and west Seattle in 24 hours, an all-time record. Seattle experienced flooded roads, sinkholes, and landslides. 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.[525]

9 2.3 Likelihood of Future Occurrences

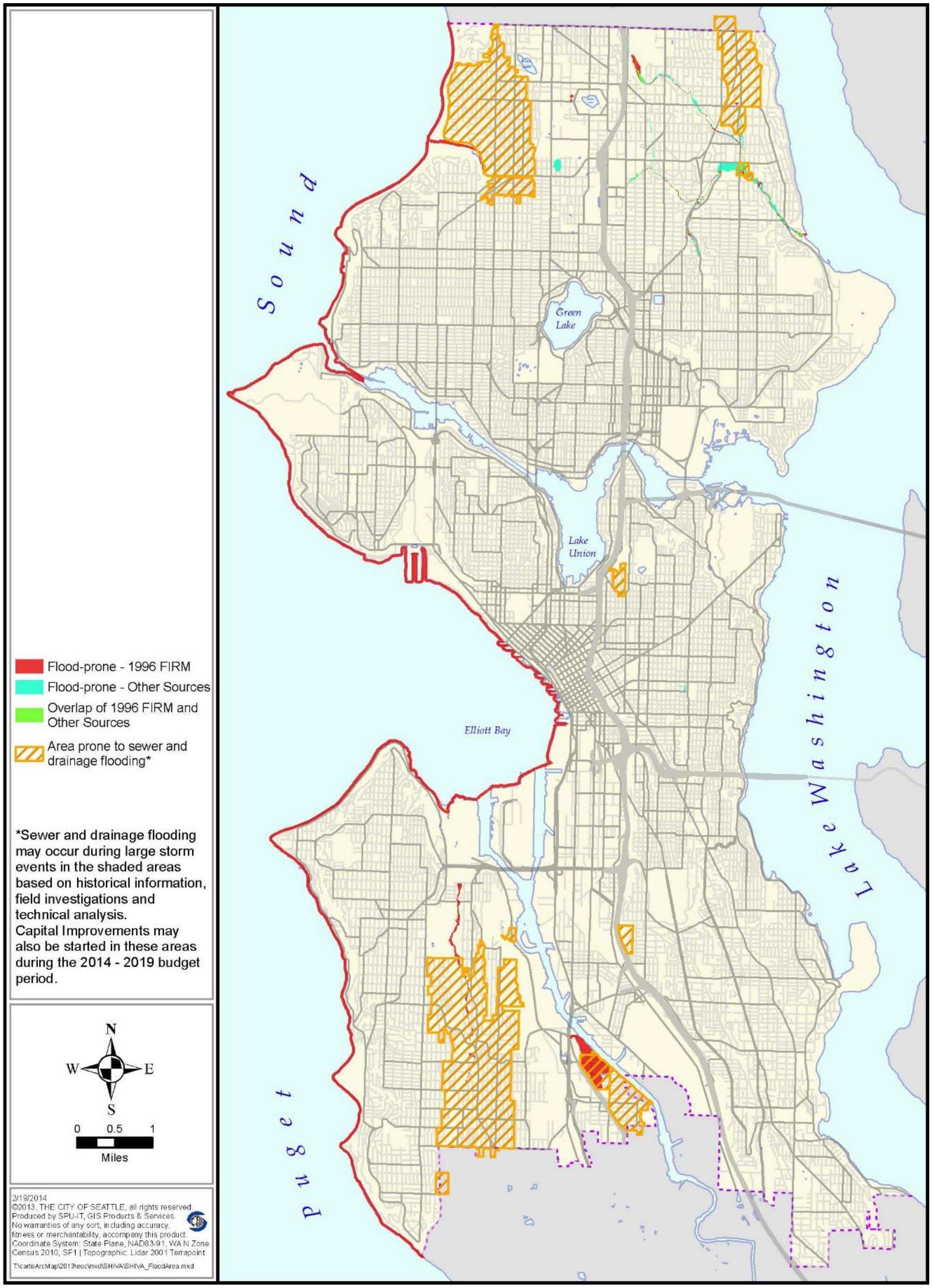
Seattle will experience flooding in the future. The principal unknown factor is the severity of future events. Seattle Public Utilities has examined the amount of rainfall collected in its gauges between 1978 and 2007. It discovered a small but statistically significant trend towards short-duration, high-intensity 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), who projects that the number of days with more than 1 inch of rain will increase by 6% to 20% by the 2050s.[526] Additionally, CIG projects that coastal flooding will increase due to sea level rise extending the reach of waves in a storm surge.[527] SPU is already upgrading the city's drainage system in critical areas.

9 2.4 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 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.[528] 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.[529]

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

Figure 9-3. Areas with Heightened Flood Risk



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.[530] However, by the time the water flow reaches the lower Duwamish in Seattle, flooding is not expected as tidal effects will govern.[531]

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.[532] 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.[533] 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.

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.[534] Other flood control measures include log booms that prevent debris from blocking the spillway and rock installations that prevent erosion of the dam. The Army Corps states that the dam can control water up to a 140-year flood event.[535]

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 two-thirds 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, and water stored in Lake Youngs is used instead. Since 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.

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.

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.

Many of the low-lying coastline areas, especially the more heavily used parts of the waterfront, are protected by seawalls. In 2017, the City completed major repairs to its aging downtown seawall. The repaired wall is expected to last more than 75 years.

As previously stated, sea-level rise will make coast flooding worse. The projected amount of sea-level rise in Seattle is 4 to 56 inches by 2100, depending on the amount of land movement.[536] The city estimates that the top of the downtown seawall will still be 3 ft above the new water level projections for 2100.[537] Other seawalls could be overtopped if they are not modified or replaced.

Lifeline Exposures:

- The sewer and drainage system is naturally exposed to flooding because it is part of the infrastructure to help control runoff. Sewer and drainage mains run along most of Thornton, Longfellow and Piper's Creeks; along most of the coast of West Seattle; South Park; Interbay; portions of Magnolia's coast; and Myrtle Edwards Park.

- About a ½ mile of SCL transmission lines run through the Longfellow Creek 100-year floodplain and the northern transmission lines cross the Thornton Creek floodplain.
- Seattle's northern water supply line crosses the Thornton Creek floodplain.

Transportation Exposures:

- Seattle's Puget Sound facing marine terminals are exposed to coastal flooding.
- The BNSF rail corridor, which runs along Puget Sound north of the Ship Canal, is exposed to flooding although landslides are a more common threat.
- Lake City Way and 35th Ave NE in North Seattle are bisected by Thornton Creek.
- Many residential streets in the South Park neighborhood are in the 100-year floodplain. West Marginal Way runs alongside it.
- Beach Drive SW in West Seattle runs along Puget Sound and is exposed to coastal flooding.

9 2.5 Consequences

Flooding in Seattle is a regular occurrence, but Seattle's flooding problem is not as severe as the rest of Western Washington. The situation may be changing, however, with climate change projections signaling that urban flooding may become a larger threat. Flooding is frequently part of a larger storm event.

Climate researchers project that Seattle will experience more extreme precipitation events, but there is a large amount of uncertainty in their predictions. In response, Seattle's drainage system is being retrofitted to add surge capacity.

The Duwamish Valley is not likely to flood. Even in the event of a major release of water from the Howard Hanson dam, the river is likely to remain within its banks.

Areas near streams and in natural bowls will be at some risk of localized ponding. The main risk is to property, the majority of which is residential. This residential flooding has a much less pronounced effect on the local economy since the economic base remains unaffected. Nevertheless, a flood could make transportation difficult in the affected areas. The low depth and water velocity of this type of flood mean it is mainly an economic rather than a safety risk.

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.

While a Duwamish Valley flood is unlikely, the consequences of a flood would be severe. The dominant land use in the Duwamish Valley is industrial. 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. The Duwamish Valley houses many hazardous materials.

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 the fatality that occurred in Madison Valley during the 2006 storm showed. While that case had unique circumstances, with the extra high curb structure acting like a small dam, it is possible for a similar set of circumstances to arise again and put lives in danger.

9 2.6 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 that 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.

9.3 Snow and Ice

- Seattle's weather is regulated by the Pacific Ocean, which remains relatively even 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.
- While Seattle does not receive as much snow on average as many parts of the country, snowfall is not uncommon and can be heavy.
- Accurate weather records began only about 100 years ago, but based on historical accounts, Seattle's winters seem to have been colder and snowier in the 19th and early 20th centuries.
- Meteorologists have made great strides in forecasting snow and ice storms. Roughly 80% of snow storms in the Puget Sound lowlands occur when cold air from the interior of the continent pushes through the Frasier Gap near Bellingham and meets a low-pressure system coming off the ocean. If the cold front lingers, snow and ice can be on the ground for weeks.[538]
- Snow and ice impede transportation and because most social and economic activity is dependent on transportation, snow and ice have serious impacts, especially if it remains on roadways for many days.
- Other significant impacts from snow are:
  - Public safety impacts resulting from the inability to get emergency vehicles where they need to go.
  - Utility outages as power demand peaks and pipes freeze. Power losses during extreme cold have resulted in deaths from carbon monoxide poisoning when victims attempted to keep warm by lighting charcoal fires indoors.
  - Economic losses due to business closures and lost wages by workers unable to get to work or required to stay home with children when schools and childcare facilities close.
- Seattle does not have dedicated snow plows. Trucks have to 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.
- Snow load has collapsed roofs, most recently in 1996/97.

9 3.1 Context

Seattle's winter weather is shaped by the Cascade and 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 by 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.[539]

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.[540] 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.[541]

Because Seattle does not see routine snow events, the City lacks the snow clearing capacity that cities in the upper Midwest and Northeast have. During major snows 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 snow storm.[542] 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.[543] Access to emergency services can be impaired. During exceptional storms, structures can be damaged. This happened in the 1996/97 storm when a number of roofs collapsed. Energy use skyrockets, placing a demand on power generation and distribution systems. Elsewhere in the nation, energy demand spikes have reached crisis levels. During the 1993/94 winter, some parts of Pennsylvania had to ration power. In some cases, those with low or fixed incomes cannot afford the extra expense and must suffer through the cold.[544]

SDOT 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. Once 1 inch of snow has accumulated, SDOT begins plowing roads, prioritizing those that are critical for major institutions and emergency services, and those leading to Seattle's major employers.[545]

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.[546] Another account claims that Massachusetts alone lost around $1 billion in wages and profits due to snow during the 2014-2015 winter season.[547]

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.[548] 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 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 snow storm 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 the socially isolated.

9 3.2 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.[549] Other historical records that extend back beyond modern record keeping indicate that Seattle was colder and snowier in the past.

Data from the National Climatic Data Center for the Sandpoint weather station shows that from 1990 to 2018 there have been 45 days of measured snowfall. This includes 19 days of snow accumulation of less than 1 inch and 26 days between 1 to 8 inches. These events occurred as early as November and as late as March. **Error! Reference source not found.** in the Community Profile indicates the snowfall from O ctober through March between 1948 and 2009.

December 1861. Very cold, with an unofficial record temperature of -4 degrees Fahrenheit. Newspapers mentioned ice-skating on Lake Union covered in six inches of ice.

Winter 1880. Estimated 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. Total of 18.4 inches of snow in 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.

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. 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.[550]

November 2010. Seattle received 1-2 inches of snow, causing dangerous road conditions. A cargo plane skidded off the runway at SeaTac airport, causing flights delays. Three fatalities were attributed to accidents caused by the icy road conditions. High winds caused power outages as temperatures dropped into the 20s.[551]

January 2012. 3-9 inches of snow fell throughout the area with subsequent freezing rain. Metro reduced service by 30%. 6,500 Seattle City Light customers experienced power outages.

February 2017. SeaTac airport records 7.1 inches of snow, almost twice the average yearly amount.[552] Power outages occurred, affecting 110,000 Puget Sound Energy customers and 11,000 Seattle City Light customers.

9 3.3 Likelihood of Future Occurrences

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.[553] 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.[554]

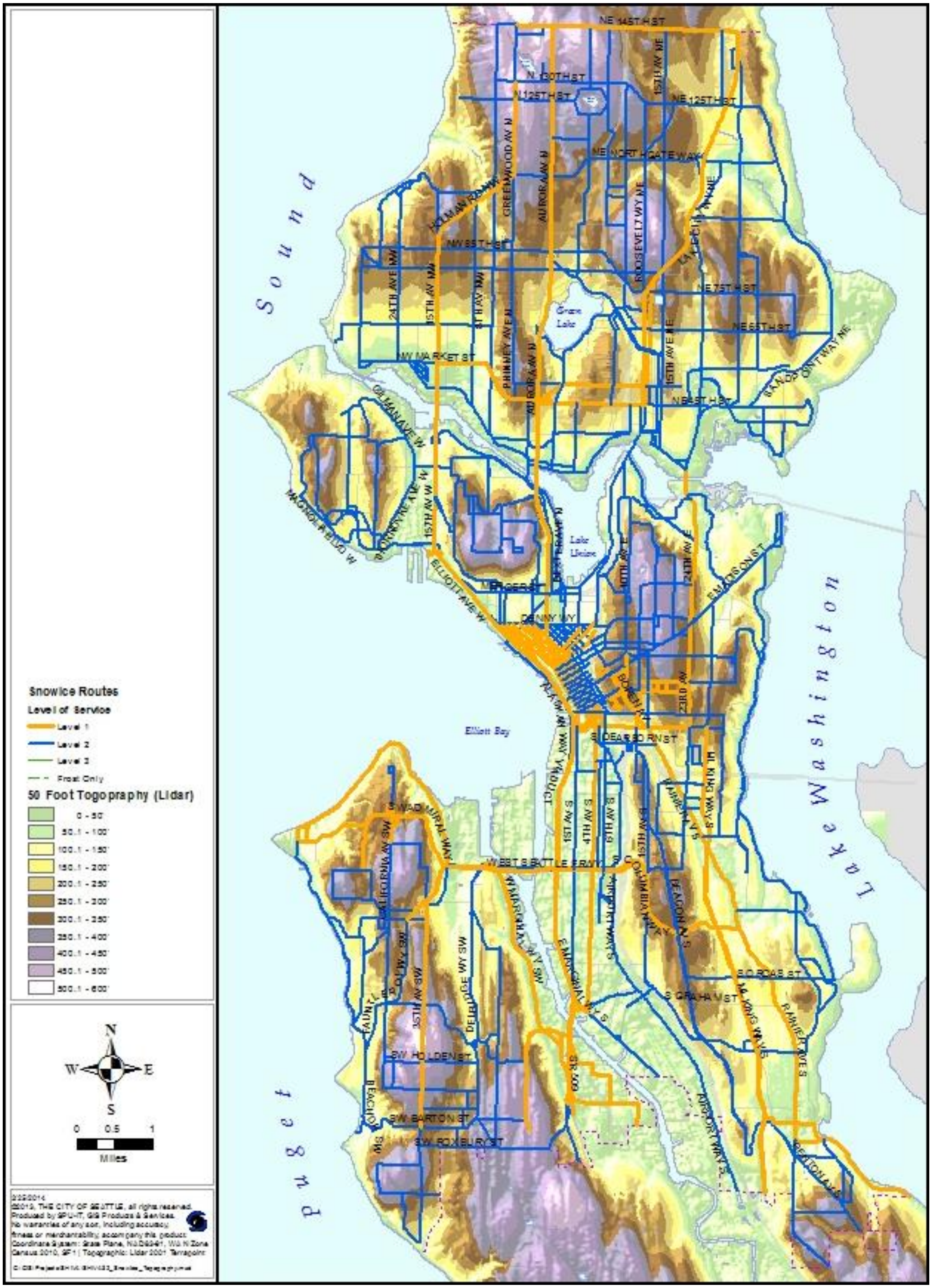
9 3.4 Vulnerability

Seattle's geology and climate increase the city's vulnerability to snowstorms. First, 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 streets that serve them. Second, the relative infrequency of heavy snowstorms makes it challenging to plan a response and discourages the use of City funds for dedicated equipment.

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 for them in shelters during winter, many remain on the streets in harsh conditions. Seattle's unsheltered population has grown by around 90% since 2009. The city's low-income and aging residents typically bear the most consequences of winter storms. People without back-up sources of heat suffer from the cold during outages. In 2006, several incidents of carbon monoxide poisoning occurred when people attempted to burn charcoal indoors to maintain heat.

Anyone needing 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 more 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. Children are

Figure 9-4. Snow and Ice Routes by Service Level



another vulnerable population because they play on dangerous, icy streets. Several 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 snow storms if they cannot get to work or their employer closes due to weather conditions.

9 3.5 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 2008 experience 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. Non-designated streets will face longer impairments. The City does not have enough snow removal equipment to plow every street in the city.

Power outages during snow storms and the cold weather that often accompanies them remains a serious threat. Hypothermia and carbon monoxide poisoning will continue to be risks.

A snow storm may slow the local economy. Hourly workers will lose wages, plane flights will be cancelled, and retail stores and restaurants will 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 the local government, responding to a snowstorm will likely 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.[555] 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. The frigid weather places increased demands on the power system 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 snow storms 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.

9 3.6 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 the snow fails to materialize; if snow does come and the city has not prepared, significant transportation problems arise.

9.4 Water Shortages

- In 2018, Cape Town, South Africa, became dangerously close to running out of water. Reservoirs were dry, causing the city to impose extreme water restrictions, including a 50-liter limit per person per day.[556] The restrictions have postponed a water shortage crisis for now, but Cape Town's experience shows how drought, climate change, and water management practices can lead to a water shortage even in a large, well-established city.
- 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. "Phased Curtailments" occur in four stages: Advisory, Voluntary, Mandatory, and Emergency. While the curtailments would mitigate a greater disaster, they would have increasingly severe impacts on residents and businesses.
- The City of Seattle supplies water to people and businesses within the city limits and to many customers in King County and southwest Snohomish County through wholesale water deliveries. It depends on its two Cascade watersheds, the South Fork Tolt and Cedar Rivers, for its water supply. Both of these reservoirs are managed for instream flows for fish.
- Wells in the Highline area provide limited supplemental back-up for peak loads and emergencies.
- 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. Since the early 1990s, conservation programs, plumbing code changes and pricing have all contributed to reduced water use in the region.
- Maintaining public health is the highest priority in managing a water shortage. In extreme conditions, shortages can result in a degradation of water quality, reduction in the flow of water available for firefighting or sufficiently low pressure that water cannot reach certain areas.
- In an Emergency Curtailment, both stringent restrictions and surcharges will be imposed. Such restrictions would be an economic burden on businesses that are heavy water users and customers without the means to pay for surcharges.

9 4.1 Context

Water shortages develop when the supply of water cannot meet demand. The cause can be either a decreased supply, a rise in demand, or both. They 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.

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. The extent of its demand also depends on the weather. The colder the winter, the more power required.

Seattle Public Utilities (SPU) manages reservoirs in the Cascade Mountains to provide water supply for consumption and fisheries, as well as to provide flood management and hydropower generation. During the spring, SPU captures runoff from melting water from the winter snowpack and rainfall and stores the runoff in city-owned reservoirs. Water remains there until the demand increases and releases from storage are required. During peak demand, water is drawn from the reservoirs at a greater rate than it is being replaced. This yearly cycle of recharge and draw-downs 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 is not forecasted well in advance. If the "water-budget" is not renewed each year, Seattle could face a multi-year 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 Cedar supplies two-thirds of the city's water, 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. The Highline wells provide water in emergencies and peak water use periods.[557] 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 on "water grid" that can provide water from outside sources in a shortage.

As for power, Seattle City Light (SCL) gets most of the power it generates from dams on the Skagit and Pend Oreille Rivers. 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. 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 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. SPU and SCL, with real-time information about snowpack, can typically forecast 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.

SPU uses several data and forecasting tools to monitor water resources.[558] They work with USGS to monitor stream flows and the Natural Resources Conservation Service (NRCS) to monitor snow. Additionally, SPU monitors daily weather forecasts and 30- and 90-day multi-season climate outlooks. They also track 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. It allows 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. While the population that is served by SPU has steadily risen since 1975, 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, significant increases in water and sewer rates and an economic slow-down. Between 1990 to 2016, annual water consumption decreased about 28%, while population increased by 28%. SPU currently serves 1.4 million retail and wholesale customers in King and Snohomish counties. Average water consumption in 2015 was 121 million gallons per day (mgd).

Peak water demand has fallen even more than annual average demand since the 1980s. In the 1980s, hot summer weather could produce peak day consumption of over 325 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.

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.[559]

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 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. A major contamination incident could cause a water shortage. A detection of harmful bacteria such as E. Coli could call for a temporary shutoff to certain affected areas.

9 4.2 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 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.[560]

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.[561] 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 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.

9 4.3 Likelihood of Future Occurrences

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% by 2070 to 2099.[562] 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.[563] 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.[564]

Demand is the critical variable. Total consumption and demand is 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 will face at least a short-term challenge. SPU forecasts that demand will increase gradually to 147 mgd by 2039, and then decline to stay relatively flat at 137 mgd through 2060.[565] Despite the forecasted increase, SPU states there is less than a 10% probability that Seattle will need a new water supply source before 2060.

The challenges are different for SCL. The CIG 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.[566] The authors caution that, in the near term, annual production will be more influenced by other factors, like El Niño/La Niña events, than climate change.

Historically, SCL's peak demand is in the winter when stream flows are also at their peak. Demand in the summer is checked by the low market penetration of air conditioning systems locally. Based on American Housing Survey data, only 33.7% of Seattle-area homes have air conditioning. However, central air conditioning is becoming more commonplace in newly constructed apartments. Seattle has seen a fourfold increase in apartments offering air conditioning over the past decade.[567] While this trend may appear to signal increased future energy demands, newly constructed apartments are so energy efficient that overall demand is still expected to decrease.[568] 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 adaption to climate change will be easier in the winter than the summer.

9 4.4 Vulnerability

The main direct vulnerability in urban areas in a water shortage are financial, as water restrictions and/or price increases are put in place to lower demand and protect supply. Both drinking water and power could be affected. 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.[569] Often, only one system is affected by dry weather.

Overall, the water system seems to have a higher probability of being affected than the power system. The water system cannot supplement supplies from outside the immediate region; SCL's power system can, as it has access to the regional power 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.

Maintaining stream flows for salmon is also a challenge for the utilities. 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 even west of the Cascade Mountains.[570] Fires that occur near the watersheds can degrade surface water supplies by increasing turbidity, impacting aquatic species, and reducing reservoir storage.[571] 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.

SPU and SCL are publicly owned utilities, and any increased costs from water shortages are often be transferred to their customers in the form of higher rates. SPU rates are projected to increase at 5.2% annually for six years, beginning in 2018.[572] 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.

9 4.5 Consequences

Seattle has a water shortage risk that is likely to increase with climate change; however, an even bigger driver will be demand. 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.

9 4.6 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 seems to be little reason to activate the Emergency Operations Center. As with other "creeping" hazards, the City 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.

9.5 Windstorms

- The Puget Sound region experiences strong windstorms, including ones with hurricane force winds known as mid-latitude cyclones. These storms are wider that tropical storms. The largest of these was the 1962 Columbus Day Storm. 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.[573] 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. Between 1950 and 2005 there were 94 tornados in Washington and most were weak. Those in the Puget Lowland were mostly associated with the Puget Sound Convergence Zone.[574]
- Power outages are the most wide-spread problem caused by windstorms. The 2006 storm overwhelmed Seattle City Light when 49% of its customers lost power. 95% of customers were restored within two days, but full restoration took a week.
- Structural damage is the costliest consequence of windstorms. Much of the damage comes from falling trees.[575] Damage can occur at wind speeds as low as 32 mph and destroy wood frame structures at speeds around 100 mph. Seattle's building code requires new structures to withstand 85 mph for three seconds (with modifications to be made for location), but Seattle also has many older buildings. Almost 90,000 homes in Seattle were built before 1939.
- 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.
- 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.
- Floating bridges are vulnerable to wind and wind-driven waves. The Hood Canal Bridge sunk in 1979 and the I-90 Bridge sunk in 1990.

9 5.1 Context

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.[576] 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 wind storms 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 metrological 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.[577]

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. 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. 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. 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 to occur in the Puget Sound area was an F3.

9 5.2 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. Official records at the Federal Building show one occurrence of 65-69 mph winds.[578] A weather station at the Federal Building in downtown Seattle showed that between 1935 and 1959, wind speed exceeded 50 miles per hour 37 times and 60 mph six times.[579]

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.

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. Nevertheless, the damage was widespread. Throughout the region, 46 people died, 53,000 houses were damaged, and the power went out in many areas of Washington. 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.

3/26/1971. Sixty mph winds forced the closure of the Evergreen Point Bridge. The wind also ripped panels off the Seafirst 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.

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.

11/24/1983. The “Thanksgiving Day Storm.” Downed trees were a leading cause of outages that left 75,000 without power in King County. 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 Infrastructure Failure chapter).

11/16/1991. 400,000 were left without power in the Seattle area after the worst storm since the Thanksgiving Day Storm of 1983.

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 road 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.[580]

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. 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.[581] The damage was increased because the trees were in leaf. The North Puget Sound and coastal areas received the strongest winds.

9 5.3 Likelihood of Future Occurrences

Western Washington will continue to experience periodic 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, concluded that the modeled increases in the frequency of extreme wind events due to climate change was minor compared to the expected natural variability.[582]

9 5.4 Vulnerability

Tree density and wet soils are the biggest factors in the amount of damage produced from windstorms in the Pacific Northwest. Tall conifers are often shallow rooted and prone to being uprooted, especially when the ground is saturated with water. The ground is often saturated in the 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.

Falling trees and branches are the major hazard in windstorms. They 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. Finally, trees pose a direct hazard to homes and people.

Wind can cause direct damage to buildings. Seattle's Building Codes, which are built on the International Building Code, specify that structures must withstand a load caused by a three second wind gust of 85 miles per hour. Structural engineers apply this speed to structures using a formula to calculate wind load. Seattle's coast and hills affect this load. Winds are stronger over water and along hillsides. Areas on [Wind Speed Up Areas] that are shown in purple and red are prone to stronger winds. During a windstorm on December 12, 1995, a ship just outside of Elliott Bay reported a gust of 90 mph, exceeding the design threshold.

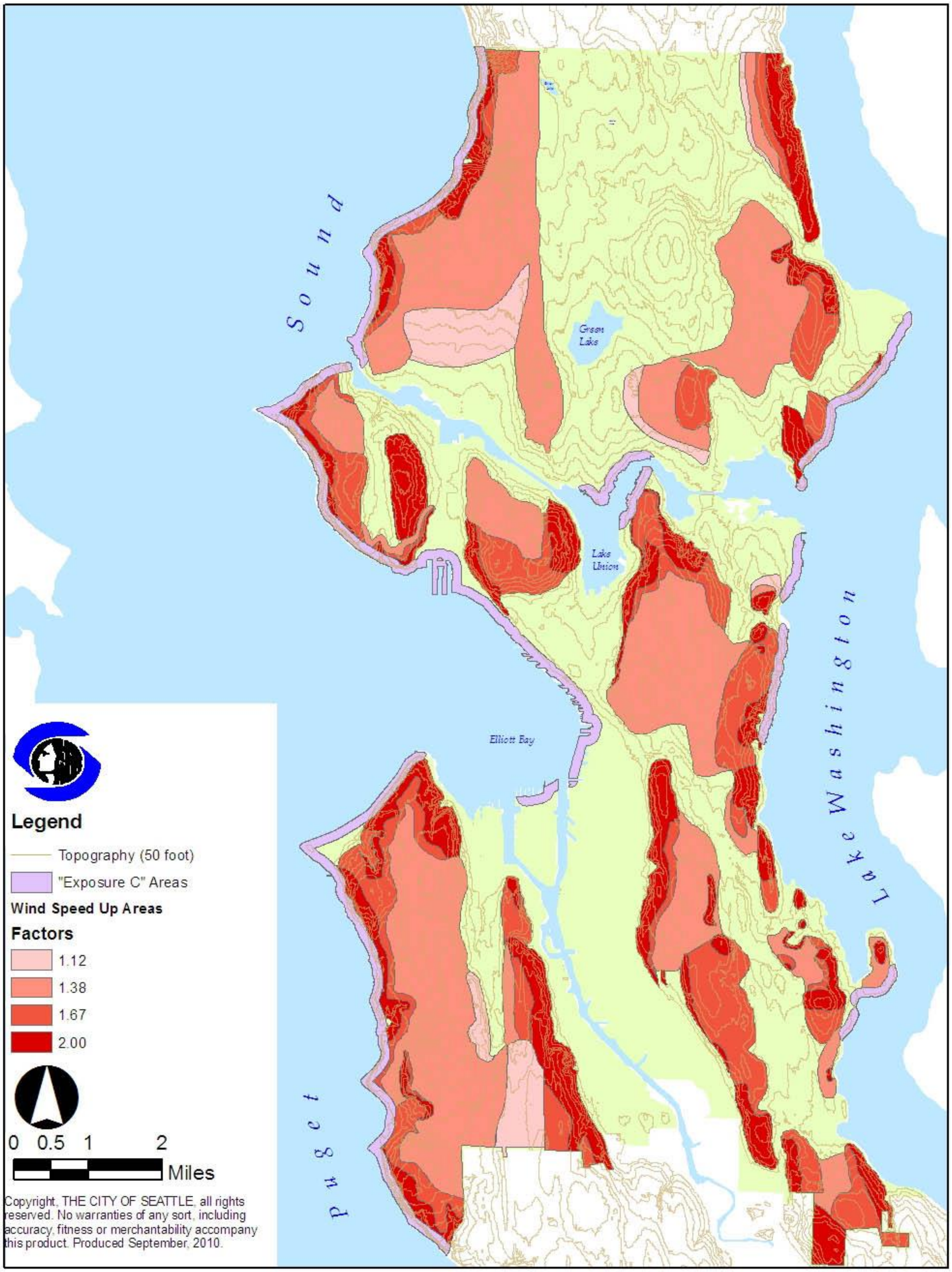
Areas with limited access, such as Magnolia, can become isolated if trees fall on the few roads that lead into them. North and West Seattle, which are the most heavily forested, may have a higher vulnerability of property damage than the rest of the city.

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.[583] 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.[584] 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.

Figure 9-5. Wind Speed-Up Areas



9 5.5 Consequences

Windstorms are a regular part of Pacific Northwest weather as are rain-driven flooding and snow. They cause direct physical damage to structures, infrastructure for power and telecommunications, and coastal bluffs. Falling trees can also cause fatalities. 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 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.

Even moderate wind speed can damage buildings. Wind speeds as low as 32 mph can drive objects through walls.[585] 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.[586] Winds have exceeded this threshold in Seattle, especially in areas where the topography increases wind speeds, demonstrating that widespread structural failures are possible.

Besides doing extensive property damage directly, wind can devastate vegetation and utility lifelines. The 2006 storm caused great damage to City property and infrastructure, with preliminary damage estimates at $16 million.[587]

Besides being an inconvenience to property owners and municipal governments who must clean up debris, falling trees are also a safety risk. In the 2006 windstorm, over 300 trees blocked roadways in King County,[588] including dozens of arterials in Seattle.[589]

Power outages are another widespread problem. Parts of the Eastside lost electricity for days after the 1993 Inauguration Day Storm. These outages also affect traffic lights, making driving a long and difficult process. Finally, falling trees and branches, downed power lines, and transformer explosions are health risks.

The bridges pose another safety risk. If a windstorm develops suddenly, as in 1983, it could hit them before the State Department of Transportation could close them preemptively.

Seattle has experienced severe windstorms regularly. The most likely situation is that this pattern will not change. 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.

9 5.6 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.

10. 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.

10.1 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 x. The tables and charts below summary what is in these zones.

Table 10-1. Land Use in Liquefaction Prone Areas

Area	Acres	% of Seattle	% of Area
Seattle	53178.37	100%	
Liquefaction Prone Areas	8029.46	15%	100%
Property in Areas	**6172.02**	**12%**	77%
Commercial/Mixed-Use	718.78	1%	9%
Easement	2.07	0%	0%
Industrial	1510.42	3%	19%
Major Institution and Public Facilities/Utilities	2024.07	4%	25%
Multi-Family	217.96	0%	3%
Parks/Open Space/Cemeteries	463.74	1%	6%
Reservoirs/Water Bodies	2.92	0%	0%
Single Family	490.97	1%	6%
Unknown	17.31	0%	0%
Vacant	723.76	1%	9%
Right of Way in Areas	**1857.44**	**3%**	23%

Figure 10-1. Summary of Land Use in Liquefaction Prone Areas

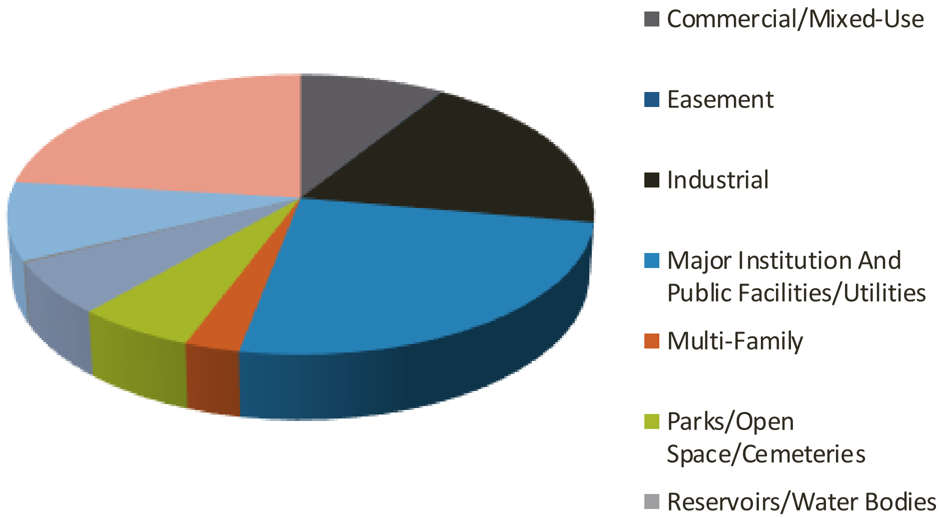


Table 10-2. Estimated Population, Structures and Assessed Value in Liquefaction Prone Areas

Item	Number	Est Pop
Number of Buildings	9,300	na
Number of Single Family Units	4,156	8,561
Number of Multi-Family Units	12,591	25,937
Gross Sq. Footage	103,009,257	
Residential Gross Sq. Footage	22,499,159	
Commercial Gross Sq. Footage	64,599,876	
Total Assessed Value	$ 21,996,732,623	
Estimated Residential Population Exposed		34,499

Table 10-3. Critical Facilities in Liquefaction Prone Areas.

Facility Type	Number
Medical and Health Services	4
Government Function	6
Protective Function	12
Schools	2
Hazardous Materials Storage Sites	23
Bridges	42
Major Tunnels	1
Water	12
Waste Water	12
Communications	0
Energy	22
Human Services	9
High Population	4
Total	***149***

Table 10-4. Facilities with Concentrated Vulnerable Populations in Liquefaction Prone Areas

Facility Type	Number
Adult Family Homes	4
Boarding House	3
Child Care Centers	17
Nursing Home	1
Intermediate Care Facility	0
Total	***25***

Table 10-5. Zoning in Liquefaction Prone Areas

Zoning Area	Acres	% of Seattle	% of Zone
Seattle	53178.37	100%	
Liquefaction Zones	8029.46	15%	100%
Property in Area	**6172.02**	**12%**	77%
Unzoned	0.13	0.00%	0.00%
Commercial - C1	121.90	0.23%	1.52%
Commercial - C2	142.57	0.27%	1.78%
Downtown Harborfront - DH1	31.29	0.06%	0.39%
Downtown Harborfront - DH2	10.87	0.02%	0.14%
Downtown Mixed Commercial - DMC	16.30	0.03%	0.20%
Downtown Mixed Residential/Commercial - DMR	2.43	0.00%	0.03%
Industrial Buffer - IB	82.79	0.16%	1.03%
Industrial Commercial - IC	243.83	0.46%	3.04%
Downtown, International District Mixed - IDM	16.33	0.03%	0.20%
Downtown, International District Residential - IDR	0.01	0.00%	0.00%
General Industrial - IG1	2187.77	4.11%	27.25%
General Industrial - IG2	1610.65	3.03%	20.06%
Lowrise - LR1	50.47	0.09%	0.63%
Lowrise - LR2	86.97	0.16%	1.08%
Lowrise - LR3	120.16	0.23%	1.50%
Major Institution - MIO	149.01	0.28%	1.86%
Multi-Family, Midrise - MR	15.53	0.03%	0.19%
Neighborhood Commercial - NC1	23.56	0.04%	0.29%

Neighborhood Commercial - NC2	55.45	0.10%	0.69%
Neighborhood Commercial - NC3	53.43	0.10%	0.67%
Downtown, Pike Place Market - PMM	0.84	0.00%	0.01%
Downtown, Pioneer Square - PSM	36.39	0.07%	0.45%
Single Family - SF 5000	541.63	1.02%	6.75%
Single Family - SF 7200	468.28	0.88%	5.83%
Single Family - SF 9600	85.06	0.16%	1.06%
Neighborhood Commercial, Seattle Mixed-SM	14.27	0.03%	0.18%
Neighborhood Commercial, Seattle Mixed - SMI	3.37	0.01%	0.04%
Neighborhood Commercial, Seattle Mixed Residential - SMR	0.75	0.00%	0.01%
Right of Way in Area	**1857.44**	**3.49%**	23.13%

Table 10-6. Growth Centers in Liquefaction Prone Areas.

Urban Centers / Villages and Manufacturing Centers	Acres	% Seattle	% Area	% Center
Seattle	53178	100%		
All Hub and Residential Urban Villages	*5714.5*	*10.75%*		
All Urban Centers	*5715.5*	*6.98%*		
All Manufacturing / Industrial Center	*5716.5*	*11.10%*		
Liquefaction Zones	8029.46	15%	100%	
Hub and Residential Urban Villages in Zone	590.48	1.11%	10.01%	10.33%
Urban Centers in Zone	386.95	0.73%	4.82%	10.43%
Manufacturing / Industrial Center in Zone	5172.76	9.73%	64.42%	87.67%

Table 10-7. Wildlife Areas in Liquefaction Prone Areas.

	Acres	% Seattle
Seattle	53178	100%
Liquefaction Zones	8029.46	15%
All Wildlife Habitat Areas	3749.89	7.05%
Wildlife Habitat in Liquefaction Prone Areas	391.52	0.74%

10.2 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 10-8. Land Use in Landslide Prone Areas

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Landslide Prone Area	4471.43	8%	100%
Property in Area	**3342.46**	**6%**	75%
Commercial/Mixed-Use	61.24	0%	1%
Easement	0.03	0%	0%
Industrial	61.39	0%	1%
Major Institution And Public Facilities/Utilities	134.36	0%	3%
Multi-Family	234.23	0%	5%
Parks/Open Space/Cemeteries	327.83	1%	7%
Reservoirs/Water Bodies	0.00	0%	0%
Single Family	1468.48	3%	33%
Unknown	4.79	0%	0%
Vacant	1050.11	2%	23%
Right of Way in Area	**1128.97**	**2%**	25%

Figure 10-2. Summary of Land Use in Landslide Prone Area

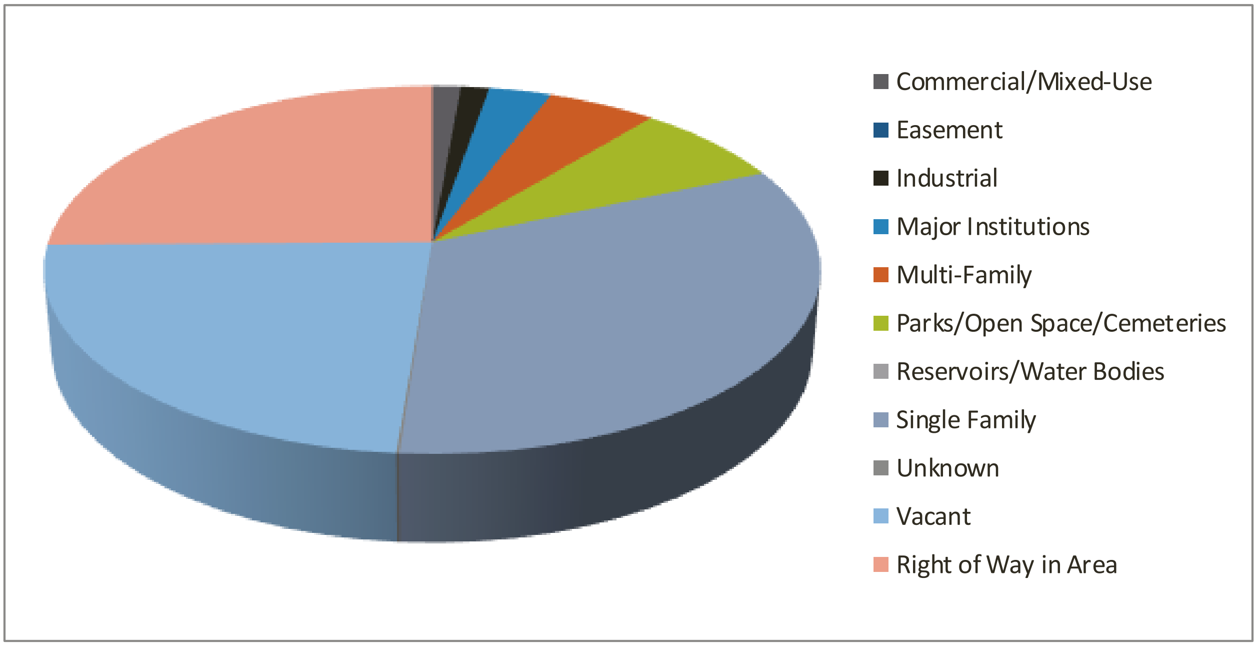


Table 10-9. Estimated Population, Structures and Assessed Value in Landslide Prone Area

Number of Buildings	13,084	Est. Pop
Number of Single Family Units	10,381	21385
Number of Multi-Family Units	10,517	21665
Gross Sq. Footage	49,433,018	
Residential Gross Sq. Footage	40,122,719	
Commercial Gross Sq. Footage	6,055,902	
Total Assessed Value	$ 12,626,534,807	
Estimated Residential Population		43050

Table 10-10. Critical Facilities within 50ft of Landslide Prone Areas

Medical and Health Services	0
Government Function	0
Protective Function	1
Schools	2
Hazardous Materials Storage Sites	0
Bridges	79
Major Tunnels	0
Water	2
Waste Water	1
Communications	1
Energy	1
Human Services	0
High Population	0
Total	***87***

Table 10-11. Facilities with Concentrated Vulnerability Populations within 50ft of Landslide Prone Areas

Adult Family Homes	13
Boarding House	0
Child Care Centers	5
Nursing Home	1
Intermediate Care Facility	0
Total	***19***

Table 10-12. Zoning in Landslide Prone Areas

Zoning Area	Acres	% of Seattle	% of Area
Seattle	53178.37	100%	
Landslide Prone Area	4471.43	8%	100%
Parcel area in zone	**3342.46**	**6%**	75%
Unzoned	0.23	0.00%	0.01%
Commercial - C1	24.03	0.05%	0.54%
Commercial - C2	23.02	0.04%	0.51%
Downtown Harborfront - DH1	0.00	0.00%	0.00%
Downtown Harborfront - DH2	0.00	0.00%	0.00%
Downtown Mixed Commercial - DMC	2.60	0.00%	0.06%
Downtown Mixed Residential/Commercial - DMR	2.00	0.00%	0.04%
Industrial Buffer - IB	45.87	0.09%	1.03%
Industrial Commercial - IC	1.90	0.00%	0.04%
Downtown,International District Mixed - IDM	0.00	0.00%	0.00%
Downtown, International District Residential - IDR	0.00	0.00%	0.00%
General Industrial - IG1	20.42	0.04%	0.46%
General Industrial - IG2	32.96	0.06%	0.74%
Lowrise - LR1	113.40	0.21%	2.54%
Lowrise - LR2	96.33	0.18%	2.15%
Lowrise - LR3	95.17	0.18%	2.13%
Major Institution - MIO	27.85	0.05%	0.62%
MPC			
Multi-Family, Midrise - MR	12.13	0.02%	0.27%
Neighborhood Commercial - NC1	3.88	0.01%	0.09%
Neighborhood Commercial - NC2	3.05	0.01%	0.07%
Neighborhood Commercial - NC3	10.78	0.02%	0.24%
Downtown, Pike Place Market - PMM	0.00	0.00%	0.00%
Downtown, Pioneer Square - PSM	0.00	0.00%	0.00%
Single Family - SF 5000	1215.51	2.29%	27.18%
Single Family - SF 7200	1173.04	2.21%	26.23%
Single Family - SF 9600	431.72	0.81%	9.66%
Neighborhood Commercial, Seattle Mixed- SM	4.12	0.01%	0.09%
Neighborhood Commercial, Seattle Mixed - SMI	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed Residential - SMR	1.03	0.00%	0.02%
Right of Way	**1128.97**	**2.12%**	25.25%

Table 10-13. Urban Growth Centers / Villages and Manufacturing Centers

Urban Centers / Villages and Manufacturing Centers	Acres	% Seattle	% Area	% Center
Seattle	53178	100%		
All Hub and Residential Urban Villages	*5714.5*	*10.75%*		
All Urban Centers	*5715.5*	*6.98%*		
All Manufacturing / Industrial Center	*5716.5*	*11.10%*		
Landslide Prone Area	4471.43	8%	100%	
Hub and Residential Urban Villages in Zone	87.20	0.16%	1.95%	1.53%
Urban Centers in Zone	30.85	0.06%	0.69%	0.83%
Manufacturing / Industrial Center in Zone	141.63	0.27%	3.17%	2.40%

Table 10-14. 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%
Wildlife Habitat in Landslide Prone Areas	1473.54	2.77%

10.3 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 10-15. Land Use in Post-Lahar Sedimentation Area

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Post-Lahar Sedimentation Area	3463.73	6.51%	100.00%
Parcel area in area	**2778.94**	**5.23%**	80.23%
Commercial/Mixed-Use	136.50	0.26%	3.94%
Easement	0.36	0.00%	0.01%
Industrial	1005.90	1.89%	29.04%
Major Institution And Public Facilities/Utilities	1239.45	2.33%	35.78%
Multi-Family	21.47	0.04%	0.62%
Parks/Open Space/Cemeteries	7.18	0.01%	0.21%
Reservoirs/Water Bodies	1.95	0.00%	0.06%
Single Family	95.92	0.18%	2.77%
Unknown	0.88	0.00%	0.03%
Vacant	269.31	0.51%	7.78%
Right of Way in area	**684.79**	**1.29%**	19.77%

Figure 10-3. Summary of Land Use in Post-Lahar Sedimentation Area

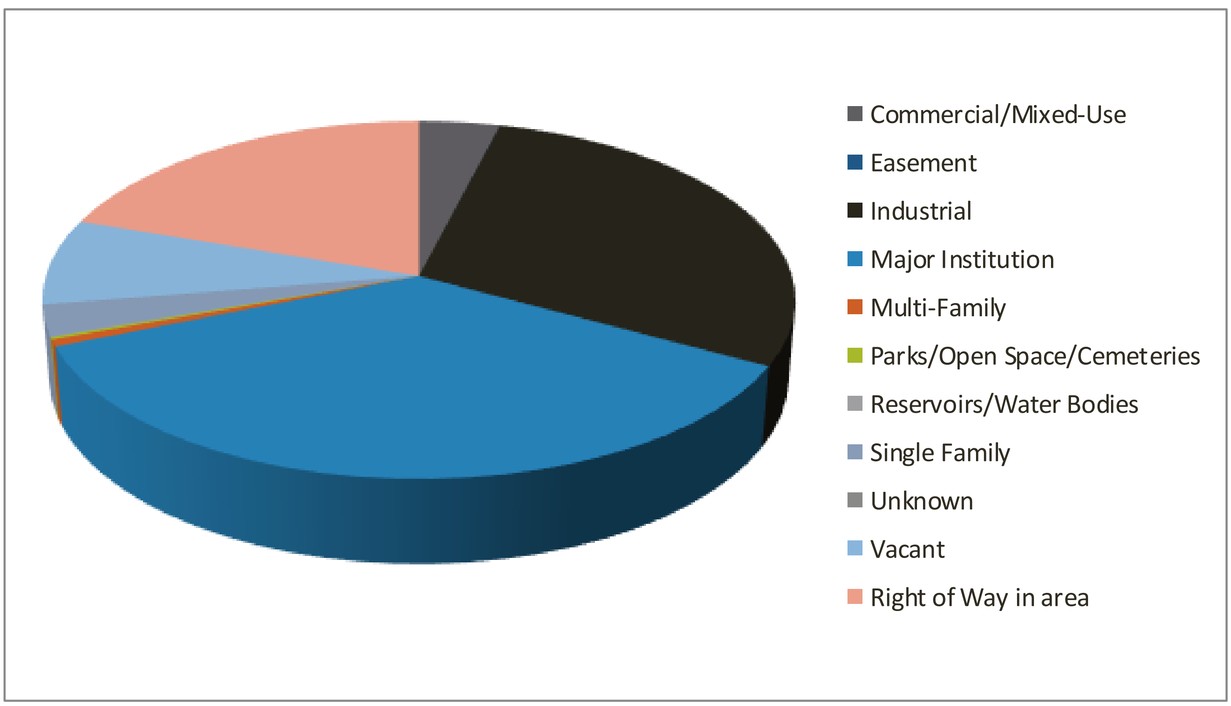


Table 10-16. Estimated Population, Structures and Assessed Value in Post-Lahar Sedimentation Area

Number of Buildings	2,536	Est. Pop
Number of Single Family Units	847	1745
Number of Multi-Family Units	726	1496
Residential Gross Sq Footage	1,906,099	
Commercial Gross Sq Footage	29,047,215	
Total Assessed Value	$ 4,998,383,962	
Estimated Residential Population		3240

Table 10-17. Critical Facilities in Post-Lahar Sedimentation Area

Medical and Health Services	2
Government Function	0
Protective Function	2
Schools	0
Hazardous Materials Storage Sites	15
Bridges	23
Major Tunnels	0
Water	1
Waste Water	2
Communications	0
Energy	2
Human Services	4
High Population	0
Total	***51***

Table 10-18. Facilities with Concentrated Vulnerable Population in Post-Lahar Sedimentation Area

Adult Family Homes	0
Boarding House	0
Child Care Centers	3
Nursing Home	0
Intermediate Care Facility	0
Total	***3***

Table 10-19. Zoning in Post-Lahar Sedimentation Area

Zoning Area	Acres	% of Seattle	% Area
Seattle	53178.37	100%	
Post-Lahar Sedimentation Area	3463.73	7%	100%
Parcel area in area	**2778.94**	**5%**	80%
Unzoned	0.06	0.00%	0.00%
Commercial - C1	13.13	0.02%	0.38%
Commercial - C2	7.07	0.01%	0.20%
Downtown Harborfront - DH1	0.00	0.00%	0.00%
Downtown Harborfront - DH2	0.00	0.00%	0.00%
Downtown Mixed Commercial - DMC	0.00	0.00%	0.00%
Downtown Mixed Residential/Commercial - DMR	0.00	0.00%	0.00%
Industrial Buffer - IB	69.26	0.13%	2.00%
Industrial Commercial - IC	29.04	0.05%	0.84%
Downtown,International District Mixed - IDM	0.00	0.00%	0.00%
Downtown, International District Residential - IDR	0.00	0.00%	0.00%
General Industrial - IG1	1580.59	2.97%	45.63%
General Industrial - IG2	951.69	1.79%	27.48%
Lowrise - LR1	3.99	0.01%	0.12%
Lowrise - LR2	19.94	0.04%	0.58%
Lowrise - LR3	5.91	0.01%	0.17%
Major Institution - MIO	0.00	0.00%	0.00%
Multi-Family, Midrise - MR	0.00	0.00%	0.00%
Neighborhood Commercial - NC1	0.00	0.00%	0.00%
Neighborhood Commercial - NC2	2.60	0.00%	0.08%
Neighborhood Commercial - NC3	10.46	0.02%	0.30%
Downtown, Pike Place Market - PMM	0.00	0.00%	0.00%
Downtown, Pioneer Square - PSM	0.00	0.00%	0.00%
Single Family - SF 5000	84.10	0.16%	2.43%
Single Family - SF 7200	1.10	0.00%	0.03%
Single Family - SF 9600	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed- SM	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed - SMI	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed Residential - SMR	0.00	0.00%	0.00%
Right of Way in Area	**684.79**	**1.29%**	19.77%

Table 10-20. Urban Growth Centers / Village and Manufacturing Centers

Urban Centers / Villages and Manufacturing Centers	Acres	% Seattle	% Area	% Center
Seattle	53178	100%		
All Hub and Residential Urban Villages	*5714.5*	*10.75%*		
All Urban Centers	*5715.5*	*6.98%*		
All Manufacturing / Industrial Center	*5716.5*	*11.10%*		
Post-Lahar Sedimentation Zone	3463.73	6.51%	100.00%	
Hub and Residential Urban Villages in Zone	127.61	0.24%	3.68%	2%
Urban Centers in Zone	0.00	0.00%	0.00%	0%
Manufacturing / Industrial Center in Zone	3211.49	6.04%	92.72%	54%

Table 10-21. 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%
Wildlife Habitat in Post-Lahar Sedimentation Zone	23.06	0.04%

10.4 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 10-22. Land Use in Worst Case Tsunami Inundation Area

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Worst Case Tsunami Inundation Area	2234.58	4%	100%
Parcel area in Area	**1710.63**	**3%**	77%
Commercial/Mixed-Use	218.48	0%	10%
Easement	0.70	0%	0%
Industrial	362.80	1%	16%
Major Institutions	835.34	2%	37%
Multi-Family	15.36	0%	1%
Parks/Open Space/Cemeteries	47.21	0%	2%
Reservoirs/Water Bodies	3.02	0%	0%
Single Family	21.03	0%	1%
Unknown	5.58	0%	0%
Vacant	201.12	0%	9%
Right of Way in Area	**523.95**	**1%**	23%

Figure 10-4. Summary of Land Use in Worst Case Tsunami Inundation Area

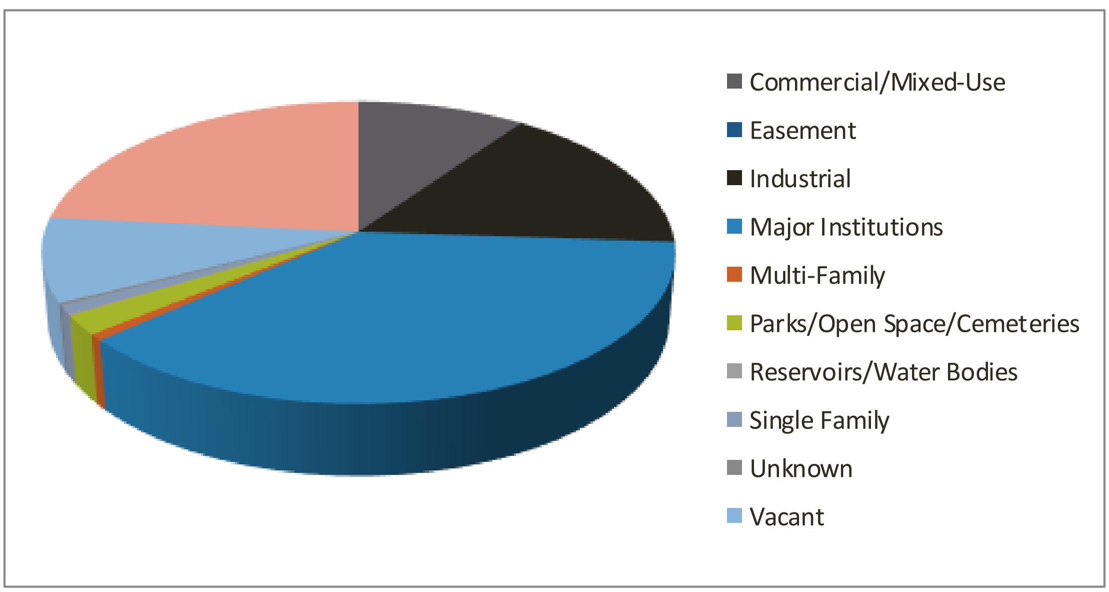


Table 10-23. Estimated Pop., Structures and Assess Value in Worst Case Tsunami Inundation Area

		Est. Pop
Number of Buildings	1,339	
Number of Single Family Units	256	527
Number of Multi-Family Units	2,846	5863
Gross Sq. Footage	41,209,932	
Residential Gross Sq. Footage	5,283,843	
Commercial Gross Sq. Footage	26,323,583	
Total Assessed Value	$ 8,790,180,758	
Estimated Residential Population		6390

Table 10-24. Critical Facilities in Worst Case Tsunami Inundation Area

Medical and Health Services	1
Government Function	0
Protective Function	2
Schools	0
Hazardous Materials Storage Sites	11
Bridges	37
Major Tunnels	1
Water	0
Waste Water	0
Communications	0
Energy	2
Human Services	1
High Population	4
Total	***59***

Table 10-25. Facilities with Concentrated Vulnerable Pop. In Worst Case Tsunami Inundation Area

Adult Family Homes	0
Boarding House	0
Child Care Centers	2
Nursing Home	0
Intermediate Care Facility	0
Total	***2***

Table 10-26. Zoning in Worst Case Tsunami Inundation Area

Zoning Area	Acres	% of Seattle	% of Area
Seattle	53178.37	100%	
Worst Case Tsunami Inundation Area	2234.58	4%	100%
Parcel area	**1710.63**	**3%**	77%
Unzoned	0.11	0.00%	0.01%
Commercial - C1	7.83	0.01%	0.35%
Commercial - C2	13.59	0.03%	0.61%
Downtown Harborfront - DH1	32.60	0.06%	1.46%
Downtown Harborfront - DH2	10.73	0.02%	0.48%
Downtown Mixed Commercial - DMC	8.93	0.02%	0.40%
Downtown Mixed Residential/Commercial - DMR	4.15	0.01%	0.19%
Industrial Buffer - IB	3.83	0.01%	0.17%
Industrial Commercial - IC	177.93	0.33%	7.96%
Downtown, International District Mixed - IDM	0.73	0.00%	0.03%
Downtown, International District Residential - IDR	0.00	0.00%	0.00%
General Industrial - IG1	1111.92	2.09%	49.76%
General Industrial - IG2	200.17	0.38%	8.96%
Lowrise - LR1	1.57	0.00%	0.07%
Lowrise - LR2	4.37	0.01%	0.20%
Lowrise - LR3	1.11	0.00%	0.05%
Major Institution - MIO	0.00	0.00%	0.00%
Multi-Family, Midrise - MR	3.64	0.01%	0.16%
Neighborhood Commercial - NC1	25.25	0.05%	1.13%
Neighborhood Commercial - NC2	4.60	0.01%	0.21%
Neighborhood Commercial - NC3	1.22	0.00%	0.05%
Downtown, Pike Place Market - PMM	0.14	0.00%	0.01%
Downtown, Pioneer Square - PSM	26.83	0.05%	1.20%
Single Family - SF 5000	8.92	0.02%	0.40%
Single Family - SF 7200	60.21	0.11%	2.69%
Single Family - SF 9600	0.25	0.00%	0.01%
Neighborhood Commercial, Seattle Mixed- SM	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed - SMI	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed Residential - SMR	0.00	0.00%	0.00%
Right of Way in area	**523.95**	**0.99%**	23.45%

Table 10-27. Urban Centers / Villages and Manufacturing Centers in Worst Case Tsunami Inundation Area

Urban Centers / Villages and Manufacturing Centers	Acres	% Seattle	% Area	% Center
Seattle	53178	100%		
All Hub and Residential Urban Villages	*5714.5*	*10.75%*		
All Urban Centers	*5715.5*	*6.98%*		
All Manufacturing / Industrial Center	*5716.5*	*11.10%*		
Worst Case Tsunami Inundation Area	2234.58	4%	100%	
Hub and Residential Urban Villages in Zone	0.00	0.00%	0.00%	0.00%
Urban Centers in Zone	186.29	0.35%	8.34%	5.02%
Manufacturing / Industrial Center in Zone	1825.89	3.43%	81.71%	30.94%

Table 10-28. Wildlife Areas in Worst Case Tsunami Inundation Area

	Acres	% Seattle
Seattle	53178	100%
Worst Case Tsunami Inundation Area	2234.58	4%
Wildlife Habitat Areas	3749.89	7.05%
Wildlife Habitat in Worst Case Tsunami Inundation Area	391.52	0.74%

Table 10-29. Land Use in Lake Union Seiche Area

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Lk. Union Seiche Area	144.11	0%	100%
Property in area	**144.11**	**0%**	100%
Commercial/Mixed-Use	84.89	0%	59%
Easement	0.00	0%	0%
Industrial	2.46	0%	2%
Major Institutions	17.29	0%	12%
Multi-Family	0.89	0%	1%
Parks/Open Space/Cemeteries	4.74	0%	3%
Reservoirs/Water Bodies	0.01	0%	0%
Single Family	19.24	0%	13%
Unknown	1.26	0%	1%
Vacant	6.30	0%	4%
Right of Way in area	**0.00**	**0%**	0%

Figure 10-5. Summary of Land use in Lake Union Seiche Area

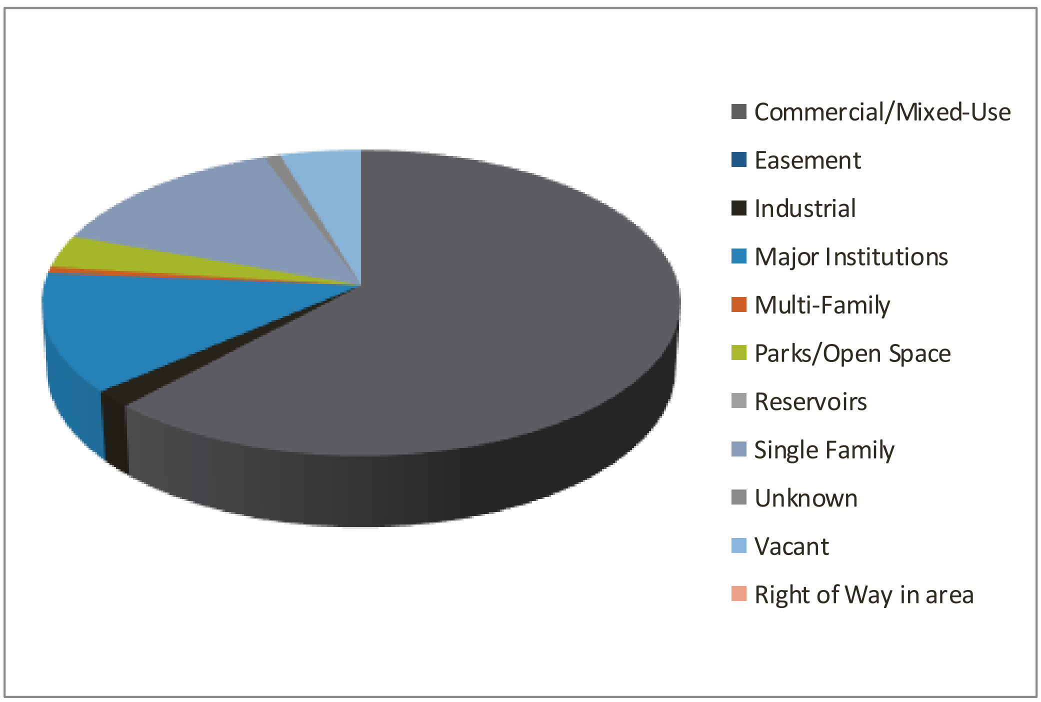


Table 10-30. Estimated Population, Structures, and Assessed Value in Lake Union Seiche Area

Number of Buildings	530	Est. Pop
Number of Single-Family Units	77	159
Number of Multi-Family Units	100	206
Gross Sq. Footage	2,113,176	
Residential Gross Sq. Footage	281,073	
Commercial Gross Sq. Footage	1,445,938	
Total Assessed Value	$ 702,618,934	
Estimated Residential Population		365

Table 10-31. Critical Facilities in Lake Union Seiche Area

Medical and Health Services	0
Government Function	1
Protective Function	0
Schools	0
Hazardous Materials Storage Sites	0
Bridges	1
Major Tunnels	0
Water	0
Waste Water	0
Communications	0
Energy	0
Human Services	0
High Population	0
Total	***2***

Table 10-32. Facilities with Concentrated Vulnerable Populations in Lake Union Seiche Area

Adult Family Homes	0
Boarding House	0
Child Care Centers	0
Nursing Home	0
Intermediate Care Facility	0
Total	***0***

Table 10-33. Zoning in Lake Union Seiche Area

	Acres	% of Seattle	% of Area
Seattle	53178.37	100%	
Lk. Union Seiche Area	144.11	0.27%	100%
Property in area	144.11	0.27%	100%
Unzoned	0.01	0.00%	0.01%
Commercial - C1	1.86	0.00%	1.29%
Commercial - C2	73.91	0.14%	51.29%
Downtown Harborfront - DH1	32.60	0.06%	22.62%
Downtown Harborfront - DH2	0.00	0.00%	0.00%
Downtown Mixed Commercial - DMC	0.00	0.00%	0.00%
Downtown Mixed Residential/Commercial - DMR	0.00	0.00%	0.00%
Industrial Buffer - IB	20.67	0.04%	14.34%
Industrial Commercial - IC	8.86	0.02%	6.15%
Downtown, International District Mixed - IDM	0.73	0.00%	0.51%
Downtown, International District Residential - IDR	0.00	0.00%	0.00%
General Industrial - IG1	20.40	0.04%	14.16%
General Industrial - IG2	0.00	0.00%	0.00%
Lowrise - LR1	0.00	0.00%	0.00%
Lowrise - LR2	3.74	0.01%	2.59%
Lowrise - LR3	0.62	0.00%	0.43%
Major Institution - MIO	0.00	0.00%	0.00%
Multi-Family, Midrise - MR	0.00	0.00%	0.00%
Neighborhood Commercial - NC1	0.00	0.00%	0.00%
Neighborhood Commercial - NC2	0.00	0.00%	0.00%
Neighborhood Commercial - NC3	0.00	0.00%	0.00%
Downtown, Pike Place Market - PMM	0.00	0.00%	0.00%
Downtown, Pioneer Square - PSM	0.00	0.00%	0.00%
Single Family - SF 5000	14.03	0.03%	9.73%
Single Family - SF 7200	0.00	0.00%	0.00%
Single Family - SF 9600	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed- SM	0.01	0.00%	0.01%
Neighborhood Commercial, Seattle Mixed - SMI	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed Residential - SMR	0.00	0.00%	0.00%
Right of Way	**0.00**	**0.00%**	0.00%

Table 10-34. Urban Growth Centers in Lake Union Seiche Area

Urban Centers / Villages and Manufacturing Centers	Acres	% Seattle	% Area	% Center
Seattle	53178	100%		
All Hub and Residential Urban Villages	*5714.5*	*10.75%*		
All Urban Centers	*5715.5*	*6.98%*		
All Manufacturing / Industrial Center	*5716.5*	*11.10%*		
Seiche Area	2234.58	4%	1551%	
Hub and Residential Urban Villages in Zone	5.79	0.01%	0.26%	0.10%
Urban Centers in Zone	3.02	0.01%	0.14%	0.08%
Manufacturing / Industrial Center in Zone	0.00	0.00%	0.00%	0.00%

Table 10-35. Wildlife Areas in Lake Union Seiche Area

	Acres	% Seattle
Seattle	53178	100%
Worst Case Tsunami Inundation Area	2234.58	4%
Wildlife Habitat Areas	3749.89	7.05%
Wildlife Habitat in Seiche Area	0	0.00%

10.5 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 10-36. Land use in Flood Prone Areas

	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Flood Area (1996 FIRM & other)	388.39	0.73%	100.00%
Property in area	**328.81**	**0.62%**	84.66%
Commercial/Mixed-Use	18.35	0.03%	4.72%
Easement	0.00	0.00%	0.00%
Industrial	50.06	0.09%	12.89%
Major Institutions	47.45	0.09%	12.22%
Multi-Family	13.82	0.03%	3.56%
Parks/Open Space	72.77	0.14%	18.74%
Reservoirs	0.81	0.00%	0.21%
Single Family	69.90	0.13%	18.00%
Unknown	0.62	0.00%	0.16%
Vacant	55.03	0.10%	14.17%
Right of Way in Area	**59.58**	**0.11%**	15.34%

Figure 10-6. Summary of Land use in Flood Prone Areas

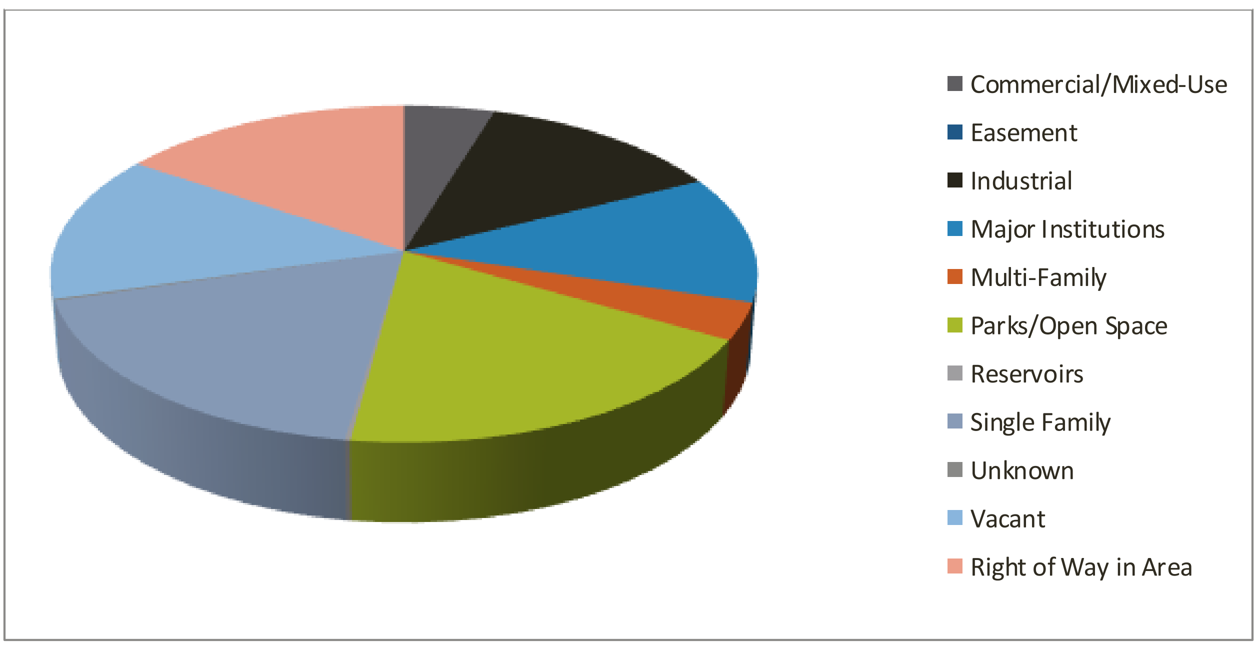


Table 10-37. Estimated Population, Buildings and Assessed Value in Flood Prone areas

Number of Buildings	1,722*	Est. Pop
Number of Single-Family Units	1,182	2435
Number of Multi-Family Units	2,038	4198
Gross Sq Footage	9,596,454	
Residential Gross Sq Footage	5,139,396	
Commercial Gross Sq Footage	3,802,382	
Total Assessed Value	$ 3,569,721,500	
Estimated Residential Population		6633

Table 10-38. Critical Facilities in Flood Prone Areas

Medical and Health Services	0
Government Function	0
Protective Function	0
Schools	1
Hazardous Materials Storage Sites	0
Bridges	14
Major Tunnels	0
Water	1
Waste Water	0
Communications	0
Energy	0
Human Service Support	1
High Population	0
Total	***17***

Table 10-39. Facilities in Concentrated Vulnerable Populations in Flood Prone Areas

Adult Family Homes	0
Boarding House	0
Child Care Centers	0
Nursing Home	0
Intermediate Care Facility	0
Total	***0***

Table 10-40. Zoning in Flood Prone Areas

	Acres	% of Seattle	% Area
Seattle	53178.37	100%	
Flood Area (1996 FIRM & other)	388.39	0.73%	100.00%
Zoning	**328.81**	**0.62%**	84.66%
Unzoned	0.01	0.00%	0.00%
Commercial - C1	11.36	0.02%	2.92%
Commercial - C2	4.85	0.01%	1.25%
Downtown Harborfront - DH1	4.18	0.01%	1.08%
Downtown Harborfront - DH2	0.00	0.00%	0.00%
Downtown Mixed Commercial - DMC	0.00	0.00%	0.00%
Downtown Mixed Residential/Commercial - DMR	0.00	0.00%	0.00%
Industrial Buffer - IB	2.91	0.01%	0.75%
Industrial Commercial - IC	2.90	0.01%	0.75%
Downtown,International District Mixed - IDM	0.00	0.00%	0.00%
Downtown, International District Residential - IDR	0.00	0.00%	0.00%
General Industrial - IG1	34.64	0.07%	8.92%
General Industrial - IG2	48.22	0.09%	12.41%
Lowrise - LR1	7.89	0.01%	2.03%
Lowrise - LR2	8.55	0.02%	2.20%
Lowrise - LR3	4.62	0.01%	1.19%
Major Institution - MIO	149.01	0.28%	38.37%
Multi-Family, Midrise - MR	0.00	0.00%	0.00%
Neighborhood Commercial - NC1	11.72	0.02%	3.02%
Neighborhood Commercial - NC2	1.60	0.00%	0.41%
Neighborhood Commercial - NC3	1.46	0.00%	0.38%
Downtown, Pike Place Market - PMM	0.00	0.00%	0.00%
Downtown, Pioneer Square - PSM	0.00	0.00%	0.00%
Single Family - SF 5000	51.48	0.10%	13.25%
Single Family - SF 7200	93.45	0.18%	24.06%
Single Family - SF 9600	40.91	0.08%	10.53%
Neighborhood Commercial, Seattle Mixed- SM	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed - SMI	0.00	0.00%	0.00%
Neighborhood Commercial, Seattle Mixed Residential - SMR	0.00	0.00%	0.00%
Right of Way	**59.58**	**0.11%**	15.34%

Table 10-41. Urban Growth Centers in Flood Prone Areas

Urban Centers / Villages and Manufacturing Centers	Acres	% Seattle	% Zone	% Center
Seattle	53178	100%		
All Hub and Residential Urban Villages	*5714.5*	*10.75%*		
All Urban Centers	*5715.5*	*6.98%*		
All Manufacturing / Industrial Center	*5716.5*	*11.10%*		
Flood Area (1996 FIRM & other)	388.39	0.73%	100.00%	
Hub and Residential Urban Villages in Zone	11.52	0.02%	0.02%	0.20%
Urban Centers in Zone	7.71	0.01%	0.01%	0.21%
Manufacturing / Industrial Center in Zone	119.58	0.22%	0.22%	2.03%

Table 10-42. Wildlife Areas in Flood Prone Areas

	Acres	% Seattle
Seattle	53178	100%
Flood Area (1996 FIRM & other)	388.39	0.73%
Wildlife Habitat Areas	3749.89	7.05%
Wildlife Habitat in Urban Flood Areas	56.77	0.11%

Table 10-43. Land Use in Urban Flood Areas

Area	Acres	% Seattle	% Area
Seattle	53178.37	100%	
Urban Flood Prone Areas	3312.57	6.23%	100.00%
Property in Area	**2398.31**	**4.51%**	72.40%
Commercial/Mixed-Use	157.00	0.30%	4.74%
Easement	0.00	0.00%	0.00%
Industrial	66.46	0.12%	2.01%
Major Institutions	189.86	0.36%	5.73%
Multi-Family	284.92	0.54%	8.60%
Parks/Open Space/Cemeteries	40.46	0.08%	1.22%
Reservoirs	0.00	0.00%	0.00%
Single Family	1410.64	2.65%	42.58%
Unknown	5.42	0.01%	0.16%
Vacant	243.55	0.46%	7.35%
Right of Way	**914.26**	**1.72%**	27.60%

Figure 10-7. Summary of Land Use in Urban Flood Prone Areas

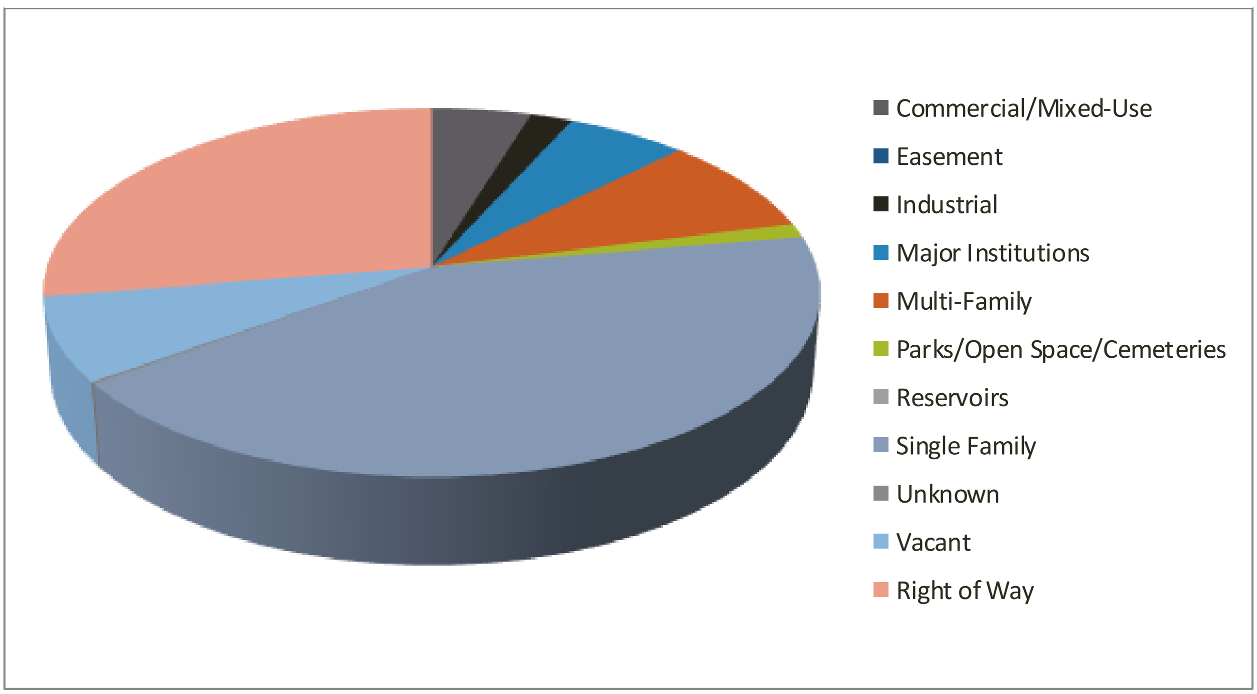


Table 10-44. Estimated Population, Buildings, and Assessed Value in Urban Flood Prone Areas

Number of Buildings	***11,483***	***Est. Pop***
Number of Single Family Units	***8,505***	***17,520***
Number of Multi-Family Units	***10,637***	***21,912***
Residential Gross Sq Footage	***27,796,973***	
Commercial Gross Sq Footage	***4,187,463***	
Total Assessed Value	***$ 5,054,230,233***	
Estimated Residential Population		39,433

Table 10-45. Critical Facilities in Urban Flood Prone Areas

Medical and Health Services	1
Government Function	0
Protective Function	3
Schools	9
Hazardous Materials Storage Sites	0
Bridges	3
Major Tunnels	0
Water	1
Waste Water	2
Communications	0
Energy	3
Human Services	7
High Population	0
Total	***29***

Table 10-46. Facilities with Concentrated Vulnerable Populations in Urban Flood Prone Areas

Adult Family Homes	13
Boarding House	6
Child Care Centers	13
Nursing Home	4
Intermediate Care Facility	0
Total	***36***

11. APPENDIX B: SCENARIOS

This section provides two scenarios for each hazard: a Most Likely and a Maximum Credible. The scenarios are used to create the hazard rankings found in the beginning of this document.

11.1 Earthquakes

11 1.1 Most Likely Scenario

A M6.7 deep earthquake centered near Seattle occurs during business hours. The earthquake is similar to the 2001 Nisqually Earthquake but a little more powerful. 10 unreinforced masonry buildings partially collapse in the Pioneer Square and Sodo areas. 200 have to be red tagged and 1000 are yellow tagged. The ground is saturated with water causing widespread liquefaction, lateral spread, and landslides.

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.
Displaced Households 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.
Structures	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	2	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 landsides have also been triggered destroying several homes and damaging 10-20 apartment buildings and businesses.

11 1.2 Maximum Credible Scenario

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 hazardous materials.

Category	Impact (1- 5)	Effects
Frequency	2	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.
Displaced Households 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.
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.
Structures	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.

Category	Impact (1- 5)	Effects
Transportation	5	Damage to surface, air and marine transportation systems is extreme. All major surface routes into the city are damaged and impassible. Retrofitting of bridges ensure 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.

11 1.3 Alternate Scenario

Because earthquakes are so complex, it is impossible to convey the earthquake hazard consequences without briefly mentioning megathrust 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 a position of having to help coastal communities even as it struggles with huge losses.

11.2 Landslide Scenarios

11 2.1 Most Likely Scenario

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 damaged. A few major roads blocked. Several roads 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.
Displaced Households 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 loss, 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.
Structures	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.

11 2.2 Maximum Credible Scenario

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. An explosion occurs when a train carrying Bakken crude oil is knocked into Puget Sound by a landslide.

Category	Impact 1 = low 5 = high	Narrative
Frequency	2	This scenario is considered 1 in 1000 event.
Geographic Scope	3	Almost all of the area identified as landslide prone is affected (8% of the Seattle's landmass).
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
Displaced Households 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.
Structures	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.

Category	Impact 1 = low 5 = high	Narrative
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.

11.3 Volcanic Hazards

11 3.1 Most Likely Scenario

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. People who work in Seattle and live in South King County and Pierce County have a hard time commuting to work.

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	2	The only affected area 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 South King County but work in Seattle are displaced. Seattle residents who work in South King County lose their work places.
Health Effects, Deaths and Injuries	1	The incident causes no deaths or injuries in Seattle.
Displaced Households 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.
Structures	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	1	The post-lahar sedimentation will not be likely to cause secondary hazards but will complicate the Duwamish restoration.

11 3.2 Maximum Credible Scenario

Mt. Rainier erupts. Despite lack of known precedent, a lahar reaches Seattle. 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 would blanket the region and the Green River Valley would be 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 much structural damage which takes time to repair.
Health Effects, Deaths and Injuries	2	Despite the heavy physical damage, the incident causes no casualties due to timely warning provided by the USGS. Some people with existing respiratory problems are hospitalized from the ash exposure.
Displaced Households and Suffering	2	89 people 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.
Structures	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/m3; wet compacted ash is 1,000 to 2,000 kg/m3).
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 waste water 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 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 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.

11.4 Tsunamis and Seiches

11 4.1 Most Likely 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. Elliott Bay has strong currents of 4-5 knots in various locations for 4 hours. Cables on the I-90 Bridge over Lake Washington are damaged.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	**2**	Seiches have occurred on multiple occasions in the Seattle area since the late 19th 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.
Displaced Households 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 and Elliott Bay and require rescuing.
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.
Structures	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.
Cascading Effects	2	The seiche undermines slopes in 12 locations causing landslides.

11 4.2 Maximum Credible Scenario

A Seattle fault earthquake triggers a tsunami like the one that occurred here in 900 AD. This tsunami occurred 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 around 900 AD. 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.
Displaced Households 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.
Environment	3	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.
Structures	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 impassible 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

11.5 Disease

11 5.1 Most Likely Scenario

A new strain of influenza sweeps across Seattle in December, affecting the young and healthy as well as those with chronic health conditions. 1,500 people fall ill in Seattle, 190 have to be hospitalized, and 8 people die from the virus. The virus is not as severe as the pandemics of the early and mid-century. The peak exposure period lasts 6 weeks. 5 schools hit especially hard having to close for one week.

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 similar to the 2009 H1N1 virus.
Geographic Scope	5	The virus strikes the entire Central Puget Sound region.
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	8 people die, 1,500 become ill and 190 need to be hospitalized.
Displaced Households and Suffering	1	No families are physically displaced from their homes, but 5 schools are closed for a week and major events are cancelled.
Economy	2	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.
Structures	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	1	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.

11 5.2 Maximum Credible Scenario

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 world-wide. 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 keeps 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.
Displaced Households 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.
Structures	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.
Cascading Effects	2	The disease does not directly cause secondary effects, but the staffing reductions makes the City harder to operate. Several non-life threatening landslides occur during this time, but the City is not able to respond due to staffing shortages.

11.6 Attacks

11 6.1 Most Likely Scenario

Domestic violent extremist actors target an animal research facility. After first releasing the animals they burn and bomb the facility. One guard is killed in the attack.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Seattle has experienced arson and bombing by extremist 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.
Displaced Households 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.
Structures	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.

11 6.2 Maximum Credible Scenario

A well-armed, well organized group affiliated with international terrorists launches a planned attack using a mix of automatic weapons and improvised explosive devices (IED) during the Westlake Mall tree lighting ceremony. The initial attack focuses on blocking natural exit routes in an attempt to move the panicked crowd of several thousand in the direction of several command detonated IEDs. The IEDs, which include metal shrapnel to maximize casualties, cause many critical injuries and fatalities, which overload EMS and hospitals. After the initial assault a splinter group leaves the mall before it is surrounded. The well-armed gunmen engage in a series of running gun battles with law enforcement with the intention of causing confusion, hampering the response, and increasing the number of casualties. This group is cornered in the Sodo area and killed. The gunmen in the mall take hostages and set fires.

Category	Impacts Low = 1 High = 5	Narrative
Frequency	2	This scenario is Complex Coordinated Attack (CCA) similar to the attacks in Mumbai, India and Paris, France. Such an attack has not occurred in the United States. The difficulty of staging this type of attack balanced by two actual occurrences yields an assessment of a 1 in 1000 chance of occurring per year.
Geographic Scope	4	The attack affects a nine-block area of downtown: the mall and the eight blocks surrounding it. It also affects the SODO neighborhood.
Duration	2	Due to the danger to law enforcement, it takes 3 days to subdue the attackers.
Health Effects, Deaths and Injuries	3	34 people are killed in the attack. 42 people require hospitalization and 212 are treated and released.
Displaced Households and Suffering	3	The attack occurs in a commercial area so no residences are affected, but people working and visiting downtown need to be moved out of the area. The splinter group that escapes causes the Mayor to order a shelter-in-place for the whole city. Many vulnerable residents are not able to get essential commodities and access medical care.
Economy	2	The attack closes a big section of downtown for three days. Westlake Mall suffers extensive damage. It takes the mall one month to re-open. Retail businesses located in it miss a whole holiday shopping season.
Environment	1	The attack causes no significant damage to the environment.
Structures	2	No buildings are destroyed, but the IEDs and firefight inside the mall heavily damage it.
Transportation	4	The Metro tunnel and surface streets surrounding the Mall are closed causing significant delays getting into and through downtown. The shelter-in-place order does not affect infrastructure but renders many critical services inaccessible.
Critical Services and Utilities	4	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. 2 responders are killed and 3 wounded. The shelter-in-place order renders many services inaccessible.
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	1	The attack is extremely deadly and disruptive, but it does not cause any significant secondary incidents.

11.7 Social Unrest

11 7.1 Most Likely Scenario

A political protest in the downtown core escalates to violence between the protestors and counter protesters over opposing political ideologies. Nearby properties are vandalized. Anarchist groups 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 occurs 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.
Displaced Households and Suffering	3	One hotel is evacuated when protestors gain access and will not leave; 250 guests need alternative shelter for the night. Splinter groups target minority neighborhoods for vandalism and destruction of property.
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.
Structures	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.

11 7.2 Maximum Credible 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, to terrorize them and drive them out of the area. 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 firebombed. 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.
Displaced Households 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.
Structures	3	34 buildings are destroyed and 75 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.

11.8 Cyber Attacks and Disruptions

11 8.1 Most Likely Scenario

1,500 City of Seattle employee computers are infected by a ransomware attack. Most of the infected computers are from Seattle Public Utilities (SPU) and the Municipal Court. The attackers threaten to delete all computer data if they are not paid $90,000 in crypto currency. The attackers disable the Seattle Public Utilities (SPU) website and the municipal court electronic filing system. 120,000 SPU customers have their personal and financial information stolen by hackers. It takes 3 weeks to remove the malware from the computers and restore online services to the city.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	The City of Seattle has never experienced an attack to this scale but does face hacking attempts daily. Frequency was increased to a 3 however because attacks are becoming increasingly sophisticated, increasing the chances of one being successful. Other urban municipalities have faced ransomware attacks, including Atlanta and Anchorage in 2018.
Geographic Scope	5	The attack has regional impacts in King and Snohomish Counties, as SPU serves nearby cities.
Duration	4	SPU billing and customer services are severely limited for 2 weeks. The attack does not affect water delivery to current customers. The Municipal Court cannot hear cases for 3 weeks due to the electronic filing system outage and is back logged for months. 1,500 city employees cannot use their computers for 3 weeks and must find alternate ways to complete their duties.
Health Effects, Deaths and Injuries	1	The attack does not cause any fatalities or injuries.
Displaced Households and Suffering	1	The attack does not displace households. Water delivery is not impacted.
Economy	2	The economic impact is mostly felt in city government. The City of Seattle has to pay millions of dollars to recover and secure files and is faced with hundreds of lawsuits from SPU customers who had their personal data breached.
Environment	1	The attack does not damage the environment.
Structures	1	The attack does no damage to buildings.
Transportation	2	As a precaution, Seattle Department of Transportation stops Seattle Streetcar service and their Intelligent Transportation System, reverting traffic lights back to timers. Commuters who rely on the Streetcar are delayed and traffic backs up heavily in downtown.
Critical Services and Utilities	1	Most disruptions are inconveniences. People cannot pay bills or contact SPU about customer service concerns online. Employees are overwhelmed with the amount 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.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	1	There are no cascading effects.

11 8.2 Maximum Credible Scenario

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	2	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.
Displaced Households 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.
Structures	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.

Category	Impacts 1 = low 5 = high	Narrative
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	3	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, but it is directed mostly at the federal level.
Cascading Effects	4	The attack causes wide-spread power outages. Many control systems that prevent hazardous materials releases are offline.

11.9 Fires

11 9.1 Most Likely Scenario

A fire erupts at 1:30 am in an 11-story Seattle Housing Authority apartment building in Capitol Hill. It quickly spreads to half of the building's 220 units. 82 SFD firefighters respond to the fire. It takes them 6 hours to fully extinguish the flames. Fire alarms allow most residents to evacuate without harm but 2 people are killed and 25 are seriously injured. 105 apartments are destroyed, and 150 residents are displaced.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	4	Large fires have occurred with regularity in Seattle, and there have been 3 fires at Seattle Housing Authority (SHA) buildings within the last decade. However, none of the previous SHA fires have resulted in casualties or displaced families of this magnitude. Overall trends show a decrease in the annual number of structural fires, but property losses show no decrease.
Geographic Scope	2	The apartment fire is centered on a single site, but the response requires a few road closures in Capitol Hill.
Duration	2	The fire takes 6 hours to extinguish but it takes inspectors 2 days to secure the building.
Health Effects, Deaths and Injuries	2	2 people are killed and 25 are critically injured from burns and smoke inhalation.
Displaced Households and Suffering	4	150 low-income residents are displaced and need new permanent housing, but there are no available vacancies in other SHA buildings. An additional 150 residents need temporary shelter while the building is inspected.
Economy	1	SHA takes a big loss, but the general economy does not suffer.
Environment	1	There are no environmental impacts.
Structures	2	Half of the apartment building is destroyed, and the other half will require repairs to utilities before residents can move back in.
Transportation	2	Most of the city is not impacted, but road closures in Capitol Hill cause increased traffic and cause some busses to reroute.
Critical Services and Utilities	2	SFD must commit many resources. Several eastside companies that would normally backfill are not available because they are on assignment in eastern Washington fighting wildland fires. As a result, SFD must reduce its level of service.
Confidence in Government	1	SFD is able to effectively fight the fire. The public wishes the City of Seattle had stricter regulations on SHA buildings, but ultimately blames SHA for the fire.

Category	Impacts 1 = low 5 = high	Narrative
Cascading Effects	2	The fire causes a hazardous material incident.

11 9.2 Maximum Credible Scenario

A freight train carrying crude oil derails 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	2	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 toxic smoke and heat. The lack of adequate safety infrastructure in the tunnel adds to the casualties. 230 people are injured.
Displaced Households 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.
Structures	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.

Category	Impacts 1 = low 5 = high	Narrative
Confidence in Government	3	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.

11.10 Infrastructure and Structural Failure Scenarios

11 10.1 Most Likely Scenario

A 42" water main breaks near a bridge. The release of water undermines a bridge pier 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	2	The damage takes 2 days to repair. It takes an additional day for full service restoration.
Health Effects, Deaths and Injuries	1	There are no deaths or injuries as a result of the break.
Displaced Households and Suffering	2	Water and gas service to a school and nursing home is 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.
Structures	2	The water floods 5 buildings and undermines their foundations.
Transportation	2	The nearby bridge and streets near the break must be closed, causing a temporary blockage. Fears are voiced about the effect of the water on the bridge, but it is not damaged.
Critical Services and Utilities	2	The breakages of the water, gas, and sewer lines force utility outages in the surrounding neighborhood. Public safety services are not affected.
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.

11 10.2 Maximum Credible Scenario

The Interstate 5 Ship Canal Bridge collapses over Lake Union at 8:30 am on a weekday. Vehicles plunge into the lake and a ship is struck below. The bridge displaces a large amount of water, causing localized flooding in homes and businesses along the lake's shore. 42 People are killed by debris or water and 181 are injured. A major power transmission tower is damaged in the collapse causing a few neighborhoods to lose power for 48 hours. It will take months to rebuild the bridge, and traffic must be diverted onto lower capacity roads.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	1	A major bridge collapse has never occurred within Seattle, but has occurred in other parts of the state (Tacoma Narrows Bridge, Skagit River bridge) and in other urban cities in the U.S. (Oakland, CA; Minneapolis, MN; Atlanta, GA)
Geographic Scope	4	The area directly affected by the collapse is less than 1 mile, but homes and businesses around Lake Union are affected. The entire city is affected by unprecedented traffic delays for months.
Duration	5	It takes one week to remove debris from the water and secure the remaining parts of the bridge. It will take months to rebuild the bridge and repair structures damaged by the rubble.
Health Effects, Deaths and Injuries	3	Both levels of the bridge (express lanes and non-express lanes) were full due to rush hour traffic, resulting in 42 fatalities and 160 serious and minor injuries. 21 people are injured by falling debris or tsunami impact on the ground.
Displaced Households and Suffering	4	330 people who live near the bridge or on houseboats need temporary shelter while their homes are repaired, or the remaining parts of the bridge are secured. 2,500 people experience a 3-day power outage.
Economy	3	The overall economy suffers because goods cannot be transported via I-5.
Environment	3	The bridge strikes a large fishing vessel, causing thousands of gallons of oil to spill into lake union. Intervention is required to clean the spill.
Structures	2	The bridge itself is destroyed. 7 houseboats and businesses along lake union are red-tagged. Power infrastructure must be replaced near the bridge
Transportation	4	Critical services are accessible via alternate routes, but heavy traffic persists for months as vehicles are rerouted to lower-capacity roads. Busses must be rerouted, causing transit delays.
Critical Services and Utilities	3	A power outage lasts for 48 hours in parts of the city. Emergency services are slowed because of heavy traffic on alternative routes. Fiber cables along the bridge are cut, causing a temporary communications outage for 25% of the City. Grocery stores and businesses in North Seattle must wait longer to receive shipments from distributors.
Confidence in Government	5	The public's anger is first directed mostly at Washington State who managed the bridge but shift towards the city when unprecedented traffic delays continue for months.
Cascading Effects	3	The bridge collapse triggers localized flooding and hazardous materials spill in Lake Union, and a power-outage in surrounding neighborhoods.

11.11 Power Outage Scenarios

11 11.1 Most Likely Scenario

An accident and fire in an underground vault cuts power to a large part of downtown for three days. The City is able to acquire generators to partially meet demand, but many businesses must shut their doors. Many residents of downtown high-rises are unable to walk the stairs to their apartments.

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. The scenario here is based on two outages in the late 80's and early 90's.
Geographic Scope	3	A major section of downtown and Belltown goes dark during hot weather in August.
Duration	2	Full power is restored in 3 days.
Health Effects, Deaths and Injuries	2	No one is killed in the incident but one Seattle City Light line worker is critically injured. 18 people contract a food borne illness when they consume non-refrigerated food.
Displaced Households and Suffering	2	A Seattle Housing Authority property in Pike Place Market loses power. Many residents are disabled or elderly. Most have no other place to go. Altogether 65 people need shelter.
Economy	2	The Pike Place Market loses power in the middle of high tourist season. 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	1	The environment is not directly affected by this incident.
Structures	1	No buildings are impacted by the power outage.
Transportation	2	Surface transportation in the affected area is disrupted. Traffic lights are dark and operate as four way stops. The downtown transit tunnel loses power.
Critical Services and Utilities	2	Aside from the power outage itself, critical services and utility services are able to be maintained at street level. High-rises lose elevator and water service.
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.

11 11.2 Maximum Credible Scenario

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 black outs 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.
Displaced Households 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.
Structures	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.

11.12 Excessive Heat Events

11 12.1 Most Likely Scenario

Seattle experiences an event slightly more extreme than the previous milestone, the 2009 heat wave. Temperatures are over 90 °F for seven straight days with two over 100 °F. Lows are over 70 °F. The heat has built slowly making it easier for people to adjust. A major festival is happening at Seattle Center and a road race is scheduled. One nursing home loses its air conditioning system.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	It is projected that Seattle's heat events will become more severe in the future due to climate change. It seems likely that the previous record of 103 ° will be broken. This scenario captures an event that is more severe than the 2009 extreme heat event. Because a breaking of the current record is viewed as likely by the 2050s this event is given the highest frequency rating.
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	2	2 people die from heat stroke and 103 need medical attention. One nursing home does not have adequate cooling for residents.
Displaced Households 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	1	The heat stresses plants but does not damage whole areas or ecosystems.
Structures	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 imped 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 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.

11 12.2 Maximum Credible Scenario

Seattle experiences an unprecedented heat event. Temperatures are over 90 °F for 14 consecutive days with three over 100 °F. Temperatures do not sink below 75 °F overnight. The heat has built quickly making it harder for people to cope. A major festival is happening at Seattle Center and a road race is scheduled. Despite cooling efforts, one bascule bridge is stuck open. Crime is a worry for older residents who won't open their windows.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	Seattle has never come close to experiencing a heat event this extreme. Because Seattle has broken the 100 °F mark, this scenario is not viewed as unrealistic. Additionally, climate change researchers project that future extreme heat days could increase by 6.5 °F by the 2050s. It is viewed as having a 1 in 100 chance of occurring per year.
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	4	The most severe part of the heat wave lasts for fourteen days. The longer a heat wave lasts the more its consequences grow. The night time temperatures do not dip below 75 °F which makes the event more dangerous.
Health Effects, Deaths and Injuries	4	70 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.
Displaced Households 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.
Structures	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.

11.13 Flooding Scenarios

11 13.1 Most Likely Scenario

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, taking out 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	5	This is regional storm. All of Seattle and the surrounding areas are affected.
Duration	2	The storm lasts 4 days.
Health Effects, Deaths and Injuries	1	No one is killed or injured during the storm.
Displaced Households 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.
Structures	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. Busses 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 organizes sandbagging. This effort and the success of detention ponds are credited to the City.
Cascading Effects	1	The release of raw sewage is a significant problem but does not necessitate an immediate emergency response.

11 13.2 Maximum Credible Scenario

An atmospheric river remains pointed at Western Washington for nine days. The whole region is flooding. Periods of extremely heavy rain occur (1" per hour). A king tide also occurs during this time. In Seattle, creeks flood. South Park is flooded due to the King Tide and drainage problems. Urban flooding occurs in 12 locations. 36 major landslides are triggered due to increase in ground water. Levees on the Duwamish appear to be weakening.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	2	This scenario is based on ARkStorm, a USGS project. The ARkStorm is estimated to be a 500 to 1000-year event. It is a more extreme form of atmospheric river than has been experienced in Seattle historically, but it has roots in a powerful storm that struck California in 1961-2. Furthermore, climate scientists project that that extreme precipitation events may be increasing and a there may be a tendency of the jet stream to remain locked in one pattern for an extended time. It is prudent to plan for the two possibilities to combine. Such an event would be unprecedented, but it is not unrealistic.
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 nine 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.
Displaced Households 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	2	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.
Structures	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.
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.

11.14 Snow and Ice Scenarios

11 14.1 Most Likely Scenario

A major snow storm strikes Seattle during a weekday. The snow had been predicted reducing the commute load. Snow alternates with cold temperatures. A combined 12" of snow accumulates. It remains on the ground for a week. As the snow is melting another storm dumps freezing rain on it. The freezing rain snaps branches causing scattered power outages.

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 snow storm would be similar to those that have occurred recently (e.g., 2008, 1996). 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	3	Snow falls for three consecutive days. It remains frozen on the ground for four days then a warm front moves in and rapidly melts the accumulation.
Health Effects, Deaths and Injuries	2	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.
Displaced Households 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 waste water system.
Structures	2	The snow collapses the roofs of 5 buildings causing them to be red tagged.
Transportation	2	The storm is forecasted. Seattle is able to start pre-treatment of roads and Metro is able to chain buses. These actions mitigate the effects of the storm beginning mid-day. The commute is very bad but could have been much worse. During the next three days roads have snow accumulations because the snow is falling faster than roads can be plowed. Once the snow stops, the arterials are cleared to specifications in the Seattle Snow and Ice Plan, but residential streets remain snowbound.
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.

11 14.2 Maximum Credible Scenario

Seattle has a winter similar to those it had in the 19th century. Multiple snow storms hit the region straining snow removal budgets. In the biggest storm 24" falls in 36 hours on top of 12" existing base. The storm begins as freezing rain and transitions to snow. The intensity of the storm was missed in most forecasts. It begins mid-day. Roofs collapse. After the storm, extreme cold sets in, freezing Lake Union.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	3	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. This scenario envisions a set of storms marginally worse than the 19th century incidents.
Geographic Scope	5	The whole Central Puget Sound region is affected by this storm.
Duration	4	The entire incident lasts two and a half 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.
Displaced Households and Suffering	3	2 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 235 people need shelter. Many in the general public begin to run out of food and medicine.
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.
Structures	2	6 buildings suffer collapsed roofs.
Transportation	4	Surface transportation experiences major degradation. While snow is falling Seattle crews are unable to keep up with intensity of the storm. After the snow stops falling they are able to catch up within 48 hours but residential streets remain nearly impassible. Airports must halt flights until the snow stops.
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.

Category	Impacts 1 = low 5 = high	Narrative
Confidence in Government	3	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 snow storm causes many traffic accidents including a gas tanker that crashes and burns. Ice and extreme cold have caused power and water outages.

11.15 Water Shortages

11 15.1 Most Likely Scenario

Low winter snowpack followed by a hot, dry summer and a cold fall. Water levels in the Cedar fall below the level of outfall. Seattle Public Utilities (SPU) uses pumps to bring water into transmission pipelines. Mandatory water usage restrictions go into effect. Businesses like landscaping operations experience hardships.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	Regional water shortages occur when the amount of water in the City's watersheds is not enough to meet demand. Often weather-related shortages like this one in can be somewhat reliably forecast based on climate models. Climate scientists project that snowpack will decline substantially by the end of the 21st century, and summers will become drier. Seattle has had dry conditions at least 14 times in the past 100 years. This scenario is a about a once every 10 to 50-year event.
Geographic Scope	5	A weather-related water shortage would affect all of Seattle and the suburban customers of Seattle Public Utilities. This shortage is a regional event.
Duration	5	Weather related water shortages are long duration emergencies. The most serious period of this shortage lasts from June until November.
Health Effects, Deaths and Injuries	1	No one is directly killed or injured as a result of the water shortage.
Displaced Households and Suffering	2	No households are displaced due to the shortage and the water supply is sufficient to meet basic human needs. Restrictions on non-essential water usage (e.g., lawn watering) bring inconvenience to the general public.
Economy	2	Businesses that use large amounts of water like landscapers, contractors begin to lose revenue due to curtailed operations.
Environment	2	A dry winter and spring stresses plants. Restrictions on watering cause many to die.
Structures	2	No structures are damaged as a result of the water shortage, but the dry conditions create ideal conditions for brushfires. A car fire on I-5 ignites a slope along Beacon hill. The fire spreads rapids and destroys 3 homes and heavily damages 7 others.
Transportation	1	The water shortage doesn't have any significant impacts on the transportation system
Critical Services and Utilities	3	The primary impact is on water service. Seattle City Light must curtail power generation to preserve stream flows for endangered salmon. Seattle City Light avoids power surcharges and restrictions but has to forego power sales to other utilities which hurts its bottom-line. Impacts on other critical services are limited. Seattle Public Utilities is able to maintain enough water pressure for firefighting. Hospitals have adequate water for operations.

Category	Impacts 1 = low 5 = high	Narrative
Confidence in Government	1	The effects of the low snowpack and dry weather are apparent to the public. They see mandatory water regulations as an inconvenient but necessary step to preserve water for critical uses.
Cascading Effects	2	The extreme dry weather contributed to a serious brush fire. The fire was not a disaster by itself.

11 15.2 Maximum Credible Scenario

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 have 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 21st 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.
Displaced Households and Suffering	3	No households are displaced due to a lack of potable water, but water restrictions and surcharges are hardships for much 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.
Structures	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.

Category	Impacts 1 = low 5 = high	Narrative
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.

11.16 Windstorm Scenarios

11 16.1 Most Likely Scenario

Seattle faces another storm similar to the 1993 or 2006 storms: numerous downed trees, scattered outages, limited structural damage. Seattle City Light's aggressive tree trimming mitigates power outages and its power outage management system speeds up restoration.

Category	Impacts 1 = low 5 = high	Narrative
Frequency	5	The Seattle had experienced major windstorms similar to this scenario nearly every decade.
Geographic Scope	5	Mid-latitude cyclones are wide storms. The one in this scenario affects the entire Central Puget Sound region.
Duration	1	The storm itself lasts for eight hours. Short term response and recovery lasts for another three days.
Health Effects, Deaths and Injuries	2	Nobody is killed in the storm, but 8 people are injured by debris.
Displaced Households and Suffering	2	Building damage, power outages, and urban flooding drive 60 people from their homes. 25% of the city loses power. Seattle City Light's outage management system enables the utility to more quickly respond than it could during previous storms.
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.
Structures	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	2	The storm causes widespread power outages.

11 16.2 Maximum Credible Scenario

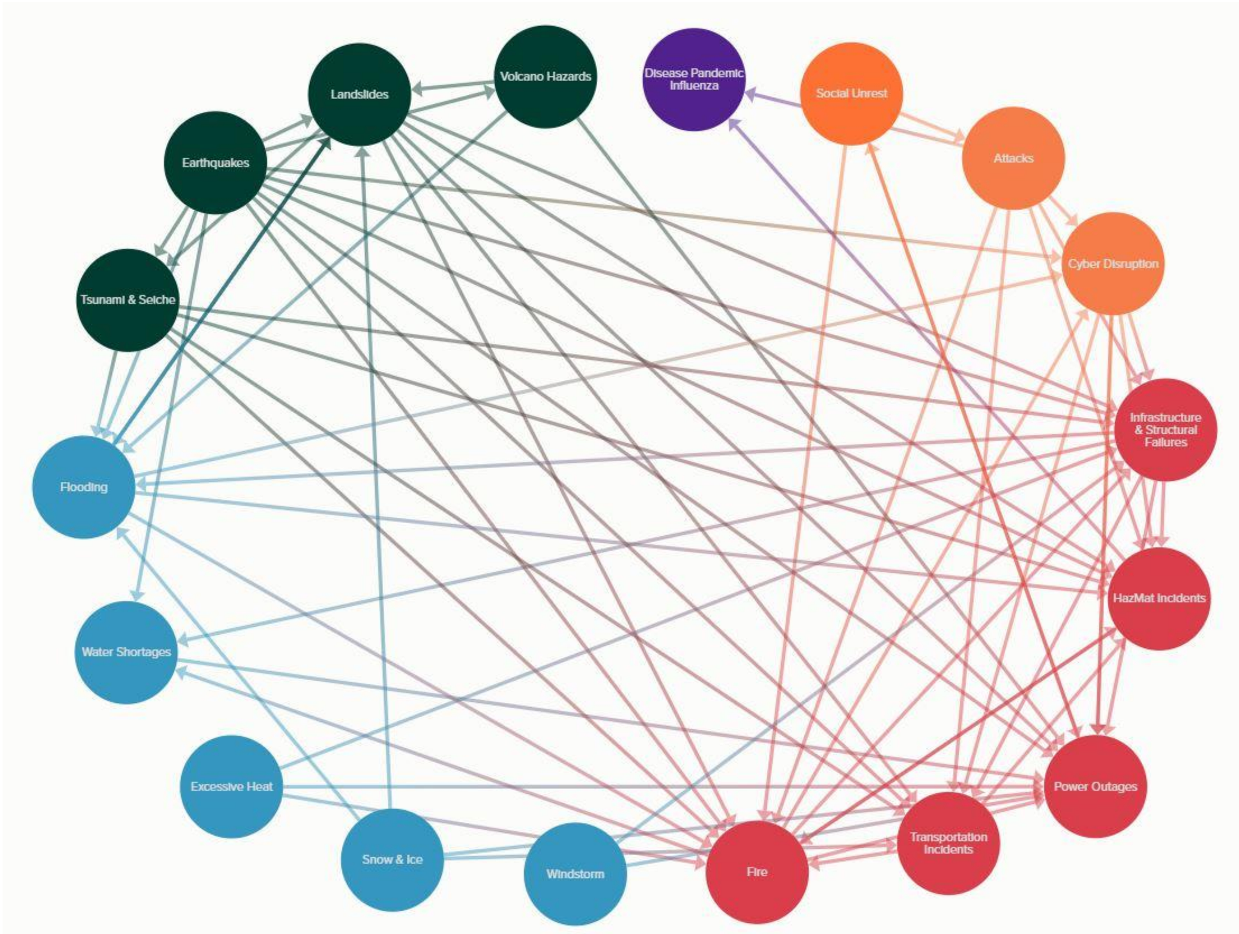
A mid-latitude cyclone similar to the 1962 Columbus Day storm hits the West Coast. Winds are recorded at 83 mph at West Point. The whole region is affected. Thousands of trees are downed, and millions of people are without power for multiple days. Waves damage a floating bridge. Several piers on waterfront 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. Coastal areas receive the strongest winds of 125 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 fully 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.
Displaced Households and Suffering	3	Building damage and power outages drive 180 people from their homes. 75% of the city loses power. Seattle City Light's outage management system enables the utility to more quickly respond than it could during previous storms.
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.
Structures	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	4	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.
Critical Services and Utilities	4	Power outages are major problem throughout the city. 75% 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 power widespread power outages and hazardous materials incidents.

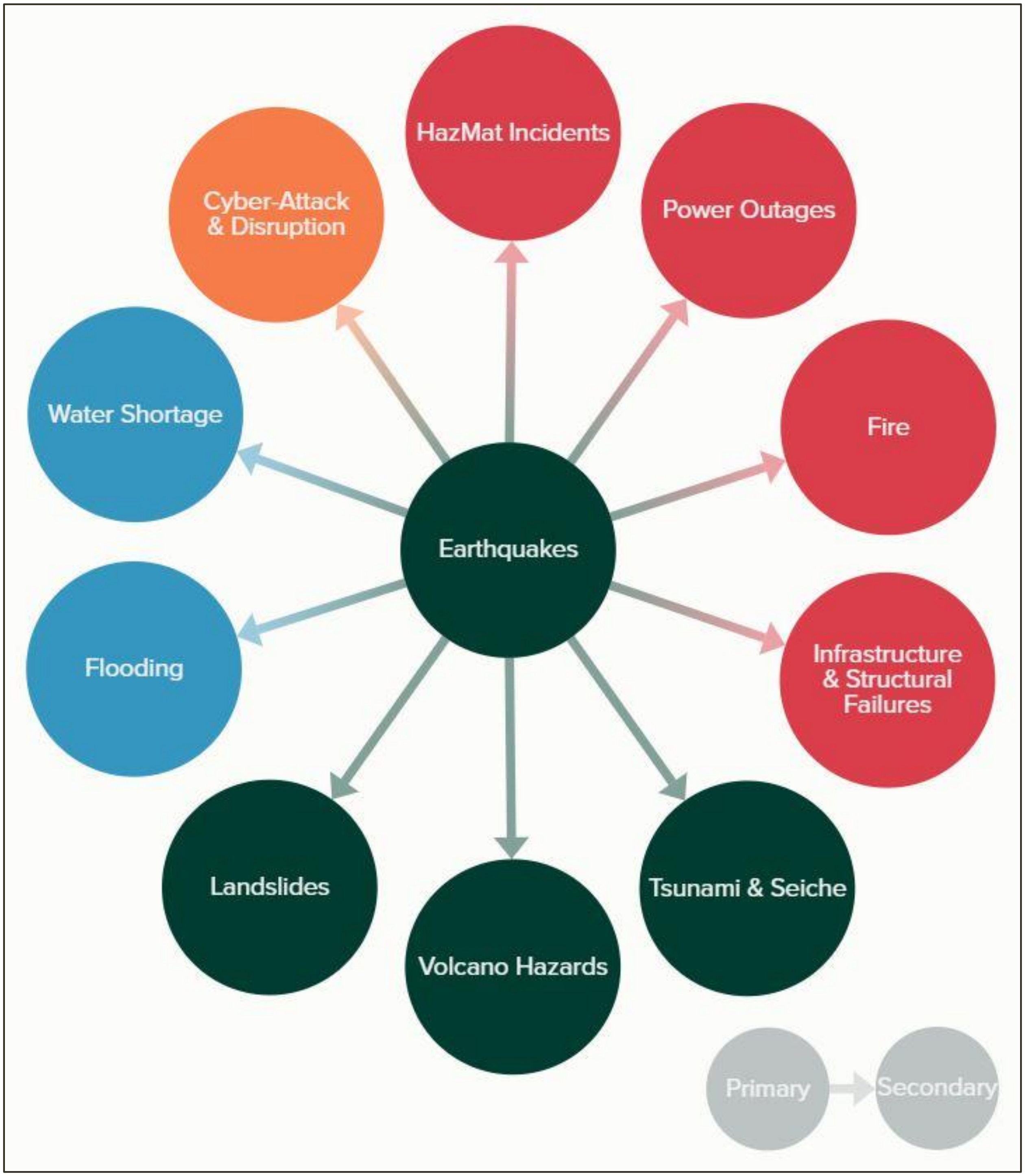
12. APPENDIX C: RELATIONSHIPS BETWEEN HAZARDS

This section expands on Table 2.3 by diagraming the relationships between hazards. Considering hazards individually risks siloing our understanding of the totality of the risk. This section makes clear that most large disasters will be multi-hazard.

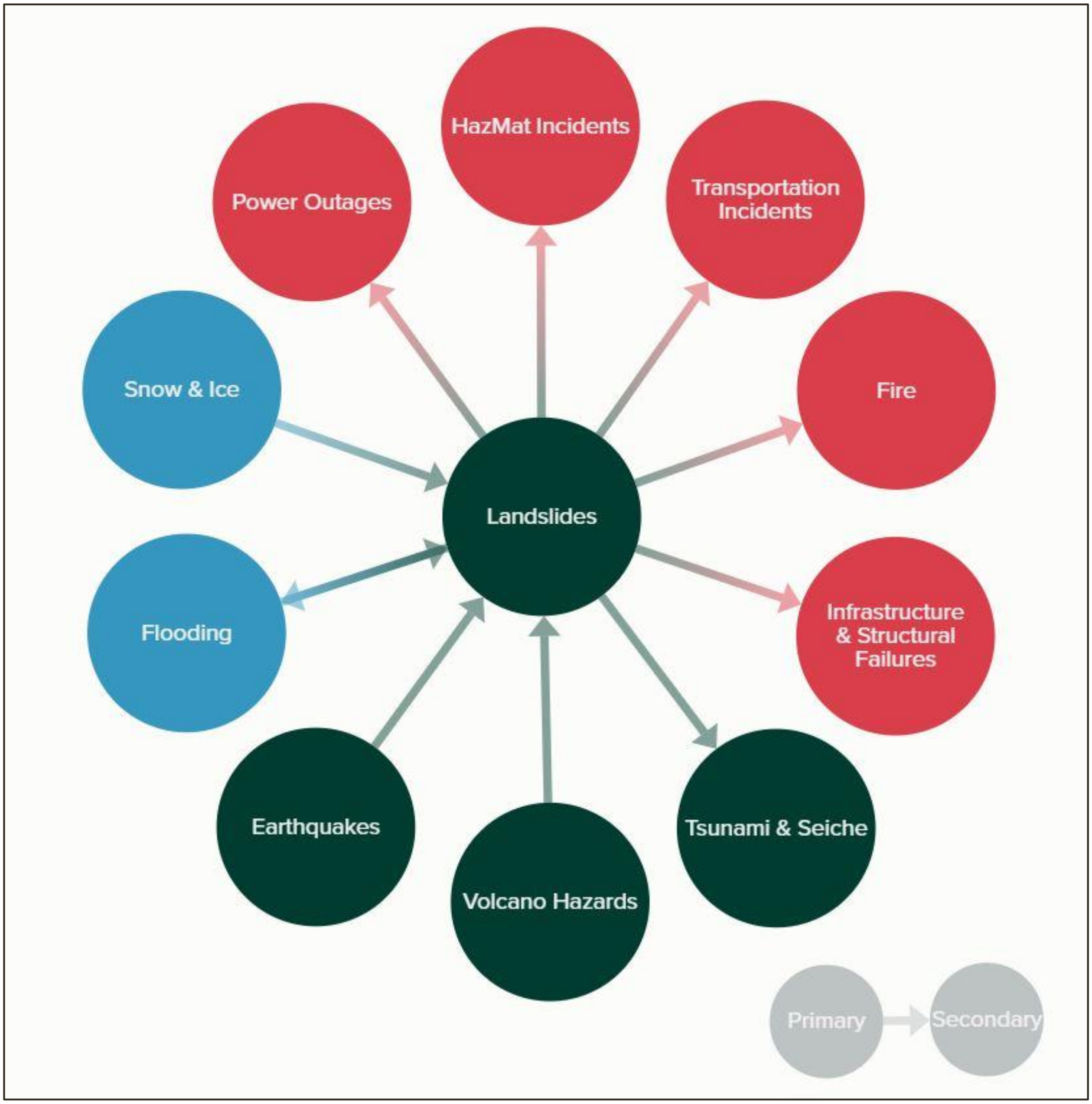
12.1 General Relationships



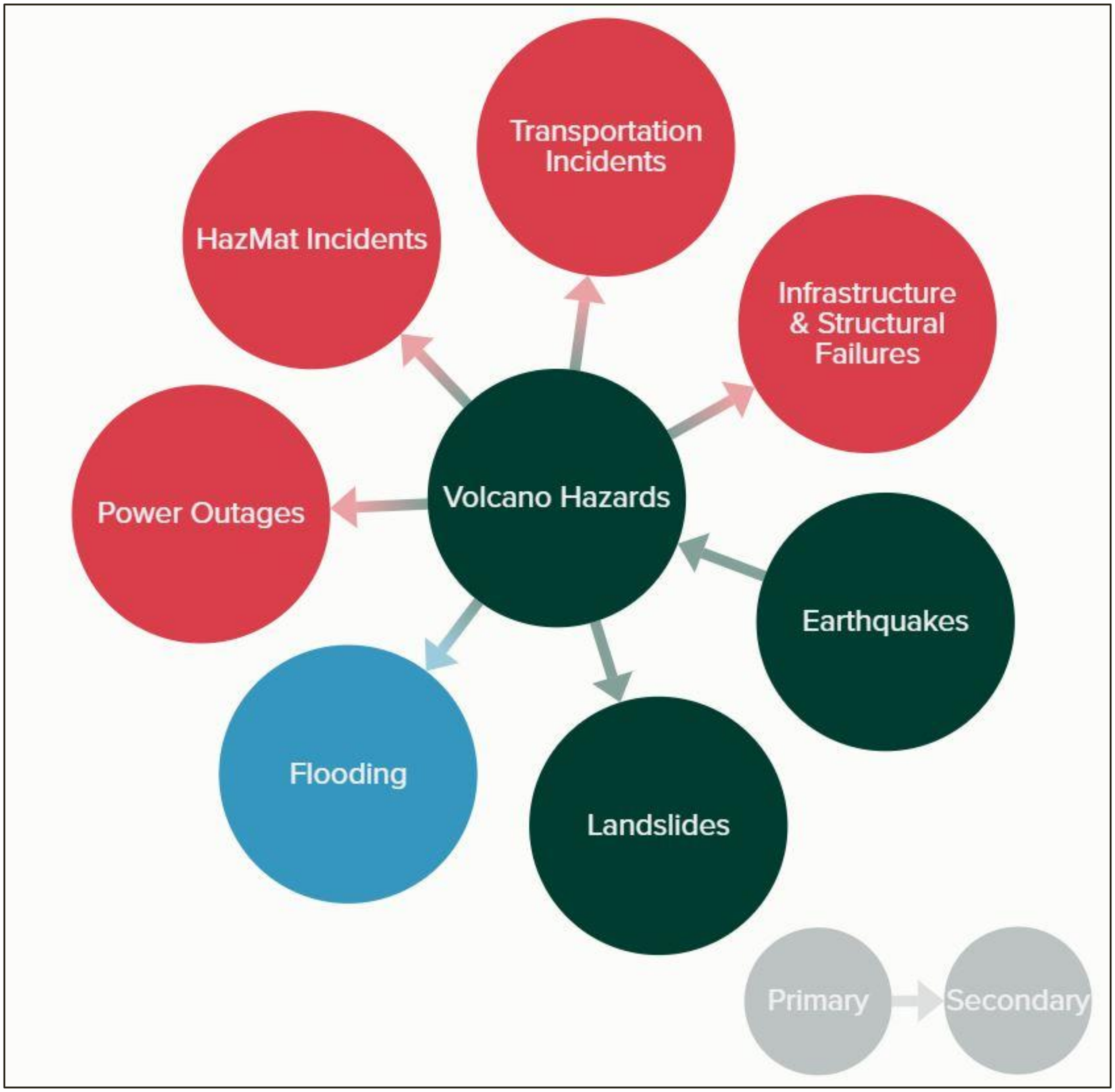
12.2 Earthquakes



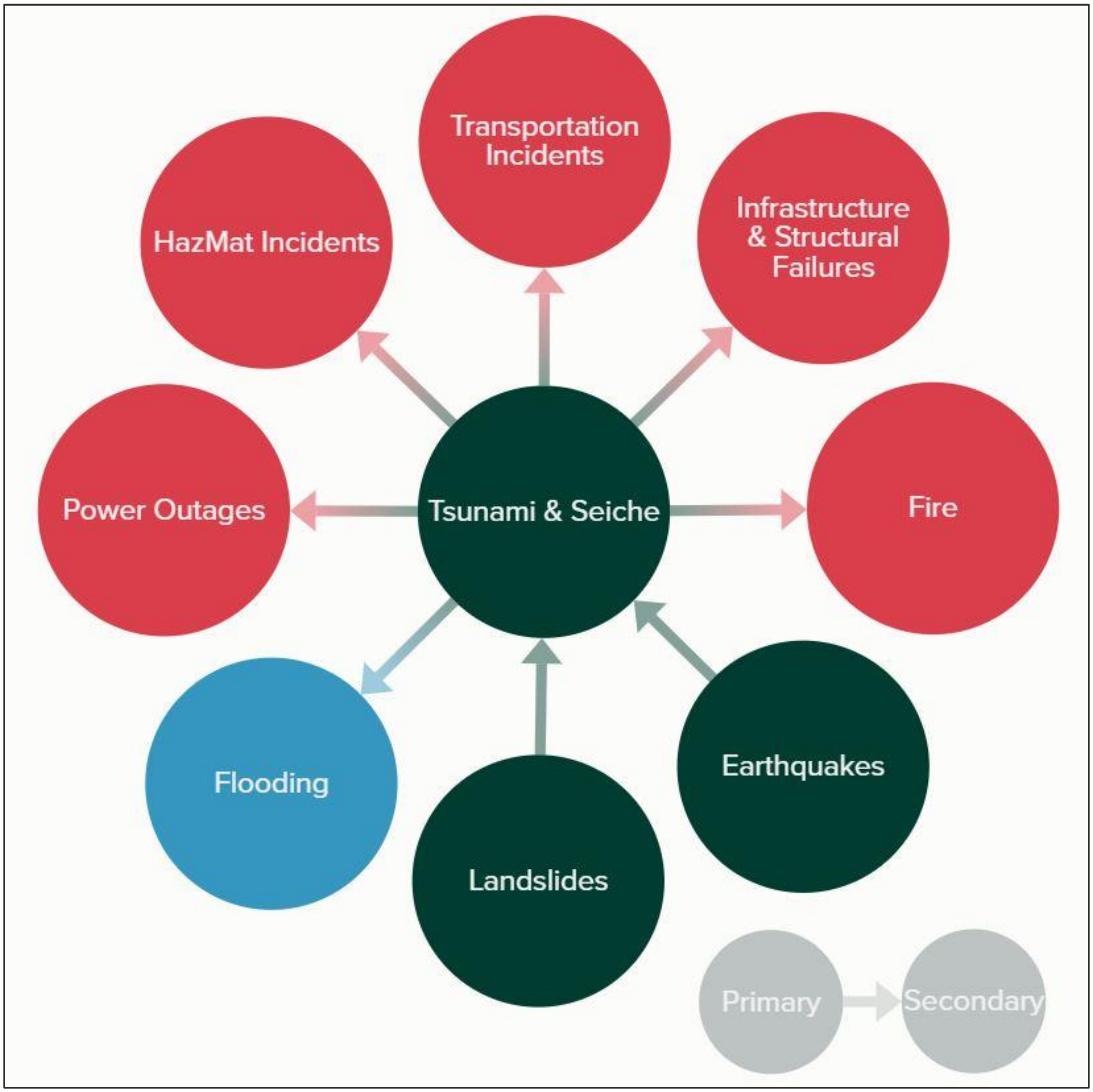
12.3 Landslides



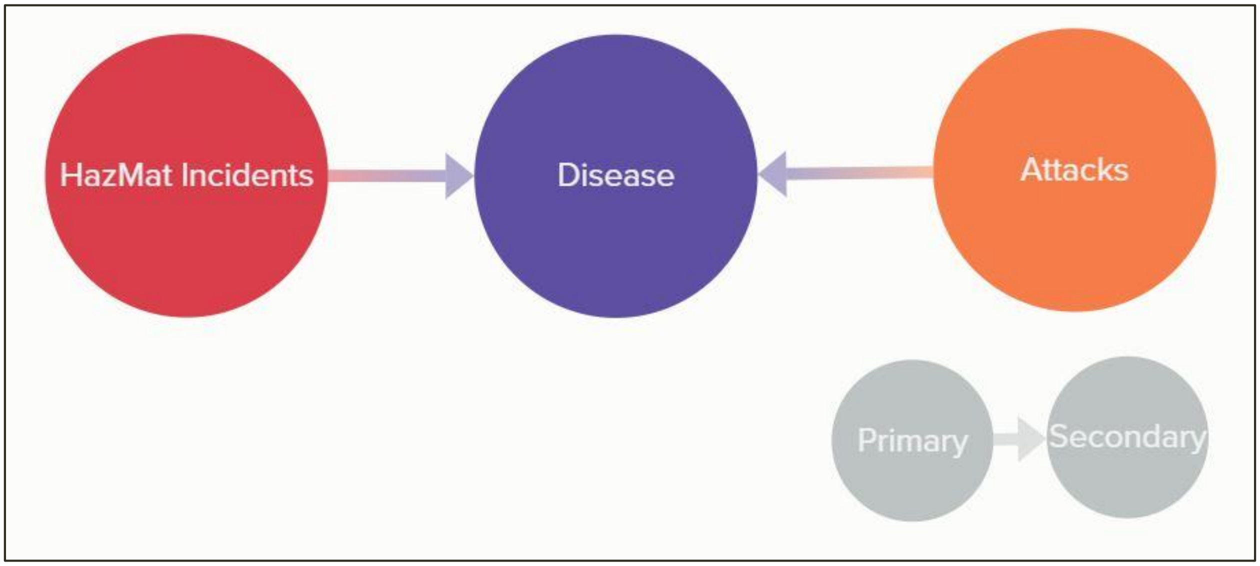
12.4 Volcano Hazards



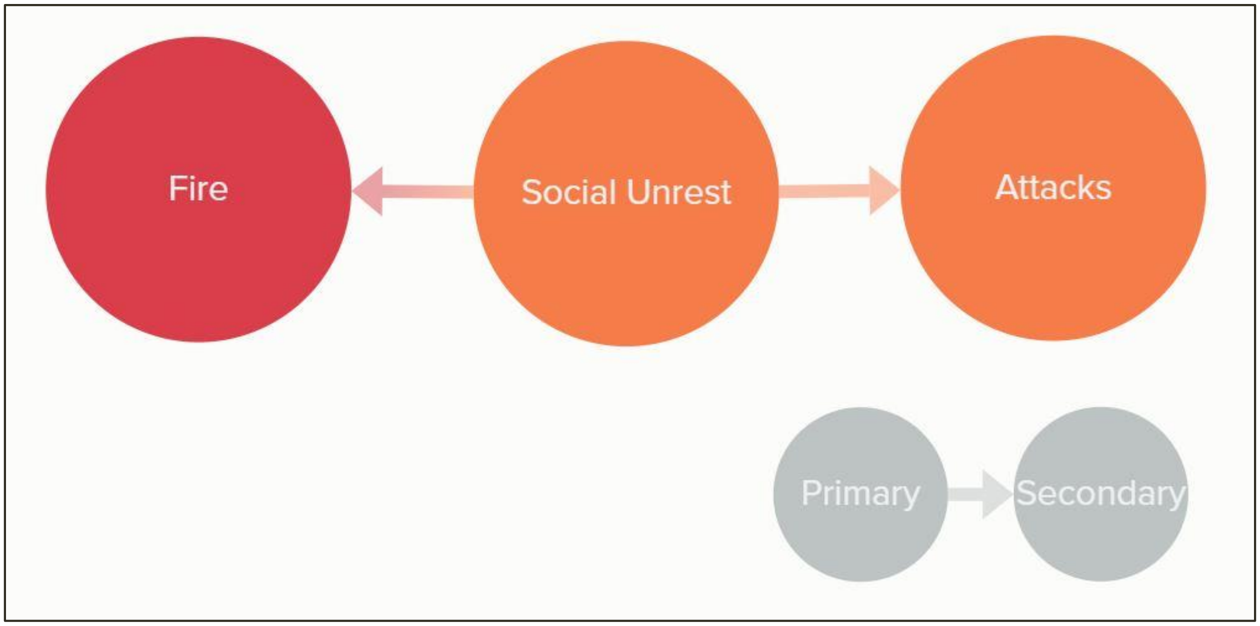
12.5 Tsunamis and Seiches



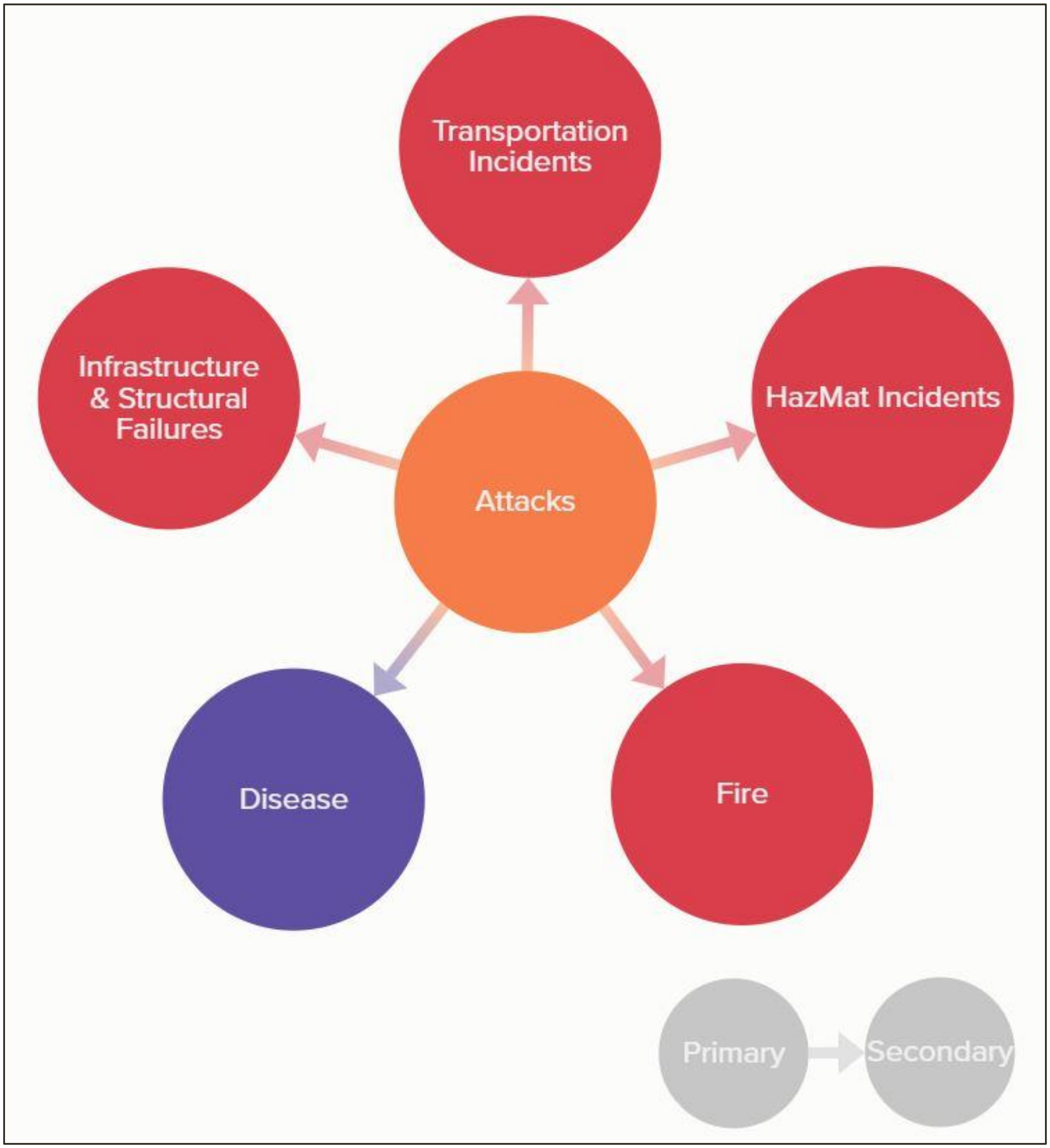
12.6 Disease / Pandemic Influenza



12.7 Social Unrest

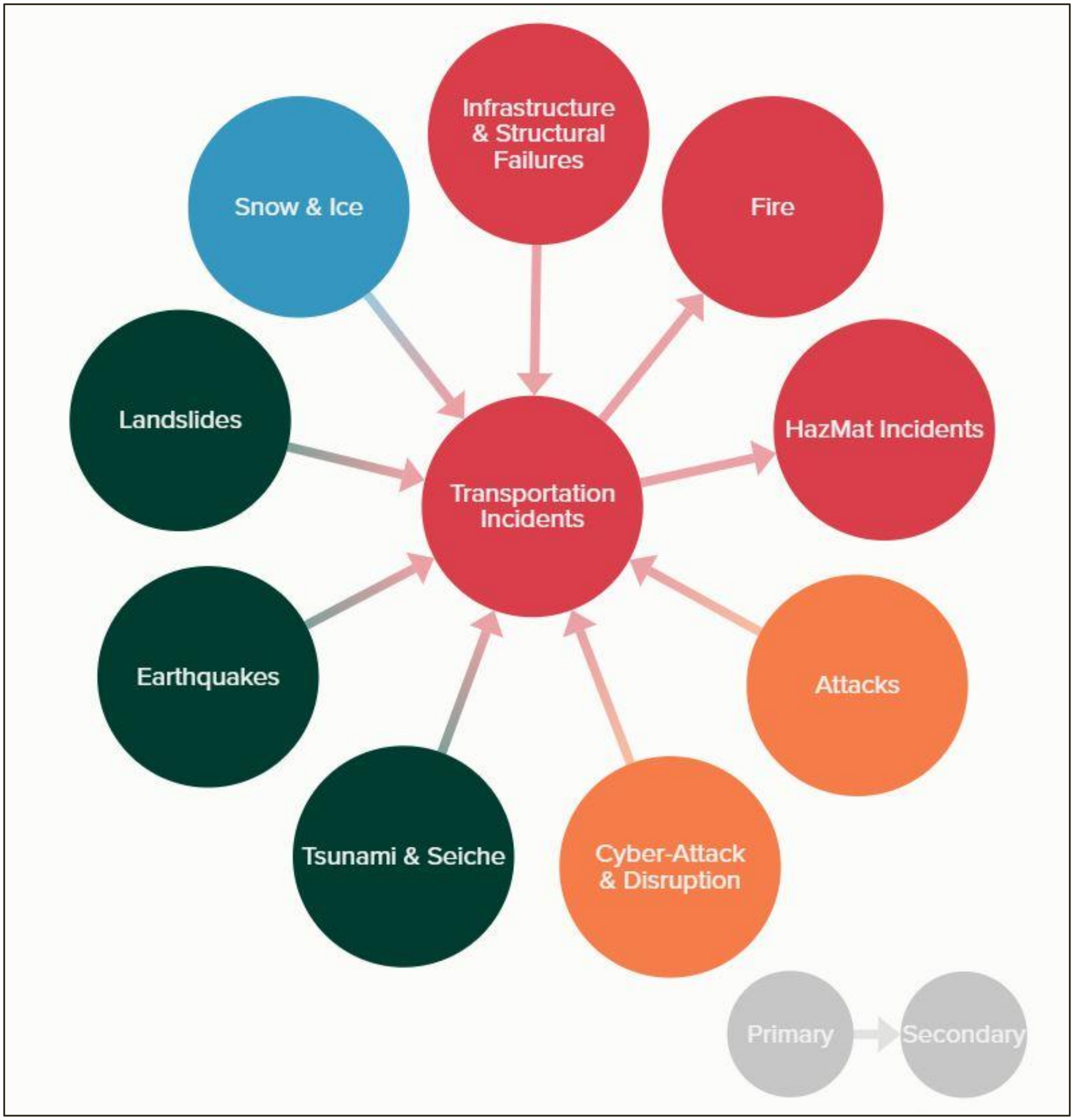


12.8 Attacks

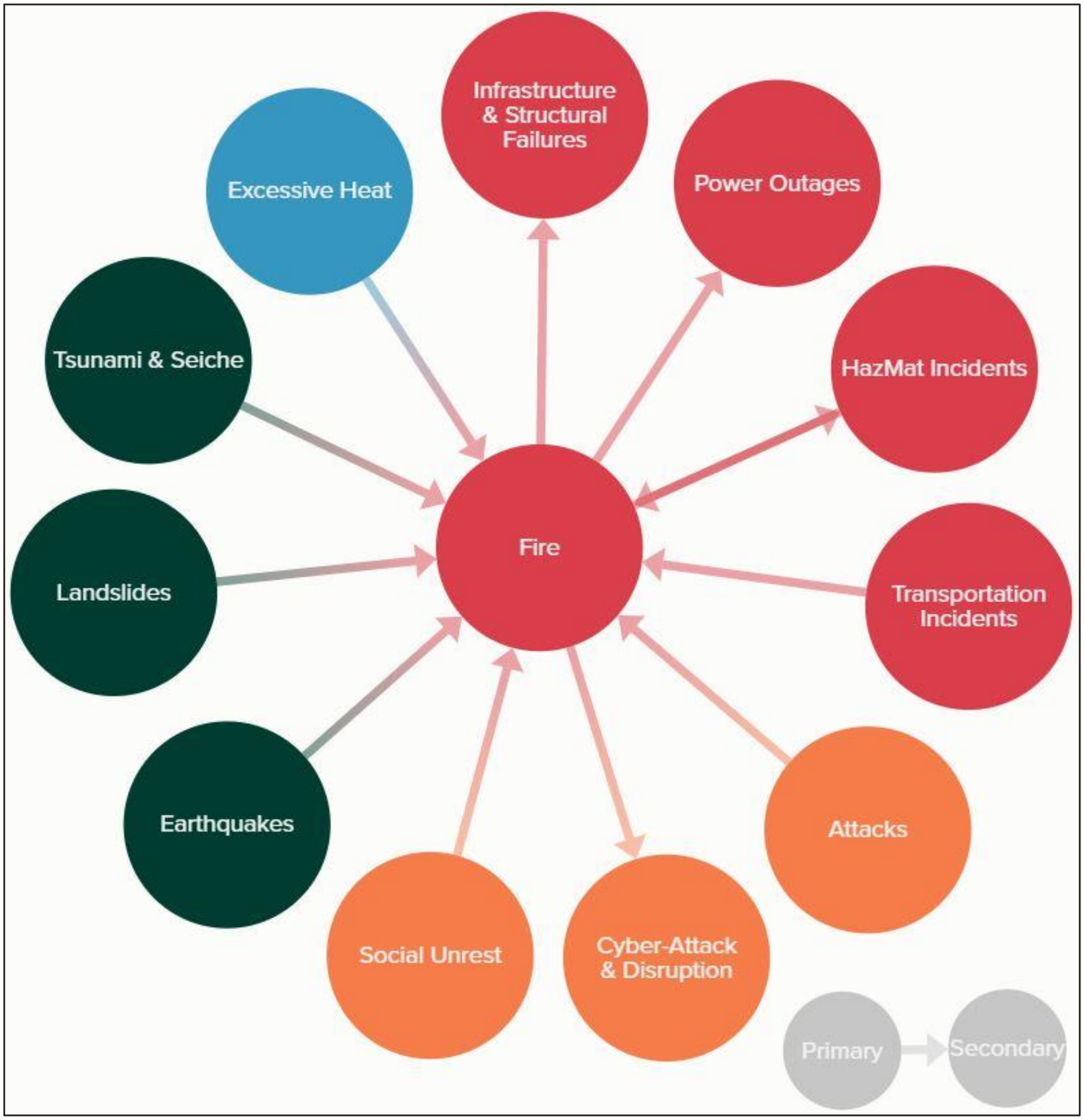

Transportation Incidents
Infrastructure & Structural Failures
HazMat Incidents
Attacks
Disease
Fire
Primary
Secondary

12.9 Cyber-Attack and Disruption

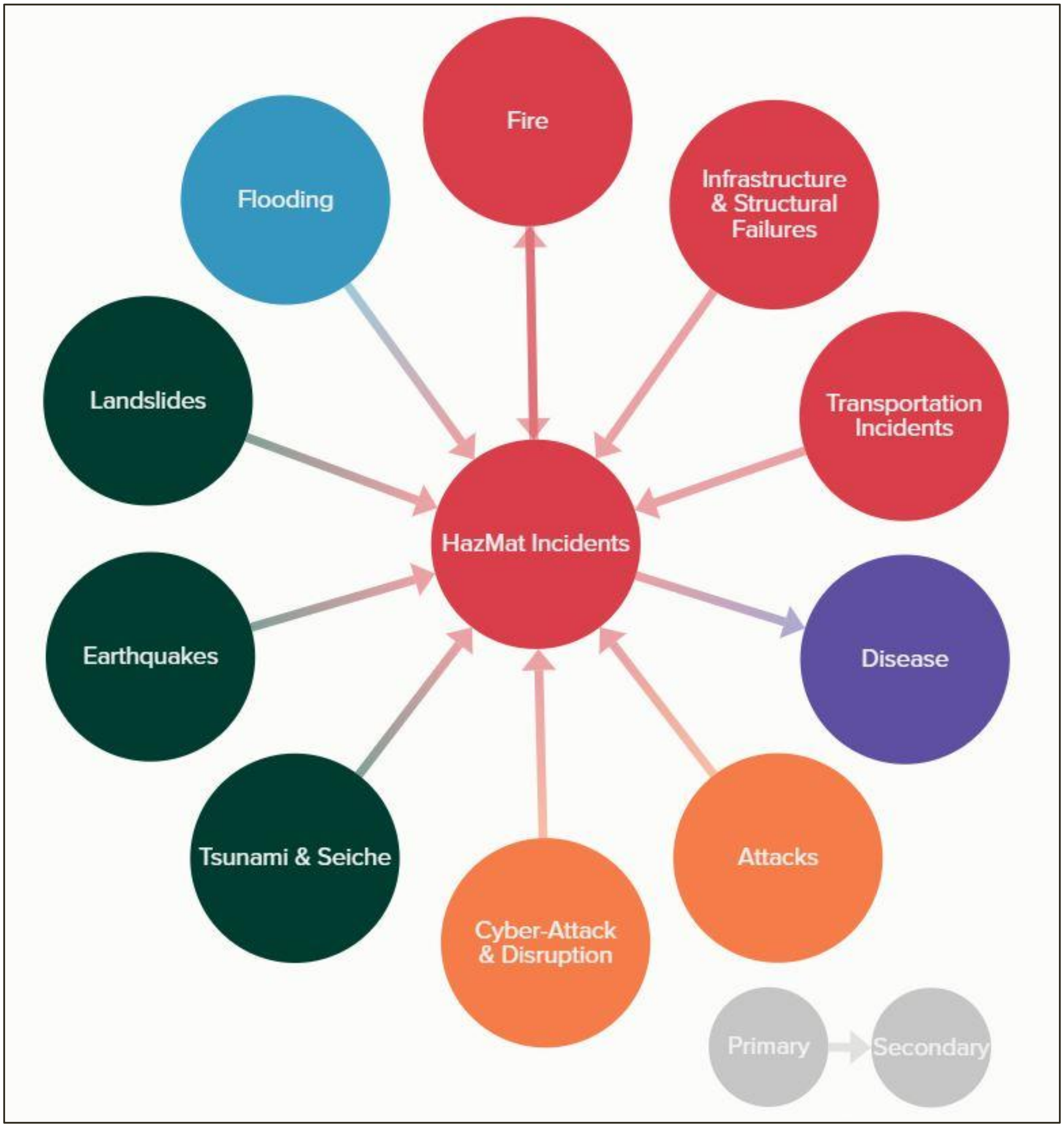
12.10 Transportation Incidents



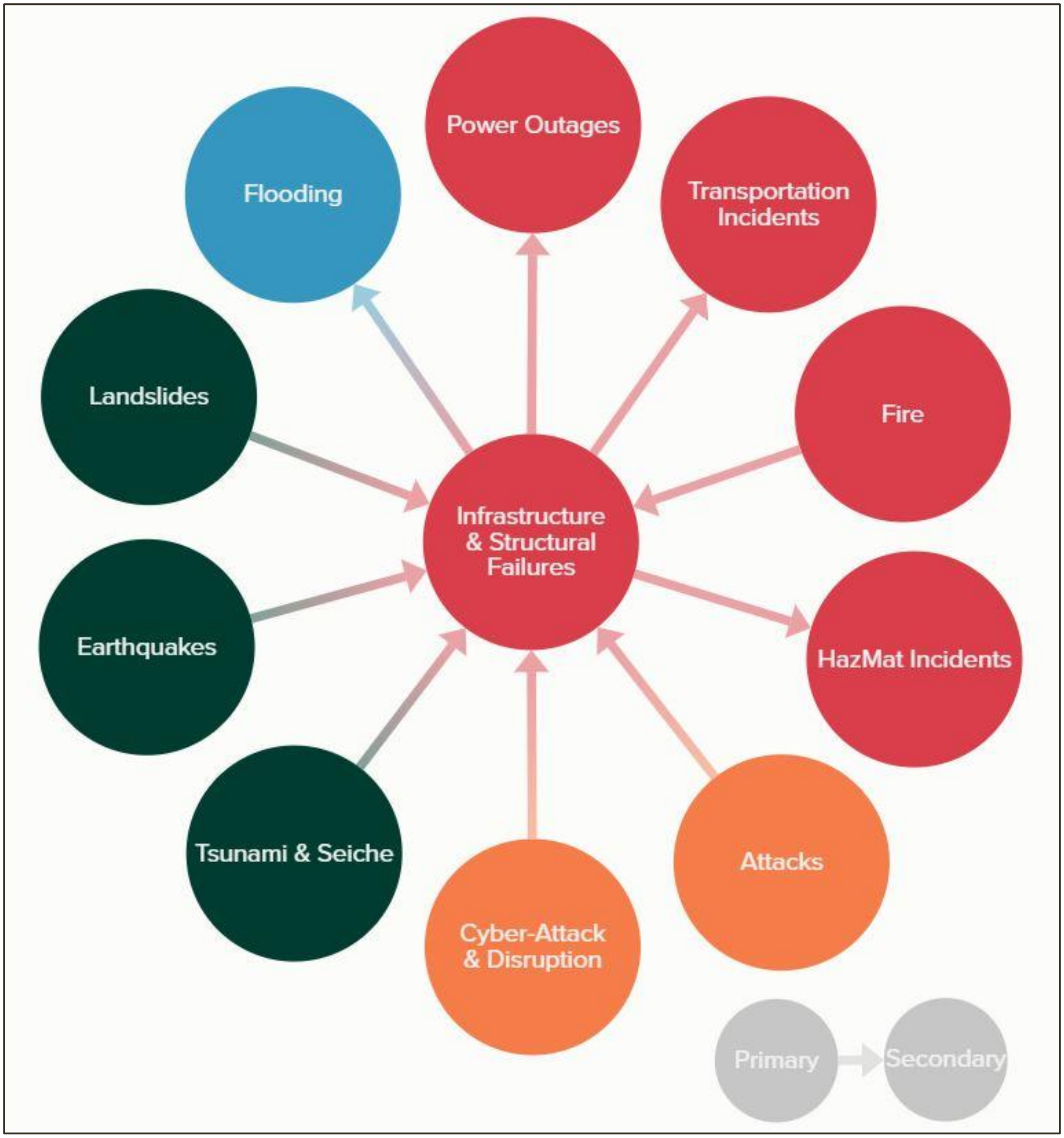
12.11 Fires


Infrastructure & Structural Failures
Excessive Heat
Power Outages
Tsunami & Seiche
HazMat Incidents
Fire
Landslides
Transportation Incidents
Earthquakes
Attacks
Social Unrest
Cyber-Attack & Disruption
Primary
Secondary

12.12 Hazardous Materials Incidents

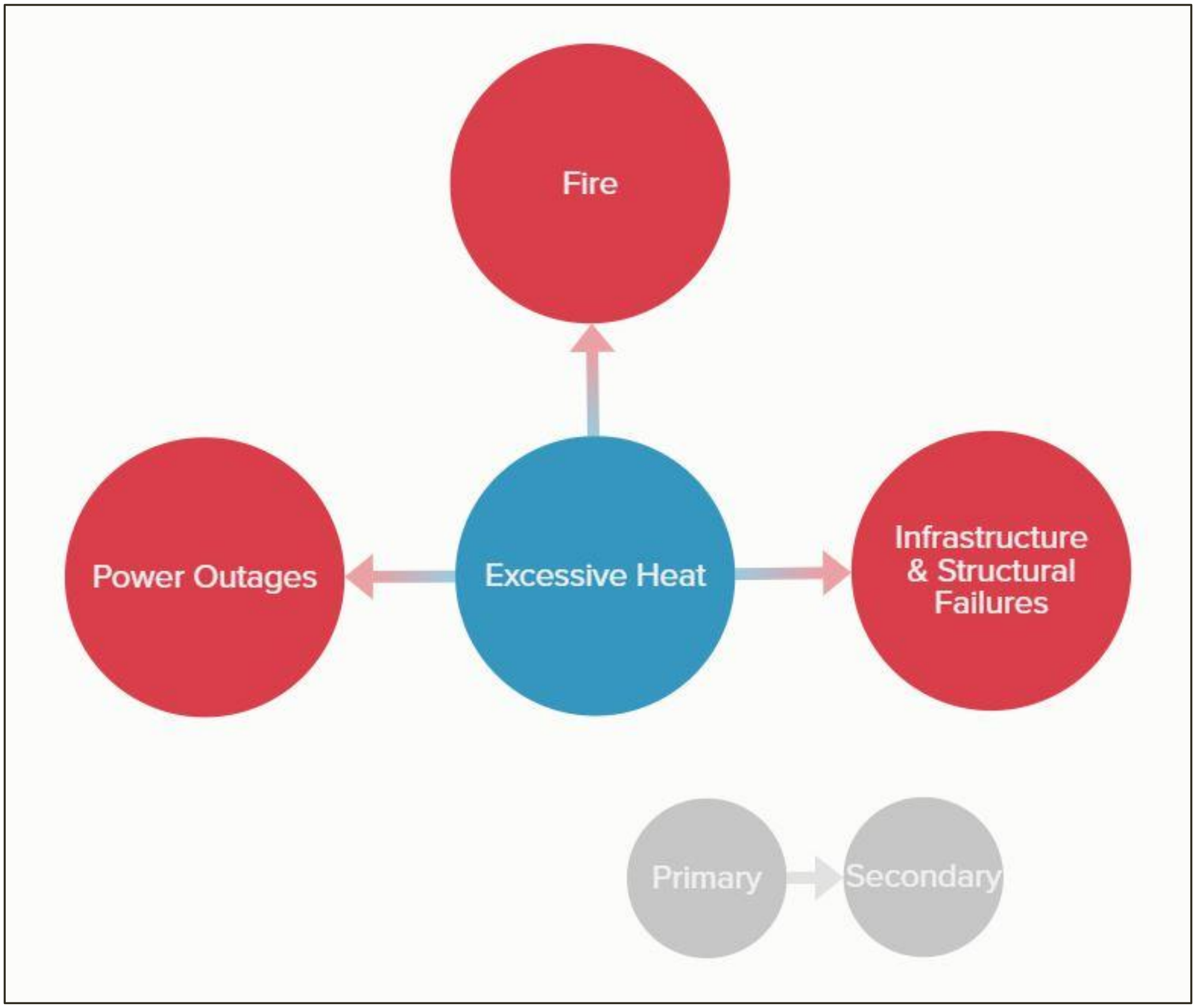


12.13 Infrastructure and Structural Failures



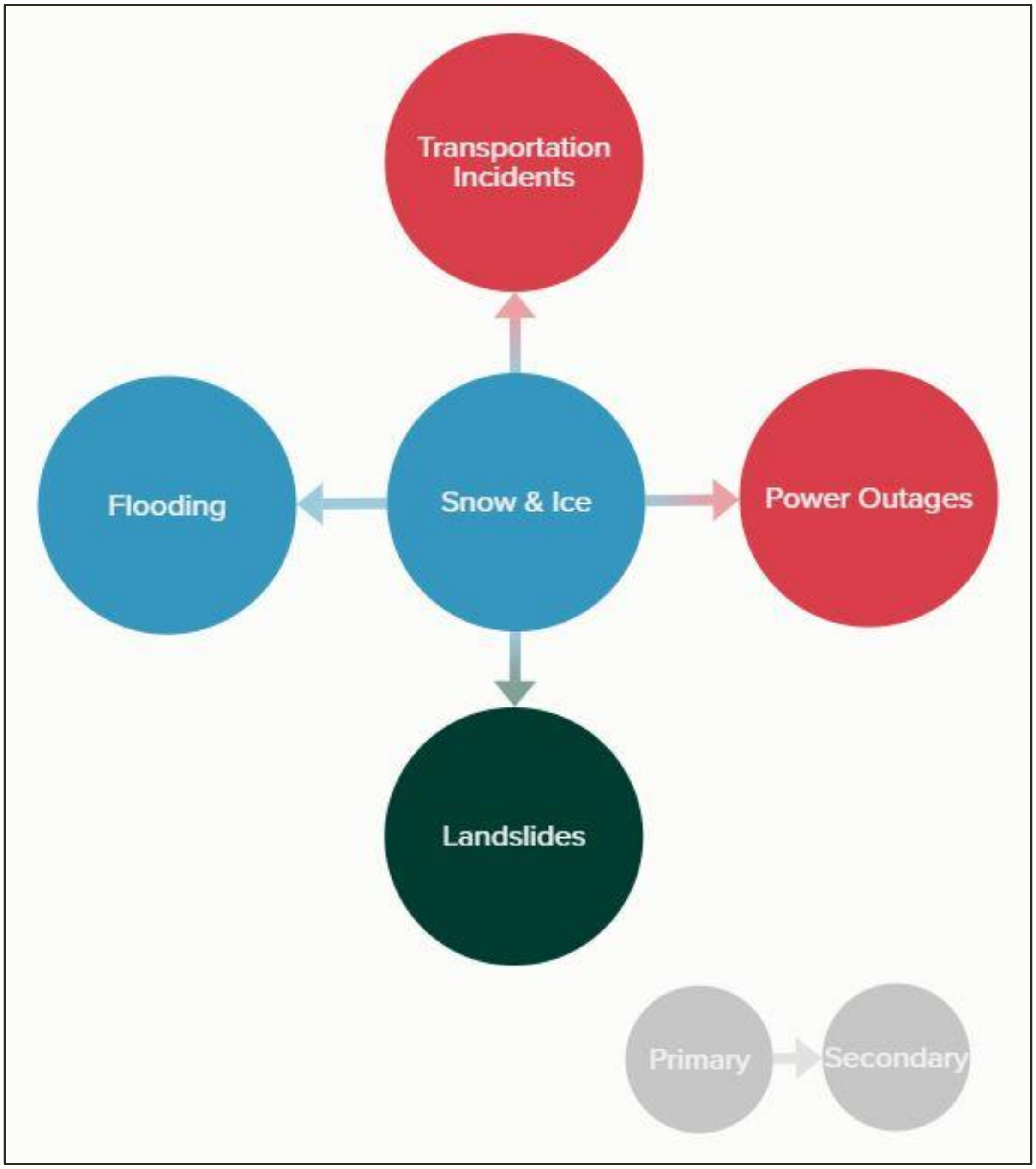
12.14 Power Outages

12.15 Excessive Heat Events

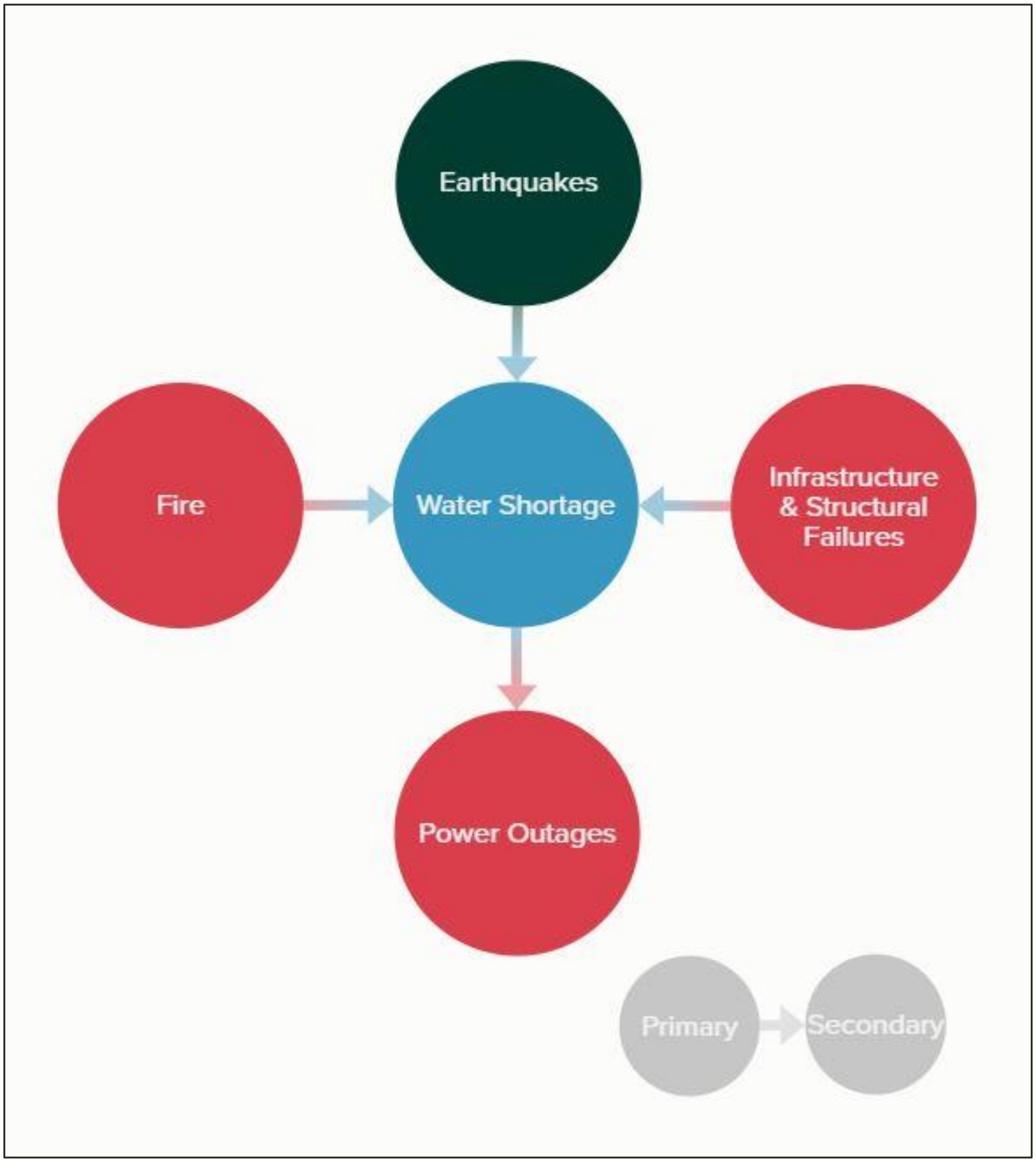


12.16 Flooding

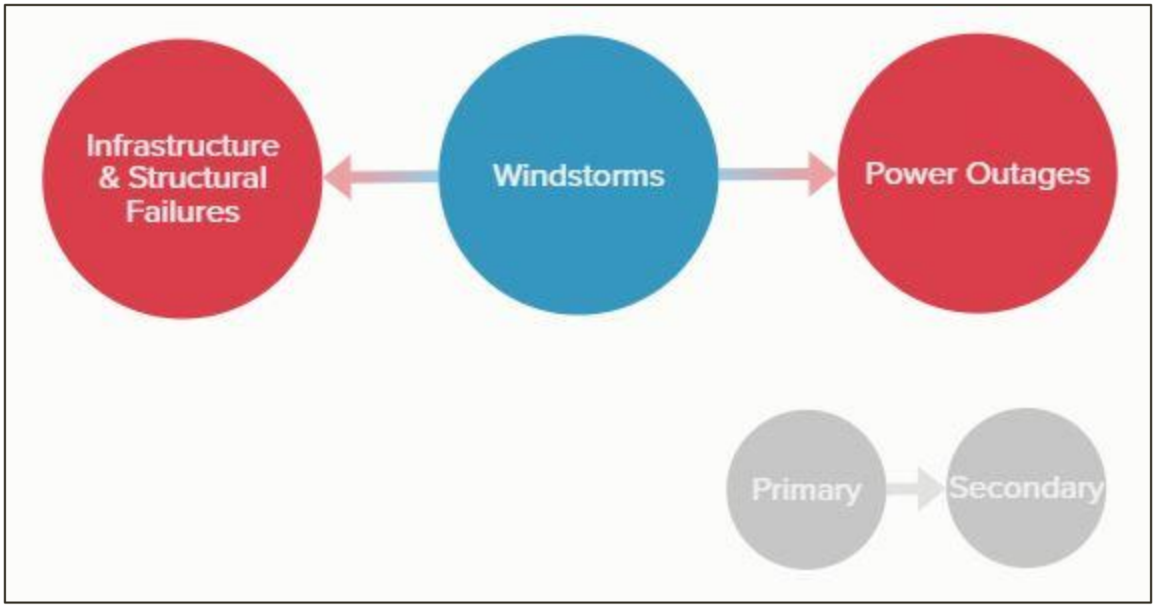
12.17 Snow and Ice



12.18 Water Shortages



12.19 Windstorms



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